
QUANTUM MATTER
2022
International Conference on Science
& Technology of Quantum Matter
JUNE 21-23 • Barcelona (Spain)
ORGANISERS
PHANTOMS foundation
CSIC
Consejo Superior de Investigaciones Científicas
DIPC
ICN2
Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA
SCAN ME

IKUR estrategia

IKUR 2030 is the Strategy to position the Basque Country as a scientific pole of international reference.

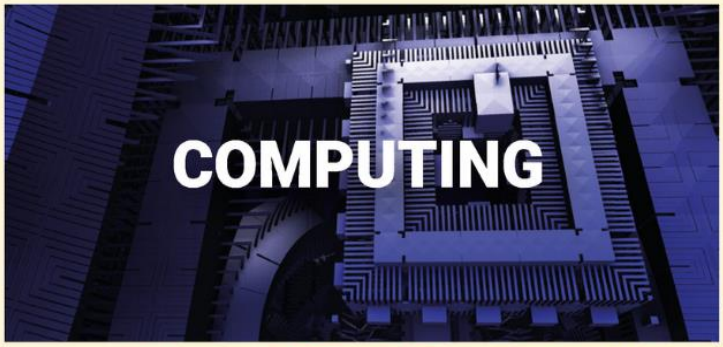
SCIENTIFIC RESEARCH AREAS

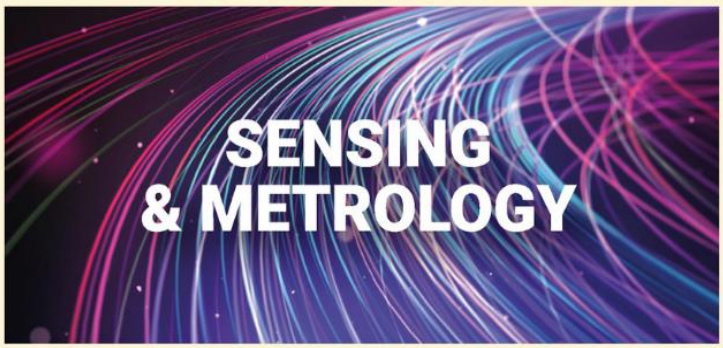
- Neurobiosciences
- Quantum Technologies
- Neutrionics
- High Performance Computing & Artificial Intelligence

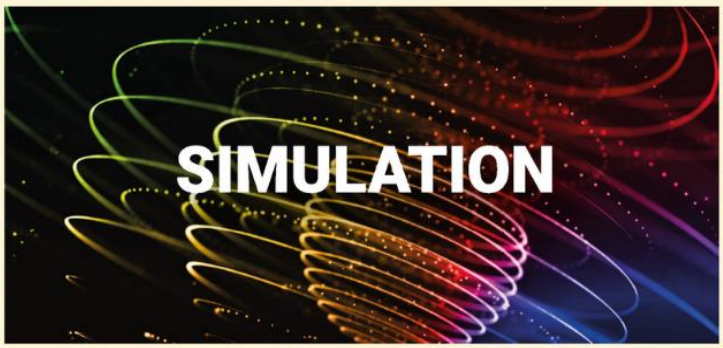
IKUR qt quantum technologies

DIPC

RESEARCH TOPICS







RESEARCH FACILITIES

bcam basque center for applied mathematics

BCMaterials Basque Center for Materials, Applications & Nanostructures

DIPC

Universidad del País Vasco / Euskal Herriko Unibertsitatea

MPC Materials Physics Center

tecnun Universidad de Navarra

CIC biomaGUNE Member of Basque Research & Technology Alliance

CIC nanoGUNE Member of Basque Research & Technology Alliance

OPPORTUNITIES

JOB OFFERS
PARTNERSHIPS
INFRASTRUCTURE
TECHNOLOGY TRANSFER

Contact: ikur@euskampus.eu

ikerbasque Basque Foundation for Science

EUSKO JAURLARITZA GOBIERNO VASCO
HEZKUNTZA SAILA DEPARTAMENTO DE EDUCACIÓN

euskampus FUNDAZIOA

INDEX

BRING OUT THE BEST OF YOUR QUBITS

Quantum Orchestration Platform:
Breakthrough Control Systems for
Quantum Computers

Any Scale. In Record Time.

quantum-machines.co

QUANTUM MACHINES

FOREWORD

On behalf of the Organising and the International Scientific Committees we take great pleasure in welcoming you to Barcelona (Spain) for the 2nd edition of the Quantum Matter International Conference & Exhibition (QUANTUMatter2022).

This event aims at gathering the various communities engaged in the science and technologies of quantum information and quantum matter, to foster the incubation of new ideas & collaborations at the forefront of quantum technologies, emerging quantum materials and novel generations of quantum communication protocols, quantum sensing and quantum simulation.
Quantum Information and Quantum Matter are two components of revolutionary treatments of information, which are becoming cornerstones for discovering and implementing disruptive paradigms in quantum computation and quantum technologies.

QUANTUMatter2022 Highlights:

- Nearly 400 participants in-person
- 39 Plenary, Keynote & Invited Speakers
- More than 120 posters
- Nearly 80 oral contributions
- 21 Exhibitors and 19 Sponsors
- 2 Parallel Workshops
- 1 day Industrial Forum in parallel to get an updated understanding of latest technology developments from worldwide industries.

We are also indebted to the following Scientific Institutions, Companies and Government Agencies for their help and/or financial support:
IKUR estrategia, CFM/CSIC, DIPC, Keysight, QTEP/CSIC, QBLOX, Quantum Machines, HQS Quantum Simulations, Single Quantum, ICEoxford, Agnostiq, Qilimanjaro, AMO GmbH, Multiverse, Pasqal, Toptica, QuiX Quantum, Oxford Instruments NanoScience and C12.

We also would like to thank all the exhibitors, speakers and participants that join us in-person this year.

We truly hope that QUANTUMatter2022 serves as an international platform for communication between science and business.

Hope to see you again in the next edition of QUANTUMatter.

QUANTUMatter2022 Organising Committee

QTEP Quantum Technologies Platform

CSIC

Developing quantum science and technology in Spain

QTEP is the quantum ecosystem created by CSIC to advance the field of quantum technologies, fostering training, research and innovation in a new generation of secure communication devices, computers and sensors based on quantum phenomena, such as entanglement or superposition.

Research

QTEP is a collaborative effort among CSIC groups and partnering academic and industrial institutions, pushing the boundaries of quantum communication, quantum computing and quantum sensing, and advancing the tools and devices to fabricate new quantum technologies.

>100	35	9
Researchers	Groups	Institutions

Contact

Instituto de Física Fundamental
C/ Serrano 113b, 28006 Madrid, Spain
Tlf: +34 9156 68 00 (ext 442461)

@qtep_csic

qtep@csic.es

qtep.csic.es

Financiado por la Unión Europea NextGenerationEU

Gobierno de España · Ministerio de Ciencia e Innovación

Plan de Recuperación, Transformación y Resiliencia

GENERAL INFO

FREE WIFI
Username: Auditori AXA
Password: auditori96

EXHIBITION & POSTER AREA
Foyer (Level 1)
Room Win (Level 0)

COFFEE BREAKS
Check the program for timetables
Location: Exhibition & Poster Area

COCKTAIL LUNCH
Offered by QUANTUMatter 2022 organisers
Tuesday June 21
Wednesday June 22
Location: Exhibition & Poster Area

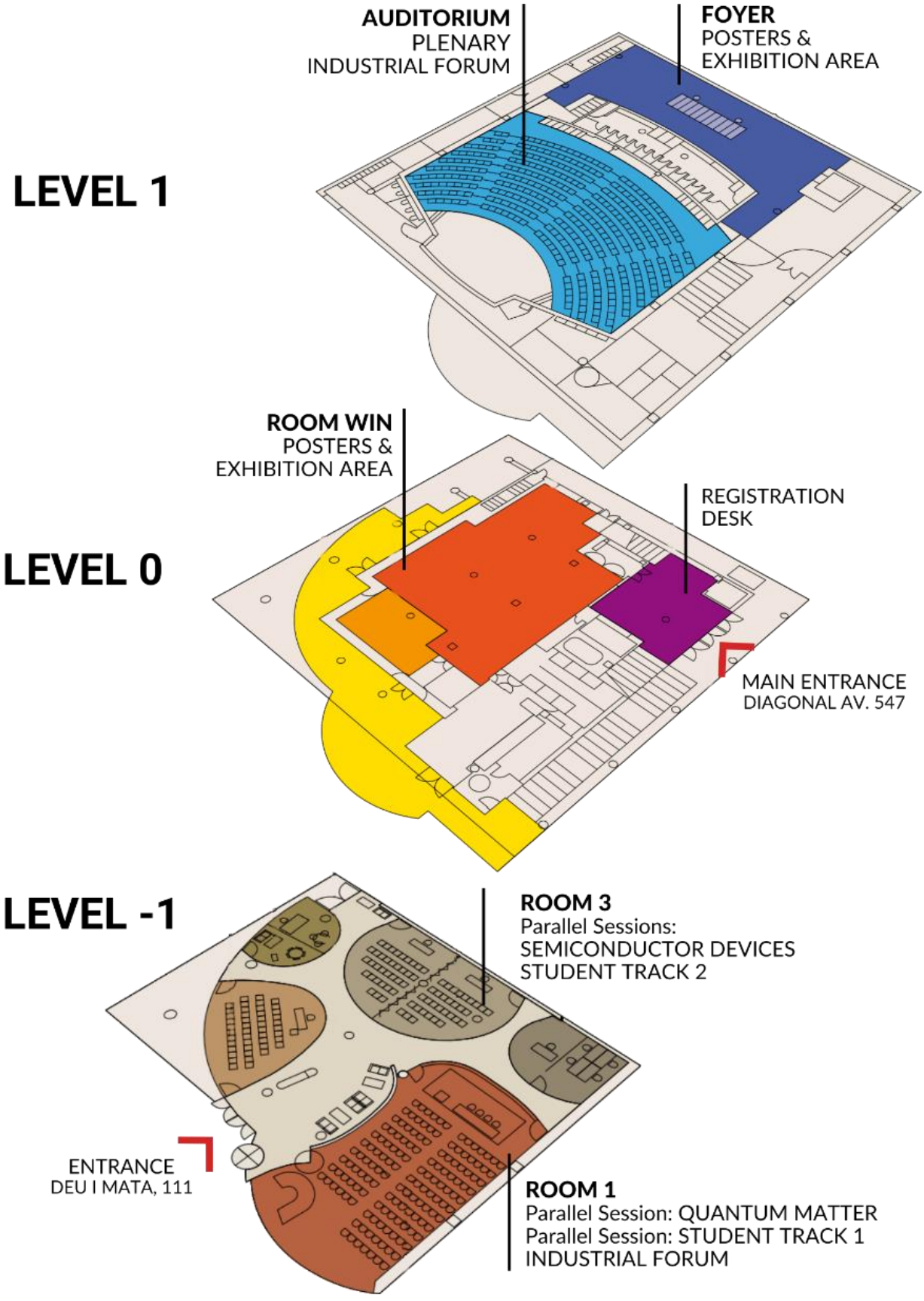
CONFERENCE DINNER*
Wednesday June 22, 21:00
Restaurant CAN CORTADA
Av. de l'Estatut de Catalunya, s/n, 08035 Barcelona
Stop metro Valldaura (line 3 – green) – 5 minutes walking
* Conference dinner NOT included in Exhibition Passes. Included only in FULL conference passes.
If you wish to attend, contact the organisers at the registration desks.

POSTERS SCHEDULE
Session A (PA) Tuesday June 21
You need to make sure you remove your poster after the afternoon coffee break on June 21
Session B (PB) Wednesday June 22
You need to make sure you remove your poster after the afternoon coffee break on June 22

E-CERTIFICATE OF ATTENDANCE
Certificates of attendance will be sent by email to all registered delegates after the congress

.

LOCATION


AUDITORIUM
PLENARY
INDUSTRIAL FORUM
FOYER
POSTERS &
EXHIBITION AREA
LEVEL 1
ROOM WIN
POSTERS &
EXHIBITION AREA
REGISTRATION
DESK
LEVEL 0
MAIN ENTRANCE
DIAGONAL AV. 547
LEVEL -1
ROOM 3
Parallel Sessions:
SEMICONDUCTOR DEVICES
STUDENT TRACK 2
ENTRANCE
DEU I MATA, 111
ROOM 1
Parallel Session: QUANTUM MATTER
Parallel Session: STUDENT TRACK 1
INDUSTRIAL FORUM

AGENDA & LOCATION

Tuesday – June 21	Room	Time
Plenary Session	Auditorium	08:45 – 18:35
Poster Session 1	Foyer & Room Win	14:30 – 15:00
Exhibition & Posters	Foyer & Room Win	–
Cocktail Lunch	Foyer & Room Win	13:25 – 14:30
Wednesday – June 22	**Room**	**Time**
Parallel Session Quantum Matter	Room 1	09:00 – 13:25
Parallel Session Student Track1	Room 1	15:00 – 16:50
Parallel Session Student Track2	Room 3	15:00 – 16:50
Plenary Session	Auditorium	17:15 – 18:55
Industrial Forum	Auditorium	09:00 – 16:45
Industrial Forum	Room 1	17:15 – 18:55
Poster Session 2	Foyer & Room Win	14:30 – 15:00
Exhibition & Posters	Foyer & Room Win	–
Cocktail Lunch	Foyer & Room Win	13:30 – 14:30
Conference dinner	Restaurant CAN CORTADA	21:00
Thursday – June 23	**Room**	**Time**
Plenary Session	Auditorium	09:00 – 17:10
Parallel Session Semiconductor Devices	Room 3	09:00 – 13:30
Exhibition	Foyer & Room Win	

Share with us your vision of the Conference.
Post your photos and comments
#Quantumatter2022

@QuantumConf

COMMITTEES

Organising Committee

Antonio Correia (Phantoms Foundation, Spain) - Chairperson
Ricardo Muiño (DIPC & CFM-CSIC, Spain)
Juan Jose Garcia-Ripoll (IFF-CSIC, Spain)
Pablo Ordejon (ICN2, Spain)

Local Organising Committee

Jordi Arbiol (ICREA/ICN2, Spain)
Leticia Tarruell (ICFO, Spain)
Pol Forn-Díaz (IFAE, Spain)
Alba Cervera Lierta (Barcelona Supercomputing Center, Spain)
John Calsamiglia Costa (Universidad Autónoma de Barcelona, Spain)
Bruno Julia (Universidad de Barcelona, Spain)
Xavier Oriols (UAB, Spain)
Francesc Perez-Murano (CNM / CSIC, Spain)
Valerio Pruneri (ICFO, Spain)

International Scientific Committee

David DiVincenzo (FZ Jülich / RWTH Aachen, Germany) – Chairperson
Stephan Roche (ICREA / ICN2, Spain) – Co-Chairperson
Ramon Aguado (ICMM/CSIC, Spain)
Deborah Berebichez (VTT, Finland)
Andrea Ferrari (University of Cambridge / CGC, UK)
Silvano de Franceschi (CEA/UGA, France)
Hugues de Riedmatten (ICFO, Spain)
Frank Koppens (ICFO, Spain)
Rosa Lopez (UIB, Spain)
Jesper Nygård (Niels Bohr Institute, Denmark)
Roman Orus (Multiverse Computing, Spain)
Gloria Platero Coello (ICMM-CSIC, Spain)
Nicolas Roch (Institut Néel CNRS, France)
Daniel Sanchez-Portal (CFM, Spain)
Henning Schomerus (Lancaster University, UK)
Felix von Oppen (Freie Universität, Germany)
Steven Touzard (NUS, Singapore)
Xavier Waintal (IRIG – CEA Grenoble, France)

SPONSORS

MAIN SPONSORS

IKUR (**www.science.eus/en/ikur**) is the Basque strategy promoted by the Education Department of the Basque Government to boost the Scientific Research in specific strategical areas and to position them at international level. Although its first focus is to enhance the generation of knowledge of excellence, in the medium and long term, it also seeks the technological development in these fields.

Born in 1999 as a joint initiative between Consejo Superior de Investigaciones Científicas (CSIC) and Universidad del Pais Vasco – Euskal Herriko Unibertsitatea (UPV/EHU), the long-term aim of CFM (**cfm.ehu.es)** is to push forward the frontiers of knowledge on advanced materials science research, by putting together stable teams with a record of excellence in scientific research. CFM quality work has been recognized by the Basque Government acknowledging its instrumental body MPC as a Basic Excellence Research Center (BERC).
CFM headquarters are located in Donostia-San Sebastián offering a well configured, high quality working environment with modern facilities, both for experimentalist and theoreticians.

The Donostia International Physics Center Foundation (DIPC - **dipc.ehu.es**) was created in 1999, the fruit of institutional collaboration between the Departments of Education and Industry of the Basque government, the University of the Basque Country, the Diputación Foral de Guipúzcoa, the San Sebastián City Hall, the Kutxa of Guipúzcoa and San Sebastián. Iberdrola S.A. also participated in the project from 2000-2003. In 2004, Naturcorp Multiservicios S.A, joined, followed by Telefónica S.A in 2005.
The DIPC was created as an intellectual centre whose main aim is to promote and catalyse the development of basic research and basic research oriented towards material science to reach the highest level. Since its creation, the DIPC has been an open institution, linked to the University of the Basque Country, serving as a platform for the internationalising of basic science in the Basque Country in the field of materials.
The DIPC Foundation has become an international point of reference in basic research in the field of the Physics of Materials. This relevance shows in the quality of the researchers who have done research stays at the Foundation, the international level of the conferences held there, and, mainly, by the importance of the scientific contributions made as a consequence of the activities carried out at the DIPC.

DIAMOND SPONSORS

Keysight (**www.keysight.com**) delivers advanced enabling technologies, and design and validation solutions to quantum researchers and service providers that help to accelerate the development of a quantum enabled world. Keysight's dedication to speed and precision extends to software-driven insights and analytics that bring tomorrow's technology products to market faster across the development lifecycle, in design, prototype validation, automated software testing and manufacturing analysis.

QTEP (**qtep.csic.es**) is a CSIC Interdisciplinary Thematic Platform (PTI). The reference for QTEP is the quantum technologies community organised around the Flagship and the Quantum Community Network. This community works on four basic research lines with growing technological interest – Quantum Metrology & Sensing, Quantum Crypto & Communication, Quantum Simulation and Quantum Computing, and includes both research institutions as well as companies. QTEP represents a community of 22 groups on 11 research centers, with strong internal collaborations, remarkable international impact and scientific production. QTEP's research spans the main quantum technology pillars, plus a strong base working on enabling technologies.

PLATINUM SPONSORS

With a dedicated team of scientists, engineers and developers we are pushing quantum technology to support scientists worldwide with our scalable qubit control and readout equipment from ultrastable DC to 18.5 GHz for academic and industrial quantum labs. The Qblox (**www.qblox.com**) control stack combines unlevelled noise performance, low-latency arbitrary control flows and can be scaled up to 100s of qubits. Our company is based in the Netherlands as a spinoff of QuTech, which enables us to implement the latest scientific insights and take a position upfront in the worldwide race towards quantum advantage. Using the technology developed at QuTech as a springboard, the Qblox team has fundamentally reimagined the architecture of quantum control to create a single integrated control stack that provides all the functionality needed to manipulate and measure quantum computers. The Qblox architecture speeds up calibration routines by orders of magnitude, saving research teams significant amounts of time and money. The Qblox team is interested in meeting experiment quantum physicists to learn about their applications and how Qblox could support their scaling needs.

Quantum Machines (QM) envisions a new technological age. A time when quantum computing revolutionizes entire industries, solves global problems, and drives unprecedented innovation. That's why we made it our mission to build the Quantum Orchestration Platform (QOP): a complete, end-to-end hardware and software quantum control solution that brings out the best of any qubit technology.
QM's QOP is the choice of the top experts around the globe. It fundamentally redefines the architecture of the quantum control stack and lets you achieve results faster than ever with the most powerful and flexible Pulse Processing Units. The full-stack hardware and software platform offers unparalleled quantum-classical integration. Teams can now implement and accelerate even the most challenging quantum algorithms imaginable right out of the box. From complex multi-qubit calibration to quantum error correction, with QOP you write your sequences as easily as writing pseudocode and run them with the industry's lowest feedback latencies and the fastest runtimes.
Built on an architecture that scales into 1000s of qubits and is designed to match your needs at any QPU scale, the QOP allows for unprecedented advancement and speed-up of quantum technologies.

GOLD SPONSORS

HQS (**quantumsimulations.de**) provides software for materials scientists in the chemical industry, as well as in academia. Sophisticated quantum-level models of materials and their molecular properties give researchers the deeper insights they need to identify the ideal solution for their needs.

Agnostiq (**https://agnostiq.ai**) develops software tools that make quantum and high performance computing resources more accessible to enterprises and developers. Along with its algorithmic research, Agnostiq is developing Covalent, an open source workflow orchestration platform designed to help users manage and execute tasks on heterogeneous compute resources.

SINGLE QUANTUM
Excellence in photon detection

Single Quantum (**singlequantum.com**) was established as the first European company manufacturing and commercializing superconducting single photon detectors. By sharing this groundbreaking technology, we aim to create a better future!
Our multi-channel detection system has already been chosen by more than 150 academic and industrial labs all over the world to perform complex optical measurements.
The unique combination of unparalleled detection efficiency and time resolution is what makes our superconducting detectors the ideal choice for quantum communication, cryptography, infrared fluorescence spectroscopy, laser ranging and many other applications.

SINGLE QUANTUM
Excellence in photon detection

Our multi-channel detection system has already been chosen by more than 170 academic and industrial labs all over the world to perform complex optical measurements.

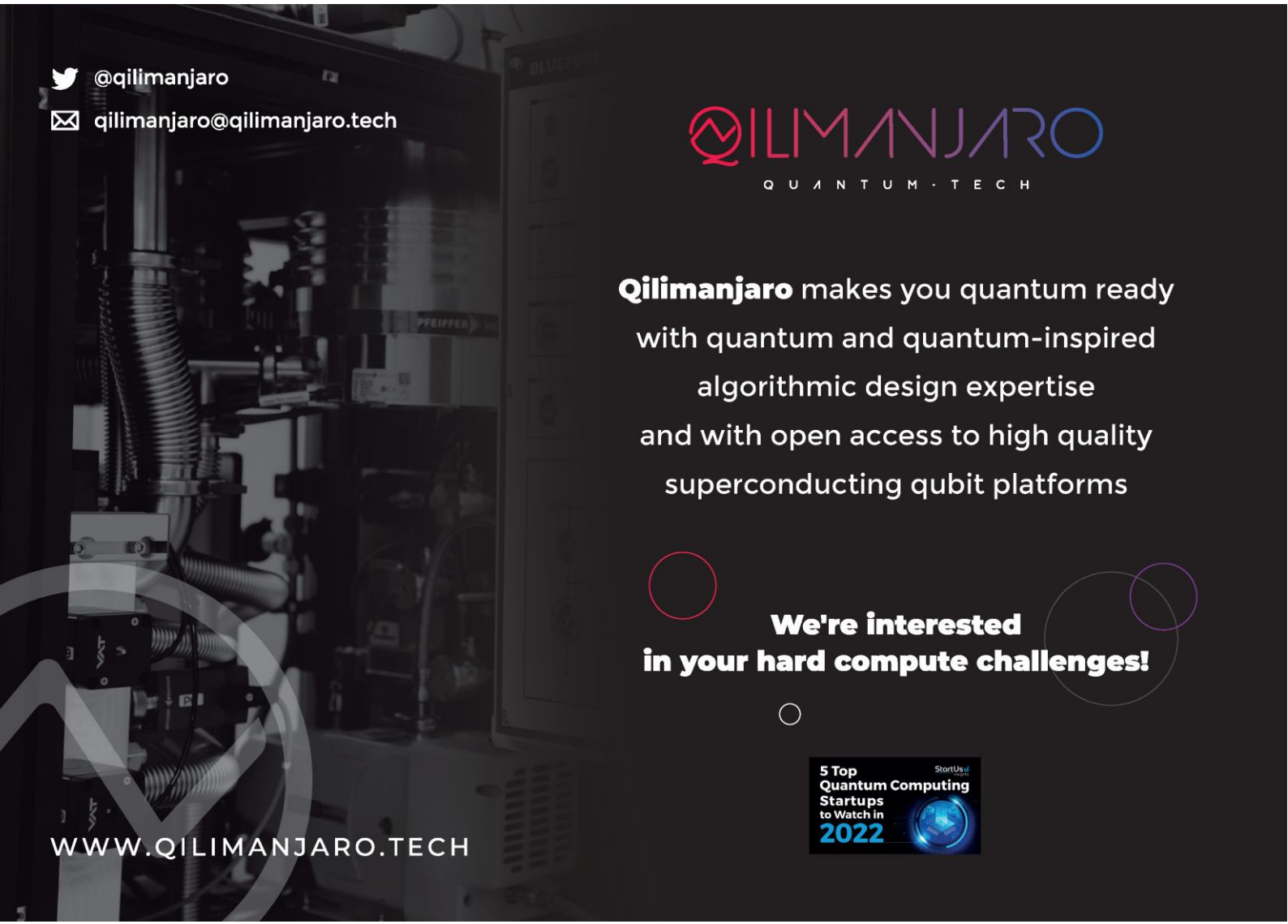
The unique combination of unparalleled detection efficiency and time resolution is what makes our superconducting detectors the ideal choice for quantum communication, QKD, infrared fluorescence spectroscopy, laser ranging, LIDAR and many other applications.

We make the world's fastest and most sensitive light sensors **limited only by the laws of physics.**

SILVER SPONSORS

TOPTICA Photonics (**www.toptica.com**) has been developing and manufacturing high-end laser systems for more than 20 years. The systems are used for demanding scientific and industrial applications in biophotonics, industrial metrology and quantum technology. TOPTICA is renowned for providing the widest wavelength coverage of lasers on the market, providing high-power lasers even at exotic wavelengths: 190 nm – 0.1 THz (corresponding to 3 mm).

Qilimanjaro Quantum Tech is a quantum computing company that began operations in 2020 as a spin-off of the Barcelona Supercomputing Center – Spanish Supercomputing Center (BSC, www.bsc.es), of the Institute High Energy Physics (IFAE, www.ifae.es) and the University of Barcelona (UB, www.ub.edu). It develops algorithmic and cloud access services as well as quantum platforms aimed at optimization, simulation and Machine Learning problems for use cases in sectors such as logistics, chemistry and finance. Qilimanjaro participates in the direction of the European Innovation Council Horizon2020 project on "Coherent Quantum Annealing". It is a member of the European Quantum Industry Consortium (QuIC) since its creation in 2021. It has been awarded as "Exponential Leader 2021" by the Generalitat de Catalunya. **www.qilimanjaro.tech**



AMOs mission as a research oriented company is to efficiently close the gap between university research and industrial application. For this purpose AMO (**www.amo.de**)identifies those topics from basic research that seem particularly suitable for industrial implementation and demonstrates these in application-oriented technology. In joint projects and bilateral cooperation, research and development results are transferred to industry for maintenance and creation of jobs. Thus nanotechnology is expected to provide considerable potential for application areas such as information technology, biotechnology and environmental technology. Headed by Prof. Max Lemme, AMO operates a high level 400 m^2 cleanroom. Furthermore, AMO offers a range of services from consulting to prototype development.

At Pasqal (**pasqal.io**), we build Programmable Quantum Simulators and Quantum Computers made of 2D and 3D Atomic Arrays. Neutral atoms trapped in optical tweezers and addressed with laser beams are ideal indistinguishable quantum systems to realize superposition and entanglement, at the heart of powerful Quantum Information Processing. It is a highly scalable platform, benefiting from tens of years of development which has brought some of contemporary physics' most spectacular achievements. We develop the lasers, the vacuum technology, the electronic controls and the full software stack to make the individual atoms accessible to quantum programmers worldwide.

PASQAL

HARNESS THE POWER OF QUANTUM COMPUTING

We are building multi-purpose quantum processors in the 100 – 1000 qubit range

A sketch of the QPU

WHO ARE WE?

Founded in 2019, PASQAL develops and markets scalable Quantum Processing Units (QPUs) that have the potential to address complex computing issues, from fundamental science to real-world grand challenges.

The company is a spin-out from Institut d'Optique Graduate School in Palaiseau (France), one of the leading quantum research centres in the world.

PASQAL is the only European company offering Quantum Processing Units with a number of qubits, level of performance and maturity allowing practical use for both industrial and academic applications as of today.

OUR OFFER

- The Quantum Computing Power can be made available to our clients:
  - Through appliances in national HPC centres / clients' premises
  - On the Cloud, with QPUs operated at PASQAL (Software as a Service & Platform as a Service)
- Clients also benefit from the support of PASQAL's expert engineers: we build with our partners Proof of Concept (PoC) studies on specific problematics related to their activities. We implement a co-design approach, centred on our partners needs, as we work closely with them on defining the problems to be solved and benchmarking with classical technics.

TECHNOLOGY

Our QPUs are built around a core of neutral atoms which can be precisely addressed, controlled and arranged in 1D, 2D and 3D geometries, thus providing outstanding flexibility to model and process various use cases and calculations.

100 qubit QPUs are available as of 2021 and 1000 qubit QPUs will be available by 2023.

Our processors are designed as accelerators which integrate easily into High Performance Computing (HPC) Centres, and are operated at room temperature. They come with a full software stack, allowing control from any standard computer.

APPLICATIONS

Our QPUs address complex computing issues, from fundamental science to real-world grand challenges that are out of the reach of today's most powerful classical computers, covering a vast range of topics: Optimisation, Simulation, Quantum Machine Learning (QML), Material Sciences, Quantum Chemistry, etc.

The core of the QPU

CONTACT

PASQAL
2 avenue Augustin Fresnel
91120 – Palaiseau - France
Web: www.pasqal.io
Email: contact@pasqal.io

Multiverse Computing provides Quantum and Quantum-Inspired software that work for real-sized problems in finance, energy, manufacturing, logistics, etc. and is the largest quantum software company in the EU.

Quantum computing can solve multi-billion problems that cannot be tackled by current or future traditional computing. That's why Multiverse Computing develops algorithms that run on quantum computers and classical solutions coming from deep-physics that work 100-1000x faster than currently used solutions on traditional computers.

Multiverse Computing applies its cutting edge knowledge to provide software which is customized to needs, giving companies a chance to derive value from the second quantum revolution. **www.multiversecomputing.com**

Multiverse is the Leading European Quantum and Quantum-Inspired Software Company

Our Technology and Team

Singularity Platform Quantum for the masses and hardware agnostic	**Quantum & Quantum-Inspired** Solutions for today and the future
Finance, Energy, Manufacturing, Space And more end-markets to come	**World-Class Team** Deep technical (9,000 citations) and business expertise

Our Numbers

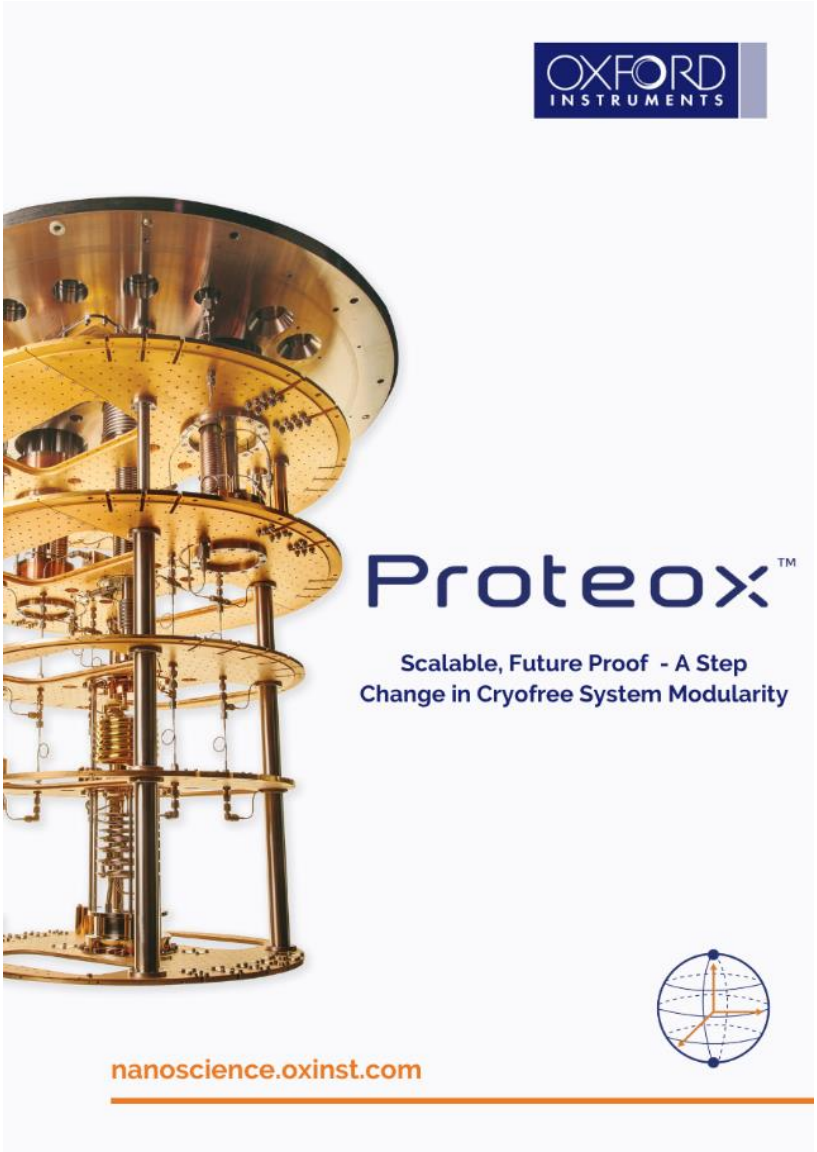
€6.8M TCV sold in 2021	**€9B TAM** By 2028 and up to $85B for long-term
22 Patents Filed in 2021 and 24 more planned in 2024	**€10M Funding** Raised to date

Mentions

BCG · The Economist · FT Financial Times · Forbes · Gartner · IBM · McKinsey & Company · sifted

BRONZE SPONSORS

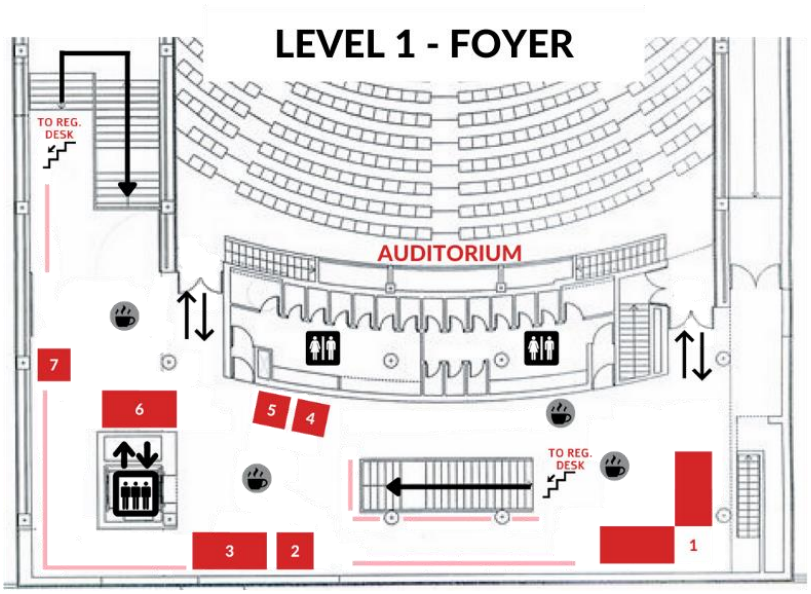
QuiX Quantum is market leader in reconfigurable Quantum Photonics hardware, delivering the next generation of solutions in Quantum Computing. Quantum computing will revolutionize the way in which information processing is performed. Integrated photonics is a key enabling technology for optical quantum computing. Our technology can realize plug&play integrated and reconfigurable quantum processors that process quantum light in a stable, accurate and fast way.



Oxford Instruments NanoScience is part of the Research and Discovery Sector at Oxford Instruments, providing advanced solutions that create unique environments and enable analytical measurements down to the molecular and atomic level, predominantly used in scientific research and applied R&D. At Oxford Instruments Nanoscience, we design, supply and support market-leading research tools that enable quantum technologies, nano technology research, advanced materials and nano device development in the physical sciences. Our tools support research to the atomic scale through creation of high performance, cryogen free, low temperature, and magnetic environments. This is based upon our core technologies in low and ultra-low temperatures, high magnetic fields and system integration with increasing levels of experimental and measurement readiness.

C12 is a French start-up that builds reliable quantum computers. The company is a spin-off from ENS launched in January 2020 by twin brothers Matthieu and Pierre Desjardins to supercharge the development of the lab's promising new quantum technology. Unlike other quantum computers, C12 uses carbon nanotubes as the fundamental building block of their processor. By combining the power of an ultra-pure material with an easy-to-manufacture semiconductor device, C12 is building a scalable platform for quantum computing. C12 is leading the next materials leap in quantum computing.

EXHIBITORS



1 KEYSIGHT → KEYSIGHT
2 AMO GmbH → AMO
3 QBLOX → QBLOX
4 Pasqal → PASQAL
5 Qilimanjaro → QILIMANJARO QUANTUM TECH
6 Quantum Machines → QUANTUM MACHINES
7 Active Technologies → Active Technologies

Posters Coffee area

8 QUANDELA → QUANDELA

9 Delft Circuits → Delft Circuits Hardware for quantum engineers

10 Toptica → TOPTICA

11 HQS → HQS QUANTUM SIMULATIONS

12 Quantum Delta → Quantum Delta the Netherlands

13 SPECS Group → SPECSGROUP

14 nu Quantum → nu QUANTUM

15 Single Quantum → SINGLE QUANTUM Excellence in photon detection

16 ICN2 / LSQUANT → ICN2 Institut Català de Nanociència i Nanotecnologia; LSQUANT Linear Scaling Quantum Transport

17 Agnostiq → agnostiq

18 Kiutra → kiutra

19 ICEoxford → ICE

20 Zurich Instruments → Zurich Instruments

Posters

Coffee area

SPEAKERS LIST


KEYNOTE

Certification of quantum systems and technologies

Antonio Acín

ICREA/ICFO, Spain

antonio.acin@icfo.eu

The need of a new paradigm for quantum certification has emerged as a consequence of the impressive advances on the control of quantum phenomena. On the one hand, complex many-body quantum systems are prepared in many labs worldwide. On the other hand, quantum information technologies are making the transition to real applications. Quantum certification is a highly transversal concept that covers a broad range of scenarios, from many-body systems to protocols employing few devices, and questions, from theoretical results and experimental demonstrations to commercial products. The talk presents recent advances on the design of efficient and scalable methods for the certification of quantum systems and quantum information protocols.

The European Quantum Initative
- from a Flagship to a Fleet -

Prof. Dr. Tommaso Calarco

Director of the Institute of Quantum Control (PGI-8), Forschungszentrum Jülich

Address: PGI-8, Wilhelm-Johnen-Straße 52425 Jülich

Contact: t.calarco@fz-juelich.de

Abstract

As the first applications leap out of research laboratories towards commercialization, the global race for leadership in the maturing field of quantum technologies is becoming ever fiercer. To retain its historical lead, kick-start a continent-wide quantum-driven industry and accelerate market uptake, the European Commission launched in 2018 the Quantum Technology (QT) Flagship, an ambitious €1 billion initiative spanning a ten year period of R&D&I. Since then, the QT Flagship has been sided by many other funding instruments, initiatives and actions, which have basically more than doubled its initial budget effectively transformed it in a whole 'quantum fleet'.

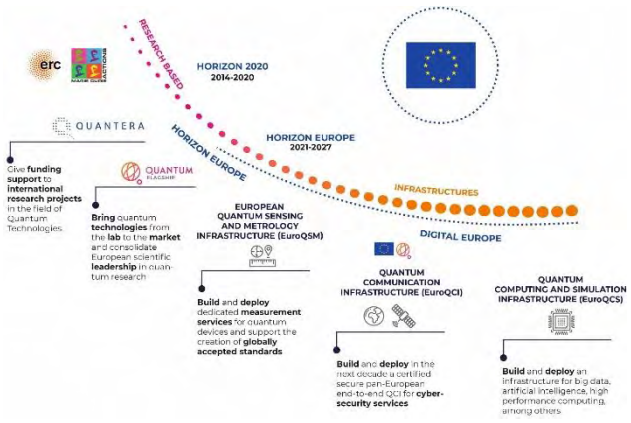


Figure 1: From a Flagship to a Fleet

This presentation will provide a broad view of the existing and planned Quantum Fleet components highlighting how the envisaged actions will realise the vision of placing Europe as a worldwide knowledge-based industrial and technological leader in the QT field.

When the complex nature of atoms can really make a difference:

ultracold erbium and dysprosium for quantum simulation

Francesca Ferlaino

University of Innsbruck – Institute for Experimental Physics , Technikerstraße 25/2 6020, Innsbruck, Austria.
Austrian Accademy of Science – IQOQI, Technikerstraße 21a 6020, Innsbruck, Austria

Francesca-Ferlaino-Group@uibk.ac.at

Abstract

Since its creation, the field of ultracold atoms has been through fantastic developments. Some of the most recent include the development of quantum-gas microscopes, atom tweezers, and various forms of interaction engineering. Each of these experimental advances has allowed new quantum phenomena to be accessed and observed. A further important development is based on the use of more exotic atomic species, whose peculiar atomic properties have allowed to broaden the horizons of investigation. This talk aims to retrace the new opportunities that have emerged from the use of quantum gases composed of the strongly magnetic erbium and dysprosium atoms from the perspective of the Innsbruck experiments. Thanks to their large magnetic moment, these species exhibit a large dipolar interaction that has allowed us to observe rotonic excitations, quantum droplets, and supersolid states. Moreover, their dense atomic spectrum has also made possible to implement new optical manipulation schemes, and more recently the observation of an Hz-wide transition in the telecom frequency region promises new possibilities in quantum optics.

References

[1] Maintaining supersolidity in one and two dimensions, E. Poli, T. Bland, C. Politi, L. Klaus, M. A. Norcia, F. Ferlaino, R. N. Bisset, L. Santos, Phys. Rev. A, 104, 063307, (2021)

[2] Two-dimensional supersolidity in a dipolar quantum gas, M. A. Norcia, C. Politi, L. Klaus, E. Poli, M. Sohmen, M. J. Mark, R. Bisset, L. Santos, F. Ferlaino, Nature, 596, 357-361, (2021)

[3] Two-dimensional supersolidity in a circular trap, T. Bland, E. Poli, C. Politi, L. Klaus, M. A. Norcia, F. Ferlaino, L. Santos, R. N. Bisset, arXiv:2107.06680, (2021)

[4] Birth, life, and death of a dipolar supersolid, M. Sohmen, C. Politi, L. Klaus, L. Chomaz, M. J. Mark, M. A. Norcia, F. Ferlaino, Phys. Rev. Lett., 126, 233401, (2021).

[5] Phase coherence in out-of-equilibrium supersolid states of ultracold dipolar atoms, P. Ilzhöfer, M. Sohmen, G. Durastante, C. Politi, A. Trautmann, G. Natale, G. Morpurgo, T. Giamarchi, L. Chomaz, M. J. Mark, F. Ferlaino, Nature Physics, 17, 356-361, (2021).

[6] Supersolidity in an elongated dipolar condensate, P. B. Blakie, D. Baillie, L. Chomaz, F. Ferlaino, Phys. Rev. Research, 2, 043318, (2020).

[7] Excitation spectrum of a trapped dipolar supersolid and its experimental evidence, G. Natale, R. M. W. van Bijnen, A. Patscheider, D. Petter, M. J. Mark, L. Chomaz, F. Ferlaino, Phys. Rev. Lett., 123, 050402, (2019).

Computing with photons

Jose Ignacio Latorre

NUS, Singapore

phyjil@nus.edu.sg

We present a scheme to compute probability distributions using a photonic chip that runs a quantum circuit in unary basis.
This methodology is applied to option pricing in finance.
The same chip can be trained to reproduced probability distributions created with a Generative Adversarial Networks philosophy.

Quantum Fractals

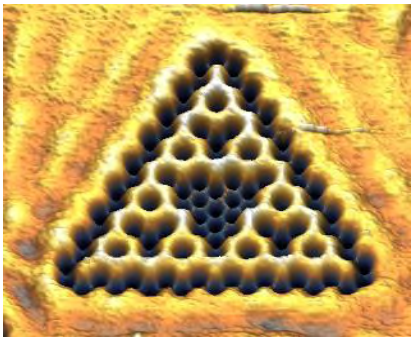
Cristiane Morais Smith

Institute for Theoretical Physics, Utrecht University, The Netherlands

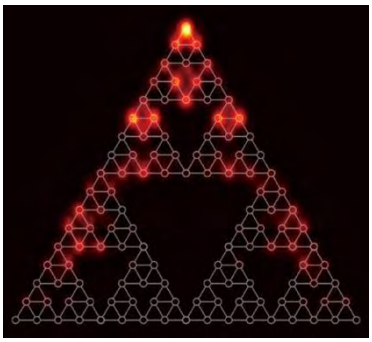
C.deMoraisSmith@uu.nl

The human fascination for fractals dates back to the time of Christ, when structures known nowadays as a Sierpinski gasket were used in decorative art in churches. Nonetheless, it was only in the last century that mathematicians faced the difficult task of classifying these structures. In the 80's and 90's, the foundational work of Mandelbrot triggered enormous activity in the field. The focus was on understanding how a particle diffuses in a fractal structure. However, those were classical fractals.

This century, the task is to understand quantum fractals. In 2019, we realized a Sierpinski gasket using a scanning tunneling microscope to pattern adsorbates on top of Cu(111) and showed that the wavefunction describing electrons in a Sierpinski gasket fractal has the Hausdorff dimension d = 1.58 [1]. However, STM techniques can only describe equilibrium properties.



Last year, we went a step beyond and using photonics experiments we unveiled the quantum dynamics in fractals. By injecting photons in waveguide arrays arranged in a fractal shape, we we able to follow their motion and understand their quantum dynamics with unprecedented detail. We built 3 types of fractal structures to reveal not only the influence of different Hausdorff dimension, but also of geometry [2].



The investigation of systems living in non-integer dimensions raises the question whether fractional calculus might be a useful concept. In the last part of this talk, I will discuss a system described by a fractional Langevin equation with white noise [3]. Fractional calculus is shown to connect different states of matter and has revealed the elusive time glass phase previously conjecture by Frank Wilczek

References

[1] S.N. Kempkes, M.R. Slot, S.E. Freeney, S.J.M. Zevenhuizen, D. Vanmaekelbergh, I. Swart, and C. Morais Smith, "Design and characterization of electronic fractals", Nature Physics 15, 127(2019) [see also 15 years of Nature Physics, Nature Physics 16, 999 (2020)].

[2] X.-Y. Xu, X.-W. Wang, D.-Y. Chen, C. Morais Smith, and X.-M. Jin, "Quantum transport in fractal networks," Nature Photonics 15, 703 (2021).

[3] R. C. Verstraten, R. F. Ozela, and C. Morais Smith, "Time glass: a fractional calculus approach", Phys. Rev. B 103, L180301 (2021).


INVITED

Light-Matter Quantum Interfaces: A Tale of Two Materials

Mete Atatüre

Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB2 1TP, United Kingdom

ma424@cam.ac.uk

Optically accessible solid-state spins offer promise routes to realising the key building block for quantum networks. Among a plethora of materials investigated actively, I will briefly highlight current progress on two promising material platforms. The first is semiconductor spins with immaculate photonic properties, but also face challenges on the quality of the spin in a spin-rich material. I will highlight how to remedy the detrimental spin noise and what can be done on the materials perspective to improve their performance. The second material platform is the group-IV colour centres in diamond, a more recent alternative spin family to the well-studied nitrogen-vacancy centre. I will focus on the most recent member of this family; the negatively charged tin-vacancy centre. This candidate offers the benefits of strong protection against phonon dephasing and robust cyclicity of its optical transitions arising from its strong spin-orbit interaction.

Moiré Heterostructures, the realm of Quantum Materials

E. Bascones[1]
M.J. Calderón[1] and A. Camjayi[2]

[1]*Instituto de Ciencia de Materiales de Madrid, Sor Juana Inés de la Cruz 3, 28049 Madrid (Spain).*

[2]*Departamento de Física, FCEyN, UBA and IFIBA, Conicet, Pabellón 1, Ciudad Universitaria. Buenos Aires 1428 CABA, Argentina*

leni.bascones@csic.es

The notion of Quantum Materials encompasses materials showing emerging quantum phenomena or topological properties. The research on correlated electron systems, topological materials and 2D crystals, once independent of each other, is now converging in the study of Moiré Heterostructures, combining layers with a stacking slightly away from commensurability. A plethora of complex electronic states like superconductivity, magnetism or correlated insulating states has been recently discovered in different Moiré heterostructures. Prominent examples are twisted bilayer graphene or trilayer graphene aligned on hBN. In the talk I will discuss the role of the electronic correlations in these systems and how to connect their effect with the properties of other quantum materials such as high-temperature superconductors.

Figures

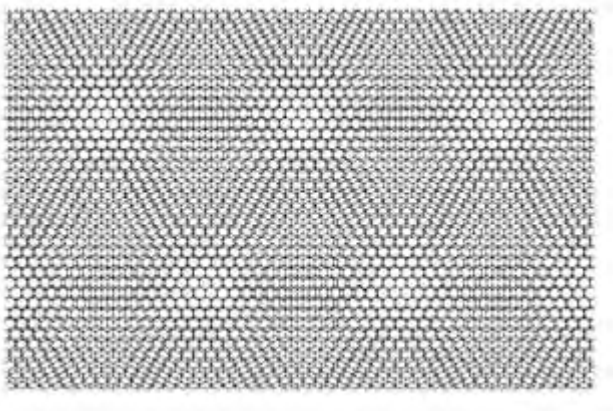


Figure 1: Sketch of a Moiré Heterostructure due to the lattice mismatch between two 2D crystals

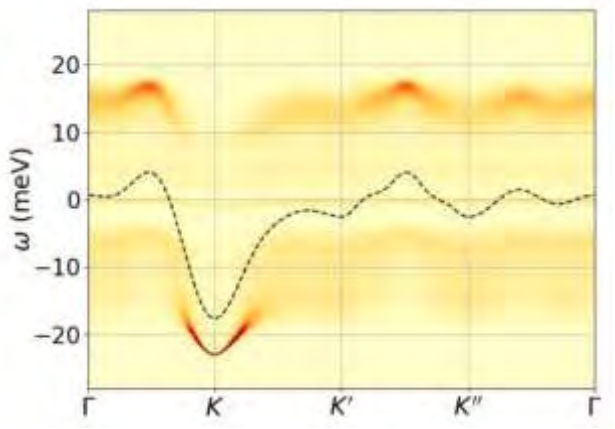


Figure 2: Effect of electronic interactions in the band structure of the moiré heterostructure formed when an rhombohedral trilayer graphene is aligned with the substrate Boron Nitride.

Addressing learning tasks with quantum devices

Jens Eisert[1,2]
M. Hinsche[1], M. Ioannou[1], A. Nietner[1], J. Haferkamp[1], Y. Quek[1], D. Hangleiter[1,3], J.-P. Seifert[4], M. C. Caro[5], E. Gil-Fuster[1], J. J. Meyer[1], R. Sweke[1]

1 Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, D-14195 Berlin, Germany
2 Fraunhofer Heinrich Hertz Institute, D-10587 Berlin, Germany
3 QuICS, University of Maryland and NIST, College Park, MD 20742, USA
4 Electrical Engineering and Computer Science, TU Berlin, D-10587 Berlin, Germany
5 Munich Center for Quantum Science and Technology, D-80799 Munich, Germany

jense@zedat.fu-berlin.de

Recent years have witnessed an enormously rapid development of quantum computational devices of intermediate size. For instances of paradigmatic settings such as sampling problems, such existing quantum devices already come close to outperforming or outperform classical supercomputers for the same task, in settings that are equipped with a precise and rigorous complexity theoretic underpinning. In this talk, we start from looking at such quantum advantage schemes that can be efficiently verified by means of local quantum measurements [1], leading to a proof-of-principle-experiment involving trapped ions [2]. These steps suggest to investigate more practically motivated quantum advantages.

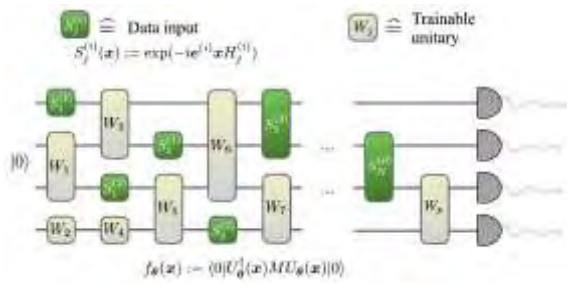


Figure 1: A parametrized quantum circuit.

In the main part of the talk, we will explore to what extent quantum-assisted machine learning tasks could be candidates for this. Specifically, we look in great detail at a proven exponential separation of quantum learners over classical ones in a meaningful quantum machine learning task [3]. Concretely, we study the comparative power of classical and quantum learners for generative modelling within the Probably Approximately Correct (PAC) framework. More specifically we consider the following task: Given samples from some unknown discrete probability distribution, output with high probability an efficient algorithm for generating new samples from a good approximation of the original distribution. Our primary result is the explicit construction of a class of discrete probability distributions which, under the decisional Diffie-Hellman assumption, is provably not efficiently PAC learnable by a classical generative modelling algorithm, but for which we construct an efficient quantum learner. We will investigate encoding non-agnostic generalization bounds (fig. 1) for quantum-assisted machine learning with parameterized quantum circuits [4]. In the last part of the talk, we will explore the possibility of learning output distributions of short quantum circuits [5], and will discuss what degree of structure is needed, after all, to expect a quantum advantage in meaningful quantum-assisted machine learning tasks.

References

[1] Closing gaps of a quantum advantage with short-time Hamiltonian dynamics, J. Haferkamp, D. Hangleiter, A. Bouland, B. Fefferman, J. Eisert, J. Bermejo-Vega, Phys. Rev. Lett. 125, 250501 (2020).
[2] Verifiable measurement-based quantum random sampling with trapped ions, in preparation (2022).
[3] Learnability of the output distributions of local quantum circuits, M. Hinsche, M. Ioannou, A. Nietner, J. Haferkamp, Y. Quek, D. Hangleiter, J.-P. Seifert, R. Sweke, arXiv:2110.05517 (2021).
[4] Encoding-dependent generalization bounds for parametrized quantum circuits, M. C. Caro, E. Gil-Fuster, J. Jakob Meyer, J. Eisert, R. Sweke, Quantum 5, 582 (2021).
[5] On the quantum versus classical learnability of discrete distributions, R. Sweke, J.-P. Seifert, D. Hangleiter, J. Eisert, Quantum 5, 417 (2021).

Plethora of Many-Body Ground States in Magic Angle Twisted Bilayer Graphene

Dmitri K. Efetov
LMU Munich, Germany
Dmitri.Efetov@icfo.eu

Twist-angle engineering of 2D materials has led to the recent discoveries of novel many-body ground states in moiré systems such as correlated insulators, unconventional superconductivity, strange metals, orbital magnetism and topologically nontrivial phases. These systems are clean and tuneable, where all phases can coexist in a single device, which opens up enormous possibilities to address key questions about the nature of correlation induced superconductivity and topology, and allows to create entirely novel quantum phases with enhanced interactions. In this talk we will introduce some of the main concepts underlying these systems, concentrating on magic angle twisted bilayer graphene (MATBG) and show how symmetry-broken states emerge at all integer electron fillings [1]. We further will discuss recent experiments including screened interactions [2], Chern insulators [4], magnetic Josephson junctions [4], quantum criticality [5], re-entrant correlated insulators at high magnetic fields [6] and discuss some of the avenues for novel quantum sensing applications [7].

References

[1] Nature, 574, 653 (2019).
[2] Nature, 583, 375–378 (2020).
[3] Nature Physics, 17, 710 (2021).
[4] arXiv:2110.01067 (2021).
[5] Nature Physics (2022).
[6] Phys. Rev. Lett. (2022).
[7] arXiv:2111.08735 (2021).

Tileable low-crosstalk 3D-integrated superconducting circuits

Peter Leek

University of Oxford, UK

peter.leek@physics.ox.ac.uk

Superconducting circuits are a leading candidate for the realization of practically useful quantum computers, in particular for near-term applications which may already be reached with circuits consisting of a few hundred qubits operated at high fidelity. Until recently, the topology of superconducting circuits has typically been constrained to two dimensions, which becomes difficult to scale as the number of qubits increases and signal wiring is needed for qubits in the middle of large arrays. In this talk I will present our progress [1] on scaling up a novel circuit architecture that builds on a tileable superconducting circuit unit cell with coaxial symmetry and 3D-integrated off-chip wiring [2], which provides a viable route to operating such large qubit arrays while maintaining a clean microwave environment [3].

References

[1] Spring et al., Science Advances 8 (2022)
[2] Rahamim et al., Applied Physics Letters 110, 222602 (2017)
[3] Spring et al., Physical Review Applied 14, 024061 (2020)

Ab initio approaches to nonequilibrium interactions in quantum matter

Prineha Narang

Harvard University, USA

prineha@seas.harvard.edu

Quantum systems host spectacular excited-state effects, but many of these phenomena remain challenging to control and, consequently, technologically under-explored. My research, therefore, focuses on how quantum systems behave, particularly away from equilibrium, and how we can harness these effects1. By creating predictive approaches to study dynamics, decoherence and photo-induced correlations in matter, our work could enable technologies that are inherently more powerful than their classical counterparts ranging from quantum information science, to ultra-high efficiency optoelectronic and energy conversion systems. In this talk, I will present a pedagogical introduction to theoretical and computational approaches to describe excited-states in quantum matter, and predicting emergent states created by strongly non-equilibrium external drives. Understanding the role of such nonequilibrium light-matter interactions in the regime of correlated electronic systems is of paramount importance to fields of study across condensed matter physics, quantum optics, and quantum chemistry. The simultaneous contribution of processes that occur on many time- and length-scales have remained elusive for state-of-the-art calculations and model Hamiltonian approaches alike, necessitating the development of new methods in theoretical and computational quantum chemistry 2–6. I will discuss our work at the intersection of ab initio cavity quantum-electrodynamics and electronic structure methods to treat electrons, photons and phonons on the same quantized footing, accessing new observables in strong light-matter coupling. Current approximations in the field almost exclusively focus on electronic excitations, neglecting electron-photon effects, for example, thereby limiting the applicability of conventional methods in the study of quantum chemical and polaritonic systems, which requires understanding the coupled dynamics of electronic spins, nuclei, phonons and photons. With our approach we can access correlated electron-photon and photon-phonon dynamics. Building on this, I will show selected examples of our approach in ab initio design of active defects in quantum materials leveraging the chemical degree-of-freedom7–9 towards selectively linking these active defects 10–12. Finally, I will present an outlook on driving quantum chemical systems far out-of-equilibrium to control the coupled electronic and vibrational degrees-of-freedom 13,14 and a pathway to link these with transport in materials15,16.

References

[1]. Head-Marsden, K., Flick, J., Ciccarino, C. J. & Narang, P. Quantum Information and Algorithms for Correlated Quantum Matter. Chem. Rev. (2020) doi:10.1021/acs.chemrev.0c00620.

[2]. Rivera, N., Flick, J. & Narang, P. Variational Theory of Nonrelativistic Quantum Electrodynamics. Phys. Rev. Lett. 122, 193603 (2019).

[3]. Flick, J., Rivera, N. & Narang, P. Strong light-matter coupling in quantum chemistry and quantum photonics. Nanophotonics 7, 1479–1501 (2018).

[4]. Flick, J. & Narang, P. Cavity-Correlated Electron-Nuclear Dynamics from First Principles. Physical Review Letters vol. 121 (2018).

[5]. Schäfer, C., Flick, J., Ronca, E., Narang, P. & Rubio, A. Shining Light on the Microscopic Resonant Mechanism Responsible for Cavity-Mediated Chemical Reactivity. arXiv [quant-ph] (2021).

[6]. Wang, D. S., Neuman, T., Flick, J. & Narang, P. Light-matter interaction of a molecule in a dissipative cavity from first principles. J. Chem. Phys. 154, 104109 (2021).
[7]. Narang, P., Ciccarino, C. J., Flick, J. & Englund, D. Quantum Materials with Atomic Precision: Artificial Atoms in Solids: Ab Initio Design, Control, and Integration of Single Photon Emitters in Artificial Quantum Materials. Adv. Funct. Mater. 29, 1904557 (2019).
[8]. Hayee, F. et al. Revealing multiple classes of stable quantum emitters in hexagonal boron nitride with correlated optical and electron microscopy. Nat. Mater. 19, 534–539 (2020).
[9]. Ciccarino, C. J. et al. Strong spin–orbit quenching via the product Jahn–Teller effect in neutral group IV qubits in diamond. npj Quantum Materials 5, 75 (2020).
[10]. Neuman, T., Wang, D. S. & Narang, P. Nanomagnonic Cavities for Strong Spin-Magnon Coupling and Magnon-Mediated Spin-Spin Interactions. Phys. Rev. Lett. 125, 247702 (2020).
[11]. Wang, D. S., Neuman, T. & Narang, P. Dipole-coupled emitters as deterministic entangled photon-pair sources. Phys. Rev. Research 2, 043328 (2020).
[12]. Neuman, T. et al. A phononic interface between a superconducting quantum processor and quantum networked spin memories. npj Quantum Information 7, 1–8 (2021).
[13]. Juraschek, D. M., Meier, Q. N. & Narang, P. Parametric Excitation of an Optically Silent Goldstone-Like Phonon Mode. Physical Review Letters vol. 124 (2020).
[14]. Juraschek, D. M., Narang, P. & Spaldin, N. A. Phono-magnetic analogs to opto-magnetic effects. Phys. Rev. Research 2, 043035 (2020).
[15]. Vool, U. et al. Imaging phonon-mediated hydrodynamic flow in WTe2. Nat. Phys. 1–5 (2021).
[16]. Varnavides, G., Jermyn, A. S., Anikeeva, P., Felser, C. & Narang, P. Electron hydrodynamics in anisotropic materials. Nat. Commun. 11, 1–6 (2020).

Exploring new scientific frontiers using programmable atom arrays

Giulia Semeghini

Harvard University, Cambridge MA, USA

semeghini@fas.harvard.edu

Abstract

Learning how to create, study, and manipulate highly entangled states of matter is key to understanding exotic phenomena in condensed matter and high energy physics, as well as to developing useful quantum computers.
In this talk, I will discuss recent experiments where we demonstrated the realization of a quantum spin liquid phase using Rydberg atoms on frustrated lattices [1] and a new architecture based on the coherent transport of entangled atoms through a 2D array [2]. Combining these results with novel technical tools on atom array platforms could open a broad range of possibilities for the exploration of entangled matter, with powerful applications in quantum simulation and information.

References

[1] G. Semeghini, H. Levine, A. Keesling, S. Ebadi, T. T. Wang, D. Bluvstein, R. Verresen, H. Pichler, M. Kalinowski, R. Samajdar, A. Omran, S. Sachdev, A. Vishwanath, M. Greiner, V. Vuletic and M. D. Lukin, Science 374 (2021) 1242-1247.

[2] D. Bluvstein, H. Levine, G. Semeghini, T. T. Wang, S. Ebadi, M. Kalinowski, A. Keesling, N. Maskara, H. Pichler, M. Greiner, V. Vuletic and M. D. Lukin, Nature 604 (2022) 451-456.

Figures

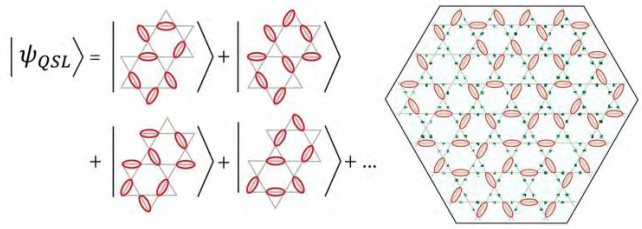


Figure 1: A quantum spin liquid state is generated using Rydberg atoms in frustrated ruby lattices [1].

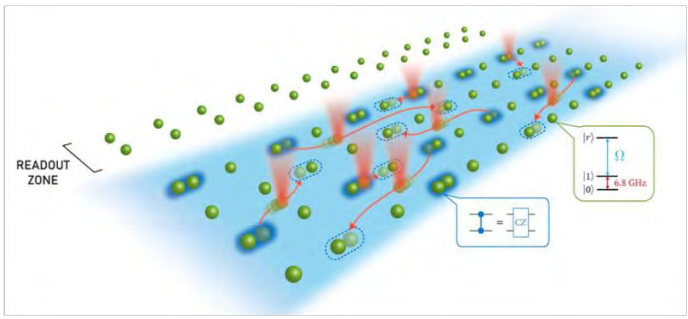


Figure 2: To achieve non-local connectivity in the quantum processor, atoms are coherently transported through the entire 2D array by means of movable optical tweezers [2].

Towards spin and valley qubits in graphene

Christoph Stampfer

[1]*JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany*

[2]*Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Jülich 52425, Germany*

stampfer@physik.rwth-aachen,de

Graphene and bilayer graphene (BLG) are attractive platforms for quantum circuits with potential applications in the area of quantum information. This has motivated substantial efforts in studying quantum dot devices based on graphene and bilayer graphene. A major challenge in this context is the missing band-gap in graphene, which does not allow to confine electrons by means of electrostatics making displacement field-gapped BLG particularly interesting.

Here we present gate-controlled single and double quantum dots in electrostatically gaped BLG [1-5]. We show a remarkable degree of control of our devices, which allow realizing electron-hole and electron-electron double quantum dot systems with single-electron occupation. In both, the single and double quantum dot devices, we reach the very few electron/hole regime, we are able to extract excited state energies and investigate their evolution in a parallel and perpendicular magnetic field. Finally, I will show data on BLG quantum dots allowing investigating the spin-valley coupling in bilayer graphene [4] as well as spin lifetimes [5]. Our work paves the way for the implementation of spin and valley-qubits in graphene.

References

[1] L. Banszerus, B. Frohn, A. Epping, D. Neumaier, K. Watanabe, T. Taniguchi, and C. Stampfer, Nano Lett. 18, 4785 (2018)

[2] L. Banszerus, S. Möller, E. Icking, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nano Lett. 20, 2005 (2020)

[3] S. Möller, L. Banszerus, A. Knothe, C. Steiner, E. Icking, S. Trellenkamp, F. Lentz, K. Watanabe, T. Taniguchi, L. Glazman, V. Fal'ko, C. Volk, and C. Stampfer, Phys. Rev. Lett. 127, 256802 (2021)

[4] L. Banszerus, S. Möller, C. Steiner, E. Icking, S. Trellenkamp, F. Lentz, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nature Communications 12, 5250 (2021)

[5] L. Banszerus, K. Hecker, S. Möller, E. Icking, K. Watanabe, T. Taniguchi, C. Volk, and C. Stampfer, Nature Communications in press - arXiv: 2110.13051 – (2022)

Figure

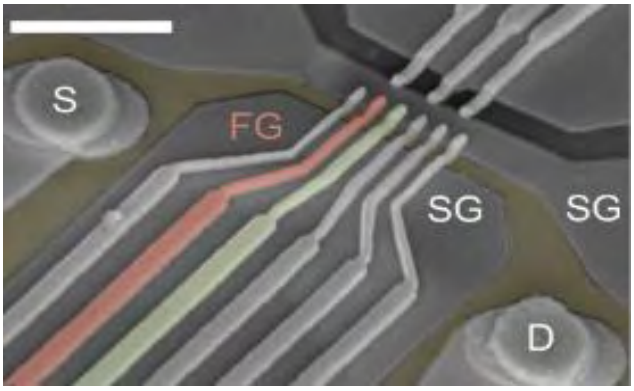


Figure 1: False-color scanning electron image of a bilayer graphene quantum dot device. The scale bar corresponds to 1 micrometer.

Quantum network technology – the second life of rare-earth crystals

Wolfgang Tittel

Delft University of Technology, QuTech and Kavli Institute of Nanoscience, Lorentzweg 1, 2628 CJ Delft, The Netherlands
University of Geneva, Department of Applied Physics, Rue de l'école de médecine 20, 1211 Geneva 4, Switzerland
Schaffhausen Institute of Technology in Geneva, Rue de l'école de médecine 20, 1211 Geneva 4, Switzerland

w.tittel@tudelft.nl

Starting with the demonstration of lasing more than 50 years ago, the special properties of rare-earth crystals and glasses have given rise to the development of numerous solid-state lasers and amplifiers, which are crucial for the functioning of today's Internet. As a fascinating generalization of their use in optical communication infrastructure, it became clear during the past decade that, when cooled to cryogenic temperatures of a few Kelvin, rare-earth crystals also promise the creation of technology for quantum communication networks [1].

I will discuss recent advances towards the development of key ingredients of such networks: the reversible storage of quantum states of light in large ensembles of rare-earth ions (fig. 1) [2], as well as the creation of single photons using individual emitters coupled to a nanophotonic cavity (fig 2) [3,4]. This is interesting from a fundamental point of view, and paves the path towards a quantum repeater, which will ultimately enable quantum communications over arbitrary distances [5].

References

[1] K. Heshami, D. G. England, P. C. Humphreys, P. J. Bustard, V. M. Acosta, J.Nunn & B. J. Sussman, J. Mod. Opti. 63, 2005 – 2028 (2016)

[2] M. Falamarzi Askarani, A. Das, J. H. Davidson, G. C. Amaral, N. Sinclair, J. A. Slater, S. Marzban, C. W. Thiel, R.L. Cone, D. Oblak & W. Tittel, Phys. Rev. Lett. 127, 220502 (2002)

[3] T. Zhong, J. M. Kindem, J. G. Bartholomew, J.Rochman, I. Craiciu, Varun Verma, S. W. Nam, F. Marsili, M. D. Shaw, A. D. Beyer, & A.Faraon, Phys. Rev. Lett. 121, 183603 (2018).

[4] A. M. Dibos, M. Raha, C. M. Phenicie, & J. D. Thompson, Phys. Rev. Lett. 120, 243601 (2018)

[5] N. Sangouard, C. Simon, H. de Riedmatten, & N. Gisin, Rev. Mod. Phys. 83, 33 (2011)

Figures

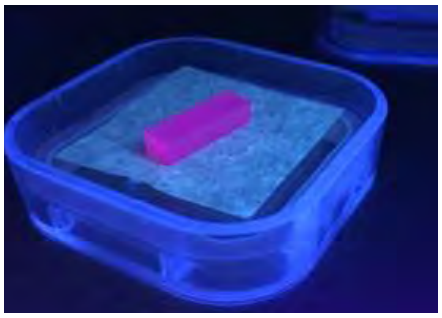


Figure 1: A Tm:$Y_3Ga_5O_{12}$ crystal used for storing quantum states of light.

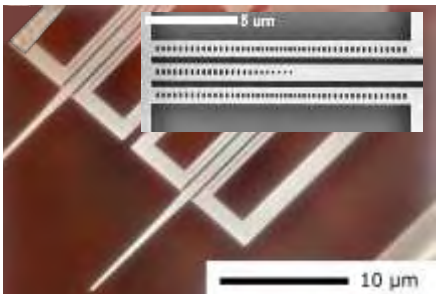


Figure 2: Silicon nano-photonic cavity on Er:$LiNbO_3$ (in collaboration with S. Gröblacher).

Designer van der Waals Heterostructures by proximity phenomena

Sergio O. Valenzuela[1,2]

1 Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain
2 Catalan Institute of Nanoscience and Nanotechnology ICN2, CSIC and the Barcelona Institute of Science and Technology (BIST), Bellaterra, 08193 Barcelona, Spain

SOV@icrea.cat

The atomically thin nature of 2D materials promotes the design of van der Waals heterostructures by proximity effects, which originate from short-range interactions [1]. This designer approach is particularly compelling for spintronics, devices, which usually harness their functionalities from thin layers of magnetic and non-magnetic materials and the interfaces between them [2] (Figure 1). In this talk, I will introduce our approach to discern proximity effects by means of spin transport dynamics, as reflected in spin relaxation anisotropy [3] and charge to spin interconversion [4]. I will also discuss the relevance of crystal symmetry and how low symmetry systems can result in unconventional charge to spin conversion components [4].

References

[1] J. F. Sierra *et al.*, Nature Nano. 16, 856–868 (2021)
[2] H. Yang, S O. Valenzuela *et al.*, Nature (2022)
[3] L. A. Benítez *et al.*, Nature Phys. 14 (2018); APL Materials 7, 120701 (2019)
[4] L. A. Benítez *et al.*, Nature Mater. 19, 170 (2020)
[5] L. Camosi *et al.*, 2D Mater. (2022) https://doi.org/10.1088/2053-1583/ac6fec

Figures

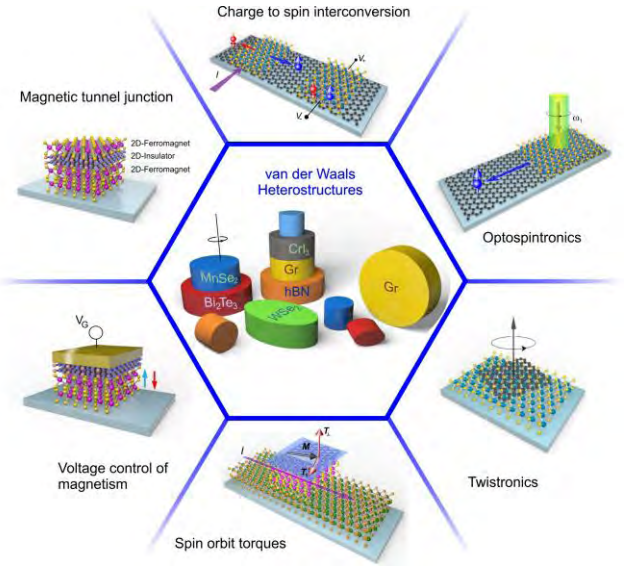


Figure 1: Spintronic devices can gain desired functionalities by stacking selected 2D materials and by proximity effects

High-throughput simulations of topological materials

Maia G. Vergniory

1.Max Planck for the Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany
2.Donostia International Physics Center, Paseo Manuel de Lardizabal, 20018 Donostia-San Sebastian, Spain

Maia.vergniory@cpfs.mpg.de

Since the theoretical proposal of the first 2D and 3D topological insulators (TIs) more than 15 years ago, solid-state realizations of topological materials have been discovered at a rapid pace. The recently developed theories of Topological Quantum Chemistry and Symmetry-Based Indicators (SIs), based on symmetry eigenvalues and irreducible representations have in particular facilitated high-throughput materials discovery and revealed that topological phases in band structures are more common than originally thought [1]. Indeed, over half of all of the known stoichiometric, solid-state, nonmagnetic materials are topological at the Fermi level, over 85% of the known stoichiometric materials host energetically isolated topological bands, and that just under 2/3 of the energetically isolated bands in known materials carry the stable topology of a TI or TCI. In this talk we will introduce topological electronic materials discovery in nonmagnetic and magnetic crystalline solids from the prediction based on TQC. We have also made all our results publicly and accessible through the Topological Materials Database (https://topologicalquantumchemistry.com/) [2].

References

[1] M.G. Vergniory, L. Elcoro, C. Felser, N. Regnault, B.A. Bernevig, Z. Wang , "A complete catalogue of High- Quality Topological Materials ", Nature 566, 480-485 (2019)

[2] All topological bands of all stoichiometric materials, Maia G Vergniory, Benjamin J Wieder, Luis Elcoro, Stuart SP Parkin, Claudia Felser, B Andrei Bernevig, Nicolas Regnault, Accepted in Science (2022), arXiv preprint arXiv:2105.09954

Figures

Figure 1: Homepage of the https://topologicalquantumchemistry.com

Realizing Repeated Quantum Error Correction in a Surface Code with Superconducting Circuits

Andreas Wallraff

Department of Physics, ETH Zurich, Switzerland

wallraff.office@phys.ethz.ch

Abstract

Quantum computers hold the promise of solving computational problems which are intractable using conventional methods. For fault-tolerant operation quantum computers must correct errors occurring due to unavoidable decoherence and limited control accuracy. In this talk, I will discuss quantum error correction implemented using the surface code, which is known for its exceptionally high tolerance to errors. Using 17 physical qubits in a superconducting circuit we encode quantum information in a distance-three logical qubit building up on recent distance-two error detection experiments [1]. In an error correction cycle taking only 1.1µs, we demonstrate the preservation of four cardinal states of the logical qubit. Repeatedly executing the cycle, we measure and decode both bit- and phase-flip error syndromes using a minimum-weight perfect-matching algorithm in an error-model-free approach and apply corrections in postprocessing. We find a low error probability of 3% per cycle when rejecting experimental runs in which leakage is detected [2]. The measured characteristics of our device agree well with a numerical model. Our demonstration of repeated, fast and high-performance quantum error correction cycles, together with recent advances in ion traps, support our understanding that fault-tolerant quantum computation will be practically realizable.

References

[1] C. K. Andersen et al., Nature Physics 16, 875–880 (2020)

[2] S. Krinner, N. Lacroix et al., arXiv:2112.03708 [quant-ph] (2021)

Figures

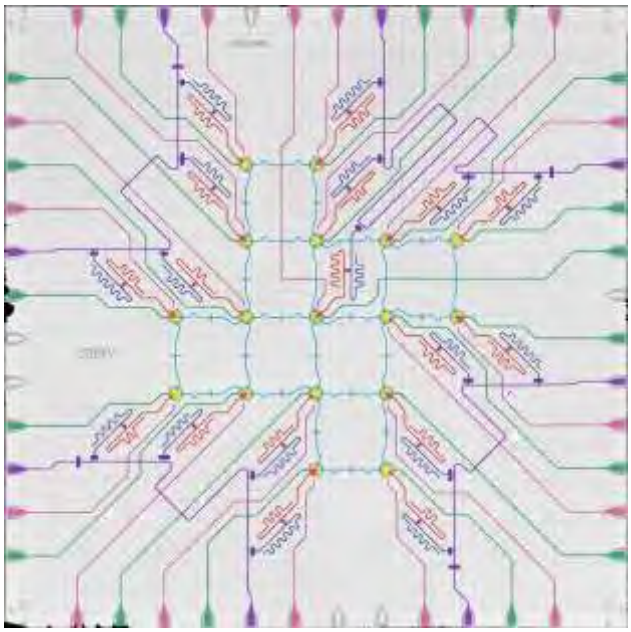


Figure 1: False-colour micrograph of a superconducting circuit with 17 qubits used for realizing quantum error correction in the surface code.

Van der Waals Materials for Superconducting Quantum Technology

Joel I-Jan Wang

Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

joelwang@mit.edu

Abstract

Van der Waals (vdW) materials – a family of layered materials including semi-metals, insulators, semiconductors, ferromagnetic materials, superconductors, and topological insulators - can be assembled in specific arrangements to create new electronic devices called vdW heterostructures. The extraordinary and versatile electronic properties of these heterostructures, in combination with their epitaxial precision, make vdW-based devices a promising alternative for constructing key elements of novel solid-state quantum computing platforms. In this talk, I will discuss hybrid superconducting quantum circuits made with vdW heterostructures, with relevance to advancing or complementing existing quantum technologies. In particular, we study the dielectric loss of hexagonal boron nitride (hBN) thin films in the microwave regime by measuring the quality factor of parallel-plate capacitors (PPCs) made of $NbSe_2$-hBN-$NbSe_2$ heterostructures integrated into superconducting circuits. The extracted microwave loss tangent of hBN is bounded to be at most in the mid-10^{-6} range in the low temperature, single-photon regime. We integrate hBN PPCs with aluminum Josephson junctions to realize transmon qubits with coherence times reaching 25 μs, consistent with the hBN loss tangent inferred from resonator measurements. The hBN PPC reduces the qubit feature size by at least two-orders of magnitude compared to conventional all-aluminum coplanar transmons, while exhibiting a high energy participation that helps to reduce unwanted qubit cross-talk. Such a lumped element device made with vdW materials is elemental for building all-vdW, merged-element qubits for extensible quantum computing schemes.

References

[1] J. I-J. Wang, D. Rodan-Legrain et al., Nature Nanotechnology 14 (2019) 120-125.

[2] J. I-J. Wang, M. A. Yamoah et al., Nature Materials 21 (2022) 398–403.

Figures

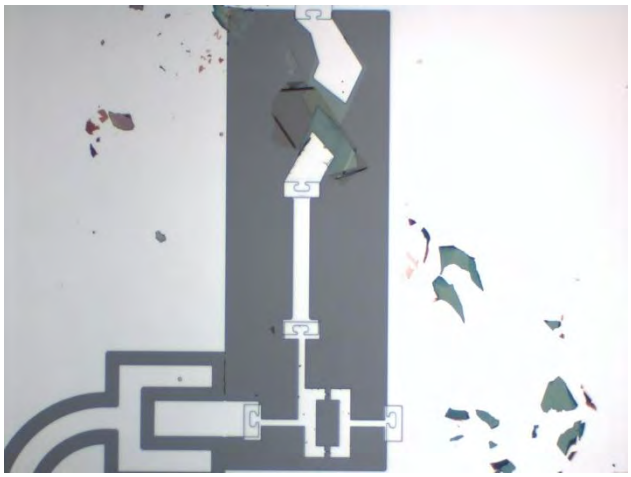


Figure 1: Parallel plate capacitor (PPC) made with $NbSe_2$-hBN-$NbSe_2$ heterostructures. The lumped element device serves as a shunt capacitor for a transmon qubit.

INDUSTRIAL FORUM

High-performance Control Systems for State-of-the-art Quantum Computing

Marc Almendros
Diego Riste, Joel Wallman

Keysight Technologies, 1400 Fountaingrove Pkwy, Santa Rosa, CA 95403, United States

marc.almendros@keysight.com

The continuous and fast progress on quantum information science is pushing the limits of electronic control systems, which requirements are getting more and more technologically challenging.
Some of these requirements are: very good signal quality, to achieve higher gate fidelities and lower crosstalk; high scalability and low footprint, to control hundreds of qubits simultaneously; real-time FPGA-based processing, for speed and for fast feedback applications -such as qubit reset or Quantum Error Correction (QEC)-; easy-to-use programming models, to allow users to focus on quantum science and Quantum Information Processing (QIP); and state-of-the-art error mitigation techniques and benchmarking, to unleashed the full capabilities of Noisy Intermediate-Scale Quantum (NISQ) processors.
In this talk we will discuss those challenges and how they can be addressed with the technological components of a modern control system stack.

Figures

Figure 1: A modular and scalable control system hardware

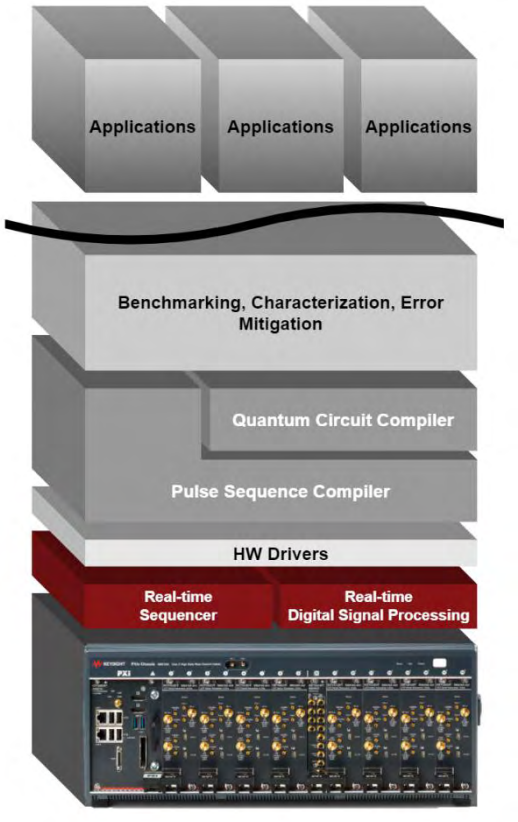


Figure 2: A full software stack solution for control systems

Quantum Computing at Google

Sergio Boixo

Google Quantum AI, 340 Main St., Los Angeles, CA 90291, USA

boixo@google.com

I will review recent work from the Google Quantum AI group. The long term goal of the group is to build a fault tolerant universal quantum computer [1]. Nevertheless, present day experimental NISQ quantum processors remain a powerful platform for scientific applications. Recent demonstrations include the observation of Time-Crystalline Eigenstate Order [2], and the validation of a promising new hybrid quantum-classical algorithm for quantum chemistry [3].

References

[1] Google Quantum AI, Nature, 595 (2021) 383.
[2] Xiao Mi. et. al., Nature, 601 (2021) 531.
[3] W. J. Hugginset. al., arXiv:2106.16235 (2021).

Figures

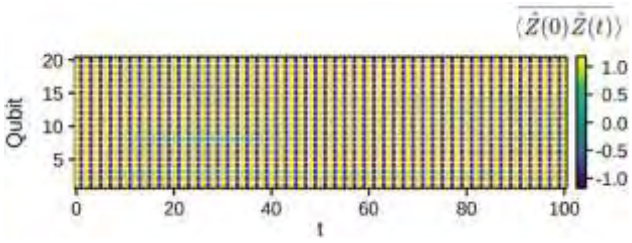


Figure 1: Autocorrelation versus time in a time-crystal experiment. The persistence of correlations over time is indicative of the observation of a time crystal [1].

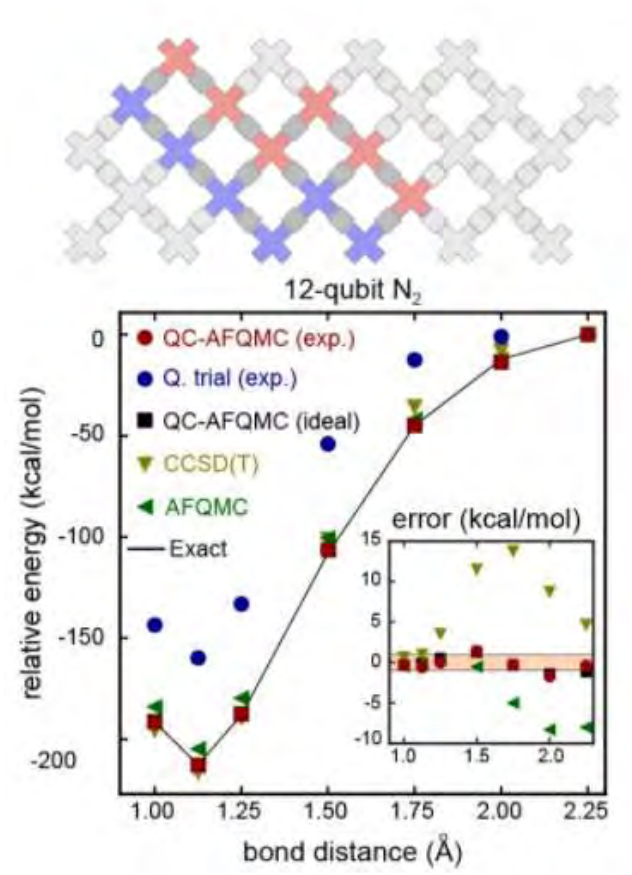


Figure 2: Potential energy surface of N2
Inset shows the error in total energy relative to the exact results in kcal/mol.
We see that a hybrid quantum-classical algorithm (QC-AFQMC) outperformed other state of the art algorithms [2].

Fully-integrated control stacks for quantum computing in the NISQ era

Cornelis Christiaan Bultink
M. Tiggelman, J. Gloudemans, D. de Jong, Y. B. Kalyoncu, J. van Oven

Qblox BV, Elektronicaweg 10, Delft, The Netherlands. contact: hello@qblox.com

Abstract

Reaching NISQ applications hinges on improvements in the gate fidelity and qubit number. Qblox supports this with time-efficient, ultralow-noise, and cost-effective control stacks. We introduce the Cluster system which incorporates up to 120 Q1 processors capable of sequencing pulses, their parameters, and measurement operations in real time [1]. This architecture speeds up experiments by orders of magnitude as it avoids the overhead caused by software-controlled loops. This speed-up is realized by multi-parameter real-time pulse modification and by on-board data processing (integrating, averaging, binning) of readout signals and storing up to 131072 measurement results per experimental run. The state-of-the-art signal noise level (14 nV/√Hz @ 1 MHz and 5 Vpp) supports improved gate fidelities and the low gain and offset drift (a few ppm/K) reduces the need for recalibrations. The Cluster supports many qubit platforms [2] with its wide frequency range from DC to 18.5 GHz while occupying less volume than 1 liter per controlled qubit. Quantify -an open-source python framework- manages the hardware stack, which allows hybrid scheduling of gate-level and pulse-level descriptions [3]. This full-stack approach opens a fast track for gate optimizations and scaling efforts towards running NISQ applications.

References

[1] W. Vlothuizen et al. (TU Delft, APS MM P48.014, 2016)
[2] Y. B. Kalyoncu et al. (Qblox, APS MM B35.00010, 2022)
[3] The Quantify-Scheduler

Figures

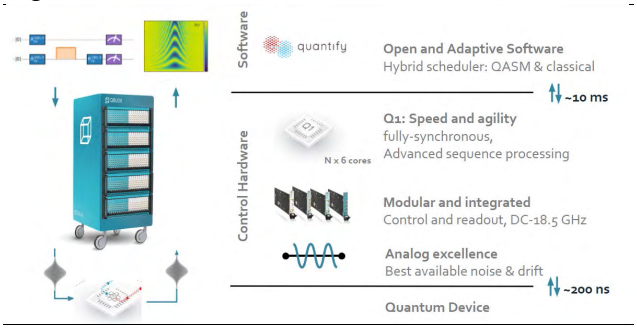


Figure 1: Qblox fully-integrated control stacks provide 4 synergistic hardware and software layers for the fastest, smallest and lowest-noise control. By directly inputting and outputting pulses in the range of DC to 18.5 GHz experimental setups are simple and scalable.

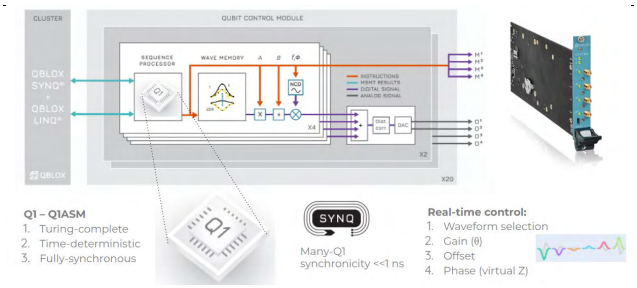


Figure 2: The control flow in the control stack is at the heart executed by the distributed Q1 processor cores (up to 120 per Cluster). These Turing-complete and time-deterministic cores operate in full synchronicity and allow for fast and independent experiment execution with real-time parameterization of pulse properties.

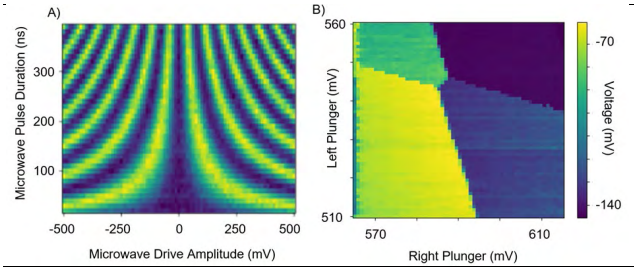


Figure 3: Examples where order-of-magnitude speed-ups are achieved through real-time on-board compiling and on-board data analysis. A) Chevron plot for tuning the pulse amplitudes and duration of a transmon qubit, measured in 23 seconds (IMPAQT consortium) B) Charge stability diagram for tuning a Si double-dot sample, measured in 180 ms (Qutech).

Quantum Natural Language Processing & Compositional Intelligence

Bob Coecke

Cambridge Quantum / Quantinuum

bob.coecke@cambridgequantum.com

Our Oxford-based CQ-team first performed Quantum Natural Language Processing (QNLP) on an IBM quantum computer [1a, 1b], and more recently also did so our own trapped ion hard- ware. Key to having been able to achieve what is conceived as a heavily data-driven task, is the observation that quantum theory and natural language are governed by much of the same compositional structure – a.k.a. tensor structure.

Hence our language model is in a sense quantum-native, and we provide an analogy with simulation of quantum systems in terms of algorithmic speed-up [forthcoming]. Meanwhile we have made all our software available open-source, and with support [github.com/CQCL/lambeq].

We will also introduce the notion of compositional intelligence, exploiting the fact that the compositional match between natural language and quantum extends to other, such as patio-temporal perception and embodiment [2a, 2b], we will argue that a new generation of AI can emerge when fully pushing this analogy, while exploitingthe completeness of categorical quantum mechanics / ZX-calculus [3a, 3b] for novel reasoning purposes that go hand-in-hand with modern machine learning.

References

[1a] BC, G. De Felice, K. Meichanetzidis, A. Toumi (2020) Foundations for Near-Term Quantum Natural Language Processing. https://arxiv.org/abs/2012.03755

[1b] R. Lorenz, A. Pearson, K. Meichanetzidis, D. Kartsaklis, BC (2020) QNLP in Practice: Running Compositional Models of Meaning on a Quantum Computer. https://arxiv.org/abs/2102.12846

[2a] V. Wang, BC (2021) Talking Space: inference from spatial linguistic meanings. https://arxiv.org/abs/2109.06554

[2b] BC (2021) Compositionality as we see it, everywhere around us. https://arxiv.org/abs/2110.05327

[3a] BC, A. Kissinger (2017) Picturing Quantum Processes. A first course on quantum theory and diagrammatic reasoning. Cambridge University Press.

[3b] BC, D. Horsman, A. Kissinger, Q. Wang (2021) Kindergarden quantum mechanics graduates (...or how I learned to stop gluing LEGO together and love the ZX-calculus). https://arxiv.org/abs/2102.10984

Accelerating the Expedition to our Quantum Future with Quantum-Classical Control

Yonatan Cohen

Quantum Machines, Israel

The journey towards practical large-scale quantum computers will traverse many challenging obstacles. Integrating quantum and classical computation at the very core of the control architecture is a necessary capability. Quantum Machines' Quantum Orchestration Platform equips researchers and developers with the most advanced quantum-classical integration available today and provides the development productivity and flexibility required to continuously advance the state-of-the-art. In this talk, we will explore how this integration is impacting the expedition towards quantum advantage and fault-tolerant quantum computers..

Useful Quantum Software for Today's Processors

Román Orús

Multiverse Computing, Paseo de Miramon 170 20004 San Sebastián, Spain

DIPC, Paseo Manuel de Lardizabal 4, 20018 San Sebastián, Spain

Ikerbasque Foundation for Science, Maria Diaz de Haro 3, 48013 Bilbao, Spain

roman.orus@multiversecomputing.com

In this talk I will explain the approach that we are taking at Multiverse Computing in order to bring useful quantum software developments for the masses. I will sketch briefly recent results on optimization, machine learning, and quantum-enhanced Monte Carlo (via quantum amplitude estimation), to a variety of problems in finance and other verticals, using real data.

Carbon nanotube spin qubit

Matthieu DESJARDINS

C12, 6 rue Jean Calvin, 75005 Paris, France

hello@c12qe.com

Abstract

Semiconductors hosted qubits have a promising path to scalability relying on two well-established industries: the silicon one and the microwave one. Among them spin qubits have recently shown high fidelity gates. [1,2,3]

One major challenge is yet the extreme sensitivity of the qubits to the host material. Thanks to their unique physical properties, I will show that carbon nanotubes are seen as promising candidates for hosting a qubit with reduced decoherence channels as well as long range interactions [4-6].

References

[1] J. Yoneda, Nature Nanotech 13, 102–106 (2018)

[2] D. Loss and D. P. DiVincenzo, Phys. Rev. A 57, 120 (1998)

[3] X. Xue, M. Russ, N. Samkharadze, B. Undseth, A. Sammak, G. Scappucci, and L. M. K. Vandersypen, Nature 601, 343 (2022)

[4] A. Cottet and T. Kontos, Physical Review Letters 105, 1 (2010),

[5] J. J. Viennot, M. C. Dartiailh, A. Cottet, and T. Kontos, Science 349, 408 (2015)

[6] T. Cubaynes, M. R. Delbecq, M. C. Dartiailh, R. Assouly, M. M. Desjardins, L. C. Contamin, L. E. Bruhat, Z. Leghtas, F. Mallet, A. Cottet, and T. Kontos, npj Quantum Information 5, 2 (2019)

Figures

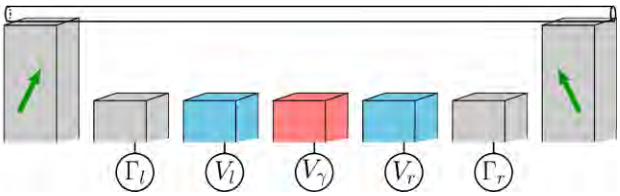


Figure 1: Schematic of the carbon nanotube lying on Source & Drain electrodes and suspended above non-collinear magnetic electrodes (gate electrodes)

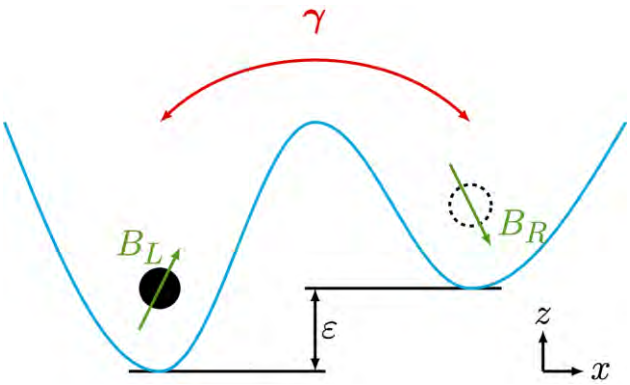


Figure 2: Schematic of the carbon nanotube spin qubit. A single electron trapped in a double potential well (blue curve). The detuning between the left and right wells is ε while the tunneling rate between the dots is γ. An inhomogeneous static magnetic field is applied.

Covalent: A tool for orchestrating large scale heterogeneous scientific workflows

Oktay Goktas PhD

Agnostiq, OneEleven, 325 Front St W, Toronto, ON M5V 2Y1, Canada

oktay@agnostiq.ai

Abstract

Covalent is an open-source workflow orchestration platform designed to help users manage and execute tasks on high performance and quantum computing resources. Covalent is a cross-platform, cross-language pythonic tool and includes a browser-based user interface to visualize, monitor and reproduce workflows across a wide spectrum of hardware resources. Covalent is developed and maintained by the team at Agnostiq. You can learn more at the Covalent website [1] or by visiting the github repository [2] to see the code.

References

[1] Agnostiq (2022), Covalent www.covalent.xyz.

[2] Agnostiq (2022), Covalent [Source code] https://github.com/AgnostiqHQ/covalent

Figures

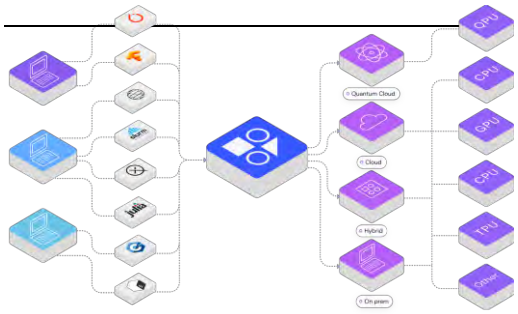


Figure 1: Users of quantum & HPC must work in a complex landscape due to numerous hardware modalities & software frameworks. To reduce effort & costs, users abstract away that complexity via a single interface, unifying hardware types, instances, environments & languages.

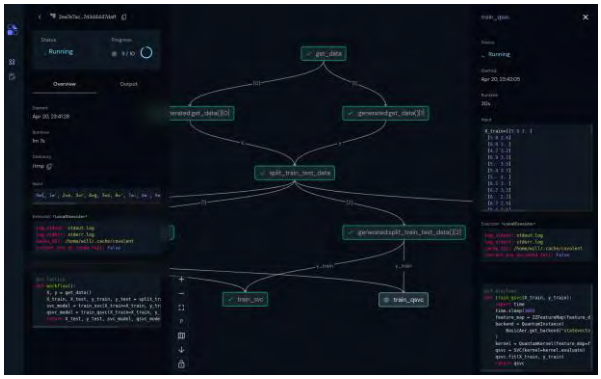


Figure 2: The dependency graph of tasks within a workflow is useful to both the user & the computer to parallelize operations. Independent tasks may be executed concurrently. The Covalent UI displays the execution progress of each workflow at the level of individual tasks.

A QCCD trapped-ion quantum computer: the early days

David Hayes
Co-authors: everyone at Quantinuum

Quantinuum, 303 S. Technology Ct. 80021 Broomfield, CO, USA

David.Hayes@Quantinuum.com

The quantum charge coupled device (QCCD) architecture is the foundational concept behind a scalable quantum computer based on mobile trapped-ions [1]. The architecture posits that by using ion transport, large-scale devices can be realized while maintaining the high-fidelity primitive operations achieved in ideal environments. The crucial technical ingredients include a scalable trap fabrication concept (Fig. 1), fine-grained control of the electromagnetic trapping fields to collect and isolate ions, the ability to remove mechanical energy from the system without disturbing stored quantum information, and localized regions used for quantum operations. Once these ingredients are combined, this system is fully-connected and can execute high-fidelity dynamic quantum circuits while minimizing any circuit overhead [2].

The Quantinuum system model H1 quantum computer is available to outside users through cloud access. In this talk, I'll present our latest internal benchmarking at both the individual component and the holistic levels. Component benchmarking includes variants of randomized benchmarking of single-qubit and two-qubit gate operations [2], mid-circuit measurements, and transport characterization. System level benchmarking includes crosstalk characterization of gates and mid-circuit measurements [3], quantum volume measurements [4](Fig. 2), and tests of chief algorithms such as quantum simulation [5] and quantum error correction [6].

Finally, I will report on recent advancements that should enable performance enhancements in future systems.

References

[1] Wineland, D. J. et al., J. Res. Natl. Inst. Stand. Technol., 103 (1998) 259-328
[2] Pino, J. M., Nature, 592 (2021) 209-213
[3] Gaebler, J. P., PRA, 104 (2021) 062440
[4] Baldwin, C.H., arXiv:2110.14808 (2021)
[5] Foss-Feig, M., PRL, 128 (2022) 150504
[6] Ryan-Anderson, C., PRX, 11 (2021) 041058

Figures

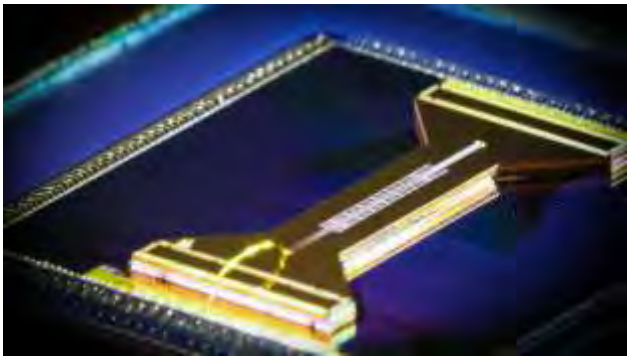


Figure 1: The trap fabricated by Honeywell that serves as the heart of Quantinuum's system model H1 quantum computer.

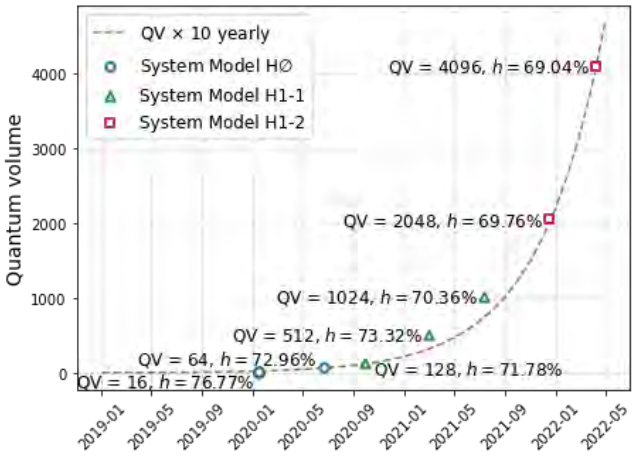


Figure 2: Quantum volume measurements on Quantinuum H-series quantum computers.

Quantum evolution kernel: Machine learning on graphs with programmable arrays of qubits

Loic Henriet
Louis-Paul Henry, Slimane Thabet, Constantin Dalyac

PASQAL, 7 rue Leonard de Vinci, 91130 Massy, France

loic@pasqal.com

The rapid development of reliable Quantum Processing Units (QPU) opens up novel computational opportunities for machine learning. Here, we introduce a procedure for measuring the similarity between graph-structured data, based on the time-evolution of a quantum system. By encoding the topology of the input graph in the Hamiltonian of the system, the evolution produces measurement samples that retain key features of the data. We study analytically the procedure and illustrate its versatility in providing links to standard classical approaches.

We then show numerically that this scheme performs well compared to standard graph kernels on typical benchmark datasets. Finally, we study a concrete implementation on a realistic neutral-atom quantum processor.

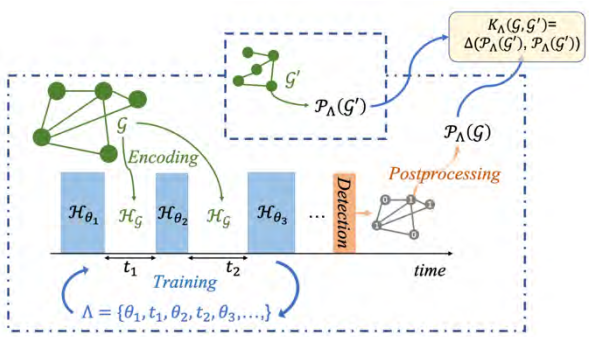


Figure 1: Schematics of the feature map at the heart of the
QE kernel.

References

[1] Henry, Thabet, Dalyac, Henriet, Phys. Rev. A 104, 032416 (2021)

HPC use cases for quantum computing

Michael Marthaler

HQS Quantum Simulations, Germany

michael.marthaler@quantumsimulations.de

Solving quantum mechanical problems is a major use case for high performance computing centers. This makes the integration of quantum computers a natural goal. In this presentation we will discuss the different quantum mechanical problems of interest and how HQS software makes NISQ computers useful in these areas.

At the intersection between quantum networking and quantum computing

Carmen Palacios-Berraquero

Nu Quantum, Uk

carmen@nu-quantum.com

Quantum computing will deliver a huge leap forward in computation and the ability to solve classes of complex problems beyond the reach of even the most powerful digital super-computers. However, at the moment there is a limit to how big a single quantum computer can scale, and this is exacerbated by the need for error correction. Analogous to the high-speed busses and networking needed for classical computing, high-performance photonic interconnections between QC nodes will be required to unlock the power of quantum computers in the medium-term, and are a comparatively unexplored yet key feature of the majority of industrial QC roadmaps.

Quantum Computing – Prospects and Challenges

Heike Riel

IBM Research, Säumerstrasse 4, 8803 Rüschlikon, Switzerland

hei@zurich.ibm.com

The field of quantum computing has evolved into a large interdisciplinary community where significant resources are invested worldwide. As a result, accelerated progress is achieved and we are at the beginning of a new age of computation, developing programmable quantum systems towards universal quantum computers. Quantum computers promise to solve certain mathematical problems that are intractable to classical computers.

Quantum computing systems are built from the bottom up reaching the limits of what can be classically simulated. The IBM Quantum Development Roadmap describes our vision of creating a quantum computing ecosystem delivering quantum applications through the cloud. This requires developing the entire quantum computing stack starting from the qubit and quantum processor technology, control electronics to software, algorithms and applications for quantum computing, implemented in the cloud and integrated with high performance computing.

In this presentation the recent developments of our quantum computing systems and the scientific advances that enabled scaling superconducting quantum processors to 127 qubits and beyond are presented. Besides scale, also quality and speed will be discussed building the key metric for measuring the performance of quantum computation. Examples of applications where the computational power of quantum computing could make a difference are provided.

Optical quantum computing with solid-states quantum light emitters

Niccolo Somaschi

Quandela, 7 rue Leonard de Vinci, Massy, France

niccolo.somaschi@quandela.com

Optical quantum computing has been shown to present several fundamental advantages compared to other approaches [1], mostly for its built-in connectivity and for the possibility to leverage well established technologies, like the photonic & telecom industry combined with the capability of large fabrication of integrated photonic circuit in top-tier foundries.

Full monolithic designs [2,3] have been proposed but the type of probabilistic qubit generators implemented, require complex resources parallelization and large processed wafer surfaces uniquely for efficient single-photon generation; the approach requires fabrication challenges, structure complexity and increasing amount of needed resources to scale the number of qubits.

By implementing solid-state sources of quantum light which can provide near-deterministic single-photon generation [4] we develop modular quantum computing platforms which are intrinsically interconnected and guarantee low resource complexity while scaling the computing power. Besides, the possibility of cluster states generation from a single device [5,6] permit to develop architectures which fully exploit the scalability of measurement-based quantum computing approaches.

In the talk I present the technology implemented in Quandela, and show examples of first quantum computing machines; I will also present some examples of protocols and software developed to provide the additional layers required to operate such QC machines.

References

[1] H. S. Zhong et al., Science, volume 370, (2020), 1460
[2] J. M. Arazzola et al., Nature 591, (2021) 54–60
[3] S. Bartolucci et al. Arxiv 2109/13760 (2021).
[4] N. Somaschi, Nat.Photon., 10 (2016) 340
[5] D. Istrati, Nat.comm., 11, (2020)
[6] D. Cogan arxiv:2108/05919, (2021)

Figure

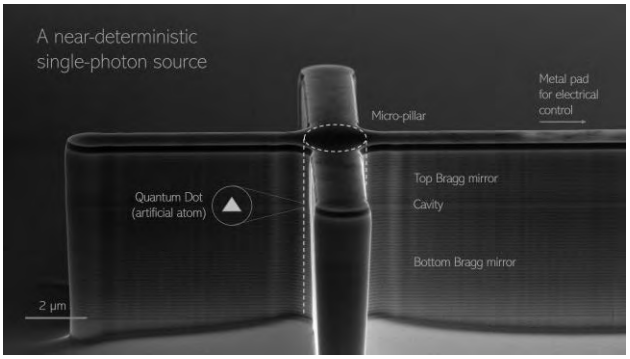


Figure 1: Solid-state quantum light source developed by Quandela

Coherent Analogue Quantum Computing - beyond the paradigm of gate based quantum computing.

Daniel Szombati

Qilimanjaro Quantum Tech. S.L., Carrer dels Comtes de Bell-Lloc, 161, 08014 Barcelona

daniel.szombati@qilimanjaro.tech

Abstract

As the full control of few-qubit systems has come to fruition in the past decade, the search has begun to engineer useful quantum processors in the NISQ era providing simulations for the industry. The most common gate-based style approach suffers from gate-errors, and can only give useful solutions if the system is fully error-corrected. We propose a different path, that of coherent analogue computing: this relies on a network of coherent flux-qubits, designed to simulate a specific quantum system. These processors can embed Hamiltonians beyond the Ising model, called non-stoquastic Hamiltonians, which are too costly for classical computers to simulate. Our approach of coherent analogue computing offers unique capabilities currently not available in the market.

ORAL PLENARY

Engineering symmetry-selective couplings of a superconducting artificial molecule to microwave waveguides

Mohammed Ali Aamir
Claudia Castillo Moreno
Simon Sundelin
Janka Biznarova
Marco Scigliuzzo
Kowshik Erappaji Patel
Amr Osman
D. P. Lozano
Simone Gasparinetti

Department of Microtechnology and Nanoscience, Chalmers University of Technology, 412 96 Gothenburg, Sweden

aamir.ali@chalmers.se

Tailoring the decay rate of structured quantum emitters into their environment opens new avenues for nonlinear quantum optics, collective phenomena, and quantum communications. Here we demonstrate a novel coupling scheme between an artificial molecule comprising two identical, strongly coupled transmon qubits, and two microwave waveguides. In our scheme, the coupling is engineered so that transitions between states of the same (opposite) symmetry, with respect to the permutation operator, are predominantly coupled to one (the other) waveguide. The symmetry-based coupling selectivity, as quantified by the ratio of the coupling strengths, exceeds a factor of 30 for both the waveguides in our device. In addition, we implement a Raman process activated by simultaneously driving both waveguides, and show that it can be used to coherently couple states of different symmetry in the single-excitation manifold of the molecule. Using that process, we implement frequency conversion across the waveguides, mediated by the molecule, with efficiency of about 95%. Finally, we show that this coupling arrangement makes it possible to straightforwardly generate spatially-separated Bell states propagating across the waveguides. We envisage further applications to quantum thermodynamics, microwave photodetection, and photon-photon gates.

References

[1] Mohammed Ali Aamir et. al., arXiv: 2202.12209

Figures

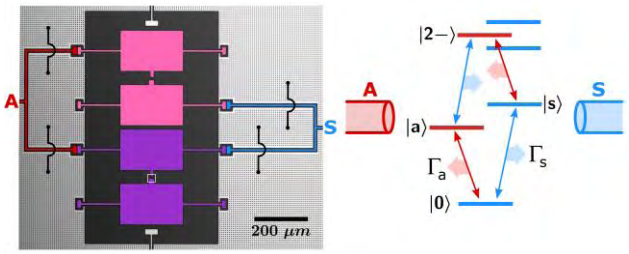


Figure 1: Device architecture and level diagram

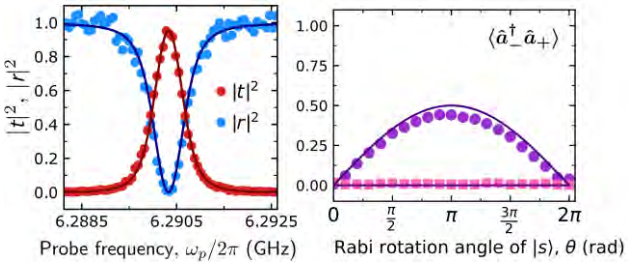


Figure 2: Two demonstrated applications; left – efficient and coherent population transfers between states of opposite symmetries, right – Formation of Bell state of two propagating modes

Hybrid classical-quantum interfaces for circuit boosts

Leandro Aolita
Roeland Wiersema, Leonardo Guerini, Renato M. S. Farias, and Juan F. Carrasquilla

Quantum Research Centre - Technology Innovation Institute, Abu Dhabi, United Arab Emirates; Mathematical Physics Department, Federal University of Rio de Janeiro, Brazil.

Leandro.Aolita@tii.ae

High-connectivity or high-depth circuits are a major roadblock for current quantum hardware. We propose hybrid classical-quantum algorithms to simulate such circuits from much shallower circuits and without swap-gate ladders. As main tool, we introduce *quantum-classical-quantum interfaces*. These cut an experimentally-problematic gate (e.g. a very long-range one) out of the circuit by random measurements and state-preparations drawn according to a classical quasi-probability simulation of the noiseless gate. As any sampling scheme based on negative quasi-probabilities, our method suffers from the infamous sign-problem. However, each interface only introduces a multiplicative statistical overhead that is independent of the on-chip qubit distance, remarkably. Hence, by applying interfaces to for instance the most long-range gates in a target circuit, significant reductions in depth (and therefore accumulated gate-infidelity) can be attained in practice. We numerically show the efficacy of our method with a Bell-state circuit for two qubits increasingly far apart on a chip, a variational ground-state solver for TF Ising model on ring lattices of increasing lengths, and with depth extensions for random circuits as well as VQEs for quantum chemistry. Our findings provide a versatile toolbox for both error-mitigation and circuit boosts tailored for noisy, intermediate-scale quantum computations.

References

1. R. Wiersema, L. Guerini, J. F. Carrasquilla, and LA, preprint: ????? (2022).
2. L. Guerini, R. Wiersema, J. F. Carrasquilla, and LA, preprint: 2112.11618 (2021).
3. G. Torlai, C. J. Wood, A. Acharya, G. Carleo, J. F. Carrasquilla, and LA, preprint: 2006.02424 (2020).
4. J. Carrasquilla, G. Torlai, R. Melko, and LA, Nature Machine Intelligence, 1 (2019), 155.

Figures

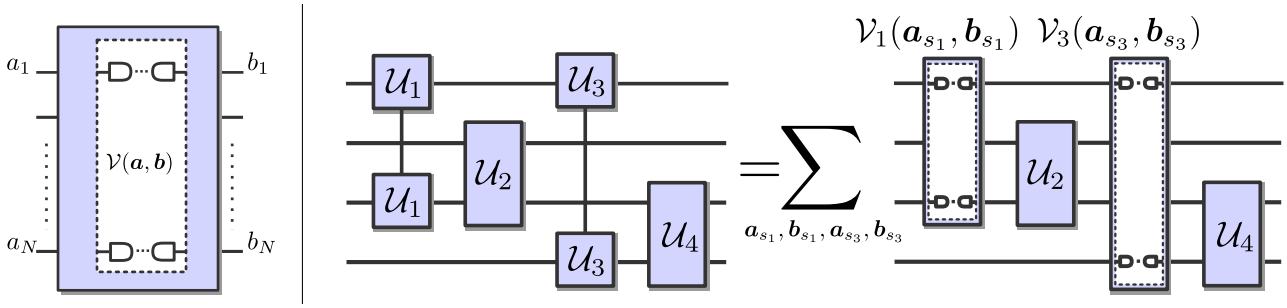


Figure 1: Schematics of our hybrid scheme. Left: A QCQ interface simulates a gate between qubits 1 and *N*. The two qubits are measured in random single-qubit bases and re-prepared in a random product state. The other *N-2* qubits are left intact. Right: A 4-qubit high-connectivity circuit is simulated with nearest-neighbour gates without swap-gate ladders, with the long-range gates substituted by QCQ interfaces. The summation represents the average over all interface outcomes sampled. The same principle can be applied to simulate entire slices of a target circuit, leading to drastic reductions in experimental-circuit depth at the expenses of a moderate statistical overhead.

Entangling a Quantum Dot Hole-Spin with a Time-Bin Photon: A Waveguide Approach for Scalable Entanglement Generation

Martin Hayhurst Appel[1,3], Alexey Tiranov[1], Simon Pabst[1], Ming Lai Chan[1], Christian Starup[1], Ying Wang[1], Leonardo Midolo[1], Konstantin Tiurev[1], Sven Scholz[2], Andreas D. Wieck[2], Arne Ludwig[2], Anders Søndberg Sørensen[1] and Peter Lodahl[1]

1. Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark
2. Lehrstuhl für Angewandte Festörperphysik, Ruhr-Universität Bochum, Bochum, Germany
3. Cavendish Laboratory, University of Cambridge, Cambridge, UK

Deterministic sources of multi-photon entanglement are essential for several quantum technologies including measurement-based quantum computing [1] and all-photonic quantum repeaters [2]. Solid state quantum dots (QDs) are an attractive platform for realizing such sources due to their excellent optical properties, the ability to host a single optically active spin qubit, and the possible integration into nanophotonic devices [3]. Here we demonstrate a new path towards on-demand Greenberger-Horne-Zeilinger and linear cluster states using a self-assembled InAs QD embedded in a photonic crystal waveguide (PCW). By combining the waveguide's polarisation selective Purcell enhancement [4] with all-optical spin control (Fig. 1(a-b)), we perform the first demonstration of entanglement between a QD hole-spin and a time-bin photon using the protocol in Fig. 1c. Using a novel self-stabilizing interferometer, we measure a 67.8% spin-photon Bell state fidelity (Fig. 1(d-e)), a 95.7% photon Hong-Ou-Mandel visibility, and a 124 Hz coincidence rate in great excess of comparable experiments with nitrogen-vacancy centres. Based on a thorough theoretical analysis and numerical simulations, we provide a path towards efficient entanglement sources capable of generating long streams of photons emitted at 10s of MHz and with photon indistinguishability suitable for achieving high fidelity fusion gates.

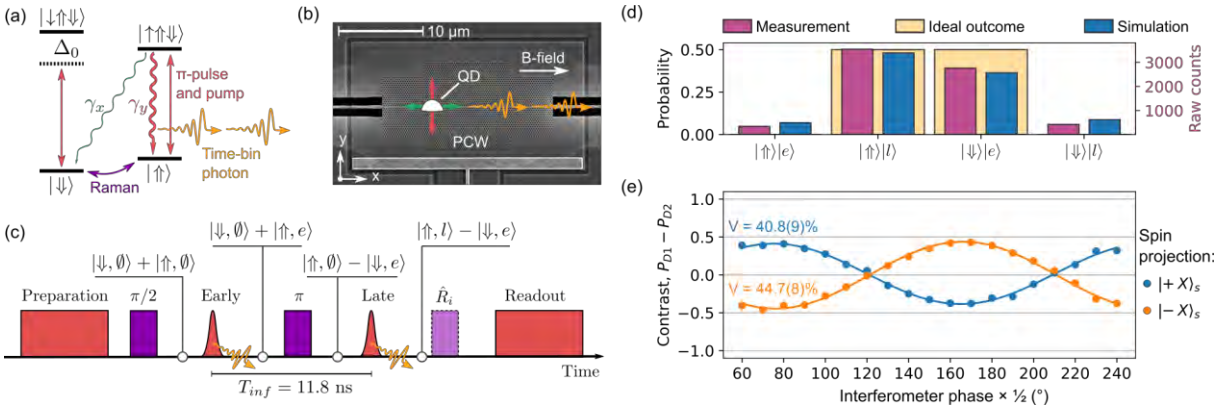


Fig. 1 (a) Positively charged QD energy level diagram. A cycling transition (red arrow) is used to emit the time-bin photon and perform spin initialization/readout, and a Raman laser coherently couples the ground state spins. (b) SEM picture of the PCW which selectively enhances the y-polarised optical dipole and provides efficient photon collection. (c) Experimental pulse sequence for Bell state generation. Ø denotes photon vacuum, and e and l denote an early or late photon emission, respectively. (d) Spin-photon correlations measured in the ZZ basis. (e) Spin-photon correlations measured in the rotated basis using a time-bin interferometer.

[1] R. Raussendorf and H. J. Briegel, Phys. Rev. Lett. 86, 5188 (2001)
[2] J. Borregaard, H. Pichler, T. Schröder, M. D. Lukin, P. Lodahl, and A. S. Sørensen, Phys. Rev. X 10, 021071(2020)
[3] P. Lodahl, S. Mahmoodian, and S. Stobbe, Rev. Mod. Phys 87, 347 (2015)
[4] M. H. Appel, A. Tiranov, A. Javadi, M. C. Löbl, Y. Wang, S. Scholz, A. D. Wieck, A. Ludwig, R. J. Warburton, and P. Lodahl, Phys. Rev. Lett. 126, 013602 (2021)

Computing Free Energies with Fluctuation Relations on Quantum Computers

Lindsay Bassman[1,*]
Katherine Klymko[1], Diyi Liu[2], Norman M. Tubman[3], Wibe A. de Jong[1]
[1]*Lawrence Berkeley National Lab, Berkeley, CA 94720*
[2]*Department of Mathematics, University of Minnesota, MN 55455*
[3]*NASA Ames Research Center, Mountain View, CA 94035*
*lbassman@lbl.gov

As a central thermodynamic property, free energy enables the calculation of virtually any equilibrium property of a physical system, allowing for the construction of phase diagrams and predictions about transport, chemical reactions, and biological processes [1]. Thus, methods for efficiently computing free energies, which in general is a difficult problem, are of great interest to broad areas of physics and the natural sciences. The majority of techniques for computing free energies target classical systems, leaving the computation of free energies in quantum systems less explored. Recently developed fluctuation relations enable the computation of free energy differences in quantum systems from an ensemble of dynamic simulations. While performing such simulations is exponentially hard on classical computers, quantum computers can efficiently simulate the dynamics of quantum systems [2]. Here, we present an algorithm utilizing a fluctuation relation known as the Jarzynski equality [3] to approximate free energy differences of quantum systems on a quantum computer. We discuss under which conditions our approximation becomes exact, and under which conditions it serves as a strict upper bound. Furthermore, we successfully demonstrate a proof-of-concept of our algorithm using the transverse field Ising model on a real quantum processor, see Figure 1. As quantum hardware continues to improve, we anticipate that our algorithm will enable computation of free energy differences for a wide range of quantum systems, providing a valuable tool for exploring thermodynamics in the quantum domain, where much remains to be discovered.

References

[1] D. A. Kofke and D. Frenkel, Handbook of Materials Modelling (2005) 683-705.
[2] S. Lloyd, Science, 273 (1996) 1073-1087.
[3] C. Jarzynski, Physical Review Letters, 78 (1997) 2690.

Figures

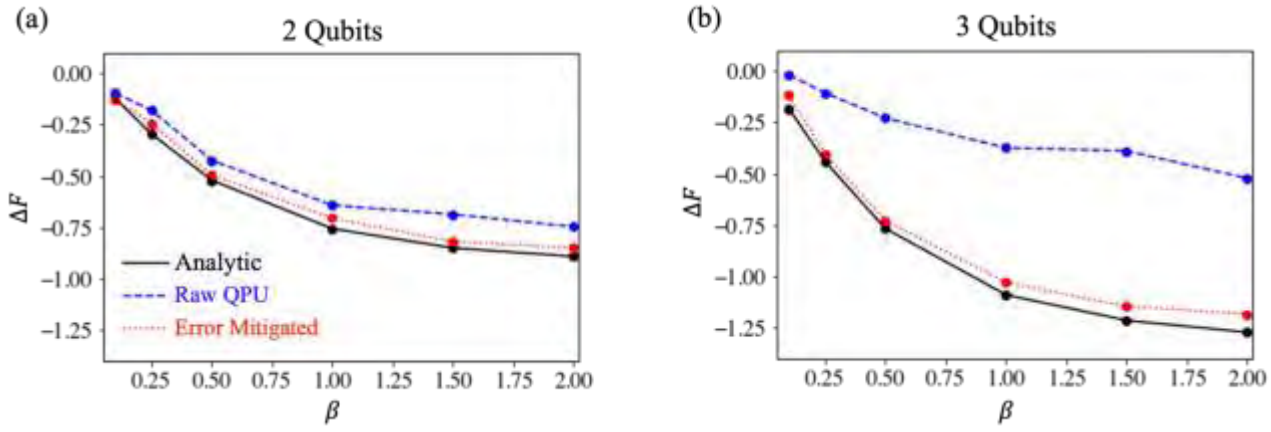


Figure 1: Approximate free energy differences for 2- and 3-qubit systems initialized at various inverse temperatures performed on an IBM quantum processing unit (QPU). The solid black line give the analytically computed values for reference. The blue dashed lines show raw results from the QPU, while the red dotted lines show these results after error mitigation has been performed.

A single hole spin with enhanced coherence in natural silicon

Presenting Author : B.Brun

Co-Authors : N. Piot[1*], B. Brun[1*], V. Schmitt[1], S. Zihlmann[1], V. P. Michal[2], A. Apra[1], J. C. Abadillo-Uriel[2], X. Jehl[1], B. Bertrand[3], H. Niebojewski[3], L. Hutin[3], M. Vinet[3], M. Urdampilleta[4], T. Meunier[4], Y.-M. Niquet[2], R. Maurand[1], S. De Franceschi[1]

1-Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France. 2-Univ. Grenoble Alpes, CEA, IRIG-MEM-L Sim, Grenoble, France. 3-Univ. Grenoble Alpes, CEA, LETI, Minatec Campus, Grenoble, France. 4-Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France.

CEA Grenoble, 17 Av des martyrs, 38000 Grenoble

boris.brun-barriere@cea.fr

Spin quantum bits in semiconductor appear to be one of the most promising technologies for the development of the quantum processor. Although electrons are the focus of modern research, holes exhibit many interesting physical properties. In particular, spin-orbit interaction allows a fully electrical control of the hole spin qubit state [1]. As a drawback, any external electric perturbation is likely to induce decoherence. Here we demonstrate for a single hole qubit in silicon the existence of sweet spots at which the qubit is decoupled from charge noise while keeping an efficient electrical driving. We first realize spin single-shot readout of the first hole accumulated in a natural silicon quantum dot made from a semi-industrial 300mm CMOS foundry. Subsequently, we characterize the hole spin g-tensor and its susceptibility to electric fields by coherent manipulation depending on the external magnetic field orientation. It reveals optimal operation points at which the longitudinal spin-electric susceptibility is minimal. At these sweet spots, we measure a Hahn-Echo decay time in the order of 100us while maintaining Rabi frequencies in the MHz range. This work opens new perspectives for quantum processing based on spin-orbit qubits.

(arXiv:2201.08637v1)

References

[1] Bosco et al, *PRX Quantum*, 2021
[2] Elzermann et al, *Nature*, 2004

Figures

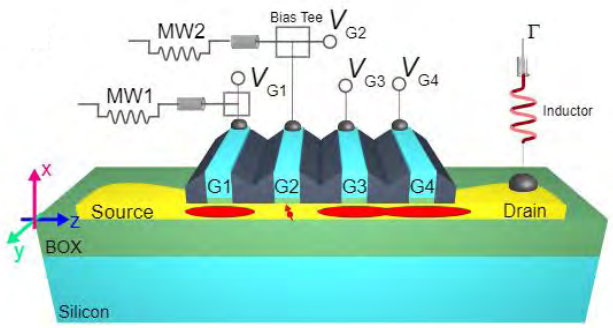


Figure 1: Simplified 3-dimensional representation of a silicon (yellow)-on-insulator (green) nanowire device with four gates. Gate 2 (G2) defines a quantum dot hosting a single hole. The drain contact is connected to an off-chip, surface-mount inductor to enable rf-reflectometry readout.

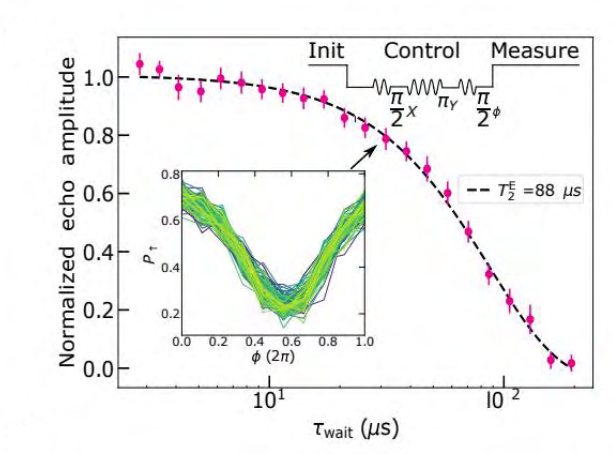


Figure 2: Normalized echo amplitude versus the free evolution time using a Hahn echo sequence (See top left inset). Black dashed line represents the Gaussian fit to extract the extended coherence time at the optimised working point.

Quantum Simulation with Circular Rydberg Atoms

Michel Brune
B. Ravon, P. Méhaignerie, Y. Machu, M. Favier, C. Sayrin, A. Muni, L. Lachaud, A. Couto, M. Poirier, S. Gleyzes.

Laboratoire Kastler Brossel, CNRS, Collège de France, 11 Pl. M. Berthelot, Paris, France

Michel.brune@lkb.ens.fr

Abstract

Neutral atoms in optical tweezers promoted to Rydberg states are one of the most promising platforms for quantum simulation. Due to their exceptional lifetime, circular Rydberg atoms additionally offer an unprecedented potential for being trapped for timescale ranging from tenth of ms up to minutes when implementing spontaneous emission inhibition in cryogenic environments [1]. With rubidium atoms, we recently demonstrated the preparation of up to 18 bottle beam optical tweezers for individual circular Rydberg atoms with a trapping time larger than several ms [2]. This achievement opens the route to first quantum simulations on exceptional timescale for e.g. investigation of out-of-equilibrium phenomena. We also developed a platform based on strontium, which offers a variety of possibilities for local optical manipulation of a circular atom by addressing its second valence electron with focussed lasers. We demonstrated the coherent optical manipulation of a circular state using its quadrupole coupling with the metastable 5d state of the ionic core [3,4]. We also observed laser cooling of a circular atom using the radiation pressure of a laser resonant with the ionic core [5]. In these experiments, ionic core excitation does not lead to significant autoionization of the circular state. This makes Sr circular states very promising candidates for merging quantum technology developed in the context of trapped ions with that based on the manipulation of Rydberg atoms.

References

[1] T. L. Nguyen, J. M. Raimond, C. Sayrin, R. Cortiñas, T. Cantat-Moltrecht, F. Assemat, I. Dotsenko, S. Gleyzes, S. Haroche, G. Roux, Th. Jolicoeur, and M. Brune, Phys. Rev. X, 8, 011032 (2018).
[2] B. Ravon et al., in preparation
[3] R. C. Teixeira, A. Larrouy, A. Muni, L. Lachaud, J.-M. Raimond , S. Gleyzes ,1 and M. Brune, Phys. Rev. Lett. 125, 263001 (2020)
[4] A. Muni, L. Lachaud, A. Couto, M. Poirier, R. C. Teixeira, J-M. Raimond, M. Brune, S. Gleyzes, Nature Physics, accepted, arXiv:2111.14504.
[5] L. Lachaud et al., in preparation.

Figures

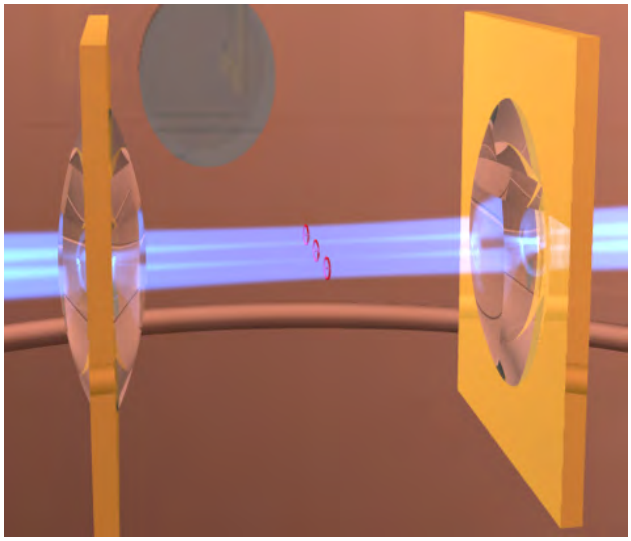


Figure 1: artist view of trapped circular Rydberg atom in a bottle beam optical tweezer.

Quantum Spain Initiative

Alba Cervera Lierta

Barcelona Supercomputing Center, Spain

alba.cervera@bsc.es

Integration of Topological Insulator Josephson Junctions in Superconducting Qubit Circuits

Malcolm R. Connolly
Imperial College London
m.connolly@imperial.ac.uk

Abstract

The integration of semiconductor Josephson junctions (JJs) in superconducting quantum circuits provides a versatile platform for hybrid qubits and offers a powerful way to probe exotic quasiparticle excitations. Recent proposals for using circuit quantum electrodynamics (cQED) to detect topological superconductivity motivate the integration of novel topological materials in such circuits.

In this talk I describe the realisation of superconducting transmon qubits implemented with $(Bi_{0.06}Sb_{0.94})_2Te_3$ topological insulator (TI) JJs using ultrahigh vacuum fabrication techniques [1]. Microwave losses on our substrates, which host monolithically integrated hardmasks used for the selective area growth of TI nanostructures, imply microsecond limits to relaxation times and, thus, their compatibility with strong-coupling cQED. We use the cavity–qubit interaction to show that the Josephson energy of TI-based transmons scales with their JJ dimensions and demonstrate qubit control as well as temporal quantum coherence. Our results pave the way for advanced investigations of topological materials in both novel Josephson and topological qubits.

References

[1] Schmitt *et al.*, Nano Letters (2022), 10.1021/acs.nanolett.1c04055

Figures

(a) (b)

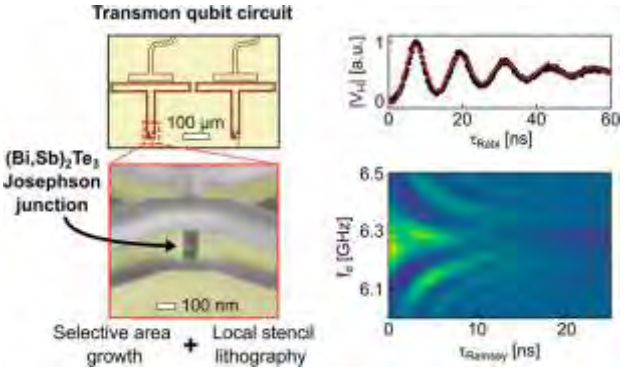


Figure 1: (a) Optical image (upper) of a niobium circuit showing a T-shaped transmon qubit island coupled to the bottom of a cavity resonator and tilted false-colour scanning electron micrograph (lower) showing the Josephson junction, comprising niobium (yellow), topological insulator (green), and the nanostencil (grey) used to shadow the junction region. (b) Rabi oscillations (upper) and Ramsey interference (lower) of the TI transmon showing coherent quantum control.

Engineering a new type of Kerr-cat qubit

Rodrigo G. Cortiñas
Nicholas E. Frattini, Jayameenakshi Venkatraman, Xu Xiao and Michel H. Devoret

Department of Applied Physics and Physics, Yale University, New Haven, CT 06520, USA

rodrigo.cortinas@yale.edu

It has become clear that to preserve quantum information one should store it in a "large quantum system". This *reversed* Schrödinger-cat paradox is a natural extension of classical error protection of information: code words should be sufficiently "far apart" to not be easily scrambled by the environment.

Since large many-body systems are hard to handle, it came as a realization that superpositions of mesoscopic states of light in a *single* degree of freedom is a comparatively simpler way to get a large quantum system [1,2]. Usually, this approach exploits the large Hilbert space of a harmonic oscillator using a nonlinear ancilla for quantum control and are generally known as bosonic codes.

The simplest members of the bosonic code family are known as "cat-codes". They are qubits formed by the quantum superposition of "distant" semiclassical states in an oscillator [2,3]. In their simplest version they do not protect the full quantum information but instead they protect a single axis of the qubit's Bloch sphere. They are then a form of classical error protection applied over a system that can be brought into a quantum superposition to perform a meaningful quantum task.

In this talk I will present the autonomously stabilized Kerr-cat qubit [4] and its new improved variation [5]. The Kerr-cat embodies a new paradigm in quantum error protection since it is encoded in a nonlinear oscillator, its stabilization is provided by Hamiltonian means and requires no ancilla. I will also discuss the experimental implementation of our cat-code, the origin of its protection and how it can be useful as an ancilla for other bosonic codes [6].

References

[1] Gottesman, Kitaev, and Preskill, Phys. Rev. A 64, 012310, Issue (2011)
[2] Mirrahimi, *et al*, New Journal of Physics, 16 (2014)
[3] Ofek, *at al, Nature, 535, (2016), 441*
[4] Grimm, Frattini, *et al.* Nature, 584 (2020) 205
[5] In preparation (2022).
[6] Puri, *et al*, Phys. Rev. X, 9, 041009, (2019)

Figures

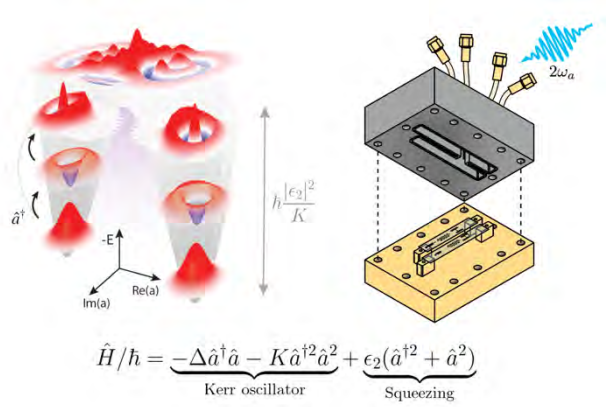


Figure 1: (left) The phase space representation of the Kerr-cat Hamiltonian, the Wigner function of its eigenstates, and (right) its physical implementation in our quantum circuit experiment.

Spanish National Quantum Plan

Ricardo Diaz Muiño

DIPC & CFM-CSIC, Spain

rdm@ehu.eus

Detecting spins by their fluorescence with a microwave photon counter

Emmanuel Flurin
E. Albertinale, L. Balembois, E. Billaud, Z. Wang, V. Ranjan, D. Flanigan, T. Schenkel, D. Estève, D. Vion, P. Bertet
Quantronics group, CEA, Saclay, France

emmanuel.flurin@cea.fr

Single-photon counters are essential for detecting weak incoherent electro-magnetic radiation.
In the optical domain, they are widely used to detect spontaneous emission from individual quantum systems, with applications in fluorescence microscopy, and in numerous areas of quantum technologies. In the microwave domain, operational single-photon counters have just recently been developed using superconducting quantum circuits [1], offering novel opportunities for detecting fluorescence or spontaneous emission at microwave frequencies. Here, we demonstrate the use of a microwave single-photon counter to detect the photons spontaneously emitted by a small ensemble of electron spins coupled to a superconducting micro-resonator [2]. In this novel spin detection scheme, each click of the detector reveals the quantum jump of an individual spin from its excited to its ground state. Besides their fundamental interest, our results also constitute a novel methodology for Electron Spin Resonance spectroscopy, it paves the way toward the readout of individual electron spins for quantum sensing at the single molecule level and quantum computation with highly coherent electron spins [3] and their nuclear registers.

Figures

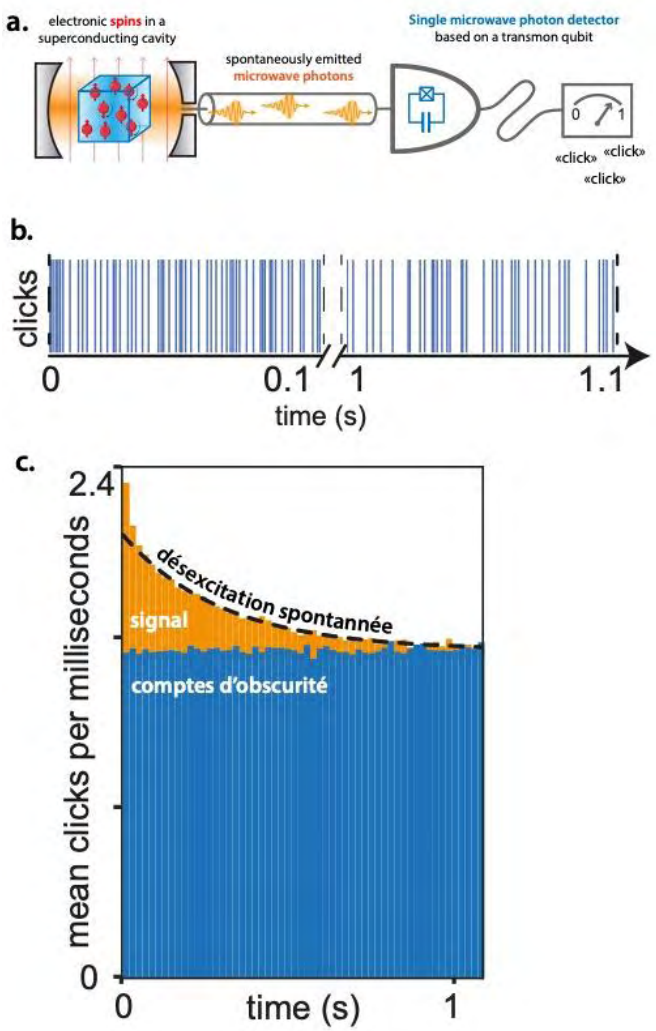


Figure 1: a) schematics of the experiment b) Instance of a measurement record of the spin fluorescence by microwave photon counting c) Average measurement, the excess counts measure the spin ensemble decay time.

References

[1] R. Lescanne, et al.,
Physical Review X, 10, 021038 (2020)
[2] E. Albertinale, et al.,
Nature 600 7889, 434-438 (2021)
[3] M. Le Dantec, et al.,
Science advances 7.51 (2021)

QTEP Initiative

Juan Jose Garcia-Ripoll

IFF/CSIC, Spain

juanjose.garcia.ripoll@csic.es

Protection of quantum information in a chain of Josephson junctions: the Magenium qubit

Eran Ginossar[4]
Paul Brookes[1], Tikai Chang[2], Marzena Szymanska[1],Eytan Grosfeld[3] , Michael Stern[2,*]

[1]*Department of Physics and Astronomy, University College London, London, WC1E 6BT, UK*
[2]*Department of Physics and Center for Quantum Entanglement Science and Technology,*
Bar-Ilan University, 52900 Ramat-Gan, Israel
[3]*Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva 8410501, Israel*
[4]*Department of Physics and Advanced Technology Institute, University of Surrey, Guildford, GU2 7XH, UK*

michael.stern@biu.ac.il

Symmetry considerations are key towards our understanding of the fundamental laws of Nature. The presence of a symmetry implies that a physical system is invariant under specific transformations and this invariance may have deep consequences. For instance, symmetry arguments state that a system will remain in its initial state if incentives to actions are equally balanced. Here, we apply this principle to a chain of qubits and show that it is possible to engineer the symmetries of its Hamiltonian in order to keep quantum information intrinsically protected from both relaxation and decoherence. We show that the coherence properties of this system are strongly enhanced relative to those of its individual components. Such a qubit chain can be realized using a simple architecture consisting of a relatively small number of superconducting Josephson junctions.

Cavity-enhanced single-shot readout of a quantum dot spin state within 3 nanoseconds

Mark Hogg[1]
Nadia Antoniadis[1], Willy Stehl[1], Alisa Javadi[1], Natasha Tomm[1], Rüdiger Schott[2], Sascha Valentin[2], Andreas Wieck[2], Arne Ludwig[2], Richard Warburton[1]

[1]*University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland*
[2]*Ruhr-Universität Bochum, 44780 Bochum, Germany*

mark.hogg@unibas.ch

The ability to perform a projective measurement of a quantum state in a single measurement iteration (single-shot readout) is an enabling technique in quantum technologies. Single-shot readout is necessary in quantum computation protocols for extracting information at the end of the computation, as well as error detection and correction as the quantum processor runs [1]. Achieving single-shot readout within the qubit dephasing time enables experiments such as measurement-based quantum feedback [2,3] and quantum trajectory tracking [4].

The spin states of optically active III-V semiconductor quantum dots (QDs) are a promising resource for quantum technologies; however single-shot readout has proven challenging due to low photon collection efficiencies and back-action induced by the readout laser. Of the small number of previous experiments to achieve single-shot readout of InAs QD spin states, the most rapid to date achieved a fidelity of 82% in a readout time of 800 ns [5], significantly longer than the maximum spin T_2^* times achieved to date (125 ns [6]).

Here we achieve single-shot readout of an InAs quantum dot spin state with a fidelity of 96% in only 3 nanoseconds, an improvement of more than two orders of magnitude and well within the achievable T_2^* time. Our approach uses a miniaturised Fabry-Perot microcavity to enhance the spin readout signal. Our work builds on the recent demonstration of an on-demand single-photon source with a record 57% efficiency using the same cavity platform [7]. The rapid readout we demonstrate opens up new possibilities for InAs QD spin states in quantum technologies.

Figures

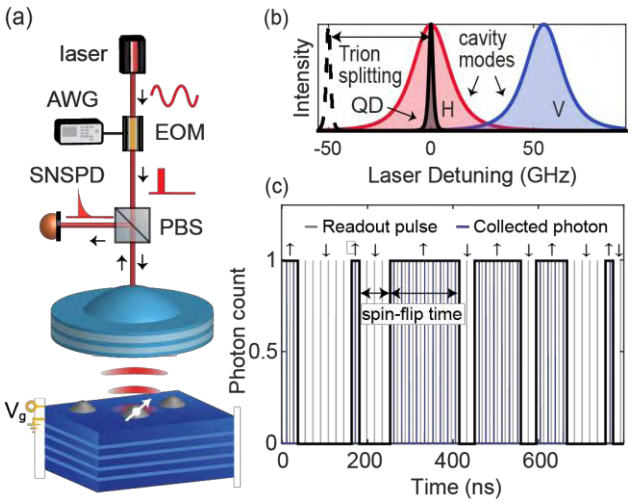


Figure 1: Tunable microcavity and single-shot readout. (a) Experimental setup. (b) Cavity enhancement of quantum dot emission. (c) Repeated single-shot readout experiments, showing quantum jumps in the QD spin state.

References

[1] Fowler, A. G. *et. al.*, Phys. Rev. A 86, 032324 (2012)
[2] Vijay, R. *et. al.*, Nature 490, 77-80 (2012)
[3] Campagne-Ibareq, P. *et. al.*, Phys. Rev. X 3, 021008 (2013)
[4] Murch, K.W. *et. al.,* Nature 502, 211-214 (2013)
[5] Delteil, A. *et. al.,* Phys. Rev. Lett 112, 116802 (2014)
[6] Jackson, D.M. *et. al.,* arXiv:2111.04624 (2021)
[7] Tomm, N. *et. al.,* Nature Nano. 16, 339-403 (2021)

IKUR Initiative

Adolfo Morais Ezquerro

Gobierno Vasco, Spain

Indistinguishability of coherent photons from from telecom-wavelength quantum dots

Tina Müller
L. Wells[1,2], M. Anderson[1,2], J. Skiba-Szymanska[1], J. Huwer[1], R.M. Stevenson[1], D.A. Ritchie[2], J. Heffernan[3], and A.J. Shields[1]

[1] Toshiba Europe Ltd, 208 Science Park, Milton Road, Cambridge CB4 0GZ, UK
[2] Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, UK
3 Department of Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

tina.muller@crl.toshiba.co.uk

The ability of two photons to interfere lies at the heart of many photonic quantum networking concepts [1] and requires that the photons are indistinguishable with sufficient coherence times to resolve the interference signals. Semiconductor quantum dots, typically emitting around 900 nm, are promising candidates for such quantum light sources, with bright and coherent single photon sources recently demonstrated [2]. Recently, efforts have been made to push emission wavelengths into the telecom bands to harness the vastly superior transmission of such photons in optical fibres for quantum network applications [3,4]. Here, we investigate the limits of coherence and indistinguishability for InAs/InP quantum dots with direct emission into the telecom C-band. We use coherence time measurements to investigate how close to the Fourier limit emission from this system can be pushed. Based on the coherent emission, we use Hong–Ou–Mandel interferometry to study the indistinguishability of the emitted photons. A sketch of our setup is shown in Fig. 1 (a), and Fig. 1 (b) shows the obtained interference visibility, which reaches 98.6±1.6% after post-selection and correction for detector resolution [4]. Our results highlight the potential of our system for the development of future quantum networking applications.

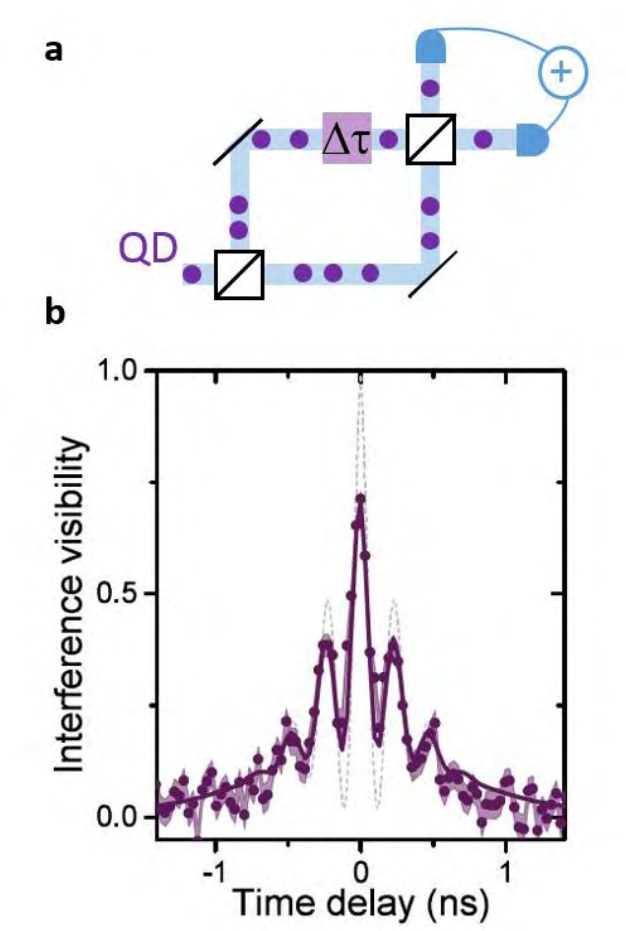


Figure 1: Indistinguishability measurement for telecom wavelength photons. (a) Hong-Ou-Mandel interferometer setup and (b) measured interference visibility from an InAs/InP quantum dot.

References

[1] E. Knill, R. Laflamme, and G. J. Milburn, Nature, 409 (2001) 46-52
[2] N. Tomm *et al.,* Nat. Nanotech., 16 (2021) 339-403
[3] Dusanowski *et al.*, Nat. Comms, 13 (2022) 748
[4] Anderson *et al.*, Appl. Phys. Lett., 118 (2021) 014003

An Intracavity Rydberg Superatom for Quantum Engineering of Light

Alexei Ourjoumtsev
Julien Vaneecloo, Sébastien Garcia

JEIP, UAR 3573 CNRS, Collège de France, PSL University, 11, place Marcelin Berthelot, 75005 Paris, France

alexei.ourjoumtsev@college-de-france.fr

We demonstrate a new approach for creating deterministic photon-photon interactions for optical quantum engineering, based on a single-ended medium-finesse optical cavity containing a mesoscopic atomic ensemble. This ensemble is made transparent by a laser beam mapping intracavity photons into Rydberg polaritons. The transparency vanishes when the cloud, acting as a single collective two-level superatom with an enhanced coupling to light, is driven from the ground to a Rydberg state. We observe collectively-enhanced Rabi oscillations between these states and optically discriminate them in a single shot with a 95% efficiency. Most importantly, we show that a change between the two internal states of the superatom induces a π phase rotation on the light reflected off the cavity. These ingredients form a complete set of tools for implementing deterministic photonic entangling gates and for generating highly non-classical light without the need for a low-volume high-finesse cavity.

References

[1] J. Vaneecloo, S. Garcia, A. Ourjoumtsev, arXiv: 2111.09088, Phys. Rev. X in press (2022).

Figures

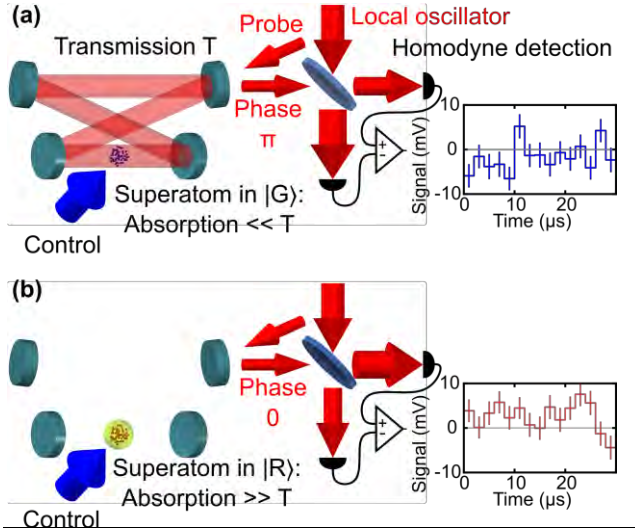


Figure 1: Optical π phase rotation conditional on the state of a two-level Rydberg superatom. A small Rydberg-blockaded cloud of cold Rb atoms, acting as a two-level superatom with a ground state $|G\rangle$ and a Rydberg state $|R\rangle$, is strongly coupled to a single-ended optical cavity. (a) When the superatom is in $|G\rangle$, the control beam (blue) creates electromagnetically-induced transparency (EIT) and converts probe photons into dark Rydberg polaritons. In this case, the absorption of the cloud being much smaller than the transmission T of the resonator's input/output coupling mirror, the system is optically overcoupled. The probe field is then reflected with a phase π, measured with a homodyne detector in our experiment. The inset shows a single-shot homodyne trace with 2μs binning, where errorbars correspond to standard errors. (b) When the superatom's state is coherently rotated to $|R\rangle$, the strong Rydberg blockade destroys the EIT and makes the system optically undercoupled: the probe field is then reflected with a phase 0, leading to a sign flip of the homodyne signal. The homodyne trace in the inset shows a quantum jump from $|R\rangle$ back to $|G\rangle$ around t=25μs.

Storage and analysis of light-matter entanglement in a fibre-integrated system

Jelena V. Rakonjac
Giacomo Corrielli, Dario Lago-Rivera, Alessandro Seri, Margherita Mazzera, Samuele Grandi, Roberto Osellame and Hugues de Riedmatten

ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

Jelena.rakonjac@icfo.eu

Quantum memories are essential in order to distribute quantum information in certain quantum repeater schemes. A high entanglement distribution rate is needed for a quantum repeater to be practical, thus requiring the use of a highly multiplexed quantum memory. Rare-earth ion-doped crystals are a particularly attractive system to use as a memory due to their long coherence times and potential multiplexability. Integration, such as by fabricating a waveguide in the crystal, opens up the possibility of directly interfacing the memory with on-chip photonic components or improving the scalability of the system.
In this work, we use a Pr^{3+}:Y_2SiO_5 crystal as a quantum memory, in which a type-I waveguide is fabricated with femtosecond laser micromachining. The memory is directly accessed with optical fibres glued to the facets of the crystal [1]. We demonstrate the capability of our fibre-integrated memory by storing single photons. We use cavity-enhanced spontaneous parametric down conversion to generate entangled photon pairs, with the signal photon at 606 nm (compatible with storage in the memory), and the idler photon at a telecom wavelength (necessary for heralding entanglement in a quantum repeater). We use the Atomic Frequency Comb (AFC) protocol [2] to store photons in the optically excited state, from 2 μs up to 28 μs (Figure 1). We also demonstrate that the entanglement of the photon-pairs is preserved after storage in the memory. We use the Franson scheme [3] to perform a tomography of the resulting light-matter entanglement in the two cases where the signals photons were stored in the AFC for 3 μs and 10 μs. The resulting two-qubit fidelity (after corrections for experimental imperfections) is (86 ± 2) % for 3 μs and (86 ± 4) % for 10 μs. The demonstrated storage time for light-matter entanglement is up to 3 orders of magnitude longer than previous demonstrations in integrated memories [4,5]. These results thus show that our fibre-integrated solid-state platform is a suitable candidate for a practical integrated quantum memory.

References

[1] J. V. Rakonjac et al, arXiv:2201.03361 (2022)
[2] M. Afzelius et al, Phys. Rev. A, 79 (2009) 052329
[3] J. D. Franson, Phys. Rev. Lett., 62 (1989) 2205-2208
[4] E. Saglamyurek et al, Nature, 469 (2011) 512-515
[5] E. Saglamyurek et al, Nat. Photonics, 9 (2015) 83-87

Figures

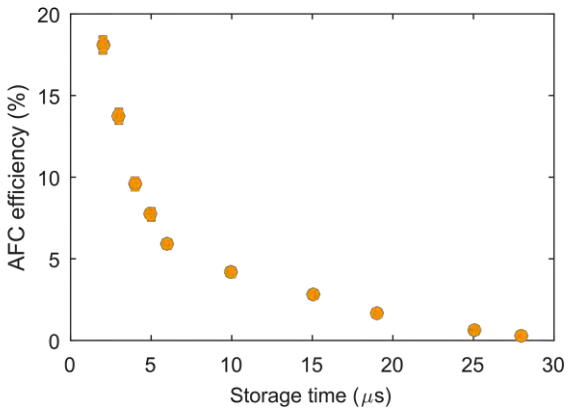


Figure 1: AFC storage efficiency of heralded single photons as a function of storage time.

Toward a spin-squeezed optical clock

John M Robinson
Yee Ming Tso, Maya Miklos, James K Thompson, Jun Ye

JILA, National Institute of Standards and Technology and University of Colorado, Department of Physics, Boulder, CO, USA

john.robinson@colorado.edu

Optical atomic clocks are the world's most precise and accurate quantum sensors. The most advanced clock comparisons are limited in their precision by the standard quantum limit [1,2], giving rise to considerable interest in employing spin squeezing to demonstrate a quantum advantage in frequency metrology. To date, clocks employing spin squeezing have been demonstrated in the microwave domain [3], or at the 10^{-13} level for optical clocks [4]. In this talk, we will present a new apparatus at JILA capable of producing spin-squeezed states for quantum metrology. We employ a cavity quantum electrodynamics architecture by loading 1000's of strontium atoms into a high-finesse optical cavity. We use this cavity to perform quantum non-demolition measurements of the collective atomic ensemble. Progress in generating metrologically useful squeezed states will be presented, and we will discuss using these states for the operation of a high performance optical clock to achieve stability below the standard quantum limit for the first time.

References

[1] Oelker, E., Hutson, R.B., Kennedy, C.J. et al. Demonstration of 4.8 × 10−17 stability at 1 s for two independent optical clocks. Nat. Photonics 13, 714–719 (2019).

[2] Bothwell T, Kennedy CJ, Aeppli A, Kedar D, Robinson JM, Oelker E, Staron A, Ye J. Resolving the gravitational redshift across a millimetre-scale atomic sample. Nature 602, 420 (2022).

[2] Cox, K., Greve, G., Weiner, J., Thompson, J.K., Deterministic Squeezed States with Collective Measurements and Feedback. Phys. Rev. Lett. 116, 093602 (2016).

[3] Pedrozo-Peñafiel, E., Colombo, S., Shu, C. et al. Entanglement on an optical atomic-clock transition. Nature 588, 414–418 (2020).

Generating massively entangled states with Rydberg-atom arrays

Tommaso Roscilde
Fabio Mezzacapo, Tommaso Comparin

Laboratoire de Physique, Ecole Normale Supérieure de Lyon, 46 Allée d'Italie, Lyon, France

tommaso.roscilde@ens-lyon.fr

Rydberg-atom arrays are emerging as one of the most promising platforms for quantum computation and quantum simulation (1). In this work we theoretically show that the non-equilibrium dynamics in large planar arrays with resonant (dipolar) XY interaction can generate massively entangled states in a scalable way. This is due to a fundamental analogy existing between the dynamics of dipolar spins in two spatial dimensions and that of an array of spins with infinite-range interactions, realizing the paradigmatic one-axis-twisting Hamiltonian. Making use of state-of-the-art methods for the non-equilibrium evolution of quantum many-body systems, we theoretically show that dipolar Rydberg atoms can realize scalable spin squeezed states at short times (2); and, most prominently, they realize Schrödinger's cat states at times scaling linearly with the number of spins (3). We observe the formation of cat states with up to N=144 spins, being limited only by the computation time. Experimental imperfections (such as randomness in the atomic positions) are included in the analysis, showing that they lead to mild reductions of the macroscopic coherence in the cat state. The possibility of transferring the Rydberg excitations to low-lying states suggests to view these multipartite entangled states as a fundamental metrological resource, allowing one to reach the Heisenberg scaling.

References

1. A. Browaeys and T. Lahaye, Nature Phys. 16, 132 (2020).
2. T. Comparin, F. Mezzacapo and T. Roscilde, Phys. Rev. A 105, 022625 (2022).
3. T. Comparin, F. Mezzacapo and T. Roscilde, in preparation (2022).

Figures

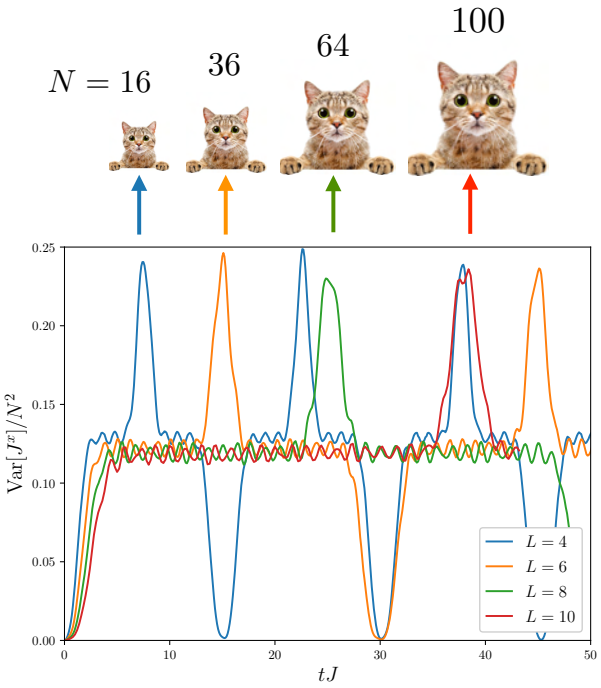


Figure 1: Scalable production of Schrödinger-cat states from the dynamics of dipolar XY spins on a *N=LxL* square lattice. The appearance of a cat state is signaled by the fact that the variance of the J^x collective-spin component, $\mathrm{Var}(J^x)$, acquires a value approaching the maximum allowed by quantum mechanics (namely $N^2/4$ for N spins).

Tunable Many-body Interactions and Induced Superconductivity in a Helical Luttinger Liquid

Bent Weber

School of Physical and Mathematical Sciences, Nanyang Technological University (NTU), Singapore 637371

b.weber@ntu.edu.sg

The interplay of topology, superconductivity, and many-body correlations in 1D has become a subject of intense research for the pursuit of non-trivial superconducting pairing. The boundaries of atomically-thin topological insulators in 2D – amongst them the quantum spin Hall (QSH) insulator [1] – provide a natural realization of strictly 1D electronic structure with linear (Dirac) dispersion and spin-momentum locking (helicity).

We show [2] that the topological edge states of the QSH insulator 1T'-WTe_2 harbour a strongly correlated 1D electronic ground state – a helical Tomonaga-Luttinger Liquid (TLL) – whose many-body Coulomb interactions can be effectively controlled by the edge state's dielectric environment.

Temperature-dependent scanning tunnelling spectroscopy measurements down to 4.2K reveal a pseudogap-like zero-bias anomaly (ZBA) within the edge state's local density of states (LDOS), with minimum strictly at the Fermi energy. Consistent with the presence of a TLL, the LDOS of this ZBA exhibits power-law scaling in both bias voltage and temperature, with a universal scaling exponent that is related to the Luttinger parameter as $\alpha=C(K+K^{-1}-2)$ ($C=1/2$ for helical systems).

A statistical analysis across tens of tunnelling points confirms [2] that K is distinct on different edges of the 1T'-WTe_2 crystal and depends on the dielectric environment of the helical edge, provided by its van-der-Waals substrate. This demonstrates tunability of a helical TLL in both its fundamental dependencies on potential and kinetic energy terms, respectively.

Finally, we show that superconductivity can be induced [3] into the 1T'-WTe_2 quantum spin Hall state by proximity-coupling to a superconducting van-der-Waals substrate, giving rise to an induced superconducting order parameter as large as 0.6meV in WTe_2, stable beyond a B=2T magnetic field [3].

References

[1] M.S. Lodge, S.A. Yang, S. Mukherjee, and Bent Weber*, *Atomically Thin Quantum Spin Hall Insulators.* Advanced Materials 33 (2021), 2008029.

[2] J. Jia, E. Marcellina, A. Das, M. S. Lodge, B.K. Wang, D.-Q. Ho, R. Biswas, T.-A. Pham, W. Tao, C.-Y. Huang, H. Lin, A. Bansil, S. Mukherjee, and Bent Weber*, *Tuning the Many-body Interactions in a Helical Luttinger Liquid* (under review)

[3] W. Tao, Z.J. Tong, A. Das, D.-Q. Ho, Y. Sato, M. Haze, J. Jia, Y. Que, F. Bussolotti, K.E.J. Goh, B. Wang, H. Lin, A. Bansil, S. Mukherjee, Y. Hasegawa, and Bent Weber*, *Multiband superconductivity in strongly hybridized 1T'-WTe_2 / $NbSe_2$ heterostructures*" Physical Review B 105 (2022), 094512

Quantum logic with spin qubits crossing the surface code error threshold

Xiao Xue[1]
Maximilian Russ[1], Nodar Samkharadze[2], Brennan Undseth[1], Amir Sammak[2], Giordano Scappucci[1], Lieven M. K. Vandersypen[1]

1 QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, Netherlands
2 QuTech and Netherlands Organization for Applied Scientific Research (TNO), Stieltjesweg 1, 2628 CK Delft, Netherlands

Contact: x.xue-1@tudelf.nl

Abstract

High-fidelity control of quantum bits is paramount for the reliable execution of quantum algorithms and for achieving fault-tolerance, the ability to correct errors faster than they occur [1]. The central requirement for fault-tolerance is expressed in terms of an error threshold. Whereas the actual threshold depends on many details, a common target is the ~ 1% error threshold of the well-known surface code [2, 3]. Reaching two-qubit gate fidelities above 99% has been a long-standing major goal for semiconductor spin qubits. These qubits are well positioned for scaling as they can leverage advanced semiconductor technology [4, 5].

Here we report a spin-based quantum processor in silicon with single- and two-qubit gate fidelities all above 99.5%, extracted from gate set tomography [6]. The average single-qubit gate fidelities remain above 99% when including crosstalk and idling errors on the neighboring qubit. Utilizing this high-fidelity gate set, we execute the demanding task of calculating molecular ground state energies using a variational quantum eigensolver algorithm [7]. Now that the 99% barrier for the two-qubit gate fidelity has been surpassed, semiconductor qubits have gained credibility as a leading platform, not only for scaling but also for high-fidelity control.

References

[1] D. A. Lidar and T. A. Brun, Cambridge university press (2013).
[2] Robert Raussendorf and Jim Harrington, Phys. Rev. Lett. (2007) 98, 190504.
[3] A. G. Fowler, et al., Phys. Rev. A (2012) 86, 032324.
[4] A. M. J. Zwerver et al.,arXiv:2101.12650 (2021).
[5] X. Xue et al., Nature (2021) 593, 205–210.
[6] X. Xue et al., Nature (2022) 601, 343–347.
[7] S. McArdle, et al., Rev. Mod. Phys. (2020) 92, 015003.

Coherent control of a multi-qubit dark state in waveguide quantum electrodynamics

Maximilian Zanner
Tuure Orell, Christian M. F. Schneider, Romain Albert, Stefan Oleschko, Mathieu L. Juan, Matti Silveri, Gerhard Kirchmair

University of Innsbruck, Technikerstr.21a, Innsbruck, Austria

Maximilan.zanner@uibk.ac.at

The coherence properties of an atom or superconducting qubit strongly depend on the electromagnetic environment. Typical circuit QED experiments protect the qubit mode from decay into dissipative modes by placing it into a cavity. Effectively, a reduction of the available mode density reduces the free-space spontaneous emission rate of the qubit. In waveguide QED the qubit is strongly coupled to a continuous mode spectrum, thus it decays rapidly. Collective effects between multiple qubits can be utilized to create subradiant states that decouple from the dissipative waveguide environment. In our experiment we strongly couple two pairs of transmon qubits to the fundamental propagating mode of a rectangular waveguide. We show that the decay of the four qubit dark state is strongly suppressed, exceeding the waveguide-limited lifetimes of the individual qubits by two orders of magnitude [1]. We characterize the dark state by measuring the coherence time in a Ramsey experiment and perform a pulsed spectroscopy into the two-excitation manifold, which can only be accurately modeled by taking into the account the bosonic nature of the transmons [2].

References

[1] Zanner et al., Nature Physics, Issue 3 (to appear)(2022)
[2] Orell et al., arXiv:2112.08134

Figures

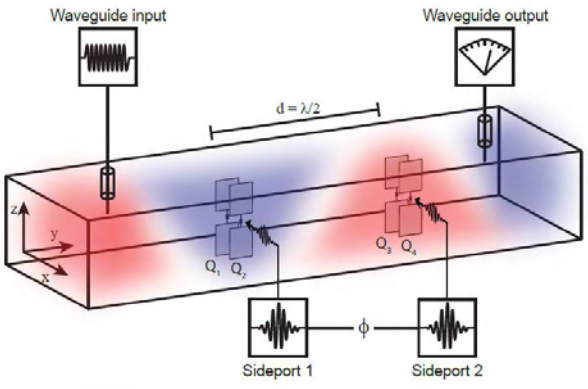


Figure 1: Waveguide QED setup containing 4 transmons and two additional drive ports for local addressing. Additionally, the waveguide transmission can be measured via the waveguide in- and output.

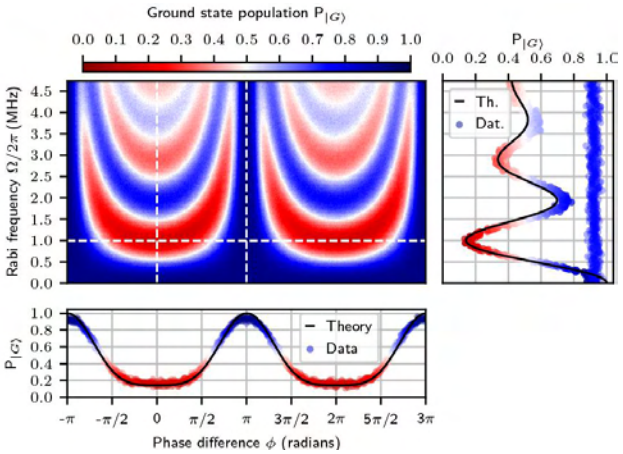


Figure 2: The dark state only shows Rabi oscillations when it is driven with the corresponding phase-relation, that matches the symmetry condition.

Witnessing Quantum Correlations in a Nuclear Spin Ensemble via a Proxy Qubit

Leon Zaporski[1,*]
Dorian A. Gangloff[1,*], Jonathan H. Bodey[1,*] Clara Bachorz[1], Daniel M. Jackson[1], Gabriel Ethier-Majcher[1], Constantin Lang[1], Edmund Clarke[2], Maxime Hugues[3], Claire Le Gall[1], Mete Atatüre[1]

[1]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, UK
[2]EPSRC National Epitaxy Facility, University of Sheffield, Broad Lane, Sheffield, S3 7HQ, UK
[3]Universite Cote d'Azur, CNRS, CRHEA, rue Bernard Gregory, 06560 Valbonne, France

lz412@cam.ac.uk

A coherent ensemble of spins interfaced with a proxy qubit is an attractive platform to create many-body coherences and probe the regime of collective excitations. An electron spin qubit in a semiconductor quantum dot is a realisation of such an interface to a dense nuclear spin ensemble consisting of multiple high-spin species. In this work, we demonstrate a species-selective spin-state reconstruction of a nuclear ensemble that exploits its response to the electron-mediated injection of collective nuclear excitations [1,2]. Following optical preparation of a reduced-variance, polarised nuclear state [1,2], we probe the electron spin population as a function of the ESR detuning. Figure 1a displays two example ESR spectra for positive (top) and negative (bottom) mean nuclear polarisation. The difference of ESR Rabi frequencies $\Omega_{\pm}$, corresponding to nuclear resonances blue- and red-detuned from the ESR, is used to obtain information about nuclear populations. The sum over reconstructed species-resolved polarisations, expressed as an asymmetry-commensurate mean field, exceeds threefold the expected mean field for a classically correlated ensemble (Fig. 1b). This stark deviation follows from a spin ensemble that contains inter-particle coherences, and manifests the formation of a dark many-body state [3]. Honing further control over the nuclear-state coherences shown here offers a route to a quantum memory hosted in a low-polarisation decoherence-free subspace [3].

Figures

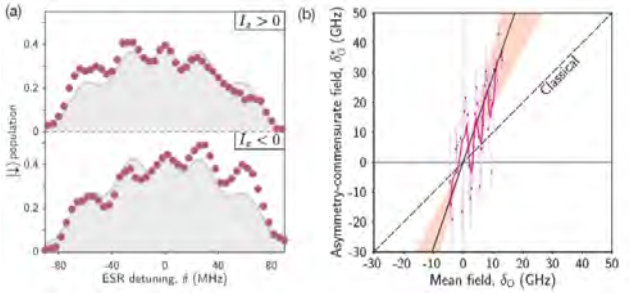


Figure 1 (a) Electron $|\downarrow\rangle$ population as a function of ESR detuning δ, following a 1-μs drive for positive (top) and negative (bottom) prepared Overhauser shifts. Grey curves are reference spectra at zero-polarisation ($I_z = 0$). (b) Derived asymmetry-commensurate Overhauser field versus Overhauser field setpoint. The solid black curve is a fit to the data with a slope of 2.9(1). The shaded coral region indicates the range of indium concentrations x = 0.25-0.75. The dashed line with a slope of 1 is the mean field that would be reconstructed for a classical nuclear state. Solid curve is the data passed through a first-order Savitzky-Golay filter with a 1.6-GHz window. Error bars indicate a 67% confidence interval.

References

[1] D. A. Gangloff et al, "Quantum interface of an electron and a nuclear ensemble," Science 364, 62–66 (2019).
[2] D. A. Gangloff et al, "Witnessing quantum correlations in a nuclear ensemble via an electron spin qubit," Nature Physics 17, 1247–1253 (2021)
[3] J. M. Taylor, C. M. Marcus, and M. D. Lukin, "Long-Lived Memory for Mesoscopic Quantum Bits," Phys. Rev. Lett. 90, 4 (2003).

Quantum Interference between Identical Photons from Remote Quantum Dots

Liang Zhai
Giang N. Nguyen, Clemens Spinnler, Julian Ritzmann, Matthias C. Löbl, Andreas Wieck, Arne Ludwig, Alisa Javadi, Richard J. Warburton

University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland
Ruhr-Universität Bochum, DE-44780 Bochum, Germany
liang.zhai@unibas.ch

remote quantum dots photons and standard linear optics. The average CNOT process fidelity is ~88% and the output entanglement fidelity is ~85%. Such an entangled state marks a first step towards involving multiple – not just one – quantum-dot based single-photon sources for quantum applications. Our results establish gated GaAs quantum dots as interconnectable sources to scale the creation of identical single photons.

Advances in photonic quantum technologies calls for creation, manipulation and detection of a large number of identical single photons. Self-assembled quantum dots represent a semiconductor platform that creates single photons in a near-deterministic manner [1]. They benefit from the established semiconductor fabrication facilities; they can be integrated into various nano- and micro-structures. For applications, however, a significant roadblock is the poor quantum coherence upon interfering single photons created by two or more independent quantum dots [2, 3]. In other words, the photons created by different quantum dots are not identical.

Here, we present two-photon interference with a 93% interference visibility (Fig. 1) from two quantum dots separated in different cryostats [2]. This high visibility is achieved under rigorous conditions: no Purcell enhancement, no temporal post-selection, no narrow spectral filtering, and no frequency stabilisation. The key to the high value is the employment of gated GaAs quantum dots in a p-i-n diode [4]. Exploiting the current photonic engineering technologies, our result presents a route to creating single photons with more than 99% similarity in every aspect from separate quantum-dot based photon sources.

The identical photons allow a photon-photon entangled state to be created. We demonstrate a CNOT operation using the

Figures

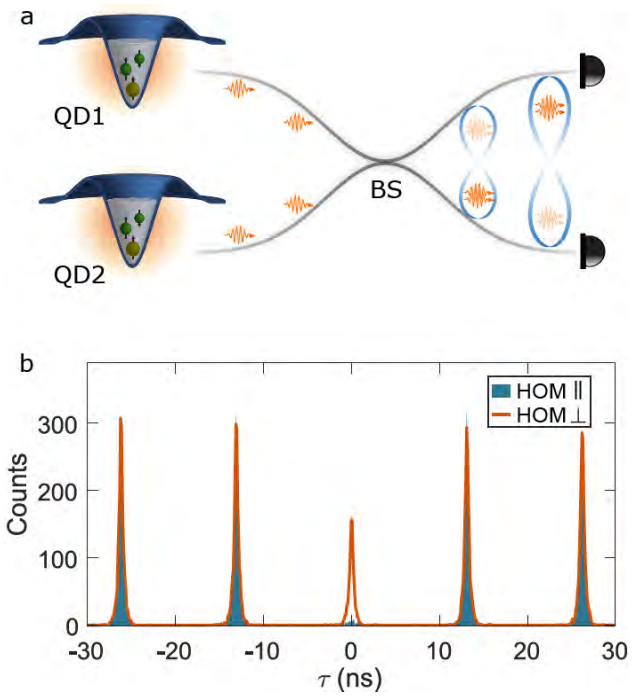


Figure 1: Hong-Ou-Mandel interference between photons from two separate quantum dots. (a) A sketch of the interference experiment. (b) Hong-Ou-Mandel (HOM) experiment showing an interference visibility of 93%.

References

[1] N. Tomm, et al., Nat. Nanotechnol. 16, 399 (2021)
[2] L. Zhai, ***et al.***, arXiv:2106.03871 (2021).
[3] J. Weber, ***et al.***, Nat. Nanotechnol. 14, 23 (2019)
[4] L. Zhai, ***et al.***, Nat. Commun. 11, 4745 (2020)

ORAL INDUSTRIAL FORUM

Efficient generation of quantum light at telecom wavelength for long-distance secure communication and quantum network applications

A. Barbiero[1,2]
J. Skiba-Szymanska[1], D. J. P. Ellis[1], T. Müller[1], R. M. Stevenson[1], L. Goff[3], D. A. Ritchie[3] and A. J. Shields[1]

[1] *Toshiba Europe Limited, Cambridge Research Laboratory, 208 Science Park, Milton Road, Cambridge, CB4 0GZ, UK*
[2] *Department of Physics and Astronomy, University of Sheffield, Hounsfield Road, Sheffield, S3 7RH, UK*
[3] *Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge, CB3 0HE, UK*

andrea.barbiero@crl.toshiba.co.uk

Quantum communication networks are formed of secure links, where information can be transmitted with security guaranteed by the quantum nature of light [1]. An essential building block of such a network is a source of single photons or entangled photon pairs compatible with the low-loss fibre windows around 1310 nm or 1550 nm. In this framework, InAs quantum dots (QDs) are considered mature candidates for the generation of quantum light because they can be engineered to achieve a wide range of desired properties and are compatible with conventional semiconductor opto-electronics. However, an appropriate engineering of the photonic environment is essential to achieve efficient extraction of the emitted photons from a high-index semiconductor matrix.

I will discuss how the integration of InAs QDs into hybrid circular Bragg Gratings [2] (CBGs) operating in the telecom O-band is a promising route to meet the challenging requirements for long-haul secure communication. Moreover, I will present a design optimization of hybrid CBGs operating in the telecom C-band and introduce a variation directly compatible with electric field control [3], which paves the way for the realization of efficient and electrically driven quantum light sources.

Semiconductor QDs are the only source of quantum light able to emit directly in the telecom O-band and C-band, therefore the integration with devices that can efficiently enhance their light output is essential for experiments based on important concepts, such as teleportation or entanglement swapping, and ultimately for the large-scale diffusion of quantum technologies.

References

[1] H.J. Kimble, Nature 453 (2008) 1023–1030.
[2] J. Liu et al., *Nat. Nanotechnol.* 14, 586–593 (2019).
[3] A. Barbiero et al., arXiv:2112.13028, 2021.

Figures

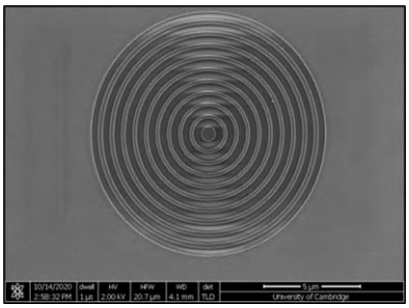


Figure 1: Example of hybrid CBG fabricated on a semiconductor slab.

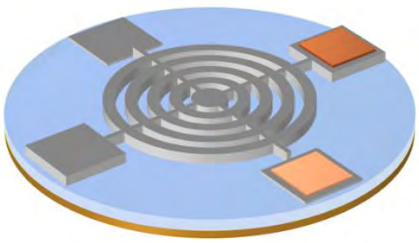


Figure 2: Modified CBG design compatible with electric field control.

Development of the quantum processing units (QPUs) at IQM Finland Oy

Wei Liu
Hasnain Ahmad, Amandeep Buppal, Chun Fai Chan, Kok Wai Chan, Juho Hotri,Mate Jenei, Anton Komlev, Janne Kotilahti, Kunal Mitra, Mario Palma, Wei Qiu, Lily Yang, Liuqi Yu, Tianyi Li, Johannes Heinsoo, Caspar Ockeloen-Korppi, Jan Goetz, Juha Vartiainen, Mikko Möttönen, Juha Hassel, Kuan Yen Tan
IQM Finland Oy, Keilaranta 19, 02150 Espoo, Finland.
wei@meetiqm.com

Abstract

Realizing large-scale quantum computers is one of the most important goals of science and technology today. It will revolutionize computing technology and push the boundaries of all fields of science. As a spinout from Aalto University and VTT, IQM focuses on the realization of a quantum computer based on superconducting circuits [1,2,3]. Here, we present the fabricated devices and results achieved to date, which includes resonators with high quality factors, long qubit lifetime and 3D integration techniques.

References

[1] Liu, Wei, et al. "Development of the quantum processing units (QPUs) at IQM Finland Oy." *Bulletin of the American Physical Society 66* (2021)
[2] Heinsoo, Johannes, et al. "Fast and high-fidelity readout of transmon qubits in scalable QPU architecture." *Bulletin of the American Physical Society* (2022)
[3] Landra, Alessandro, et al. "KQCircuits, an open-source package for drawing automation of superconducting quantum processors." *Bulletin of the American Physical Society* (2022).

Figures

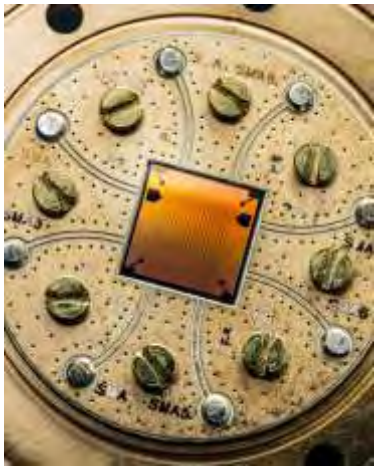


Figure 1: IQM's quantum processing unit (QPU)

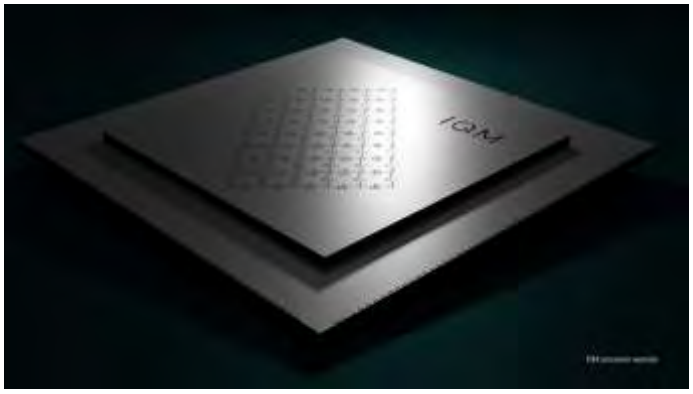


Figure 2: KQCircuits to automate the design of superconducting quantum processors.

Chemistry-aware noise mitigation on molecular simulations for NISQ hardware

David Muñoz Ramo

Quantinuum, UK

david.ramo@cambridgequantum.com

Quantum computers promise to enable the simulation of complex chemical systems is one of the main applications expected to yield quantum advantage. However, the current generation of quantum hardware is difficult to use for molecular simulations due to the high levels of noise during device operation. Improvements on hardware promise to make these simulations possible, either by improvements in fidelities and coherence time, or by making quantum error correction possible. In parallel, research in algorithms to combat noise is actively being developed.

In this talk, I'll present work performed by our team on a novel noise mitigation technique, called Partition Measurement Symmetry Verification (PMSV), which exploits the symmetries present in molecular systems to reduce noise in NISQ experiments. I will show how PMSV, alone or in combination with other noise mitigation methods, greatly helps in improving results from hardware experiments and pushes us closer to making quantum computers useful for the simulation of chemical systems. I will illustrate the performance of this technique with examples run on superconducting and ion trap hardware.

Foundry-compatible fabrication processes for superconducting circuits

Presenting Author: Daniel Pérez Lozano[1,3]
Co-authors: J. Verjauw[1,2], R. Acharya[1,3], J. Van Damme[1,3], Ts. Ivanov[1], X. Piao[1], F. A. Mohiyaddin[1], D. Wan[1], J. Jussot[1], A. M. Vadiraj[1], A. Pacco[1], L. Souriau[1], Y. Canvel[1], M. Mongillo[1], S Couet[1], I. Radu[1], A. Potočnik[1], B. Govoreanu[1], J. Swerts[1], K. De Greve[1,3].

[1]*Imec, Remisebosweg 1, Leuven, Belgium .*
[2]*Department of Materials Engineering (MTM), KU Leuven, Kasteelpark Arenberg 44 Leuven, Belgium.*
[3]*Department of Electrical Engineering (ESAT), KU Leuven, Kasteelpark Arenberg 10, Leuven, B-3001, Belgium.*

Daniel.Pérez@imec.be

Abstract

The implementation of algorithms that can provide an exponential speed-up over their classical counterparts in a fault tolerant superconducting quantum computer will require on the order of a million of physical qubits [1]. This will likely necessitate the use of industrial fabrication facilities that can provide the required circuit parameter control over large qubit counts. Currently, state of the art superconducting circuits uses fabrication processes such as shadow evaporation and lift-off techniques [2] that are incompatible with large-scale foundry capabilities. In this work, we therefore explore and develop novel approaches to manufacture high coherence superconducting circuits using foundry compatible fabrication processes and materials. We fabricated aluminium superconducting qubits with high coherence and relaxation times (up to 100 µs) and 99.94 % single qubit fidelity without the use of shadow evaporation or lift-off techniques [3]. For materials screening purposes and to characterize associated loss mechanisms, we developed a superconducting resonator platform for rapid testing and show high quality factor superconducting resonators using a variety of foundry-deposited materials such as niobium, tantalum, aluminium, niobium titanium nitride, niobium nitride and titanium nitride [4].

References

[1] Austin G. Fowler, Matteo Mariantoni, John M. Martinis, and Andrew N. Cleland Phys. Rev. A 86 (2012) 032324
[2] F. Arute, K. Arya, R. Babbush et al. Nature 574, (2019) 505–510.
[3] J. Verjauw, R. Acharya, J. Van Damme et al., arXiv:2202.10303 (2020).
[4] J. Verjauw, A. Potočnik, M. Mongillo et al. Phys. Rev. Applied 16 (2021) 014018.

Figures

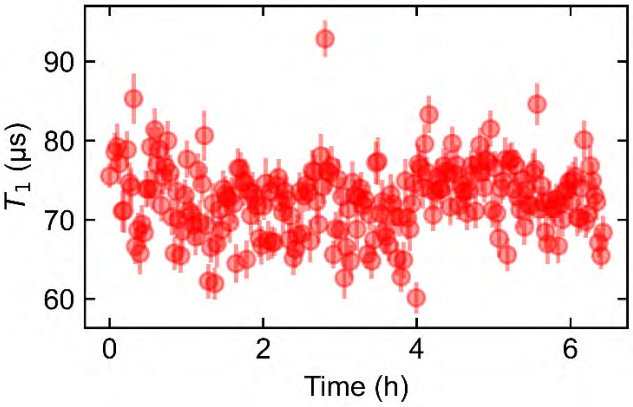


Figure 1: Qubit relaxation time measured over 6.5 hours. The highest T_1 corresponds to = 104 ± 5 µs

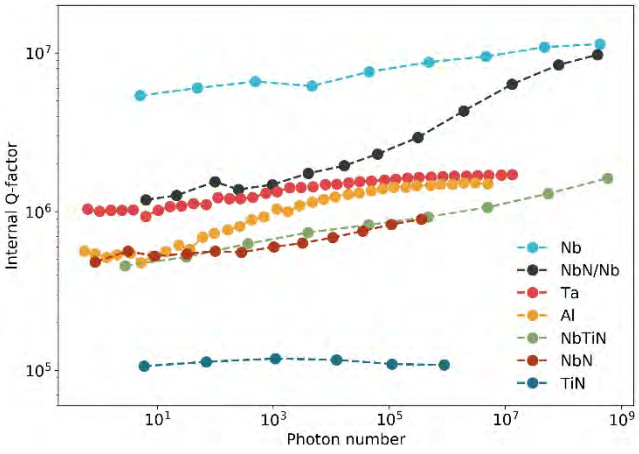


Figure 2: Resonator internal quality factor for a variety of materials as a function of photon number.

Hybrid quantum algorithms in computer vision for automated quality assessments

Presenting Author: Barry Reese
Co-Authors: Marek Kowalik
Capgemini Quantum Lab
barry.reese@capgemini.com

Image recognition and machine learning have revolutionized Quality Assessment in the past decade with improvements in computer vision algorithms and CNN's being the standard. We have created a Quanvolutional Neural Network Algorithm [1] that efficiently maps high resolution classical images to the quantum space for high quality image predictions.

Our algorithms is a bridge to using Quantum devices in the field of computer vision using a Quantum Convolution in a classical CNN stack [2]. Our hybrid model achieves higher quality predictions using much fewer training data than fully classical CNN's.

We created our quantum embedding in the following fashion.

1. We convolved the input image with many applications of random quantum circuits on input u spatially local n x n kernels. See Figure 1.
2. Our measurement consisted of a PauliZ gate which is $Z=|0\rangle\langle 0|-|1\rangle\langle 1|$ to produce our quantum encoding where output o_x = quantum state $q(i_x)$. See Figure 2.

We then made a quantum hybrid model by inputting our quantum tensor into a classical CNN and compared our results to a fully classical model. Our experiments show that the Quanvolutional Neural Network produced more accurate results using less training data as we will demonstrate in our Oral.

References

[1] Henderson, Maxwell | Shakya, Samriddhi | Pradhan, Shashindra | Cook, Tristan (2019): "Quanvolutional Neural Networks: Powering Image Recognition with Quantum Circuits": https://arxiv.org/pdf/1904.04767.pdf

[2] Cong, Iris | Choi, Soonwon | Lukin, Mikhail D. (2019): "Quantum Convolutional Neural Networks": https://arxiv.org/pdf/1810.03787.pdf

Figures

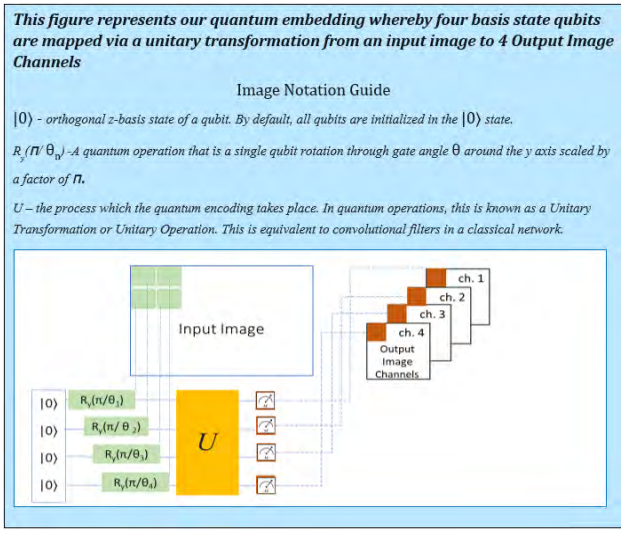


Figure 1: Mapping Classical Data to the Quantum Space for better expressability

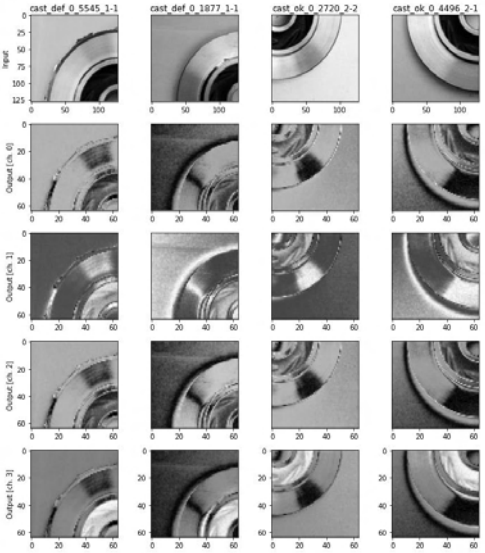


Figure 2: Effect of mapping classical data to Quantum Space using a Quantum Convolution

Integrated quantum control architecture for ultra-fast camera readout of neutral atom arrays

Presenting Author
Ramon Szmuk

Co-authors: Yonatan Cohen, Alex Kotikov

Quantum Machines, Yigal Alon St 126, Tel Aviv, Israel

ramon@quantum-machines.co

Abstract

Neutral atoms arrays are a promising platform for quantum computation and simulation. Although their qubit quality can be high even in large numbers, the path to neutral atom quantum computers satisfying the DiVincenzo criteria is brimmed with challenges. One of the major roadblocks is the necessity to precisely assemble 2D arrays of natural atoms and perform a readout well within the boundaries of coherence time. Here we demonstrate camera readout times in the order of a few milliseconds, two orders of magnitude lower than typical T_2^* times. This readout includes everything from frame capturing, processing, and feedback pulses. We show that such a fast camera readout can be achieved by combining a dedicated FPGA processor architecture with real-time control capabilities and an integrated camera readout module optimized to handle such fast operations. The possibility for a unified control platform to perform a universal set of quantum gates and such a fast readout well within coherence time directly enables the implementation of quantum error correction schemes on atom arrays.

Building quantum networks of superconducting circuits mediated by telecom photons

Steven Touzard

National University of Singapore, 21 Lower Kent Ridge Rd, Singapore, Singapore

steven.touzard@nus.edu.sg

Quantum networks consist of several nodes of quantum processors that can communicate over long-distances, for example through commercial telecom fibers. Superconducting circuits are one of the most advanced technologies to construct the quantum processors at the nodes. However, these processors operate at microwave frequencies and cannot directly make use of the existing telecommunication infrastructure to be linked to one another. The only piece still missing for quantum networks to become a reality is a device that entangles superconducting circuits with travelling telecom photons.
In this talk, I will first review the working principles of superconducting circuits as well as recent progress towards making practical quantum processors. I will then show how my simultaneous expertise in solid-state physics, atomic physics, and quantum control led to a practical design for this desired device. I will explore the challenges of fabricating such a device, as well as state-of-the-art techniques to overcome them.

Figures

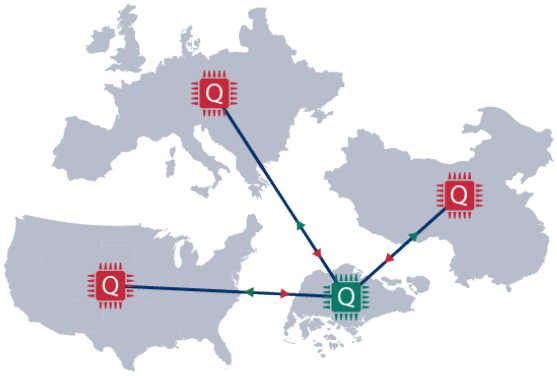


Figure 1: Schematic of a large-scale quantum network. A controlled quantum processor (green) is entangled with independent quantum processors (red) through telecommunication fibers (blue).

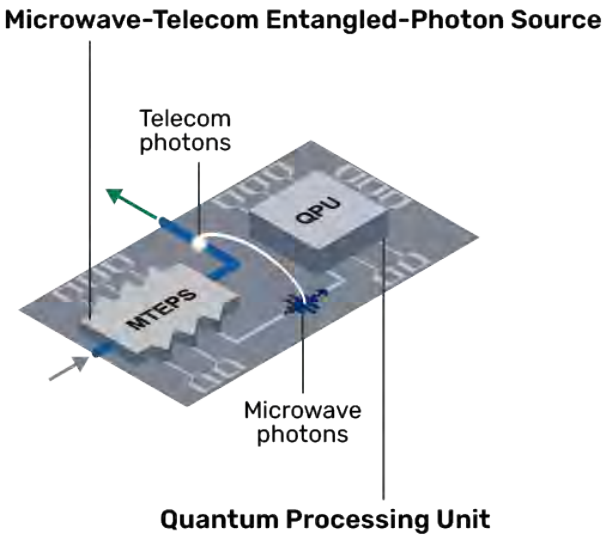


Figure 2: Schematic of the proposed device. The MTEPS sends entangled coherent states to a commercial telecommunication fiber and a QPU.

ORAL QUANTUM MATERIALS

Engineering topological superconductivity in twisted bilayer graphene

Julien Barrier
A.I. Berdyugin, P. Kumaravadivel, N. Xin and A.K. Geim

University of Manchester, Manchester, U.K.

julien.barrier@manchester.ac.uk

Topological insulators have been the subject of an intense research effort, as they could host excitations with non-trivial braiding statistics like Majorana fermions or non-abelian anyons, quasiparticles proposed as a basis for fault-tolerant quantum computers [1,2].

We propose that twisted bilayer graphene (tBLG) Josephson junctions can realize such topological excitations. When the twist angle is significantly smaller than 1°, the superlattice consists of large (~µm wide) triangular domains with alternating Bernal (AB/BA) stacking order. In this system the domain boundaries allow valley-polarised 1D helical states with four gapless 1D states on each side of the triangular domains, propagating in opposite directions for valley K and K' [3,4].

In our Josephson junctions, the supercurrent persists deep into the quantum Hall regime, i.e. under magnetic fields breaking the time-reversal symmetry, ensuring s-wave pairing. We observe pockets of superconductivity in Landau levels at all magnetic fields below the critical field of the superconducting contacts, attributed to Andreev bound states propagating along 1D helical channels.

Our results show that tBLG is a particularly appealing system to engineer topological superconductivity. We provide evidence of the topological nature of the domain boundaries, a decisive step towards realizing exotic quasiparticles.

References

[1] Alicea, J. Rep Prog Phys, 75, 076501 (2012)
[2] Beenakker C. Annu Rev Conden Ma P 4, 113-136 (2013
[3] Huang, S. et al., Phys Rev Lett 121, 037702 (2018)
[4] Xu, S. et al., Nat Commun 10, 1-5 (2019)

Charge to spin conversion in epitaxial 2D $CrTe_2/Bi_2Te_3$ grown by MBE

Presenting Author A. Dimoulas[1]
N. Figueiredo-Prestes[2], P. Tsipas[1], N. Reyren[2], P. Pappas[1], A. Lintzeris[1], S. Fragkos[1], H-Y. Jaffres[2], M. Heuken[3], P. Seneor[2], J-M George[2]
[1]*NCSR Demokritos, Athens, Greece*
[2]*UMP CNRS, Thales, UP-Saclay, Palaiseau France*
[3]*AIXTRON SE, Herzogenrath, Germany*
a.dimoulas@inn.demokritos.gr

Abstract

2D $CrTe_2$ FM /Bi_2Te_3 TI heterostructures [1] are grown on 1 ML MoS_2 (WS_2)/sapphire substrates by MBE. Their physical properties are evaluated by in-situ RHEDD, STM and ARPES as well as Raman and XRD. A pure $CrTe_2$ phase is obtained at low T_g ~ 225 ^{0}C showing PMA and T_c ~160 K. Mixed Cr_xTe_y phases, due to Cr self-intercalation are obtained at high T_g ~ 500 C with a T_c near or above 300K. In $CrTe_2$, the topological Hall effect is observed below 100 K, indicating the presence of skyrmions [2]. Spin torque second harmonic measurements show a large field-like (FL) torque which indicates charge-spin conversion arising from the topological surface states [3]. Partial magnetization reversal is observed at 150 K (Fig.2) in an AHE configuration, induced by current pulses of ~ 1 x 10^7 A/cm^2 passing through the Bi_2Te_3 TI.

Acknowledgements: Financial support from H2020 FET PROACT project SKYTOP-824123

References

[1] X. Zhang et al., *Nat. Commun.* 12, 2492 (2021)
[2] J. Chen et al., Nano Lett. 19, 6144 (2019)
[3] P.M. Haney et al., *PRB* 87, 174411 (2013)

Figures

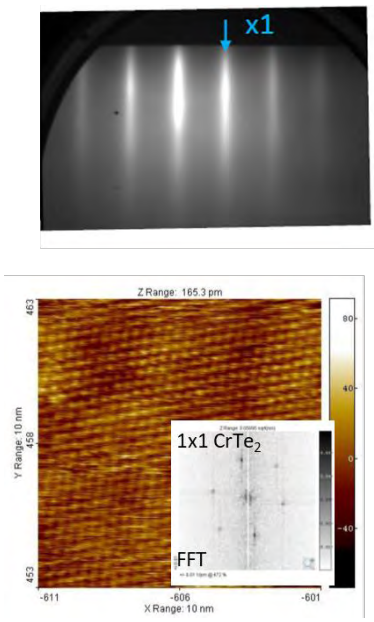


Figure 1: In situ Surface analysis showing a pure 1x1 CrTe2 phase in the epitaxial film. Top: RHEED pattern; bottom: STM and fast Fourier transform pattern

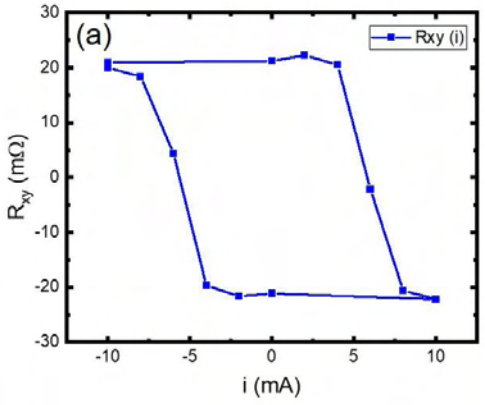


Figure 2: Magnetization reversal in $CrTe_2/Bi_2Te_3$ obtained in an AHE configuration under current pulses through the Bi_2Te_3 topological insulator

Majorana bound states in encapsulated bilayer graphene

Fernando Peñaranda
Ramón Aguado, Elsa Prada, Pablo San-Jose

Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas (ICMM-CSIC), Madrid, Spain.

fernando.penaranda@csic.es

The search for robust topological superconductivity and Majorana bound states continues, exploring both one-dimensional (1D) systems such as semiconducting nanowires and two-dimensional (2D) platforms. In this work we study a 2D approach based on graphene bilayers encapsulated in transition metal dichalcogenides that, unlike previous proposals involving the Quantum Hall regime in graphene[2,3], requires weaker magnetic fields and does not rely on interactions.

The encapsulation induces strong spin-orbit coupling on the graphene bilayer, which in turn has been shown to open a sizeable gap and stabilize fragile pairs of helical edge states[4]. We show that, when subject to an in-plane Zeeman field, armchair edge states can be transformed into a p-wave one-dimensional topological superconductor by laterally contacting them with a conventional superconductor. We demonstrate the emergence of Majorana bound states (MBSs) at the sample corners of crystallographically perfect flakes, belonging either to the D or the BDI symmetry classes depending on parameters.

We compute the phase diagram, the resilience of MBSs against imperfections, and their manifestation as a 4π-periodic effect in Josephson junction geometries, all suggesting the existence of a topological phase within experimental reach.

References

1. F. Peñaranda, R. Aguado, E. Prada, and P. San-Jose, arXiv:2202.00593v2 (2022).
2. P. San-Jose, J. L. Lado, R. Aguado, F. Guinea, and J. Fernandez-Rossier, Phys. Rev. X 5, 041042 (2015).
3. F. Finocchiaro, F. Guinea, and P. San-Jose, 2D Materials 4, 025027 (2017).
4. J. O. Island, X. Cui, C. Lewandowski, J. Y. Khoo, E. M. Spanton, H. Zhou, D. Rhodes, J. C. Hone, T. Taniguchi, K. Watanabe, L. S. Levitov, M. P. Zaletel, and A. F. Young, Nature 571, 85 (2019).

Figures

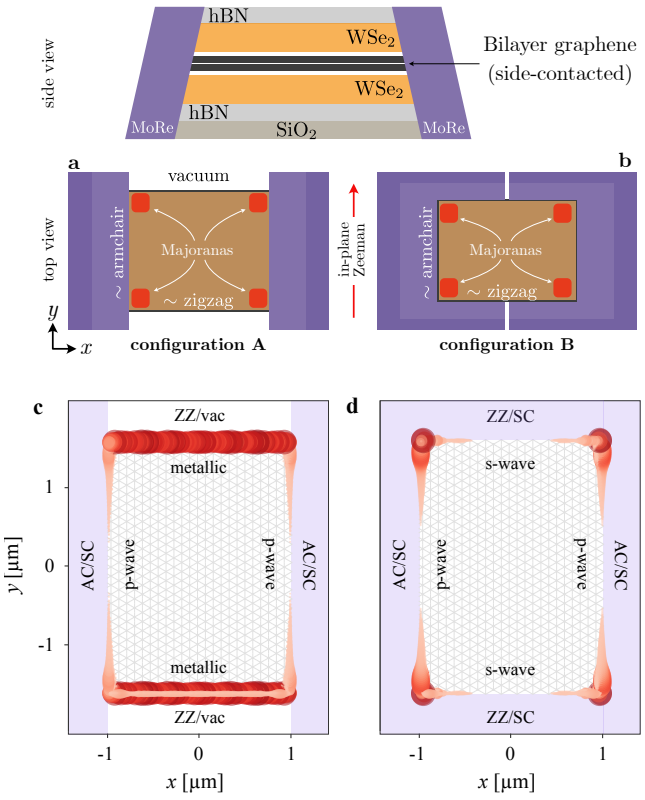


Figure 1: Top and lateral views of the proposed device configurations A and B (a-b). Spatial density of Majorana delocalised zero modes (c) and Majorana bound states (d) on top of the lattice.

Influence of disorder on vortex Majorana states in 3D topological insulators

Jukka Vayrynen
Rafal Rechcinski, Dmitry Pikulin, Roman Lutchyn

Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907 USA

vayrynen@purdue.edu

Abstract

Majorana states hosted in vortex cores of topological insulator/superconductor heterostructures present a promising alternative to nanowire-based approaches. Vortices can be pinned to anti-dots pre-fabricated in the superconductor; large anti-dots are relatively simple to fabricate and ensure that weak magnetic fields are sufficient to induce a required quantum of flux. However, it has thus far been unclear whether current topological insulator materials are clean enough to sustain Majorana vortex modes with a sizable gap to excitations. Also, if the anti-dot is too large, the level spacing of subgap vortex states may become too small even in a clean case. In this talk, I will present our numerical studies of the vortex subgap spectrum as a function of disorder, chemical potential, and the anti-dot size. We employ a two-dimensional low-energy description of the topological insulator surface, which allows as to simulate large system sizes with vortices up to 1 μm in diameter. We connect our results to existing mobility measurement data to translate the level of disorder in existing materials to our simulated disorder model.

References

[1] Deng, Bonesteel, Schlottmann, J. Phys.: Condens. Matter 33 035604 (2020)
[2] Ziesen, Hassler, J. Phys.: Condens. Matter 33, 294001 (2021)

Figures

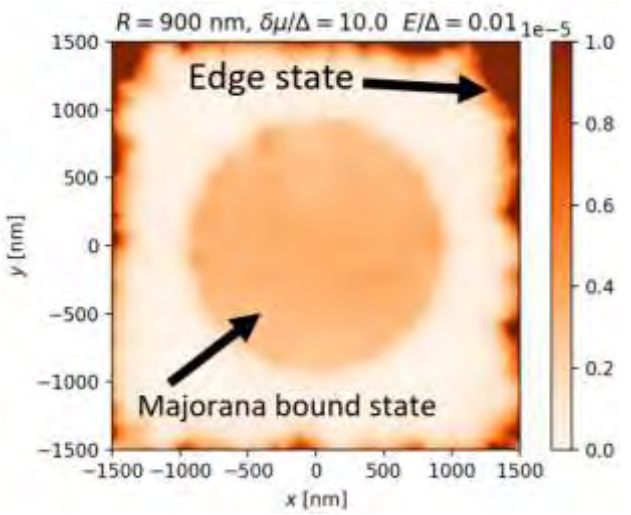


Figure 1: Majorana bound state wave function in disordered vortex of radius 900 nm.

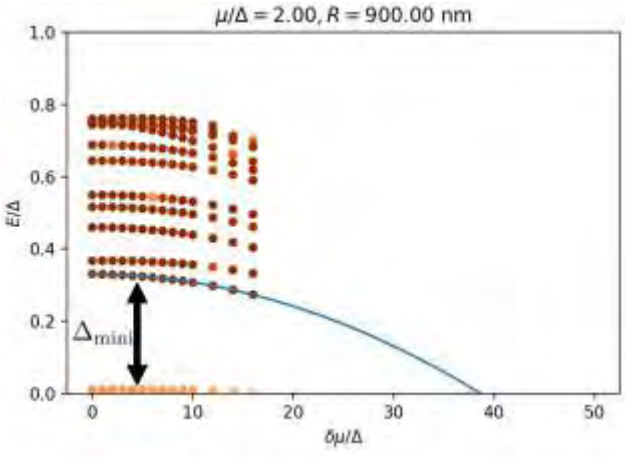


Figure 2: Energy spectrum of Andreev bound states inside of anti-dot (with trapped vortex) as a function of disorder strength on TI surface. For an antidot with micron radius critical disorder RMS is about 40 meV.

Van-der-Waals nano-photonics

Panaiot G. Zotev[a*], Yue Wang[b], Luca Sortino[c], Toby Severs Millard[a], Nic Mullin[a], Donato Conteduca[b], Mostafa Shagar[a], Armando Genco[a], Jamie Hobbs[a], Thomas F. Krauss[b], A.I. Tartakovskii[a**]

[a]*Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK*
[b]*Department of Physics, University of York, York, YO10 5DD, UK*
[c]*Nanoinstitute Munich, Faculty of Physics, Ludwig-Maximilians-Universität, München, 80539, Munich, Germany*
[*]p.zotev@sheffield.ac.uk [**]a.tartakovskii@sheffield.ac.uk

Van-der-Waals materials have been the focus of many research efforts since the discovery of graphene [1]. Further observations of a direct bandgap [2] and single photon emission [3] from monolayers of transition metal dichalcogenides (TMDs) have bolstered the importance of materials which consist of covalently bonded layers stacked into bulk crystals due to van-der-Waals interactions. In the past, the role of these layered materials has been limited to few-layer active media often integrated with nano-photonic structures fabricated from other more traditional materials, such as silicon [4] or gallium phosphide [5], for the enhancement of light emission properties. More recent works have involved the etching of nano-photonic architectures directly into layered materials such as hBN [6] and TMDs [7]. These are promising for the fabrication of such structures due to large refractive indices [7], low absorption within a large portion of the visible spectrum and the advantages which result from their van-der-Waals attractive nature to a wide variety of substrates. In our work, we utilize well established techniques to fabricate nano-photonic resonators with a range of geometries (see Fig. 1(a)) from a diverse set of van-der-Waals materials which exhibit Mie resonances as shown in Figs. 1(b)-(e). Signatures of strong coupling between excitonic features of TMDs and anapole modes were also observed as most clearly shown in Figs. 1(c)-(e). We demonstrate Purcell enhancement of emission from a TMD monolayer due to a nano-resonator mode induced in another material of the same family. Our subsequent observation of the formation of bright single photon emitters in a WSe_2 monolayer transferred onto WS_2 nano-antennas may lead to Purcell enhancement of quantum emission in a structure fabricated entirely from layered materials. Due to the weak van-der-Waals interaction with the SiO_2 substrate, we were able to employ an atomic force microscopy (AFM) cantilever in the repositioning of double-pillar (dimer) nano-antennas to achieve ultra-small gaps ($\approx$ 10 nm as shown in the left inset of Fig. 1(f)). This may enable applications such as stable optical trapping of quantum emitters and Purcell enhancement factors above 150 as shown by the simulations in Fig. 1(f).

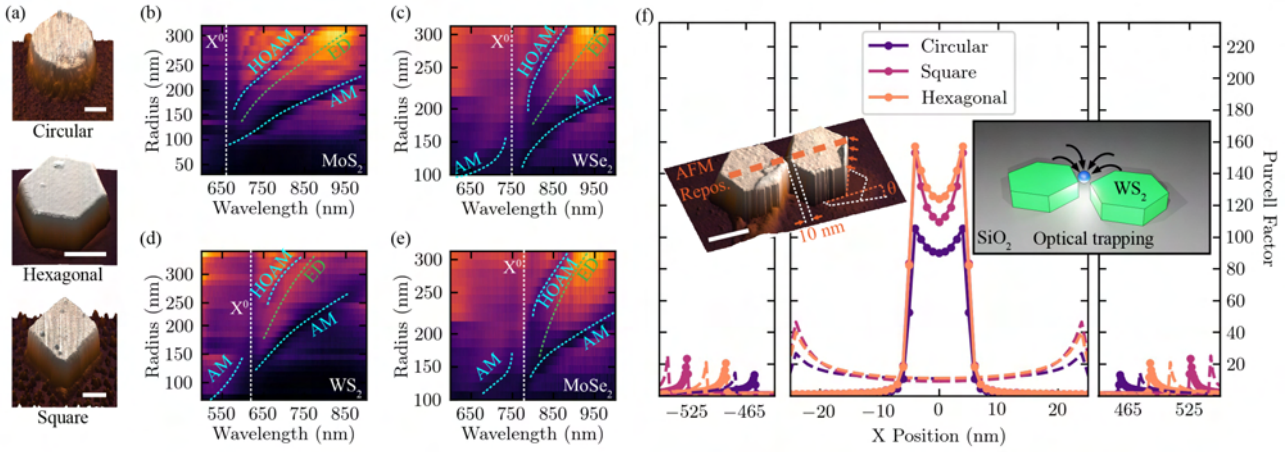


Figure 1: **Van-der-Waals nano-antenna experiments and simulations.** **(a)** AFM scans of fabricated geometries of layered material nano-antennas. **(b)-(e)** Dark field spectra of fabricated nano-antennas in different TMD materials exhibiting an electric dipole (ED) resonance, anapole (AM) and higher order anapole (HOAM) modes which anti-cross with the neutral exciton resonance (X^0). **(f)** Purcell enhancement of emission for an AFM repositioned hexagonal WS_2 dimer with a gap of 10 nm (solid lines) and an as fabricated 50 nm gap (dashed lines) at positions shown by the thick dashed line in the left inset. Left inset: AFM repositioning method to achieve a 10 nm dimer gap. Right inset: Schematic of optical trapping simulation of colloidal quantum dots. Scale bars = 200 nm.

References

[1] Novoselov, K. et al. *Science*, 306(2004), 666-669.

[2] Mak, K. et al. *Physical Review Letters*, 105(2010), 136805.

[3] Srivastava, A. et al. *Nature Nanotechnology*, 10(2015), 491-496.

[4] Li, Y. et al. *Nature Nanotechnology*, 12(2017), 987-992.

[5] Sortino, L. et al. *Nature Communications*, 10(2019), 5119.

[6] Fröch, J. et al. *Advanced Optical Materials*, 7(2019), 1801344.

[7] Verre, R. et al. *Nature Nanotechnology*, 14(2019), 679-683.

ORAL QUANTUM SEMICONDUCTOR

Persistence of symmetry-protected Dirac points at the surface of the topological crystalline insulator SnTe upon doping

Olga Arroyo Gascón[1,2]
Yuriko Baba[2], Jorge I. Cerdá[1,*], Oscar de Abril[3], Ruth Martínez[2], Francisco Domínguez-Adame[2] and Leonor Chico[2]

[1] *Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas, C/ Sor Juana Inés de la Cruz 3, E–28049 Madrid, Spain.*
[2] *GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain.*
[3] *Departamento de Estructuras y Física de Edificación, Universidad Politécnica de Madrid, E–28031 Madrid, Spain.*
** Deceased.*

o.arroyo.gascon@csic.es

We study the effect of a non-magnetic donor impurity located at the surface of the SnTe topological crystalline insulator [1]. Specifically, the changes on the surface states due to a Sb impurity atom are analyzed by means of first-principles simulations of pristine and impurity-doped SnTe. Both semi-infinite and slab geometries are considered within the ab-initio approach, and minimal and Green's function continuum models are also proposed with the same goal. We find that the Dirac cones are shifted down in energy upon doping; this shift strongly depends on the position of the impurity with respect to the surface. Moreover, the width of the impurity band shows an even-odd behavior by varying the position of the impurity. We compare slab and semi-infinite geometries, demonstrating that in the doped semi-infinite system the surface states remain gapless and their spin textures are unaltered. Besides its fundamental interest, tuning the Dirac cones of topological insulators can be of interest for transport and spintronic applications [2].

References

[1] O. Arroyo-Gascón, Y. Baba, J. I. Cerdá, O. de Abril, R. Martínez, F. Domínguez-Adame and L. Chico, arXiv:2108.06619 (2021).
[2] J. Liu, T. Hsieh, P. Wei *et al.* Nature Materials 13 (2014) 178–183.

Figures

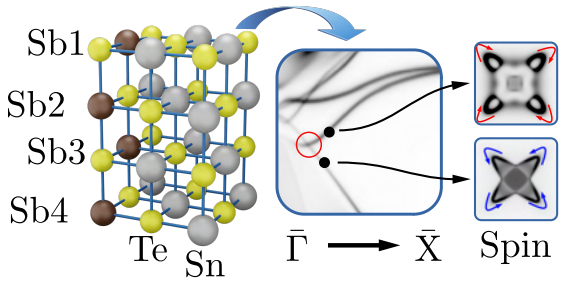


Figure 1: Left panel: SnTe slab unit cell. Sb impurities are highlighted in brown. Central panel: projected density of states (PDOS(***k***,E)) maps of Sb-doped SnTe. Right panel: PDOS(k_x,k_y,E) maps and spin textures below and above the Dirac point.

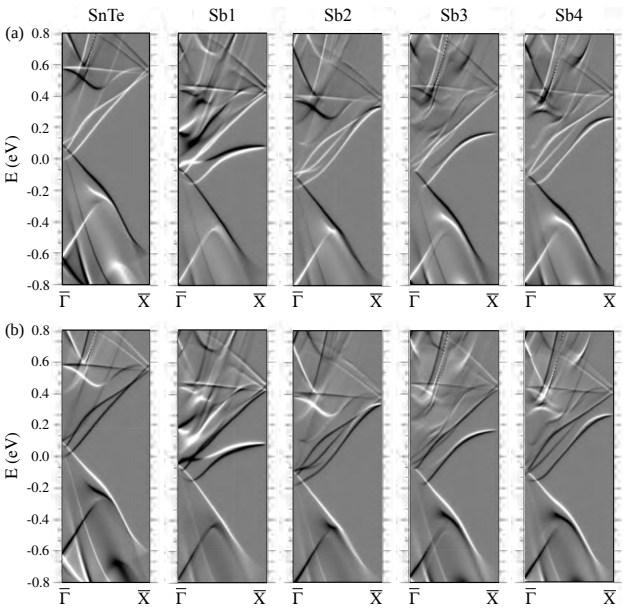


Figure 2: Magnetization maps (a) M_x(***k***,E) and (b) M_y(***k***,E) for the semi-infinite pristine and Sb-doped SnTe. White and black shades represent positive and negative M_i(***k***,E), respectively.

Impact of the electric field in high Chern number Quantum Anomalous Hall states

Yuriko Baba[1,2]
Mario Amado[3], Enrique Díez[3], Francisco Domínguez-Adame[1], Rafael A. Molina[2]

[1]*GISC, Universidad Complutense de Madrid*
[2]*IEM, Consejo Superior de Investigaciones Científicas*
[3]*USAL-NANOLAB, Universidad de Salamanca*
yuribaba@ucm.es

Topological magnetic insulators have been discovered as a new platform for observing Quantum Anomalous Hall states with high Chern number C. In three-dimensional structures of stacking layers of magnetically doped and undoped topological insulators, the number of chiral edge channels can be controlled by the width and number of layers. More specifically, samples of Cr-doped $Bi_2(Se,Te)_3$ have been recently measured by Zhao *et al.* [1] in transport experiments showing this feature up to C = 5.

In this work, we explore the possibilities of tuning the chiral channels of the aforementioned materials in the presence of electric fields in multilayered structures [2]. The external field tunes the Chern number and changes the number of topological channels dinamically. The tunability has a remarkable impact on the transport properties of pristine and disordered samples.

References

[1] Zhao, Y. F. *et al.*, Nature, **588** (2020) 419
[2] Wang, Y.X. and Li, F., Physical Review B, **104** (2021) 035202

Figures

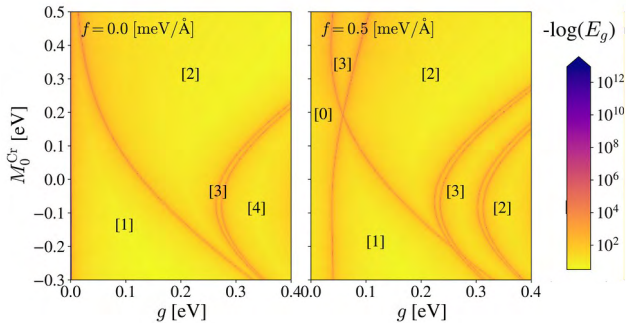


Figure 1: Phase map of the gap E_g as a function of the inverted mass in the Cr-doped layers M_0^{Cr} and the Zeeman splitting g for zero electric field and f = 0.5 meV/A. The Chern number is indicated in square brackets.

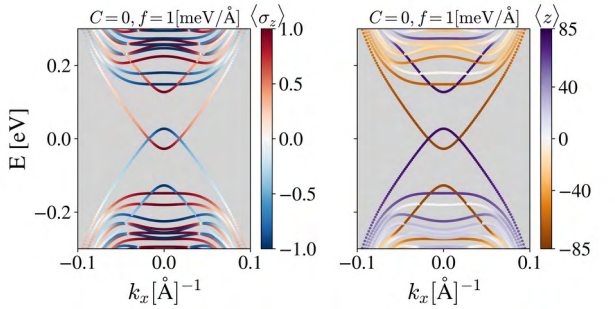


Figure 2: Collapse of the bands and modification of the Chern number due to the Stark effect in a multilayer sample with C=1 at zero electric field and C=0 with f = 1 meV/A. The colors represent the expected value of spin σ_z and z in the left and right pannel, respectively.

Nonlocal Signals of Orbital Angular Momentum Transport in Graphene

L. M. Canonico
M. Vila, T.G. Rappoport and Stephan Roche
ICN2, Universitat Autònoma de Barcelona, Edifici ICN2 Campus de la, Av. de Serragalliners, s/n, 08193 Bellaterra, Barcelona, Spain.
luis.canonico@icn2.cat

In the last decades, the development and the successes accumulated by the field of spintronics demonstrated that harnessing the quantum degrees of freedom of the matter is the most prominent pathway for further technological development. Following the lines set by spintronics, orbitronics explore the possibility of manipulating the orbital angular momentum of the carriers to store and process information using the orbital Hall effect as its main lever. In resemblance to the spin Hall effect, the orbital Hall effect refers to the appearance of a transverse orbital angular momentum current after applying a longitudinal electrical field [1].

Contributions for the orbital Hall effect are separated as intra- and inter-atomic contributions since they refer to the localized atomic and motion orbital angular momentum, respectively [2,3]. Despite being studied for 3D systems, recent works on 2D materials demonstrated that materials with vanishing spin Hall conductivity such as mono- [4] and bilayers [5] of transition metal dichalcogenides and gaped graphene monolayers [6] exhibit finite orbital Hall conductivity, which is given by intra- and interatomic contributions, respectively. Using the Landauer-Büttiker formalism, we show that gapped graphene devices present sizable non-local resistance signals related to conduction through dispersive edge states. Investigating the effect of weak magnetic fields on these non-local signals, we find that they exhibit a chiral behaviour with the field direction. Our results suggest that the origin of the non-local resistance signals in gapped graphene devices are described more transparently in terms of orbital angular momentum currents.

References

[1] B. A. Bernevig, T. L. Hughes, and S.-C. Zhang, PRL, 95, (2005), 06660.
[2] Cysne, T. P., Bhowal, S., Vignale, G., & Rappoport, T. G. arXiv preprint arXiv:2201.03491 (2022).
[3] Pezo, A., Ovalle, D. G., & Manchon, A. arXiv preprint arXiv:2201.05807 (2022).
[4] Canonico, L. M., et al. PRB (R) 101 (2020) 161409.
[5] Cysne, T. P., Costa, M., Canonico, L. M., Nardelli, M. B., Muniz, R. B., & Rappoport, T. G. PRL, 126(5), 056601 (2021).
[6] Bhowal, S., & Vignale, G. Physical Review B, 103(19), 195309 (2021).

Figures

Figure 1: Schematic representation of the orbital-Hall effect.

Coulomb interactions and effective quantum inertia of charge carriers in a macroscopic conductor

Presenting Author (C. Chaubet)
A. Delgard, B. Chenaud, U. Gennser, A. Cavanna, D. Mailly, P. Degiovanni
Laboratoire Charles Coulomb, L2C, Montpellier, Univerity of Montpellier, France
C2n Saclay, and ENS Lyon (France)
christophe.chaubet@umontpellier.fr

Abstract: On one hand, electrical transport across macroscopic conductors can be described in terms of lumped circuit elements, including inductances and capacitances. On the other hand, the linear response of ballistic quantum conductors can also be described in terms of inductances and capacitances of quantum origin reflecting the fermionic nature of charge carriers which leads to characteristic RC or LC time scales associated with ballistic times of flights (ref 1,2). In the present work, we demonstrate that macroscopic conductors involving a small number of conducting channels also exhibit linear response properties of quantum origin, even if their size is much larger than the electronic coherence length.

As a paradigmatic example, we study the low-frequency admittance of a quantum Hall bar of a size much larger than the electronic coherence length(ref 3). We find that this macroscopic conductor behaves as an ideal quantum conductor with vanishing longitudinal resistance and purely inductive behavior up to 1 MHz. We study the dependence of this inductance on the length of the edge channel and on the filling factor. The experimental data are well described by a scattering model for edge magneto-plasmons taking into account the effective long range Coulomb interactions within the sample. We find that the inductance's dependence on the filling factor arises predominantly from the effective quantum inertia of charge carriers induced by Coulomb interactions.

References

(1) J. Gabelli, G. F`eve, J. Berroir, B. Pla ,cais, A. Cavanna, B. Etienne, Y. Jin, and D. Glattli, Science 313, 499 (2006).
(2) J. Gabelli, G. F`eve, T. Kontos, J.-M. Berroir, B. Plac ,ais, D. Glattli, B. Etienne, Y. Jin, and M. Buttiker, PRL. 98, 166806 (2007).
(3) A. Delgard, B. Chenaud, U. Gennser, A. Cavanna, D. Mailly, P. Degiovanni, and C. Chaubet, Phys. Rev. B 104, L121301 (2021)

Figures

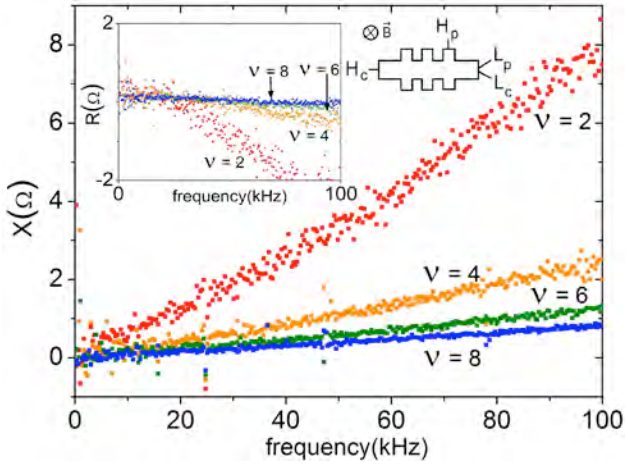


Figure 1: The reactance *X of an edge channel* as a function of the frequency *f* for different ν . Inset: The longitudinal resistance *R*(*f*) vanishes quadratically for integer filling factors

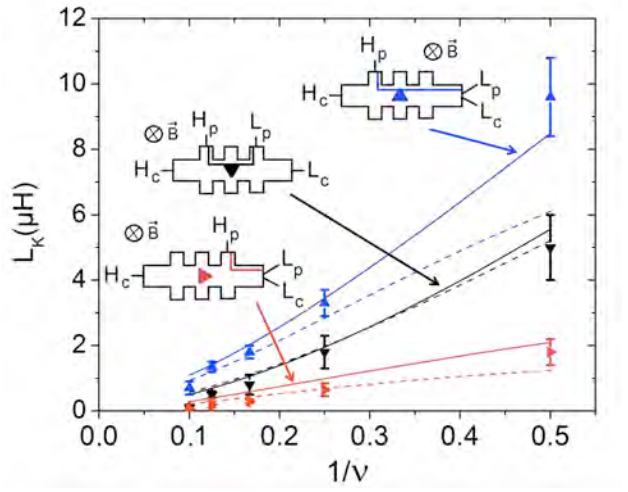


Figure 2: Quantum Inductance is proportional to the inverse of filling factor and to the length of edge channels.

Quantum Dots as Probes of 2DEG-Based Superconductor-Semiconductor Hybrid Wires

Alisa Danilenko[1]
Andreas S. Pöschl[1], Deividas Sabonis[1], Tyler Lindemann[2], Sergei Gronin[2], Geoffrey C. Gardner[2], Candice Thomas[2], Michael J Manfra[2], Charles M Marcus[1]

[1] *Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark*
[2] *Purdue University, West Lafayette, Indiana 47907, USA*

danilenko@nbi.ku.dk

We present experimental results for gate-defined lateral quantum dots coupled to a superconductor-semiconductor nanowire based on InAs/Al two-dimensional electron gas (2DEG). We demonstrate independent voltage control of coupling of multiple quantum dots to a superconducting wire on one side, and to normal semiconducting leads on the other. In the limit of sequential tunnelling, a level of a quantum dot can be used for high-resolution spectroscopy of Andreev bound states [1], with spin resolution in applied magnetic field [2]. With increased coupling, we gain experimental control over hybridization of discrete dot states with subgap Andreev states in the wire [3, 4]. This configuration may also offer the prospect of coupling two dots via an extended wire state. A high degree of experimental control as well as extension to a variety of device geometries is made possible by the hybrid 2DEG platform.

Research supported by Microsoft, the Danish National Research Foundation, and the Villum Foundation.

References

[1] F. Thomas et al, Phys. Rev. B 104, 115415 (2021)
[2] P. Recher et al, Phys. Rev. Lett. 85, 1962 (2000)
[3] D. Clarke, Phys. Rev. B 96, 201109(R) (2017)
[4] E. Prada et al, Phys. Rev. B 96, 085418 (2017)

Figures

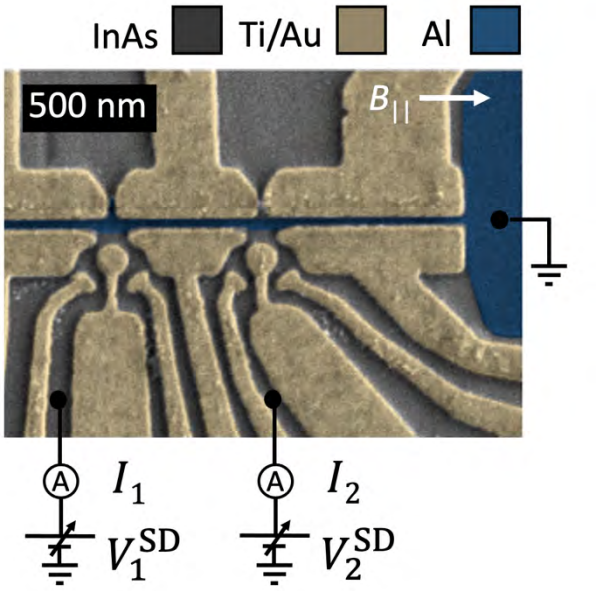


Figure 1: Scanning electron micrograph of a device, consisting of multiple gate-defined quantum dots side-coupled to a superconductor-semiconductor 2DEG nanowire.

Quantum control of two qubits spin hole gates

David Fernández Fernández[1]
Yue Ban[2]
Gloria Platero Coello[1]

[1]*Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), C. Sor Juana Inés de la Cruz 3, Madrid, Spain*

[2]*Department of Physical Chemistry, University of the Basque Country UPV/EHU, Barrio Sarriena, Bilbao, Spain*

gplatero@icmm.csic.es

Hole spins in semiconductor quantum dots (QDs) are attracting significant attention as candidates for fast, highly coherent, spin qubits [1-4]. They have long coherence time due to the weak hyperfine coupling to nuclear spins and have demonstrated to have rapid operation times due to the inherently strong spin–orbit coupling (SOC).

In this work we investigate how to control a two-hole spin qubit consisting of a triplet and a singlet hole states. For that purpose, we implement a driving protocol based on Shortcuts to Adiabaticity (STA), minimizing noise effects while enhancing robustness [5, 6]. We consider the fast quasi-adiabatic (FAQUAD) approach and analyze its feasibility to manipulate hole spin qubits and compare with other alternative protocols. We can initialize the qubit in an arbitrary state and perform a NOT gate by changing the detuning between dots. In addition, we achieve a SWAP-like two-qubits gate with a fidelity beyond error correction threshold. We study the robustness of the protocol regarding systematic errors in the detuning, as well as charge noise [7].

Furthermore, we study the direct transfer of entangled holes in QD arrays between edge sites by using inverse engineering techniques. We demonstrate that spin-conserving and spin-flipping direct transfer between edges can be achieved in a controlled way with all-electrical protocols by dynamically tuning the tunnelling rates between dots [8].

References

[1] D. Jirovec, et al., Nat. Mat. 20 (2021) 1106-1112.
[2] N. W. Hendrickx et al., Nat. Commun. 11 (2020) 3478
[3] A. Bogan, et al., PRL 118 (2017) 167701
[4] A. Bogan, et al., PRL 120 (2018) 207701
[5] Y. Ban, et al., Nanotech. 29 (2018) 505201
[6] Y. Ban, et al., Adv. Quantum Technol. 2 (2019) 1900048
[7] D. Fernández, et al., submitted
[8] D. Fernández, et al., submitted

Figures

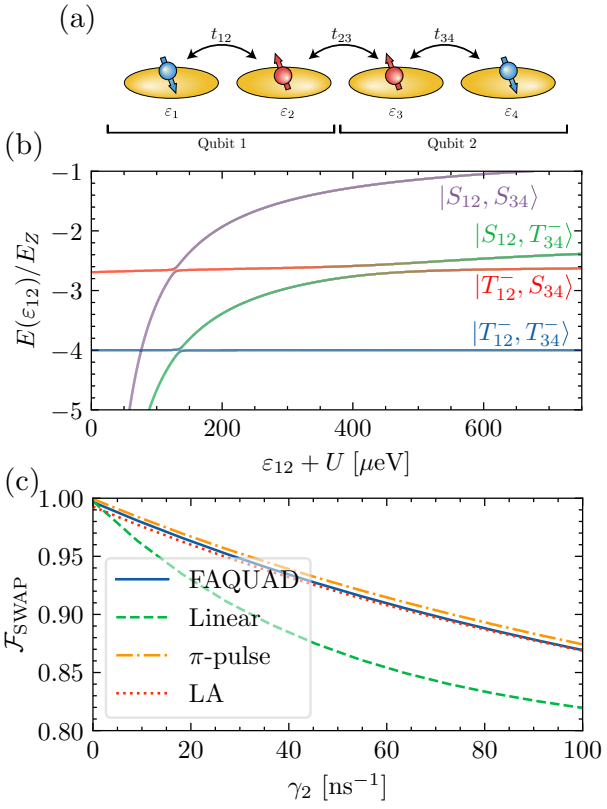


Figure 1: (a) Schematic picture of a quadruple quantum dot encoding two S-T qubits. (b) Energy level diagram of the system. (c) Fidelity of a SWAP gate against charge noise for different protocols.

Tip-Enhanced Raman Spectroscopy of Semiconductor InP-InGaP hetero-structured Nanowires:

Vanessa Hinojosa Chasiquiza[1]
Irene Mediavilla[1], Juan Jiménez[1], Lukas Hrachowina[2], Magnus T. Borgström[2], and Jorge Serrano[1]*

[1]GdS OPTRONLAB, Dept. of Condensed Matter Physics, University of Valladolid, Edificio LUCIA, Paseo de Belén 19, 47011, Valladolid, Spain
[2]Solid State Physics, Lund University, Box 118, 22100 Lund, Sweden.

Jorge.serrano@uva.es

Abstract

Raman spectroscopy is a powerful technique for the characterization of semiconductors [1,2]. The improvement of the spatial resolution is crucial for the study of semiconductor nanostructures. The cutting-edge technique for scaling down to the nanosize is tip enhanced Raman Spectroscopy (TERS) [2,3].

We present here a TERS analysis of InP/InGaP axially heterostructured Nanowires (NWs) combined with Atomic Force Microscopic technique. Fig. 1 shows the typical spectra of InP, InGaP, and a spectrum corresponding to a tunnel junction in between the InP and the InGaP segments. The green, red, and blue areas correspond to LO GaP like (InGaP), LO InP like (InGaP), and TO (InP) respectively. Those areas of interest were represented along the NWs with the same colors revealing resonances at the tunnel junction (red map) and at the undoped InGaP segment (green map), Fig. 2
This work evidences the potential of TERS for spatially resolved characterization of NW with nanometric resolution, which is very promising for the study of nanostructures for quantum devices.

References

[1] Otnes, G. et al,Nano letters, 18(5) (2018), 3038-3046.
[2] Zhao, Y. et al., Physical Review B, 104(23), (2021) 235309.
[3] Poliani, E., et al., The Journal of Physical Chemistry C, 124(51) (2020) 28178-28185.Authors, Journal, Issue

Figures

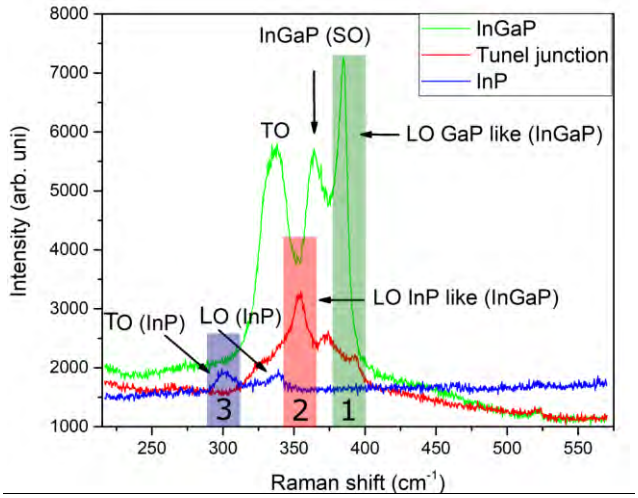


Figure 1: Typical local Raman spectra recorded on the InP, and InGaP segments and the tunnel junction (see Fig.2). The shadowed areas correspond to the spectral windows mapped in Fig.2 .

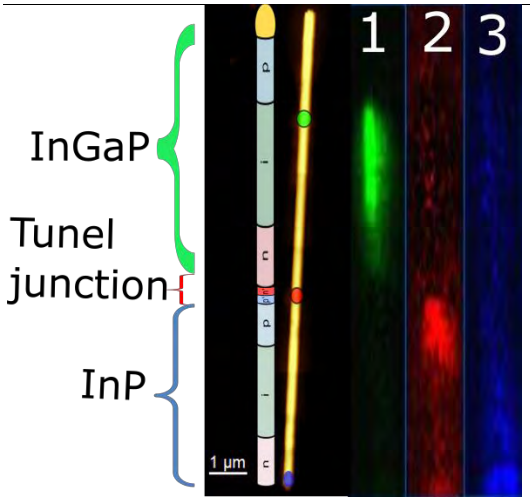


Figure 2: TERS maps along the InP/InGaP nanowire: 1) LO GaP like (InGaP) 2) LO InP like (InGaP) and 3) TO (InP) peaks ,see Fig. 1

Transition metal dihalides – van der Waals magnetic semiconductors for the superconducting spintronics and quantum technologies

M. Ilyn[1]
C. González-Orellana[1], A. Aguirre Baños[12], M. Corso[123], J. I. Pascual[2], F. S. Bergeret[13], C. Rogero[13]

[1]*Centro de Física de Materiales CSIC-UPV/EHU, Donostia-San Sebastian, Spain*
[2]*CIC nanoGUNE-BRTA, 20018 Donostia-San Sebastian, Spain*
[3]*Donostia International Physics Center, Donostia-San Sebastian, Spain*

maxim.ilin@ehu.es

A progress in the development of the superconducting qubits achieved in the last decade marked important milestones like demonstration of the commercial quantum processors with tens of nodes [1]. A most common architecture of these qubits was superconducting transmon that proved to be a reliable scheme suitable for intermediate-size systems [1]. Nevertheless, scaling up of the quantum processors requires improvement of the qubit's performance that stimulates investigation of the alternative architectures. A number of competing qubit's architectures were developed, including the semiconductor spin qubits [2] and more recently the superconducting Andreev spin qubit [3,4]. In contrast to the original idea of the Andreev spin qubit [5], where spin splitting is achieved due to the spin-orbit interaction, using of superconductor — magnetic semiconductor interfaces for implementing single-qubit operations in spin qubits was found to be more advantageous. For instance, Al/EuS bilayers were proposed for using in Andreev spin qubits to complement or even substitute the use of spin-orbit interaction [6].

A number of magnetic semiconductors suitable for creating exchange coupling in the heterostructures with superconductors is limited because majority of these compounds are antiferromagnets. In this work we present our results of investigation of the transition metal dihalides ($NiCl_2$, $NiBr_2$, $FeCl_2$ and $FeBr_2$) grown on the superconducting $NbSe_2$ substrate. We will show that these materials demonstrate collinear or non-collinear ferromagnetic ordering in the limit of a single or a few atomic layers thick films, although in bulk form they are antiferromagnets [7]. Following our previous work [8] we used a number of advanced spectroscopic and microscopic techniques to perform detailed characterization of the electronic and magnetic properties of these materials [9, 10]. Obtained results will be discussed in the context of implementation of the hybrid magnetic semiconductor -- superconductor devices for superconducting spintronics and quantum technologies.

References

[1] M. Kjaergaard et al. Annu. Rev. Condens.Matter Phys. 11(2020), 369
[2] A. Chatterjee et al. Nature Reviews Physics, 3 (2021), 157
[3] C. Javiner et al. Science 349 (2015), 1199
[4] M. Hays et al. Science 373 (2021), 430
[5] N. M. Chtchelkatchev et al. Phys. Rev. Lett. 90 (2003), 226806
[6] X. P. Zhang et al. [in preparation]
[7] McGuire, M. Crystals 7 (2017), 121
[8] D. Bikaljevic et al. *ACS Nano* 15 (2021), 14985
[9] C. González-Orellana et al. [in preparation]
[10] A. Aguirre Baños et al. [in preparation]

Electron and Hole Spin Qubits Variability in Si MOS Devices

Biel Martinez
Yann-Michel Niquet

CEA, 17 Avenue des Martyrs, Grenoble, France

Biel.martinezidiaz@cea.fr

Semiconductor spin qubits may show significant device-to-device variability in the presence of spin-orbit coupling mechanisms. Interface roughness, charge traps, layout or process inhomogeneities indeed shape the real space wave functions, hence the spin properties. It is, therefore, important to understand how reproducible the qubits can be in order to assess strategies to cope with the scattering of their properties. Here we model the variability of Larmor and Rabi frequencies due to disorder at the Si/SiO_2 interface (roughness, charge traps) in metal-oxide-semiconductor devices [1]. We consider both electron qubits (with synthetic spin-orbit coupling fields created by micro-magnets) and hole qubits (with intrinsic spin-orbit coupling). We identify charge traps as the main source of variability, we unravel the microscopic mechanisms responsible for this variability of both electrons and holes, and we analyse the implications of these results for the design of the hosting platform and for the performance of an eventual quantum processor.

References

[1] B. Martinez, Yann-Michel Niquet, Physical Review Applied, 7 (2022) 024022.

Figures

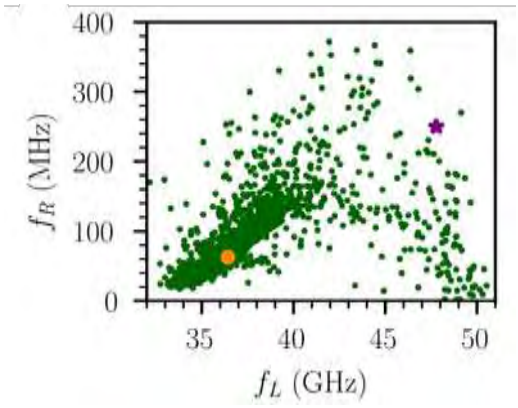


Figure 1: Hole spin qubit Rabi and Larmor frequencies for different random distribution of charge traps with density $n_i = 5 \cdot 10^{10}$ cm^{-2}. Green points show individual simulations, whereas orange point denotes ideal device properties, and purple star highlights the simulation illustrated in Figure 2.

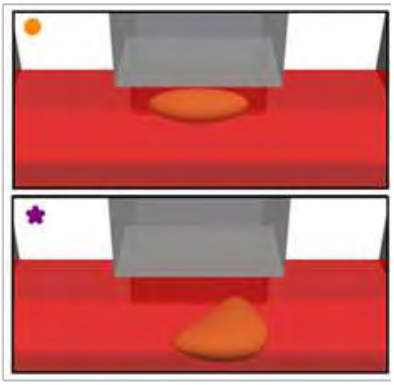


Figure 2: Squared ground state wave function for the ideal device (top panel) and for a sample charge trap distribution (bottom panel).

Unveiling the light emission of InP-InGaP hetero-structured nanowires

Irene Mediavilla Martinez[1]
Vanessa Hinojosa[1], Juan Jiménez[1], Lukas Hrachowina[2], Magnus T. Borgström[2], and Jorge Serrano[1]*

[1]*GdS OPTRONLAB, Dept. of Condensed Matter Physics, University of Valladolid, Edificio LUCIA, Paseo de Belén 19, 47011, Valladolid, Spain*
[2]*Solid State Physics, Lund University, Box 118, 22100 Lund, Sweden.*

Jorge.serrano@uva.es

The luminescence emission in semiconductor nanowires (NWs) yields valuable information on doping and crystal inhomogeneities only accessible with nanometer spatially resolved techniques such as tip-enhanced photoluminescence (TEPL) and cathodoluminescence (CL). This type of information is necessary for the development of new quantum devices [1].

We report here an investigation of the luminescence emission of a single InP-InGaP hetero-structured NW [2] by micro-photoluminescence (μ-PL), CL, and TEPL.
We have obtained a first approximation of the composition of the sample using μ-PL, which presents in the beginning of the wire (lower part) the emission associated with the InP as reflected in the low energy tail of the broad band centered at 770 nm, which is contributed by a parasitic InGaP shell. The band is redshifted along the wire due to a compositional change of the InGaP shell (Fig. 1a). The PL signal of this part of the NW is 100 times stronger than the associated with the InGaP NW section in the upper part of the NW. The SEM images (Fig. 1b) show how the wire is slightly tapered. This is due to the deposition of an InGaP shell on the bottom of the wire during the synthesis process, as reflected by CL spectra taken at different points along the wire (Fig. 1c). The spectrum is broadened showing the emission from InP in the low energy side, and the InGaP shell. The CL spectra supports the presence of the InGaP shell already observed in the μ-PL spectra, but with enhanced spatial resolution.
Finally, TEPL (Fig. 1d) enables to get a high resolution view of the NW compositional structure. In particular the heterojunctions are resolved, and one can characterize with nanometric resolution the different sections of the heterostructured NW.

The three luminescence techniques reported herein appear as complementary for the characterization of nanostructured semiconductors suitable for quantum devices, as qubits, LEDs, and solar cells [3,4].

References

[1] Lee, H. et al, Nanophotonics, 9(10)(2020), 3089-311.
[2] Otnes, G. et al, Nano letters, 18(5)(2018), 3038-3046.
[3] Gao, Q. et al, Progress inn Photovoltaic: Research and Applications, 27(3)(2019), 237-244.
[4] Minitairov, A. et al, Scientific Reports, 11(1)(2021), 1-11.

Figures

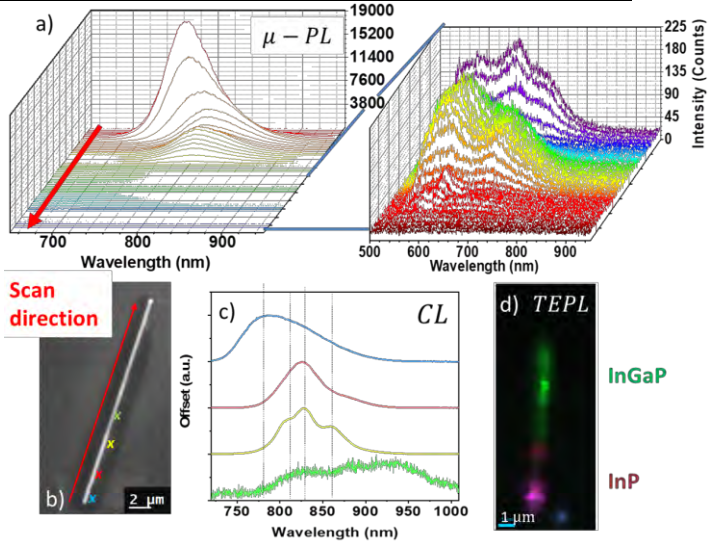


Figure 1a) μ-PL results, **1b)** SEM image (the colored dots indicate the measured points by CL), **1c)** CL spectra, **1d)** TEPL emission along the NW.

Optical cavity modes in luminescent β-Ga_2O_3:Cr nanowires for thermometry

Emilio Nogales[1]
Manuel Alonso-Orts[1], Daniel Carrasco[1], José María San Juan[2], María Luisa Nó[2], Alicia de Andrés[3], Bianchi Méndez[1]

[1] *Departamento de Física de Materiales, Fac. CC Físicas, Universidad Complutense de Madrid, Madrid 28040, Spain*
[2] *Departamento de Física, Facultad de Ciencias y Tecnología, Universidad del País Vasco, Apdo. 644, Bilbao 48080, Spain*
[3] *Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas, Cantoblanco, Madrid 28049, Spain*
Contact email: enogales@ucm.es

Gallium oxide is currently attracting great scientific and technological interest, due to several special features, some of them derived from the fact that it is an ultra-wide bandgap semiconductor [1]. Within the area of photonics, applications based on this oxide include solar-blind UV photodetectors and tuneable emitters from the near-UV to the near-IR [1]. Such potential is also being explored in the nano regime. In this work, nanophotonics applications of optical microcavities created within β-Ga_2O_3 nanowires are studied. In particular, they are designed, optimized and characterized [2]. Pairs of distributed Bragg reflectors (DBR) patterned by focused ion beam (FIB) in the waveguiding nanowires, define optical microcavities that result in widely tuneable, strong Fabry-Perot (FP) optical resonances. Experimental results and analytical models, as well as finite-difference time-domain (FDTD) simulations have allowed a thorough discussion of their photonic behaviour. These approaches allow prediction and optimization of the design and performance of the cavities. In the light of the photonic properties deduced from the β-Ga_2O_3:Cr cavities, a novel design of thermometer [3] has been developed. Thermal shifts of the characteristic R-lines of Cr^{3+} ions and the FP resonances observed by local photoluminescence are monitored. These two features result in a wide temperature sensitive range, at least from 150 K up to 550 K, with a precision around 1 K. On the other hand, the full width at half maximum of the FP peaks is nearly constant. The wide dynamic range, high spatial resolution, very high thermal and chemical stability and the fact that this material can be used in harsh environments, make these temperature sensors ideal for high electronic/optical power devices, as well as other possible applications.

References

[1] S. J. Pearton J. Yang, P. H. Cary IV, F. Ren, J. Kim, M. J. Tadjer, and M. A. Mastro, Appl. Phys. Rev. 5 (2018) 011301.
[2] M. Alonso-Orts, E. Nogales, J. M. San Juan, M. L. Nó, J. Piqueras, B. Méndez, Phys. Rev. Appl. 9 (2018) 064004
[3] M. Alonso-Orts, D. Carrasco, J. M. San Juan, M. L. Nó, A. de Andrés, E. Nogales, B. Méndez, Small 18 (2022) 2105355

Figures

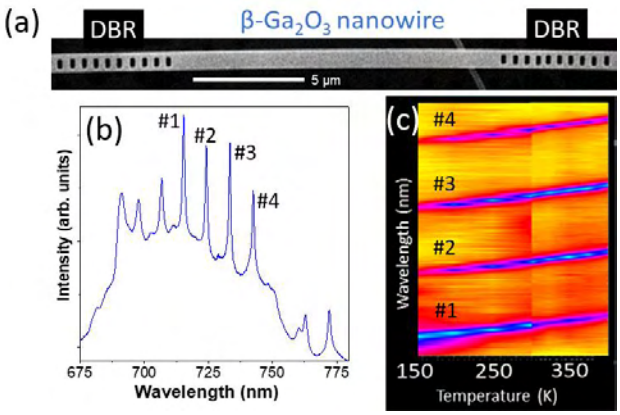


Figure 1: (a) Optical cavity created in a β-Ga_2O_3:Cr nanowire, (b) room temperature local micro-photoluminescence spectrum, (c) FP peak positions dependence on temperature.

Novel high-frequency performance of nanodevices with coherent electron-photon interactions

Xavier Oriols[1]
Matteo Villani[1], Carlos Destefani[1], Xavier Cartoixà[1] and Michael Feiginov[2]

[1] *Universitat Autònoma de Barcelona, Spain*
[2] *Technische Universität Wien, Austria*

xavier.oriols@uab.es

Typically, the performance of quantum electron device is engineered through the modulation of the transmission coefficient T(E) with the longitudinal electric field [1] solution of Gauss's equation. In this work, the transverse electromagnetic fields is considered quantized and its effects on the device dynamics is analysed with a coherent electron-photon model. The computational burden involved in the multi-time measurements of THz currents in nanodevices is minimized by invoking a Bohmian description of the light-matter interaction [2],[3] as shown in Fig. 1. For a double barrier structure, the second peak of the original transmission coefficient, without interaction with photons, splits into two new peaks due to the electron-photon interaction in the resonant case, as seen in Fig. 2. Such phenomenon, which mimics known effects predicted by a Jaynes-Cummings model in closed systems [4], exemplifies how the full quantum treatment of electrons and electromagnetic fields opens unexplored paths for engineering new THz electron devices.

References

[1]R. Landauer, IBM Journal of Research and Development 1, 223-231 (1957).
[2] X. Oriols and J. Mompart, Applied Bohmian Mechanics, 19-166 (2019).
[3] D. Marian, N. Zanghi, X. Oriols Phys. Rev. Lett. 116, 110404 (2016).
[4] M.O. Scully and M.S. Zubairy, Quantum Optics (Cambridge University Press,2008).

Figures

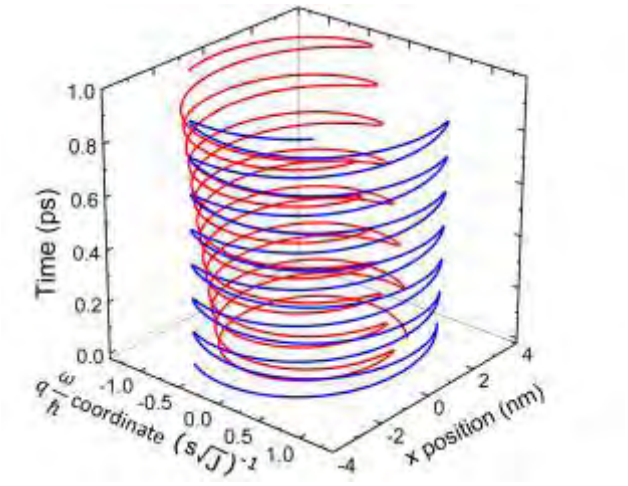


Figure 1: Typical Bohmian trajectories in the 2D electron-photon plane with x the position of the electron and q the amplitude of the mono-mode electromagnetic field.

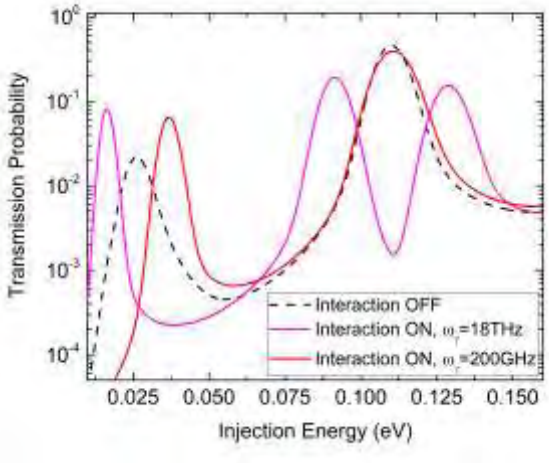


Figure 2: Transmission probability T(E) as a function of the energy of the electron entering into a double barrier potential and interacting with a mono-mode electromagnetic field with frequency ω_γ. The cases of no-interaction (dashed black), interaction with a resonant photon (magenta) and a non-resonant photon (red) are plotted.

Over one hundred microsecond electron spin coherence in an optically active quantum dot

Noah Shofer
Leon Zaporski, Jonathan Bodey, Daniel Jackson, Urs Haeusler, Dorian Gangloff, Mete Atatüre, Claire Le Gall
1. Cavendish Laboratory, University of Cambridge, Cambridge, UK

Santanu Manna, Saimon Covre da Silva, Armando Rastelli
2. Institute of Semiconductor and Solid State Physics, Johannes Kepler Universität, Linz, Austria

George Gillard, Evgeny Chekhovich
3. Department of Physics and Astronomy, University of Sheffield, Sheffield, UK

njs73@cam.ac.uk

Optically active spins in III-V semiconductor quantum dots (QDs) have the highest quality optical properties amongst solid-state spin-photon interfaces [1]. Despite the excellent optical properties of this system, preserving a spin state beyond a few microseconds has remained a challenge [2]. In this work, we implement all-optical spin control techniques [3] in GaAs/AlGaAs QDs grown via nanohole infilling [4]. Using a Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence [5] we decouple the spin qubit from the nuclear environment to sustain the electron spin coherence time up to 113(3) μs, a twenty-fold improvement compared to previous results in III-V QDs. Further, the scaling of the coherence time with the number of CPMG π-pulses indicates a near-perfect refocusing of the interaction between the electron and nuclear environment. By intersecting a microscopic model of the CPMG data with nuclear magnetic resonance spectroscopy, we arrive at a comprehensive understanding of the dephasing in this system. Our results demonstrate the possibility of combining near-ideal optical properties with a highly coherent electron spin dynamics in a solid-state platform

Figures

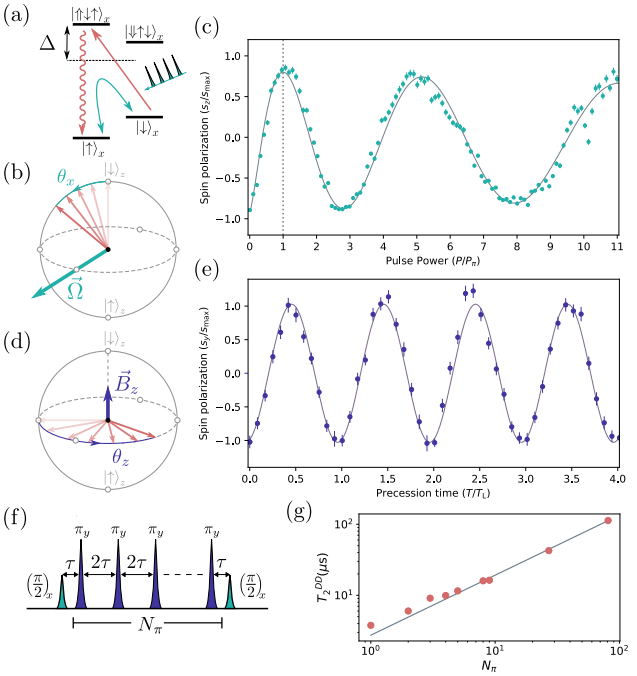


Figure 1: (a) Coherent control (green) and optical pumping (red) of the QD electron spin. (b,c) Rotation of the electron spin around the x-axis, showing characteristic Rabi oscillations dependent on pulse power. (d,e) Larmor precession of the electron spin around the z-axis. (f) CPMG pulse sequence. Successive π_y-pulses decouple the electron from the nuclear environment. (g) Electron coherence time versus number of CPMG π_y-pulses.

References

[1] N. Somaschi, et al., Nat. Photon. 10, (2016) 340-345
[2] R. Stockill, et al., Nat. Com. 7, (2016) 12745
[3] J. Berezovsky, M.H. Mikkelsen, N.G. Stoltz, L.A. Coldren, & D.D. Awschalom, Science, 320 (2008) 349
[4] M. Gurioli, Z. Wang, A Rastelli, T. Kuroda, & S. Sanguinetti, Nat. Mat., 18 (2019) 799-810
[5] H.Y. Carr & E.M. Purcell, Phys. Rev., 94 (1954) 630-638

Single-electron-shuttling in Si/SiGe

Ran Xue
Inga Seidler, Tom Struck, Simon Humpohl, Tobias Hangleiter, Hendrik Bluhm, Lars R. Schreiber

JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany

ran.xue@rwth-aachen.de

Abstract

The electron-spin in gate-defined quantum dots in a Si/SiGe heterostructure is one of the most promising qubits for scalable quantum computing. A quantum processor with sparse qubit array has been proposed exploiting an electron shuttling concept across a distance of 10 µm [1]. Here we study the feasibility of single electron shuttling by forming a propagating sinusoidal potential in a gate-defined 1-dimensional channel, namely the conveyor mode shuttling. A 99.42 ± 0.02% high single-electron shuttle fidelity over a distance of 420 nm has been demonstrated in our recent research. [2] Additionally, conveyor mode shuttling for longer distance is under investigation by using of the device depicted in Figure 1a. Only 4 signal lines are physically connected to four terminals of the 10 µm shuttle (Fig. 1b), therefore, no additional scalability complexity regarding signal generation and wiring is expected. It provides adiabatic movement of a quantum dot filled by a single electron representing the qubit (Fig. 1c). According to our theory studies on qubit decoherence mechanisms, the conveyor mode shuttling across 10 µm with high shuttling fidelity is feasible in our shuttle device. [3] Our concept is compatible with established gating technology and can be readily transferred to industrial CMOS fabrication lines.

References

[1] Boter, J. et al., arXiv:2110.00189v1 (2021)
[2] Seidler, I. et al, arXiv:2108.00879 (2021)
[3] Langrock, V. et al., arXiv: 2202.11793 (2022)

Figures

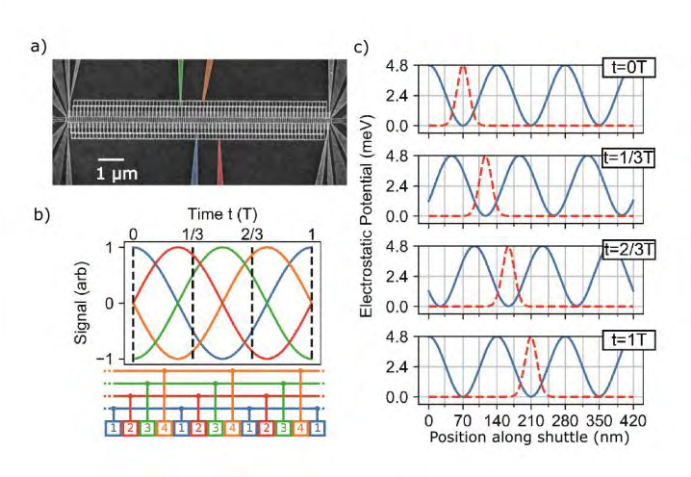


Figure 1: SiGe shuttle device for conveyor mode shuttling: a) A scanning electron micro-graph of the measured device. b) 4 sine waves with π/2 phase among each other are applied to the coloured terminals in panel a to form a propagating sinusoidal potential for conveyor mode shuttling. c) The single electron shuttling over 1 period (T), when the ground state of electron (red dashed line) is adiabatically shuttled forwards due to the confinement of electric potential (blue solid line).

Coherent interaction of a hole spin and a microwave photon

Cécile Yu[1]
Simon Zihlmann[1], José C. Abadillo-Uriel[2], Vincent P. Michal[2], Benoît Bertrand[3], Maud Vinet[3], Silvano De Franceschi[1], Yann-Michel Niquet[2], and Romain Maurand[1]

1 Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France
2 Univ. Grenoble Alpes, CEA, IRIG-MEM, Grenoble, France
3 Univ. Grenoble Alpes, CEA, LETI, Minatec Campus, Grenoble, France

romain.maurand@cea.fr

Recently, hole spins in silicon and germanium have shown increasing interest for quantum information processing owing to the advantage of manipulating their state with electric instead of magnetic microwave fields [1,2]. This is possible due to the strong spin-orbit interaction intrinsically present in the valance band of these materials. Spin-orbit coupling offers as well the possibility to couple a hole spin to the electric field component of a microwave photon.
Here we show a strong hole spin-photon interaction on a CMOS compatible platform. We find a coupling strength of 300 MHz, exceeding the spin decoherence rate and the photon decay rate by a factor 30. Our coupling largely exceeds the best figures reported so far in the case of electrons in silicon [3,4], opening the door to the achievement of high-fidelity two qubits gate with distant spins. Moreover, the dominating Rashba spin-orbit coupling allows us to tune the spin-photon coupling strength by more than one order of magnitude by simply varying the magnetic field orientation with respect to the spin-orbit field.

References

[1] F. Giustino *et al.*, *J. Phys. Mater.* 3 042006 (2020)
[2] G. Scappucci et al., *Nat Rev Mater* 6, 926–943 (2021).
[3] Borjans, F., et al., Nature 577, 195 (2020)
[4] P. Harvey-Collard, arXiv:2108.01206.

Figures

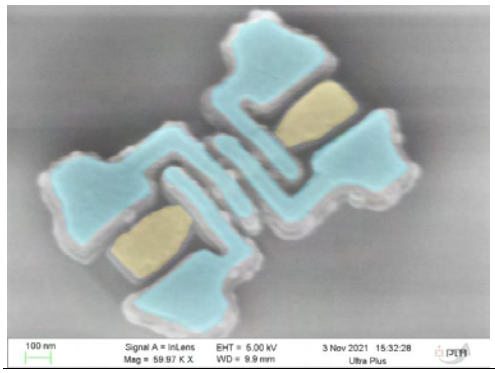


Figure 1: Colorized scanning electron micrograph of a silicon-on-insulator nanowire (yellow) with four gates (blue).

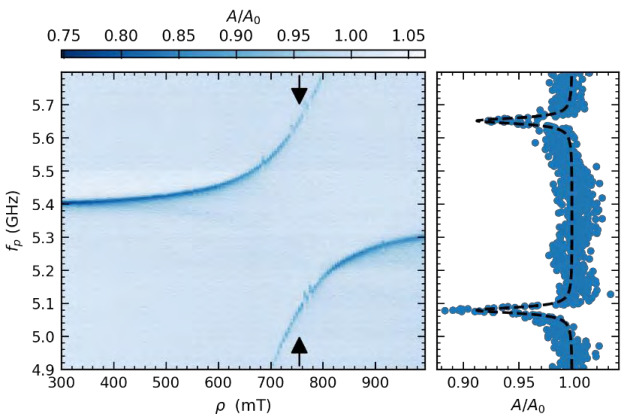


Figure 2: Transmission of the cavity as a function of in-plane magnetic field with a clear avoided crossing attributed to the strong spin-photon coupling. A line cut through the position indicated by the arrows shows a Rabi vacuum splitting of 600 MHz.

ORAL PHD STUDENT

Bell nonlocality is not sufficient for the security of standard device-independent quantum key distribution protocols

Maria Balanzó-Juandó
Máté Farkas, Karol Lukanowski, Jan Kolodynski, Antonio Acín

ICFO - Institut de Ciències Fotòniques, Av. Carl Friederich Gauss, 3, 08860-Castelldefels (Spain)

maria.balanzo@icfo.eu

One of the most profound features of Bell nonlocality is that it allows us to rule out a local realist explanation of an experiment—and thus to verify its quantum nature—without having to characterise the devices used. As such, Bell nonlocality is at the heart of various (device-independent) quantum information processing protocols, harnessing the strong correlations of nonlocal statistics. In this work, we investigate the foundational role of Bell nonlocality in the task of device-independent quantum key distribution, in particular, whether Bell nonlocality is sufficient for its security. Device-independent quantum key distribution allows two honest users to establish a secret key, while putting minimal trust in their devices. Most of the existing protocols have the following structure: first, a bipartite nonlocal quantum state is distributed between the honest users, who perform local measurements to establish nonlocal correlations. Then, they announce the implemented measurements and extract a secure key by post-processing their measurement outcomes. In this work, we show that no protocol of this form allows for establishing a secret key for a large class of nonlocal correlations. To prove this result, we introduce a technique for upper-bounding the asymptotic key rate of device-independent quantum key distribution protocols, based on a simple eavesdropping attack. Our results imply that either different reconciliation techniques are needed for device-independent quantum key distribution in the large-noise regime, or Bell nonlocality is not sufficient for this task. Going beyond the scope of the published work, I will also explain how the results extend to protocols in which only one party announces their measurement settings.

Figures

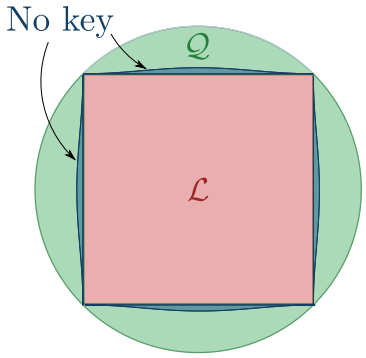


Figure 1: In this Figure, we depict the set of nonlocal correlations (green), the set of local correlations (red), and the nonlocal region which is not enough to ensure secure quantum key distribution using standard protocols, i.e., where Alice and Bob cannot extract a secure key (blue).

References

1. Máté Farkas, Maria Balanzó-Juandó, Karol Lukanowski, Jan Kolodynski, Antonio Acín, Physical Review Letters, 127, 050503 (2021).

Contextuality and memory cost of simulation of Majorana fermions

Susane Calegari
Juani Bermejo-Vega
Michał Oszmaniec

Center for Theoretical Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warszawa, Poland

calegari@cft.edu.pl

Contextuality has been reported to be a resource for quantum computation, analogous to non-locality which is a known resource for quantum communication and cryptography. We show that the presence of contextuality places new lower bounds on the memory cost for classically simulating restricted classes of quantum computation. We apply this result to the simulation of a model of quantum computation based on the braiding of Majorana fermions, namely topological quantum computation (TQC) with Ising anyons, finding a saturable lower bound in log-linear in the number of physical modes for the memory cost. The TQC model lies in the intersection between two computational models: the Clifford group and the fermionic linear optics (FLO), a framework analogous to bosonic linear optics. We extend our results and prove that the lower bound in the memory required in an approximate simulation of the FLO model is quadratic in the number of physical modes.

Algebraic Bethe Circuits

Diego García-Martín

Alejandro Sopena, Max Hunter Gordon, Germán Sierra, Esperanza López

Technology Innovation Institute, 9639 Masdar City, Abu Dhabi, United Arab Emirates.

diegogarcia91@gmail.com

The Algebraic Bethe Ansatz (ABA) is a highly successful analytical method used to exactly solve several physical models in both statistical mechanics and condensed-matter physics. Here we bring the ABA to unitary form, for its direct implementation on a quantum computer. This is achieved by distilling the non-unitary matrices that make up the ABA into unitaries using the QR decomposition. Our algorithm is deterministic and works for both real and complex roots of the Bethe equations. We illustrate our method in the spin-1/2 XX and XXZ models. We show that using this approach one can efficiently prepare eigenstates of the XX model on a quantum computer with quantum resources that match previous state-of-the-art approaches. We run numerical simulations, preparing eigenstates of the XXZ model for systems of up to 24 qubits and 12 magnons. Furthermore, we run small-scale error-mitigated implementations on the IBM quantum computers, including the preparation of the ground state for the XX and XXZ models in sites. Finally, we derive a new form of the Yang-Baxter equation using unitary matrices, and also verify it on a quantum computer.

Figures

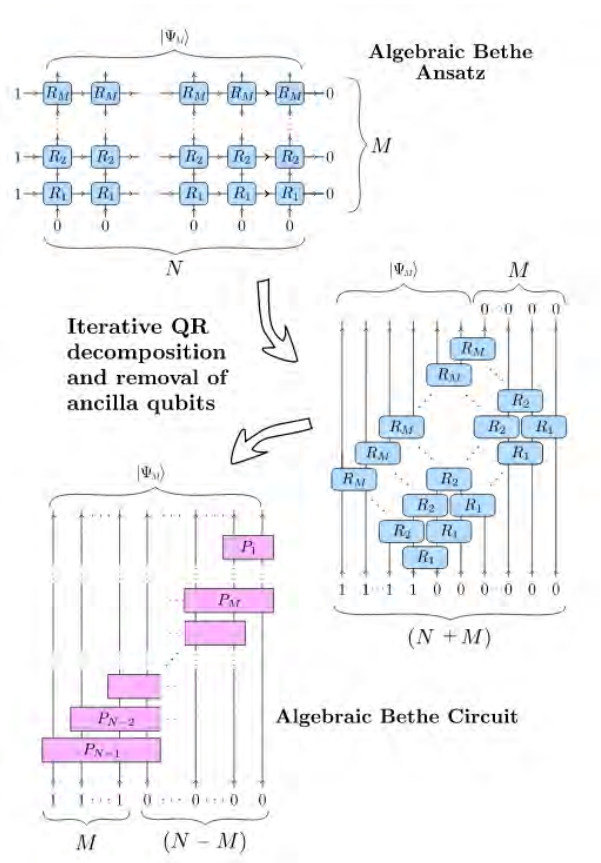


Figure 1: Conversion of the non-unitary Algebraic Bethe Ansatz into a deterministic unitary Algebraic Bethe Circuit.

References

[1] Alejandro Sopena, Max Hunter Gordon, Diego García-Martín, Germán Sierra, Esperanza López, “Algebraic Bethe Circuits” (2022), arXiv preprint arXiv: 22002.04673

Qutrit Entanglement via the Differential AC Stark Shift

Noah Goss[1,2]
Alexis Morvan[2], Bradley Mitchell[1,2], Brian Marinelli[1,2], Long Nguyen[2], Ravi Naik[2], Christian Juenger[2], Larry Chen[1], David Santiago[2], Irfan Siddiqi[2]

[1]*Quantum Nanoelectronics Laboratory, UC Berkeley*
[2] *Lawrence Berkeley National Laboratory*

noahgoss@berkeley.edu

Ternary quantum information processing in circuit quantum electrodynamics devices poses a promising alternative to its more popular binary counterpart through larger computational spaces and proposed advantages in quantum simulation.[1] The weakly anharmonic nature of transmons[2] makes them ideal candidates for operation as qutrits. Recent advancements in ternary quantum computing, such as qutrit randomized benchmarking[3] and quantum information scrambling on a qutrit device[4], have been key in enabling qutrit development and in demonstrating its value in quantum simulation. However, effectively engineering a flexible two qutrit entangling interaction remains a central challenge towards realizing the inherent scaling advantages of qutrits. In this work, we apply the differential AC Stark shift to implement a flexible, microwave activated, and tunable cross Kerr coupling between two fixed frequency transmon qutrits, expanding on similar work performed for a tunable ZZ interaction with transmon qubits[5]. We then leverage this tunable coupling to implement a scheme for an efficient and flexible high fidelity two qutrit C-Phase gate.

References

[1] Wang *et. al.* Frontiers in Physics 8, 589504 (2020)
[2] J. Koch *et al.* Phys. Rev. A 76, 042319 (2007)
[3] Morvan *et al.* Phys. Rev. Lett. 126, 210504, (2021)
[4] M. S. Blok *et al.* Phys. Rev. X 11, 021010 (2021)
[5] Mitchell *et al.* Phys. Rev. Lett. 127, 200502, (2021)

Figures

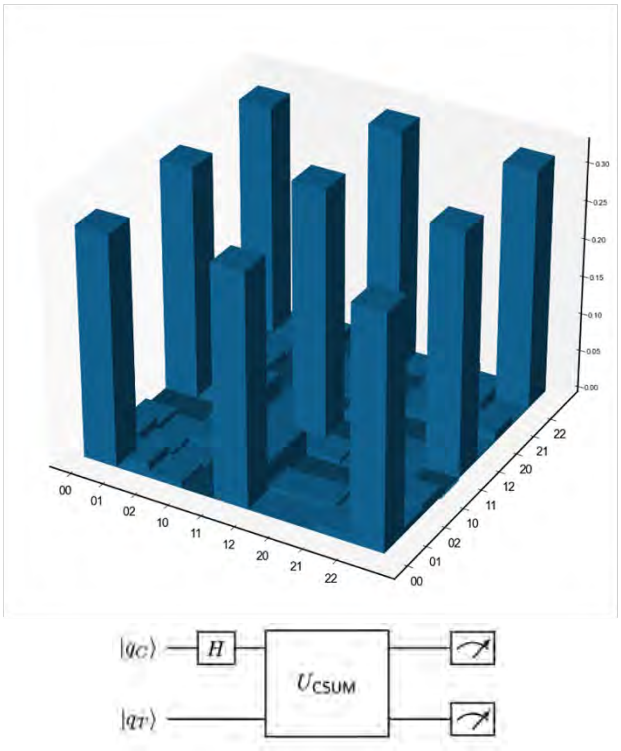


Figure 1: Experimentally reconstructed density matrix of 2 qutrit Bell State formed via our qutrit CZ gate. Our CSUM gate is performed via conjugating our qutrit CZ gate with single qutrit Hadamard gates.

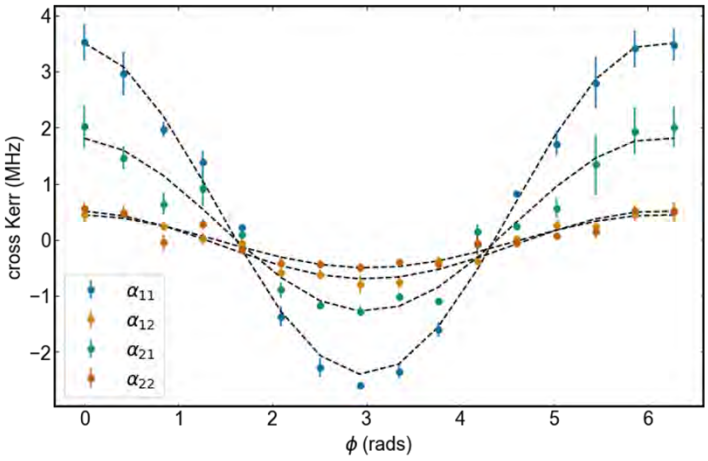


Figure 2: We demonstrate the tunable nature of our microwave activated coupling by sweeping the relative phase of our differential AC Stark drive and fitting the cross Kerr parameters to our Hamiltonian model.

Superconducting on-chip spectrometer for mesoscopic quantum systems

Ramiro H. Rodriguez
Joël Griesmar, Vincent Benzoni, Jean-Damien Pillet, Jean-Loup Smirr, Fabien Lafont, Çağlar Girit

Φ_0, JEIP, USR 3573 CNRS, Collège de France, PSL University, 11, place Marcelin Berthelot, 75231 Paris Cedex 05, France

caglar.girit@college-de-france.fr

We propose a sensitive on-chip absorption spectrometer for mesoscopic systems functioning well into the millimeter wave band, which is based on a voltage-biased superconducting quantum interference device. At its core, the Josephson effect locally converts the DC bias voltage into microwave oscillations used for the spectroscopy, with the resulting absorption spectrum conveniently measured in the device DC current-voltage characteristic. Josephson spectrometers fabricated in aluminium have a bandwidth spanning from 1 GHz up to 180 GHz, with an optimal emission linewidth of 100 MHz and an intrinsic sensitivity of 20 kHz (NEP=1.3 x10^{18} W/√Hz) at 100 GHz. We demonstrate the capabilities of the spectrometer by coupling it to a variety of superconducting systems probing quantum phenomena such as quasiparticle and plasma excitations [1]. Additionally, the spectrometer emission power can be tuned in-situ with an applied magnetic field, which allows exploring the linear and non-linear spectroscopy regimes. This enabled to investigate transitions to highly excited states, containing hundreds of photons, in a microscopic tuneable non-linear resonator in the 40-50 GHz range, constituted by an rf-squid fabricated in a separated chip [1,2]. Moreover, recently fabricated devices using niobium have their bandwidth extended up to 1.2 THz, allowing the detection of absorption peaks of superconducting circuits at frequencies as high as 310 GHz, surpassing aluminium based devices capabilities.

References

[1] J. Griesmar *et al.*, Phys. Rev. Research, 3 (2021) 043078.
[2] O. Dmytruk *et al.*, Phys. Rev. B, 104 (2021) 214508

Figures

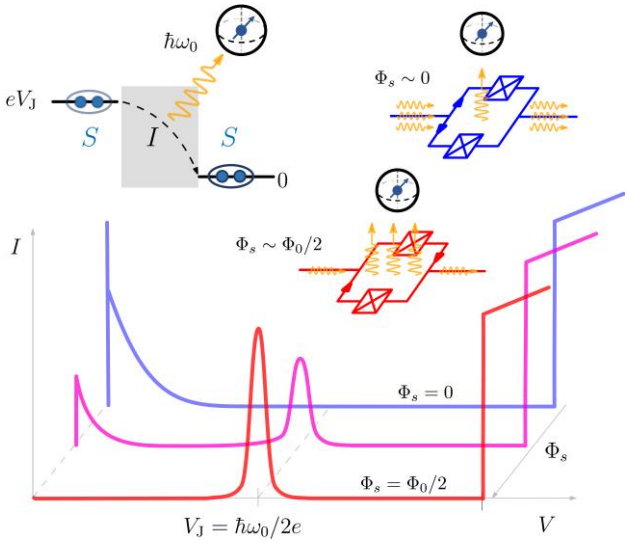


Figure 1: Principle of Josephson spectrometer.

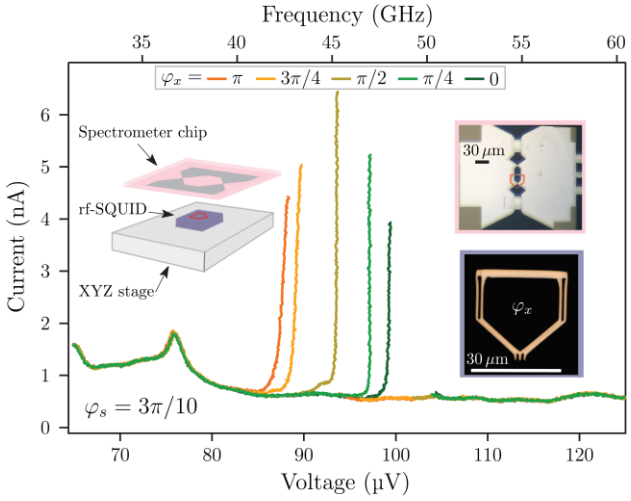


Figure 2: Linear spectroscopy of an off-chip tuneable rf-squid inductively coupled to the spectrometer

Carbon Nanostructures as Quantum Units

Fanmiao Kong[1]
Federico Lombardi[1], Yong Ni[2], William K. Myers[3], Jishan Wu[2], Lapo Bogani[1]

1. Department of Materials, University of Oxford, 16 Parks Road, Oxford, UK.
2. Department of Chemistry, National University of Singapore; 3 Science Drive, Singapore.
3. Centre for Advanced ESR, Department of Chemistry, University of Oxford, Inorganic Chemistry Laboratory, South Parks Road, Oxford, UK.

fanmiao.kong@materials.ox.ac.uk

Abstract

The application of quantum computation and quantum information processing rely on the long coherence time of the fundamental quantum unit — qubit. It has been experimentally evidenced that the electron spin in graphene nanostructures have very long coherence time [1,2], which makes them promising candidate for quantum technology applications. One particularly interesting carbon nanostructure is the zigzag segment of nanographene lattice. Recently we proved that the localized spin states in zigzag edge of a nanographene molecule exhibit exceptionally long coherence time up to 0.4 ms. It has been reported that the zigzag segments can be used to build topological nontrivial phase [3,4]. We have calculated the topological phase in more general graphene nanoribbons and show that there is a correspondence between the localized zigzag states in small nanographene molecule and long graphene nanoribbons. The topological nontrivial phase can be harnessed to build quantum spin chain or realize Majorana zero modes, making these carbon nanostructures open to wider applications.

Figures

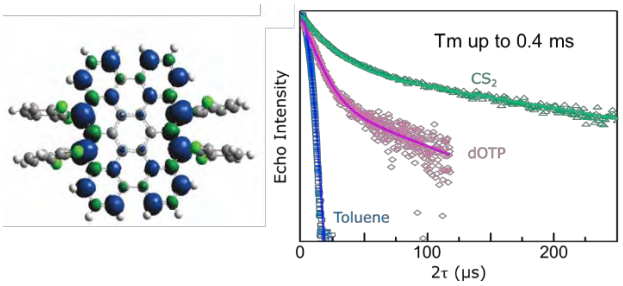


Figure 1: Left panel: The nanographene molecule and the electron spin density. Right panel: the echo intensity decay in Hahn echo measurement in different solutions.[5]

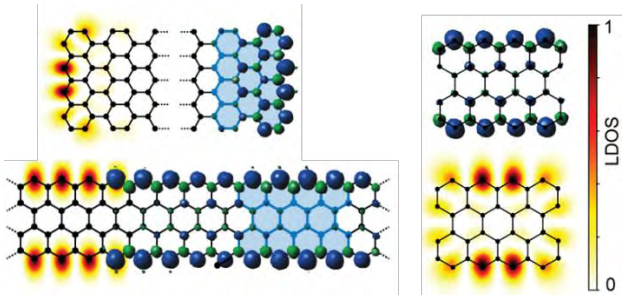


Figure 2: Localized zigzag states in nanographene molecule (right) and long graphene nanoribbons (left).[5]

References

[1] Slota, Michael, et al., Nature, 557.7707 (2018): 691-695.
[2] Lombardi, Federico, et al., Science, 366.6469 (2019): 1107-1110.
[3] Rizzo, Daniel J., et al., Nature, 560.7717 (2018): 204-208.
[4] Gröning, Oliver, et al., Nature, 560.7717 (2018): 209-213.
[5] Federico Lombardi, Fanmiao Kong, Yong Ni, William K. Myers, Jishan Wu, Lapo Bogani, Unpublished Manuscript.

Deep Learning of Quantum Entanglement

Dominik Koutný
Miroslav Ježek

Department of Optics, Palacký University, 17. listopadu 12, 77146 Olomouc, Czech Republic

koutny@optics.upol.cz

Entanglement quantification is of paramount importance to fundamental research as well as to many cutting-edge applications. Various approaches of entanglement detection have been proposed, but they usually provide only a witness or require the interference of multiple copies of the system under test [1]. It was shown that quantum tomography is necessary [2] for the exact determination of the entanglement in an unknown quantum state. The tomography yields complete information with a drawback of unfeasible scaling with the complexity of the system. Recently, artificial neural networks were exploited for the tomography by approximating the state wavefunction [3], and for entanglement witnessing. Despite these achievements, the question of how precisely the entanglement can be estimated directly from the incomplete measured data remains open. We approach this problem using deep convolutional neural networks for measurement independent strategy and with fully connected deep neural network for the measurement specific approach. We focus on the characterization of two- and three-qubit entanglement sources with imminent applications in quantum communications. We demonstrate significantly lower errors of quantum concurrence estimation from heavily undersampled Pauli measurements compared to state-of-the-art quantum tomography. We verified our approach on experimental data from quantum dot sources and parametric generators, showing the robustness to experimental errors.

References

[1] R. Islam, et al., Nature 528 (2015) 77
[2] D. Lu, et. al., Phys. Rev. Lett. 116 (2016) 230501
[3] G. Torlai, et al., Nat. Phys. 14 (2018) 447

Figures

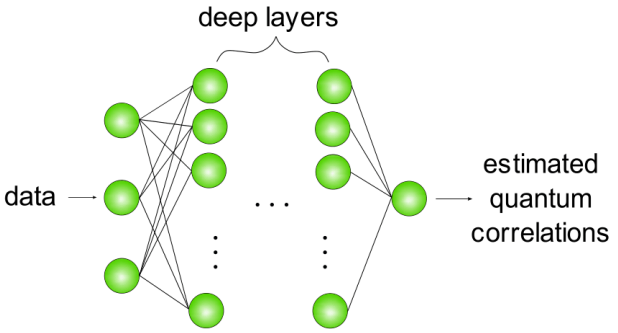


Figure 1: Schematics of measurement specific deep neural network (DNN). Informationally incomplete data from measurement projections are fed into DNN to estimate the concurrence and mutual information.

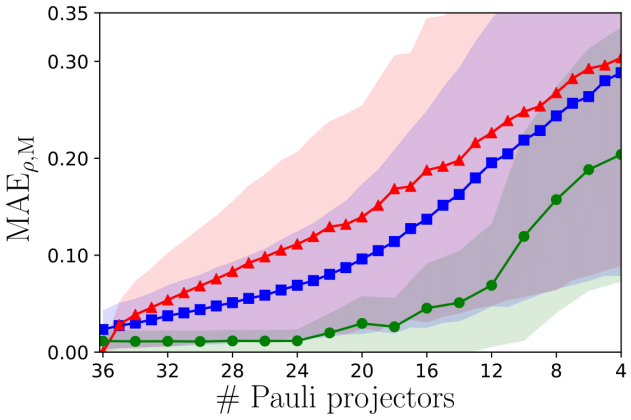


Figure 2: Depicted the mean average error of the concurrence (MAE) as a function of a number of measurement settings for the neural networks and tomographic approach. Both device independent (blue) and measurement specific (green) DNN's outperform the maximum likelihood (red) approach.

Low-noise quantum memory for quasi-deterministic single photons generated by Rydberg collective atomic excitations

Jan Lowinski
Lukas Heller, Klara Theophilo, Auxiliadora Padron-Brito, Hugues de Riedmatten

ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Spain

jan.lowinski@icfo.eu

Most of the demonstrations of quantum repeater links with ensemble-based quantum memories are based on probabilistic light-matter entanglement sources. These types of probabilistic sources lead to limitations due to a trade-off between excitation probability and fidelity of the generated state [1].
A quantum repeater architecture based on the use of deterministic single-photon sources and absorptive ensemble-based quantum memories was proposed to overcome this limitation [2].
In this work [3], we demonstrate storage and retrieval of an on-demand single photon generated by a collective Rydberg excitation [4] on a low-noise Raman quantum memory located in a different cold atomic ensemble [5]. We show that the single photons can be stored and retrieved with a signal-to-noise ratio (SNR) up to 26, preserving strong antibunching. We also evaluate the performance of the built-in temporal beam splitter offered by the Raman memory. In addition, we demonstrate that the Raman memory can be used to control the single photon waveshape.
Our results are an important step towards the implementation of efficient quantum-repeater links using single-photon sources.

References

[1] N. Sangouard et al., Reviews of Modern Physics 83 (2011) 33
[2] N. Sangouard et al, Physical Review A 76 (2007) 050301
[3] L.Heller et al., arXiv: 2111.08598
[4] Y. O. Dudin and A. Kuzmich, Science 336 (2012) 887
[5] K. F. Reim et al., Nature Photonics 4 (2010) 218

Figures

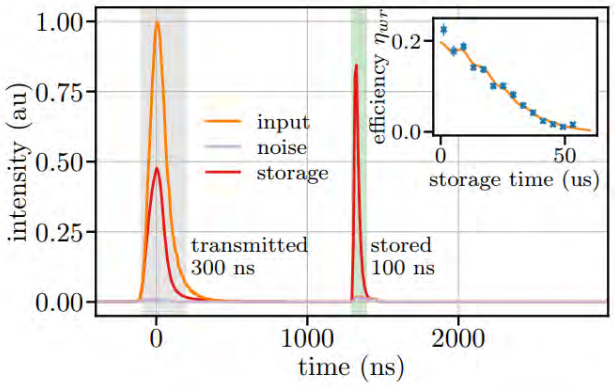


Figure 1: Photon histogram observed at the SNSPDs after the memory. The orange histogram is the input photon with no storage attempt. The red histogram presents a storage attempt and the lavender histogram is the noise. The inset shows the storage and retrieval efficiency as a function of storage time.

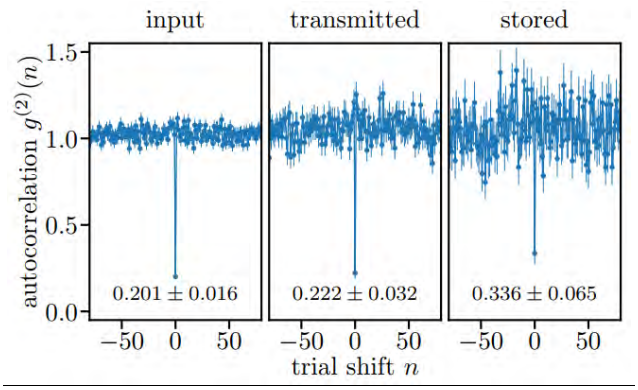


Figure 2: Autocorrelation $g^{(2)}$ as a function of shift between trials n for the input, transmitted and stored photons. For trials separated by a shift $|n| \geq 1$ the clicks are uncorrelated yielding $g^{(2)}(n) = 1$. Coincidences clicks in the same trial, $n = 0$, are much less frequent asserting the photons anti-bunching.

Dynamical phase transitions in quantum reservoir computing

Rodrigo Martínez-Peña
Gian Luca Giorgi, Johannes Nokkala, Miguel C. Soriano and Roberta Zambrini

Instituto de Física Interdisciplinar y Sistemas Complejos (IFISC, UIB-CSIC), Campus Universitat de les Illes Balears, E-07122 Palma, Spain
rmartinez@ifisc.uib-csic.es

Unconventional computing is an interdisciplinary branch of science that aims to uncover new computing and information processing mechanisms in physical, chemical, and biological systems [1]. When it comes to solving temporal tasks, reservoir computing is a machine learning example of such an approach where rich dynamical properties are exploited [2]. For big-data processing, an exceptional playground where rich dynamics can be exploited is certainly provided by quantum systems, whose exponentially large number of degrees of freedom pushes them toward computational limits that are not achievable by classical systems. This is the potential envisaged in quantum reservoir computing (QRC) [3]. Although all the previous works in the field provide examples of functioning quantum reservoir computers, a fundamental issue remains open: what conditions must a physical system fulfil to be a good quantum reservoir computer? The aim of our work is to establish the relation between the operation regime of complex computing systems and the performance of QRC [4]. For closed quantum systems, these operation regimes can be very diverse, like many-body localization or thermalization, which determine the mechanisms of spread and processing of information, as represented by the phase diagram of Fig. 1. We address the impact of these dynamical phases in QRC for networks of quantum spins, establishing that the thermal phase (regions II and IV in Fig. 1) is naturally adapted to the requirements of QRC and report an increased performance at the thermalization transition for the studied benchmark tasks. However localization (regions I and III in Fig. 1), and the presence of local conserved quantities, is detrimental for an optimal information processing performance due to a slow convergence. Uncovering the underlying physical mechanisms behind optimal information processing capabilities of spin networks is essential for future experimental implementations and provides a new perspective on dynamical phases.

References

[1] H. Jaeger, Neuromorphic Computing and Engineering, 1 (2021), 012002.
[2] M. Lukoševičius, H. Jaeger, Computer Science Review, 3 (2009), 127-149.
[3] K. Nakajima, K. Fujii, M. Negoro, K. Mitarai, and M. Kitagawa, Physical Review Applied 11 (2017), 03402 .
[4] R. Martínez-Peña, G. L. Giorgi, J. Nokkala, M. C. Soriano, and R. Zambrini, Physical Review Letters, 127 (2021), 100502.

Figures

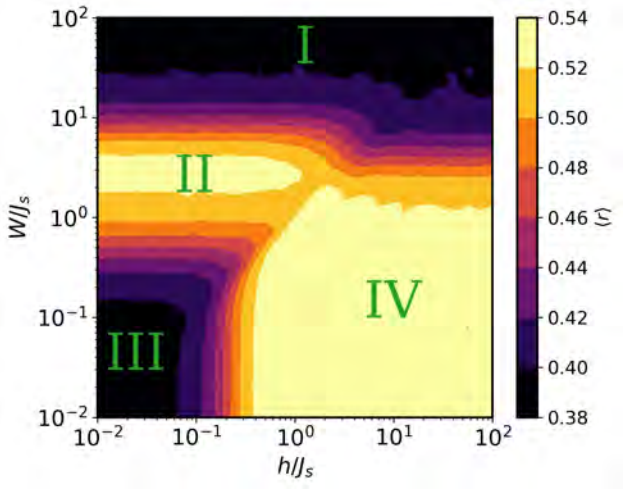


Figure 1: Phase diagram of dynamical regimes for the Transverse-field Ising model. Parameters h and W are the homogeneous magnetic field and the strength of the random heterogeneous magnetic field, respectively (in units of the interaction strength Js).

Topological protection of squeezed light in a topological photonic lattice [1]

Joaquín Medina Dueñas
Gabriel O'Ryan Pérez, Carla Hermann-Avigliano, Luis E. F. Foa Torres

Institut Català de Nanociència i Nanotecnologia (ICN2), Campus UAB, 08193 Bellaterra, Barcelona, Spain

joaquin.medina@icn2.cat

What is the role of the lattice's topology in the propagation of quantum states of light in a photonic lattice? Here we address the propagation of squeezed light in a topological one-dimensional waveguide array, exploring the evolution of photon statistics, squeezing and entanglement. We find that propagating squeezed light in a topologically protected state robustly preserves the phase of the squeezed quadrature, for both single- and two-mode squeezed states. In the latter case, the lattice's topology allows to control the entangled variables of the state. As a proof of concept, we implement a quantum teleportation protocol to compare the resulting fidelity for the topological lattice with that for a trivial lattice, showing a clear *topological advantage*. This topological protection might open a path for harnessing quantum information through light propagation in photonic lattices.

References

[1] J. Medina Dueñas, G, O'Ryan Pérez, C. Hermann-Avigliano, L. E. F. Foa Torres, Quantum 5 (2021) 526

Fast navigation of Rydberg atoms in Stark manifolds

Sabrina Patsch
A. Larrouy, R. Richaud, J.-M. Raimond, M. Brune, S. Gleyzes, C. P. Koch

Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

sabrina.patsch@fu-berlin.de

The precise engineering of quantum states is a basic prerequisite for all quantum technologies and a task which becomes more challenging with increasing dimension of the system Hilbert space. Here, we use quantum optimal control theory (OCT) to derive shaped radiofrequency (RF) pulses to navigate the Stark manifold of a Rydberg atom [1, 2].

First, we employ OCT to derive RF pulse shapes that prepare Rydberg atoms in circular states with high fidelities in the shortest possible time. Circular states couple well to microwave photons and their long lifetime makes them an ideal tool for applications in quantum technology. States with a low-angular-momentum quantum number, on the other hand, couple strongly to optical photons. Thus, the transfer from low- to high-angular-momentum states ("circularisation") opens the possibility for optical to microwave conversion, and vice versa [3].

Second, we demonstrate that OCT also enables us to accurately generate a non-classical superposition state that cannot be prepared with reasonable fidelity using standard techniques. As an example, we prepare a superposition of a low- and a high-angular-momentum state using a single shaped RF pulse. This state can be interpreted as a cat state with useful applications in quantum metrology [4].

References

[1] S. Patsch, D. M. Reich, J.-M. Raimond, M. Brune, S. Gleyzes & C. P. Koch, Physical Review A, 97 (2018) 053418.

[2] A. Larrouy, S. Patsch, R. Richaud, J.-M. Raimond, M. Brune, C. P. Koch & S. Gleyzes, Physical Review X, 10 (2020) 021058.

[3] A. Signoles, E. K. Dietsche, A. Facon, D. Grosso, S. Haroche, J. M. Raimond, M. Brune, & S. Gleyzes, Physical Review Letters, 118 (2017) 253603.

[4] A. Facon, E.-K. Dietsche, D. Grosso, S. Haroche, J.-M. Raimond, M. Brune, & S. Gleyzes, Nature, 535 (2016) 262–265.

Figures

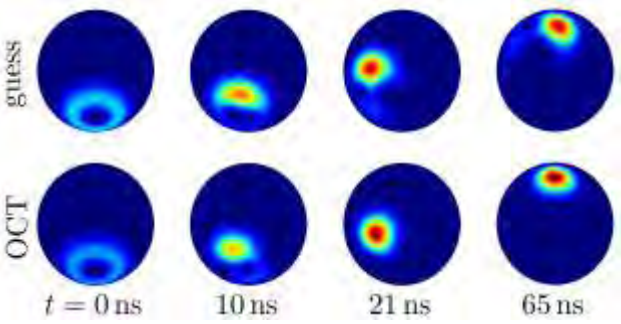


Figure 1: Evolution of the population during the circularisation on the generalised Bloch sphere. Upper panel: evolution driven by an unoptimised pulse (80% fidelity). Lower panel: evolution driven by the optimised pulse (99%).

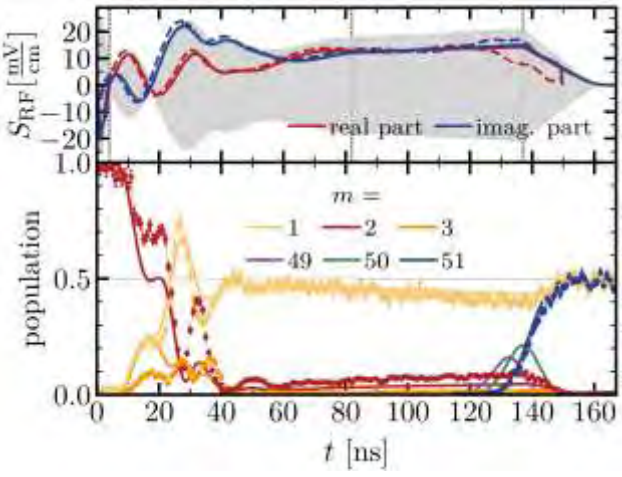


Figure 2: Preparation of the cat state. Upper panel: Optimised (solid) and adjusted (dashed) RF quadratures. Lower panel: Simulated dynamics (lines) and measured populations in the experiment (dots).

Complete device QND measurement tomography and applications to IBM-Q

Luciano Pereira
Juan José García-Ripoll
Tomás Ramos

Instituto de Física Fundamental IFF-CSIC, Calle Serrano 113b, Madrid 28006, Spain

Luciano.ivan@iff.csic.es

Quantum non-demolition (QND) measurements are a fundamental element for quantum computing. However, they are currently a limiting factor in the performance of quantum devices based on superconducting circuits. Dispersive readout, which is the standard strategy for measuring these systems, is unavoidably affected by noise such as non-dispersive errors, higher-level leakage, decoherence, and crosstalk, which reduce the quality of the readout and the QND nature of the measurement. In order to improve QND detectors, we require efficient characterization technics to identify and mitigate the source of errors. In this work, we present an efficient scaling strategy to characterize all the measurements of a device by quantum tomography. The protocol reconstructs the Choi matrices that describe the measurements of every single qubit and all the pairs of physically connected qubits. The protocol requires a bounded number of circuits for any number of qubits thanks to an efficient parallelization of the tomography. This allows us to avoid the exponential scaling of a standard QND measurement tomography. Besides, postprocessing can be also solved efficiently by parallelizing it on a classical processor. We perform an experimental implementation of the protocol to fully characterize all the detectors of a 7-qubits IBM-Q quantum device. We use the tomographic estimates to study properties of the measurement such as readout fidelity, qndness, destructiveness, and crosstalk. After that, we apply the method to characterize a custom detector composed by a standard measurement, a reset, and a conditional state preparation.

References

[1] L. Pereira, J.J. García-Ripoll, and T. Ramos, arXiv:2109.06616 (2021).

Topological phenomena in Josephson tunnel junction circuits

Léo Peyruchat
J. Griesmar, J.-D. Pillet, J.-L. Smirr, Ç. Ö. Girit

Flux Quantum Lab, JEIP, USR 3573 CNRS, Collège de France, PSL University, 11 place Marcelin Berthelot, 75231 Paris Cedex 05, France

lpeyruchat@gmail.com

Promising topological properties have been predicted in multi-terminal Josephson junctions [1], but so far they remain out of experimental reach due to lack of microscopic control over the normal weak link. Here we discuss an alternative approach based on two-terminal Josephson tunnel junctions [2,3]. In these circuits, topology naturally appears in the form of robust level crossings in the dispersion of charge states as a function of superconducting phase differences and charge offsets.

We first give a recipe for finding robust topological band crossings in simple Josephson circuits, and extend the discussion to more complex circuits with degeneracies in higher dimensions. We then present the results of a circuit-QED spectroscopy experiment of a three-junction circuit, the BiSQUID. We show that it simulates a Weyl semi-metal with robust linear band crossings in a unit cell of its three-dimensional parameter space.

This early-stage work is a first step showing that Josephson tunnel junction circuits are a promising platform to simulate topological properties inaccessible in condensed matter systems.

References

[1] R. P. Riwar, V. Nazarov, Nature Communications, 7 (2016) 11167

[2] L. Peyruchat, J. Griesmar, J.-D. Pillet, Ç. Ö. Girit, Physical Review Research 3 (2021) 013289

[3] V. Fatemi, A. Akhmerov, L. Bretheau, Physical Review Research 3 (2021) 013288

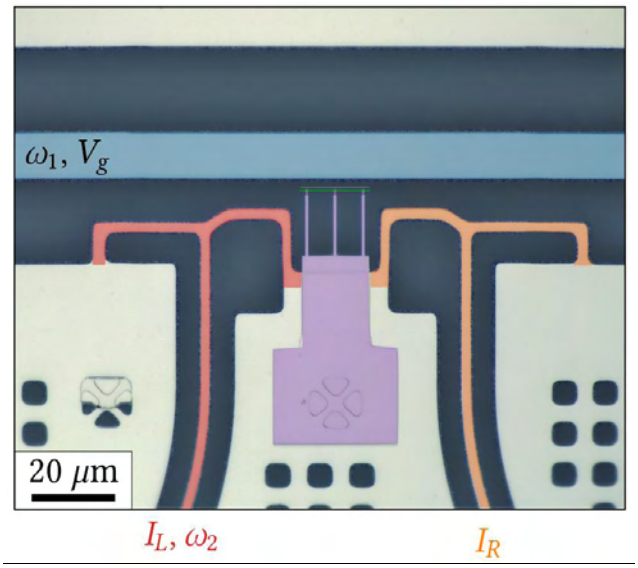


Figure 1: A BiSQUID circuit formed by three Josephson junctions in parallel is capacitively coupled to a CPW resonator. Two flux lines (red, orange) are used to control the magnetic fluxes in the BiSQUID loop and apply a second tone to excite BiSQUID transitions.

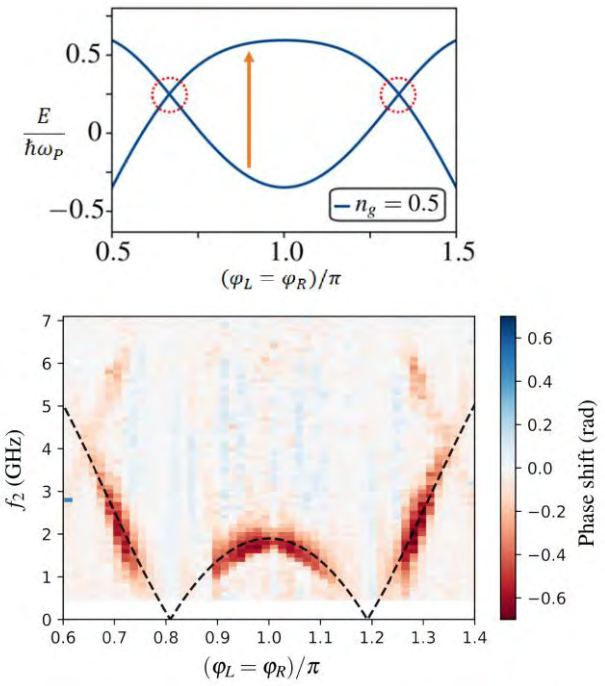


Figure 2: (top) Linear crossing of the first energy levels of a BiSQUID. Two Weyl nodes of opposite topological charges are highlighted with red crcles. (bottom) Two-tone spectroscopy of the first transition of the BiSQUID of Figure 1 showing the two topological band crossings.

Universal control of a six-qubit quantum processor in silicon

Stephan Philips[1]
Mateusz Mądzik[1], Sergey Amitonov[2], Sander de Snoo[1], Max Russ[1], Nima Kalhor[1], Christian Volk[1], Will Lawrie[1], Delphine Brousse[2], Larysa Tryputen[2], Brian Paquelet Wütz[1], Amir Sammak[2], Menno Veldhorst[1], Giordano Scappucci[1] and Lieven Vandersypen[1]

[1] *QuTech and the Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, TheNetherlands*
[2] *QuTech and Netherlands Organization for Applied Scientific Research (TNO), Delft, The Netherlands*

s.g.j.philips@tudelft.nl

Abstract

Future quantum computers capable of solving relevant problems will require a large number of qubits that can be operated reliably [1]. However, the requirements of having a large qubit count and operating with high-fidelity are typically conflicting. Spins in semiconductor quantum dots show long-term promise but demonstrations so far use between one and four qubits and typically optimize the fidelity of either single- or two-qubit operations, or initialization and readout [2,3,4,5,6,7,8]. Here we expand the number of qubits and simultaneously achieve respectable fidelities for universal operation, state preparation and measurement. We design, fabricate and operate a six-qubit processor with a focus on careful Hamiltonian engineering, on a high level of abstraction to program the quantum circuits and on efficient background calibration, all of which are essential to achieve high fidelities on this extended system. State preparation combines initialization by measurement and real-time feedback with quantum- non-demolition measurements. These advances will allow testing of increasingly meaningful quantum protocols and constitute a major steppingstone towards large-scale quantum computers.

References

[1] Vandersypen, L. M. K., et al., npj Quantum Information, vol. 3.1, pp. 1-10, 2017.
[2] Veldhorst, M., et al, Nature nanotechnology, vol. 9.12, pp. 981-985, 2014.
[3] Yoneda J., et al., Nature Nano, vol. 13, pp. 102-106, 2018.
[4] Xue X., et al, Nature 601, 343–347, 2022
[5] Noiri, A.et al., Nature 601, 338–342, 2022
[6] Mills, A.et al., arXiv:2111.11937, 2021
[7] Takeda K., et al., Nature Nano, pp. 1-5, 2021.
[8] Hendrickx N. W., et al., Nature, vol. 591, pp. 580–585, 2021

Experimental test of quantum causal influences

Iris Agresti[1]
Davide Poderini[1]
Beatrice Polacchi[1,*]
Nikolai Miklin[2,3]
Mariami Gachechiladze[4]
Alessia Suprano[1]
Emanuele Polino[1]
Giorgio Milani[1]
Gonzalo Carvacho[1]
Rafael Chaves[5]
Fabio Sciarrino[1]

[1]*Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma, Italy*
[2]*International Centre for Theory of Quantum Technologies (ICTQT), University of Gdansk, 80-308 Gdansk, Poland*
[3]*Heinrich Heine University Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf, Germany*
[4]*Institute for Theoretical Physics, University of Cologne, 50937 Cologne, Germany*
[5]*International Institute of Physics, Federal University of Rio Grande do Norte, 59078-970, P. O. Box 1613, Natal, Brazil*

*beatrice.polacchi@uniroma1.it

Abstract

Understanding cause-effects relations among phenomena is a pivotal task in several sciences. The simplest scenario to estimate the direct causal influence between two variables, without resorting to interventions on the underlying mechanism generating the correlations, is the instrumental process. This is shown in Fig. 1, where circles stand for random variables and arrows for causal links. Analogously to the better-known Bell scenario, the correlations among the variables involved in this process satisfy testable constraints (instrumental inequalities), which, if violated, can detect the presence of non-local correlations. However, this is possible only when the variable X takes three or more values. Instead, when all variables are binary, no inequality is known. Nonetheless, a novel strategy to detect non-local phenomena has been recently introduced [1], based on quantifying direct causal influences among the variables through interventions (Fig. 1b).
In our work [2], we implement this method exploiting a photonic platform equipped with an active feed-forward of information. Moreover, our setup allows fast switching between two different causal scenarios, namely the observational and the interventional instrumental scenario. Our results demonstrate a novel way to detect non-classical correlations, which goes beyond standard Bell-like inequalities, and thus might lead to new insights in quantum causality and practical applications.

References

[1] M. Gachechiladze, N. Miklin, and R. Chaves, Physical Review Letters, vol. 125, no. 23 (2020) p. 230401
[2] I. Agresti et al., Science Advances, vol. 8, issue 8 (2022) eabm1515

Figures

Figure 1: a) Observational and b) interventional instrumental scenario.

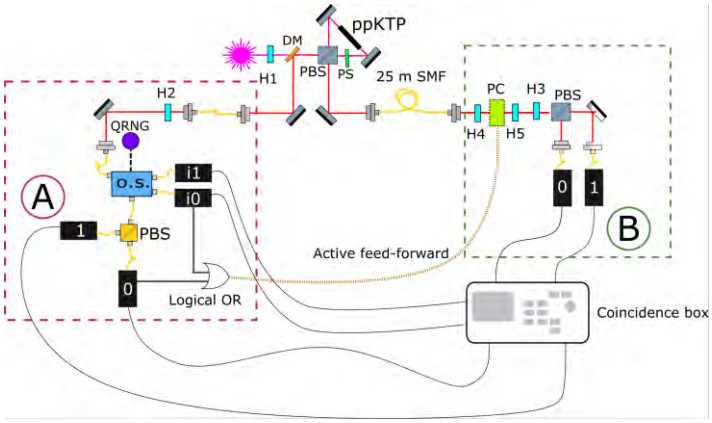


Figure 2: Experimental setup. H1,H2,H3,H4,H5 = half-wave plates; DM = dichroic mirror; PS = phase-shifter; SMF = single-mode fiber; QNRG = quantum random number generator; PBS = polarizing beam splitter; PC = Pockels cell.

Enhancing Light Collection Efficiency due to WS_2 Dielectric Nanoantennas on a Metallic Substrate

Sam Randerson
Yadong Wang, Panaiot G. Zotev, Yue Wang, Dominic Hensman, Sharada Nagarkar, Alexander I. Tartakovskii
University of Sheffield, Dept. Physics and Astronomy, Hicks Building, Hounsfield Rd, Sheffield, UK
SRanderson1@Sheffield.ac.uk

Transition metal dichalcogenides (TMDs) have a range of attractive properties allowing them to be used for manipulating light on a scale below its wavelength through a variety of structures and arrays. In particular, they have high refractive indices [1], low losses [2], and can be deposited on a range of substrates owing to van der Waals interactions [3]. Recent works have demonstrated coupling of these modes to single photon emitters (SPEs) in strained TMD monolayers placed over dielectric nanoantennas, thus enhancing their quantum efficiency [4]. However, the directionality of such SPEs still remains low with much of the light lost to the environment. Here, we simulate and fabricate a hybrid metal-dielectric nanoantenna system composed of WS_2 hexagonal monomers and dimers (single and double pillars) on a gold substrate. We show that resonant Mie modes observed in simulated scattering spectra (figure 1a) are reproduced well in experimental dark field spectroscopy (figure 1b), and that the electric field is highly confined at the antenna vertices, as shown in figures 1c and d, which leads to a Purcell enhancement of 119. Furthermore, we demonstrate that light collection efficiency can be considerably increased by a factor of 4 with a gold substrate compared to a SiO_2 substrate in simulation, as in figure 1e. This work opens possibilities for enhanced photoluminescence of coupled emitters, advances in optical trapping, and stronger non-linear effects.

References

[1] Li, Y., Chernikov, A., Zhang, X. *et al. Phys. Rev. B.* 90 (2014) 205422
[2] Verre, R., Baranov, D.G., Munkhbat, B. *et al. Nat. Nanotechnol.* 14 (2019) 679–683
[3] Geim, A., Grigorieva, I. *Nature* 499 (2013) 419–425
[4] Sortino, L., Zotev, P.G., Phillips, C.L. *et al. Nat. Commun.* 12 (2021) 6063

Figures

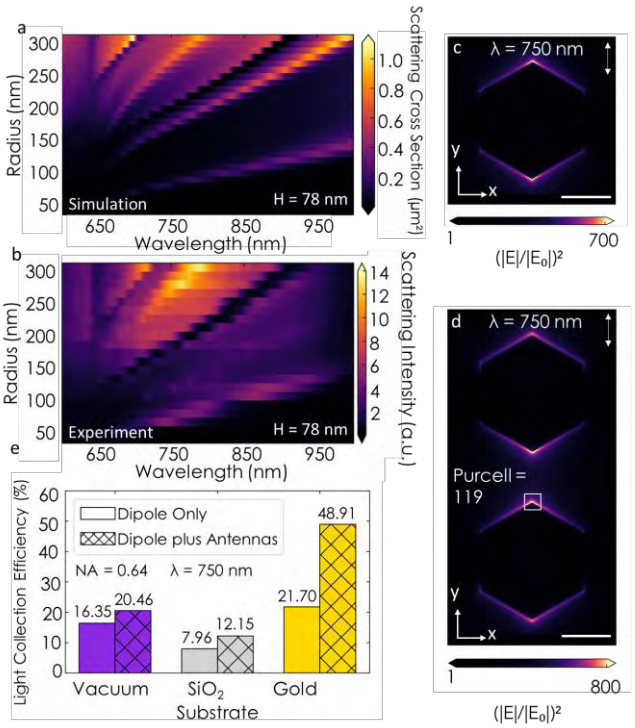


Figure 1: WS_2 hexagonal nanoantennas on gold optical characterisation and simulation. (a) and (b) show simulated and experimental scattering spectra of monomers of height 78 nm for a range of radii respectively. (c) and (d) show the top view of the electric field intensities for a monomer and dimer respectively, each with height 180 nm and radius 120 nm. White double-headed arrow shows excitation polarisation. Purcell factor is from a dipole placed 0.5 nm above the inner dimer vertex, highlighted by the white box, where the electric field is maximised. Scale bars are 100 nm. (e) shows the light collection efficiency in simulation of a dipole placed 0.5 nm above different substrates, compared to a dipole 0.5 nm above the inner dimer vertex. The numerical aperture used is 0.64 with dipole polarisation along the dimer axis and wavelength 750 nm.

Tunable unidirectional photon scattering from a pair of superconducting qubits

E. S. Redchenko[1]
Alexander V. Poshakinskiy[2], Martin Zemlicka[1], Alexander N. Poddubny[2], J. M. Fink[1]

[1]*Institute of Science and Technology Austria, 3400 Klosterneuburg, Austria*
[2]*Ioffe Institute, St. Petersburg 194021, Russia*

elena.redchenko@ist.ac.at

The ability to control the direction of scattered light in integrated devices is crucial to provide the flexibility and scalability for a wide range of on-chip applications, such as integrated photonics, quantum information processing and nonlinear optics. In the optical and microwave frequency ranges tunable directionality can be achieved by applying external magnetic fields, that modify optical selection rules [1], by using nonlinear effects [2], or interactions with vibrations [3]. However, these approaches are less suitable to control propagation of microwave photons inside integrated superconducting quantum devices, that is highly desirable. We demonstrate tunable directional scattering with just two transmon qubits coupled to a transmission line based on periodically modulated transition frequency (Fig. 1). By changing the symmetry of the modulation, governed by the relative phase between the local modulation tones, to achieve directional forward or backward photon scattering (Fig. 2). Such a device could be used for the design of topologically protected states, as a part of hardware implementation of Gottesman-Kitaev-Preskill code, and to route microwave radiation for the realization of chiral networks.

References

[1] F. Spitzer, A. N. Poddubny, I. A. Akimov, V. F. Sapega, L. Klompmaker, L. E. Kreilkamp, L. V. Litvin, R. Jede, G. Karczewski, M. Wiater, T. Wojtowicz, D. R. Yakovlev, and M. Bayer, Nature Physics, 14(10) (2018) 1043–1048.

[2] Andres Rosario Hamann, Clemens Muller, Markus Jerger, Maximilian Zanner, Joshua Combes, Mikhail Pletyukhov, Martin Weides, Thomas M. Stace, and Arkady Fedorov, Phys. Rev. Lett., 121 (2018) 123601.

[3] Amir H Safavi-Naeini, Dries Van Thourhout, Roel Baets, and Raphael Van Laer, Optica, 6(2) (2019) 213–232.

Figures

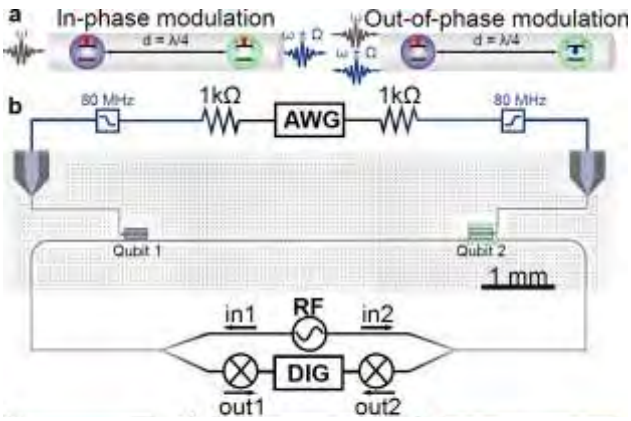


Figure 1: a, Schematic showing the scattering direction for in- and out-of-phase modulations on the qubits' transition frequency. b, Optical microscope image of the device and simplified experimental setup.

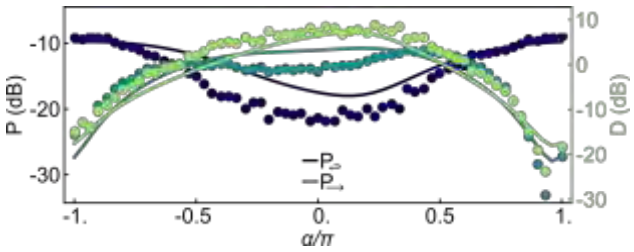


Figure 2: Coherent inelastic scattering spectrum of the Stokes component as a function of relative phase between modulation tones. Points are measured, solid lines are theory. Directivity is shown in green.

Probing quantum electromagnetic magnetic fields with subnanosecond time resolution: the single electron radar

Hubert Souquet-Basiège
Pascal Degiovanni, Gwendal Fève, Inès Safi, Benjamin Roussel

Ecole Normale Supérieure de Lyon, 46 Allée d'Italie, Lyon, France

hubert.souquet-basiege@ens-lyon.fr

In this talk we discuss how an electronic interferometer can be used to measure a time dependent electric field on a sub-nanosecond time scale based on alteration of the wave function of a single electronic excitation[1,3] propagating across a Mach-Zenhder interferometer (figure 1) when the fast varying potential is applied to one of the two branches, thereby realizing the electronic analogue of a radar.

Our key result is the electron radar equation that connects the experimental signal — the Aharonov-Bohm dependent part of the finite frequency average outgoing current — to the electronic wave function used as a probe and to the electromagnetic field to be probed. It is valid in the presence of Coulomb interactions[2] within the interferometer and quantum electromagnetic field and incorporates the back-action effects of the quantum electromagnetic field to be probed onto the electron fluid. The detection of a squeezed vacuum which exhibits time dependent quantum fluctuations will be used as an illustration of this general framework.

References

[1] B. Roussel, *et al*, PRX Quantum 2 (2021), [020314]
[2] C. Cabart, *et al*, Phys. Rev. B 98 (2018), [155302]
[3] R. Bisognin, *et al*, Nature communications 10 (2019) 1-12, [3379]

Figure

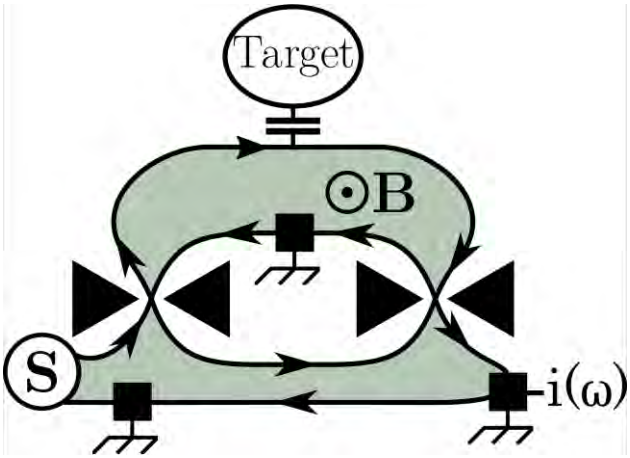


Figure 1: Draft of the electronic Mach-Zenhder interferometer in a 2D electron gas (in grey) under a strong perpendicular magnetic field. A single electron is emitted from the source (bottom left) and propagates in the edge channels of the Quantum Hall Effect (black lines) following the direction of the arrows. The Quantum point contacts (pairs of black triangles) act as beam splitters for single electrons. The upper branch is capacitively coupled to the Target to probe. The measurement is made on the output electrical current at fixed frequency (bottom right).

Towards Hole Spin Qubits in Strained Ge/SiGe Quantum-Well Heterostructures

Gonzalo Troncoso [1]
E. Kiyooka,[1] C. Tangchingchai,[1] S. Zhilmann,[1] B. Brun-Berriere,[1] V. Schmitt,[1] F. Lefloch,[1] J-M. Hartmann,[2] S. de Franceschi,[1] R. Maurand,[1]

1) Univ. Grenoble Alpes, CEA, IRIG-Pheliqs, Grenoble, France.
2) CEA, LETI, Grenoble, France.
gonzalo.troncosofernandez-bada@cea.fr

A strained germanium quantum well sandwiched between relaxed SiGe barriers can host a high mobility two-dimensional hole gas (2DHG). The low in-plane effective mass and the large spin-orbit coupling make this hole system a good candidate for quantum devices [1]. It has been used to demonstrate spin qubits [2,3] as well as Josephson field-effect transistors [4].
Here, we report the realization of quantum dot devices starting from SiGe heterostructures RPCVD-grown on 200-mm Si wafers using direct grading of the SiGe buffer (i.e. Ge concentration increasing from zero to 79%). In the investigated heterostructures the strained Ge quantum well has the same thickness (16 nm) but different depths, ranging from 22 to 55 nm. Our fabrication process consists of several steps of UV and electron beam lithography, Ion Coupled Plasma etching (ICP), Atomic Layer Deposition (ALD) and Electron Beam Metal evaporation (EBM).

At low-temperature (4 K), we measure hole mobilities as high as 10^5 cm^2/Vs for carrier densities of $3x10^{11}$ cm^{-2}. Preliminary measurements in devices with two-level gate structures (e.g. see Fig. 1) show Coulomb-blockaded hole transport and characteristic signatures of quantum-dot physics (e.g., see Fig. 2).

References

[1] G. Scappucci et al., *Nature Reviews Materials* 6, 926–943 (2021).
[2] Nico H. Hendrickx. Nat. Com. Vol. 9 Art. 2835 (2018)
[3] Daniel Jirovec. Nat. Mat. 20, 1106-1112 (2021)
[4] Vigneau F. Nano let. 19, 1023-1027 (2019).

Figures

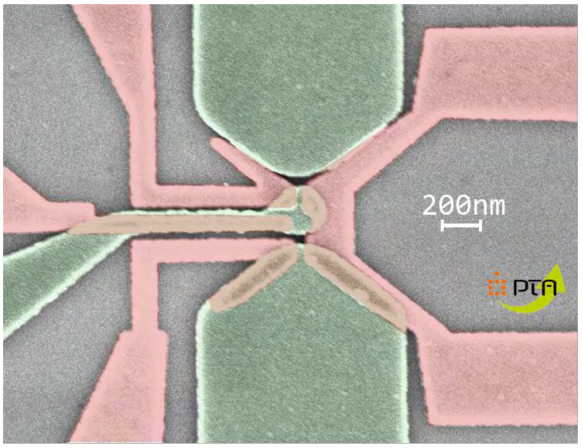


Figure 1: Colorized SEM picture of a single dot device. Red(green)-color structures correspond to the first (second) gate layer.

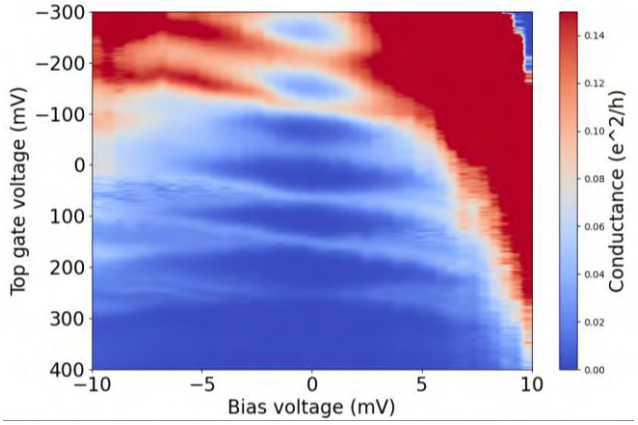


Figure 2: Coulomb diamonds for a single dot. Extracted charging energy is 5.4meV which gives an approximately dot size of 15nm.

On the superconducting critical temperature in multiband disordered $LaAlO_3/SrTiO_3$ interfaces

Giulia Venditti

Marco Grilli, Sergio Caprara

Department of Physics, "Sapienza" University of Rome

g.venditti@uniroma1.it

Abstract

$LaAlO_3/SrTiO_3$ interfaces are a nice example of a two-dimensional electron gas whose carrier density can be varied by top- and back-gating techniques. The interplay of two-dimensionality, multi-band character and disorder affects the superconducting critical temperature T_c of these heavily disordered multi-band superconductors.
We propose a realistic two band disordered model (Fig. 1) based on experimentally determined parameters [2] to study such interplay.
While confirming that a repulsive inter-band coupling favors the T_c suppression, we show that disorder alone can mix the two bands [2], generating a more pronounced suppression of the critical temperature in the vicinity of the Lifshitz transition. Finally, this study allowed us to disentangle microscopic from mesoscopic disorder effects, since the global behavior of T_c is well captured only if the strongly inhomogeneous nature of such compounds is considered.

References

[1] T. V. Trevisan, M. Schütt, R. M. Fernandes, Phys. Rev. Lett. (2018) 121, 127002

[2] G. Singh, G. Venditti, G. Saiz, G. Herranz, F. Sánchez, A. Jouan, C. Feuillet-Palma, J. Lesueur, M. Grilli, S. Caprara, and N. Bergeal, Phys. Rev. B (2022) 105, 064512

[3] G. Venditti, M. Grilli, S. Caprara, Coatings (2022) 12(1), 30

Figures

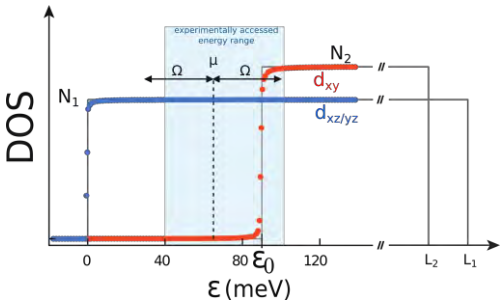


Figure 1: Sketch figure of the density of states (DOS) N_1 and N_2 as functions of the energy ε. The solid grey lines show the clean case (no disorder), while the blue and red symbols show the dirty case for both bands, with an inverse scattering time τ^{-1}= 0.4 meV. The shaded blue area corresponds to the experimental accessible chemical potential window.

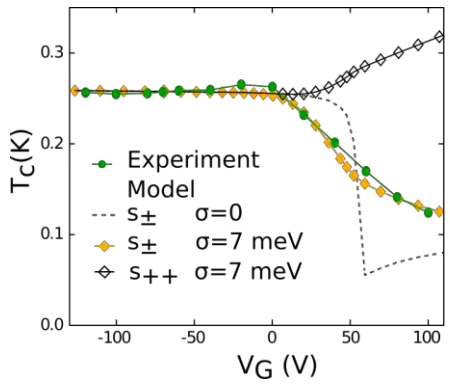


Figure 2: Experimental (green circles) and calculated superconducting T_c as a function of the gate voltage V_G both in the case of attractive (black diamonds) and repulsive (orange diamonds) interband coupling, with the variance of the chemical potential disorder σ =7 meV and τ^{-1}=0.4 meV. Dashed line shows the computed curve in absence of mesoscale disorder in the $s_{\pm}$ scenario (σ =0 meV).

The Quantum Coherence of Metal-functionalized Graphene Nanoribbons

Karen Yan, Fanmiao Kong, Michael Slota, William K. Meyers, Lapo Bogani

University of Oxford, 16 Parks Road, OX1 3PH, Oxford, United Kingdom

karen.yan@st-annes.ox.ac.uk

There are many proposals to achieve states with long coherence times in graphene. The low spin-orbit coupling, due to the low curvature and light atoms [1], and the possibility of having topologically interesting states [2] may lead to sizeable coherence and make the material most appealing.

Most investigations into the quantum properties of graphene structures have been hindered by the lack of a clean, defined structure and clear-cut edges. Recent advances in the molecular shaping of graphene, with bottom-up synthetic methods [3], have recently opened the path to graphene nanostructures with perfectly defined morphology, which can be designed atom-by-atom. Magnetic edge states with long coherence times, as predicted by theory, could be detected [4]. On the other hand, most states that are theoretically interesting need another ingredient: spin orbit coupling, as possibly produced by metals.

Here we show the coherence properties of such metal-functionalized nanoribbons, demonstrating very long coherence in the µs range even at room temperature, and analysing the spin-spin interactions, as useful for quantum information processing purposes. We specifically investigate systems containing vanadyl and cyanide ions, as they are interesting for the production of topologically nontrivial states. We use pulsed Electron Paramagnetic Resonance at Q-Band Frequency (34 GHz), and by using different pulse sequences, we examine relaxation mechanisms, resolve couplings, and manipulate spin interactions.

Our results open up a myriad of opportunities for potential applications in quantum electronic devices and offer a novel platform for the investigation of topological states of matter.

References

[1] A.H. Castro Neto et al., Rev. Mod. Phys. 81.1 (2009): 109
[2] F. Lombardi et al., Science, 366.6469 (2019): 1107-1110.
[3] Z. Zhang et al., Nano Futures 3.4 (2019): 042203
[4] M. Slota et al., Nature 557.7707 (2018): 691–695

Figures

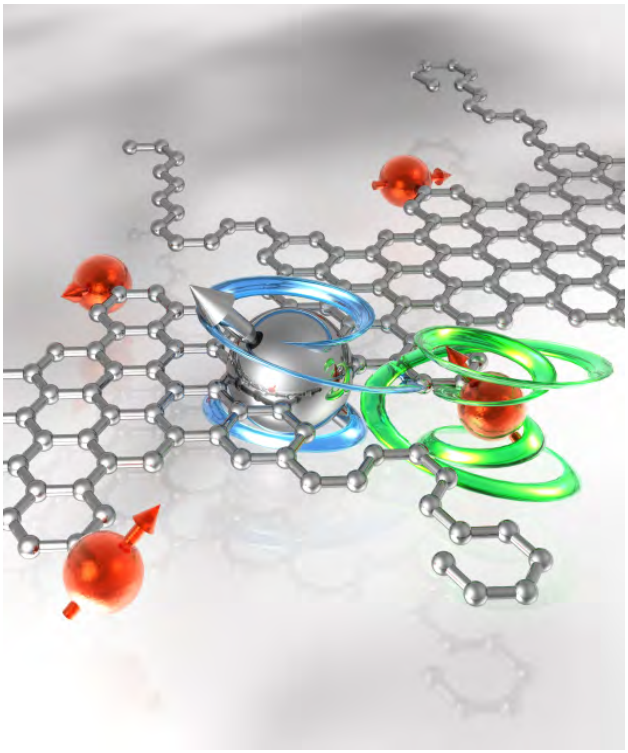


Figure 1: An illustration of a graphene nanoribbon functionalised with a vanadyl group (shown in red) and their associated quantum spin.

Cavity QED with diamond nitrogen-vacancy centers formed by carbon implantation

Viktoria Yurgens
Yannik Fontana, Andrea Corazza, Josh A. Zuber, Mark Kasperczyk, Brendan J. Shields, Patrick Maletinsky, Richard J. Warburton

Department of Physics, University of Basel, Klingelbergstrasse 82, 4055 Basel, Switzerland

viktoria.yurgens@unibas.ch

A negatively charged nitrogen-vacancy (NV) center in diamond coupled to an open Fabry-Perot microcavity is a promising spin-photon interface [1-4]. Implementation of diamond into the microcavity requires thinning it down to ~µm thickness while maintaining the NV optical coherence, a well-known challenge with standard NV creation methods. Recent studies have shown that the commonly used method, nitrogen implantation followed by annealing, results in NV centers with reduced optical coherence (linewidths above 1 GHz, 90 times the Fourier transform limit) compared to the optical coherence of NVs formed from native nitrogen [5-6]. We present an improved NV creation protocol in which we implant carbon ions instead of nitrogen ions once all diamond microstructuring has been completed. We show excellent NV optical coherence even in membranes thinner than 2 µm, with over 50% of the emitters showing optical linewidths below 150 MHz (Fig. 1). These membranes are then embedded in an open microcavity. Characterization of the cavity at cryogenic temperatures shows Q-factors up to 127 000, corresponding to a finesse of 7900 (Fig. 2). We argue that coupling the emission of a single NV center in the membrane to a cavity mode should result in a Purcell enhancement of up to 50. This would increase the success probability of remote spin-spin entanglement by more than two orders of magnitude, facilitating the scaling-up of distributed quantum networks based on spins in diamond.

[1] R. J. Barbour et al., J. Appl. Phys. 110 (2011) 053107
[2] S. Johnson et al., New J. Phys. 17 (2015) 122003
[3] R. Albrecht et al., Phys. Rev. Lett. 110 (2013) 243602
[4] D. Riedel et al., Phys. Rev. X 7 (2017) 031040
[5] S. B. van Dam et al., Phys. Rev. B 99 (2019) 161203
[6] M. Kasperczyk et al., Phys. Rev. B 102 (2020) 075312

Figures

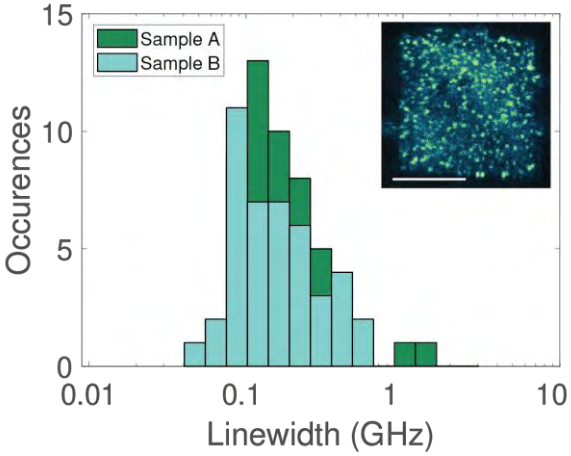


Figure 1: Linewidth distributions measured in 1.96-4.86 µm thick microstructures. Inset: confocal scan of the NV centers in one of the microstructures. (Scalebar: 10 µm)

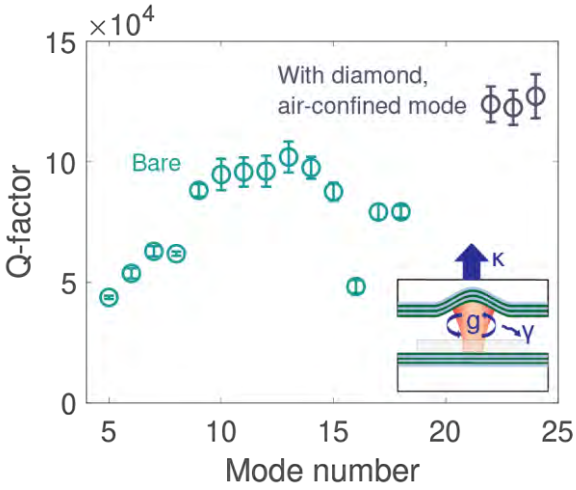


Figure 2: Q-factors of the microcavity at 4 K as a function of mode number.

POSTER

Quantum bath engineering of a high impedance microwave mode through quasiparticle tunneling

Gianluca Aiello[1,2]
Mathieu Fechant[1], Alexis Morvan[1], Julien Basset[1], Marco Aprili[1], Julien Gabelli[1], Jérôme Esteve[1]

[1]*Laboratoire de Physique des Solides, CNRS, Université Paris Saclay, Orsay, France*
[2]*Current affiliation: National Physical Laboratory, Hampton Road, London, UK*

gianluca.aiello@npl.co.uk

Abstract

Quantum bath engineering is considered a promising route to perform certain tasks in quantum information processing, such as state stabilization, passive error correction, or fast qubit initialization. In the context of circuit QED, bath engineering usually results from the interplay between coherent evolution and dissipation in the form of single photon loss.

In this talk, I will discuss a different approach [1], where engineered dissipation comes from the non-linear coupling of a microwave mode to a tunnel junction. Because the mode is sustained by a high kinetic inductance resonator made of granular Aluminum [2], its characteristic impedance is sufficiently large such that high order photon loss processes are allowed. As an example of engineered dissipation, I will focus on the regime where two photons loss processes dominate over single photon loss. The dynamics is then restricted by the quantum Zeno effect [3] to the subspace spanned by the zero and one photon Fock states turning the harmonic oscillator mode into a two-level system.

Because of causality, the junction induces a shift in the energy levels of the resonator [4]. I will show that these Lamb shifts are Fock state dependent and in good agreement with the predictions of the Kramers-Kronig relations for single quantum states in a regime of highly non-linear bath coupling.

References

[1] G. Aiello et al., ArXiv 2204.0871(2022).
[2] N. Maleeva et al., Nature Communications, 9 (2018)
[3] P. Facchi et al., J. Phys. A: Math. Theory, 41 (2008)
[4] M. Silveri et al., Nature Physics, 15 (2019)

Synthesis and Properties Investigation a High Pure and Crystalize Sample of Quantum Spin Liquid Material Ca10Cr7O28

Alshalawi, Dhoha R.[1,2]
Alonso, José M.,[2,3] Landa-Cánovas, Angel R.,[3] de la Presa, Patricia.[1,2]

1.Física de Materiales, Universidad Complutense de Madrid, Comunidad de Madrid, Spain.
2.Instituto de Magnetismo Aplicado(IMA), Madrid, Spain.
3. Instituto de Ciencia de Materiales de Madrid, Madrid, Spain.

pmpresa@ucm.es

Abstract

The $Ca_{10}Cr_7O_{28}$ has been reported as a material that display all the features expected of a quantum spin liquid [1]. The complexity of the structure always produces a secondary CaO phase that does not affect the magnetic properties but does affect the structural properties [2,3]. In this work we present a detailed study of $Ca_{10}Cr_7O_{28}$ without secondary phases, with the report of the correct ratio of starting materials and synthesis method for obtaining a single phase with high crystalline degree. The chemical cation compositional of the sample $Ca_{10}Cr_7O_{28}$ was confirmed using X-ray energy-dispersive spectroscopy (XEDS), an Electron Probe Microanalyzer (EPMA), and inductively coupled plasma optical Emission Spectrometry (ICPOES). Also, the thermo- gravimetric analysis (TGA) result confirms the composition and the chemical stability of the sample. The crystallization degree and real atomic order of our sample are confirmed by HRTEM techniques and TEM experiments result. The structural phase of the sample was characterized using a high-resolution x-ray diffractometer and Thermo diffraction at low and high-temperature measurement. The Rietveld refinement of the high-resolution diffraction pattern together with electron diffraction helped identify the sample and crystal structure and compare the result to recent studies of the compound [2,3], where the crystal structure is compatible with spin liquid character. Our results confirm that, according to D. Gyepesová et al [3], the material presents a rhombohedral symmetry and special group trigonal, hexagonal axes R3C,161 with lattice parameters a=b= 10.7677 and c= 38.0824 Å. In addition, the magnetic properties as well as specific heat and entropy of our sample of $Ca_{10}Cr_7O_{28}$ confirm the spin liquid character of this compound in agreement with similar behavior of the other quantum spin liquid materials, as expected.

References

[1] L. Balents, Nature 464 (7286), (2010) 199-208.

[2] D. Gyepesová and V. Langer, Acta Crystallographica Section C, 69, (2), (2013) 111-113.

[3] C. Balz, B. Lake, and M. Reehuis, Journal of Physics: Condensed Matter, 29, (22), (2017) 225802.

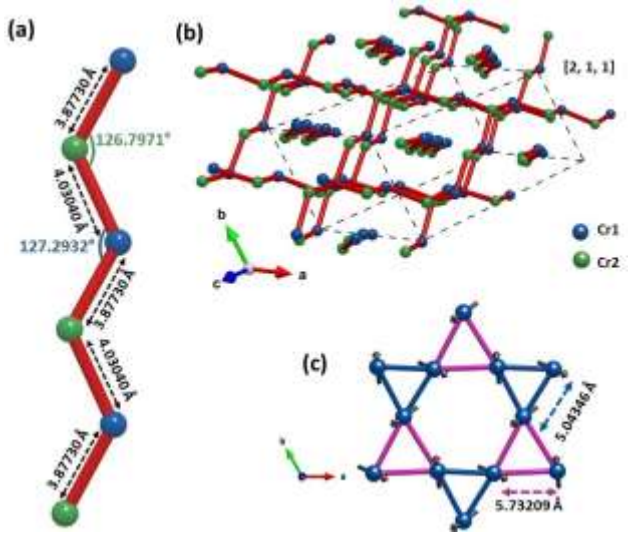


Figure 2: Crystal structure of the material $Ca_{10}Cr_7O_{28}$, (a) Cr1 and Cr2 zig zag chain with distances and angles. (b) Perspective of the zigzag chains along the [211].
(c) Distorted Kagome layer formed by Cr1 atoms with the atomic distances.

Figures

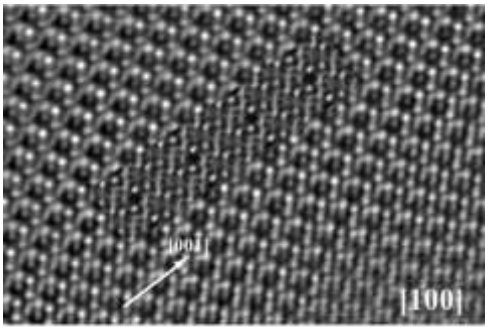


Figure 1: HRTEM image based on Rietveld refinement of the high-resolution diffraction pattern room temperature of the sample.

Gradient magnetometry with atomic ensembles

Iagoba Apellaniz [1,*]
Iñigo Urizar-Lanz [1], Zoltán Zimborás [1,2,3], Philipp Hyllus [1] and Géza Tóth [1,2,4]

[1] *Department of Physics, University of the Basque Country UPV/EHU, P. O. Box 644, E-48080 Bilbao, Spain*
[2] *Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany*
[3] *Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary*
[4] *IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain*

* iagoba.apellaniz@gmail.com

We study gradient magnetometry with ensembles of atoms with arbitrary spin. We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information. For states that are sensitive to homogeneous fields, a simultaneous measurement is needed, as the homogeneous field must also be estimated. We present a method to calculate precision bounds for gradient estimation with two spatially separated atomic ensembles. We also consider a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually, and which is a very relevant case for experiments.

References

[1] I. Apellaniz, I. Urizar-Lanz, Z. Zimborás, P. Hyllus and G. Tóth, Phys. Rev. A, 97 (2018) 053603
[2] G. Vitagliano, M. Fadel, I. Apellaniz, M. Kleinmann, B. Lücke, C. Klempt, G. Tóth, arXiv:2104.05663 (2021)

Figures

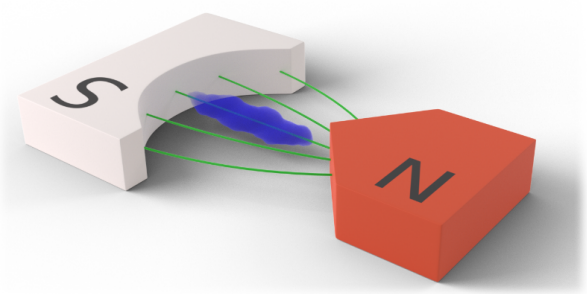


Figure 1: Schematic representation of an atomic ensemble (blue cloud) placed in a magnetic field (green lines) in a Stern-Gerlach apparatus. From the final state the gradient of the field can be estimated.

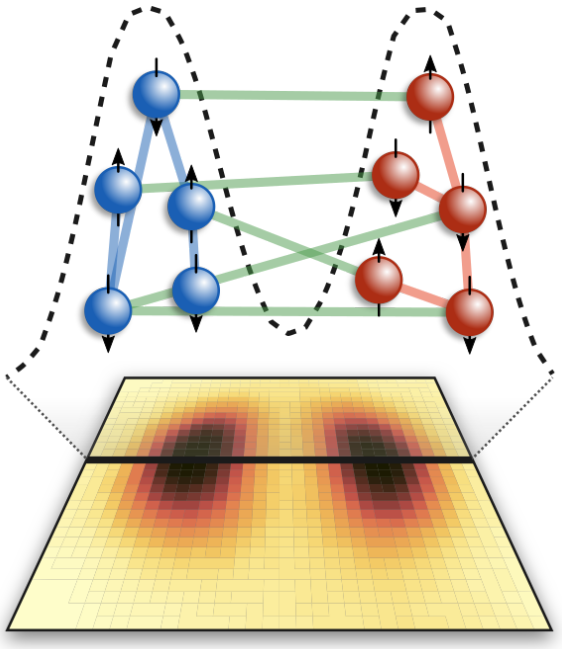


Figure 2: Atoms placed into two wells. Besides entanglement among particles belonging to the same well (red-blue lines), entanglement between the wells (green lines) can be used to overcome the shot-noise limit in gradient metrology.

Measurements of the photon coherence of the tin-vacancy in diamond

Jesús Arjona Martínez[1]
Ryan Parker[1], Kevin C. Chen[2], Romain Debroux[1], Cathryn Michaels[1], Alexander M. Stramma[1], Linsen Li[2], Isaac Harris[2], Carola M. Purser[1], Lorenzo de Santis[2,3], Matthew E. Trusheim[2,4], Dorian A. Gangloff1, Dirk Englund[2], Mete Atature[1].

[1]*Cavendish Laboratory University of Cambridge, JJ Thomson Ave., Cambridge CB3 0HE, UK*

[2]*Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

[3]*QuTech, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands*

[4]*CCDC Army Research Laboratory, Adelphi, MD 20783, USA*

ja618@cam.ac.uk

The SnV qubit in diamond promises to be a leading platform for quantum communication. It builds on the success of the state-of-the-art Nitrogen Vacancy and further provides a system that is insensitive to electric noise due to its inherent inversion symmetry. This key property results in a larger fraction of coherent photons and possible integration into nanostructures such as photonic crystal cavities [1, 2] and integrated photonics [3].

Recent work has shown control of the tin-vacancy qubit [4] as well as transform-limited linewidths [5]. In this work, we investigate the excited state coherence of the SnV and show that the $T_2 = 2\,T_1$ limit is reached with a single pulse rephasing protocol, indicating the emission of highly coherent photons. Further showing the indistinguishability of the emitted photons through Hong-Ou-Mandel measurements would pave the way for the building blocks of quantum networking, such as spin-photon entanglement or remote qubit entanglement. Furthermore, a high-purity high-efficiency source of indistinguishable photons opens the door to measurement-based quantum computation and information through multi-photon entanglement resources [6, 7].

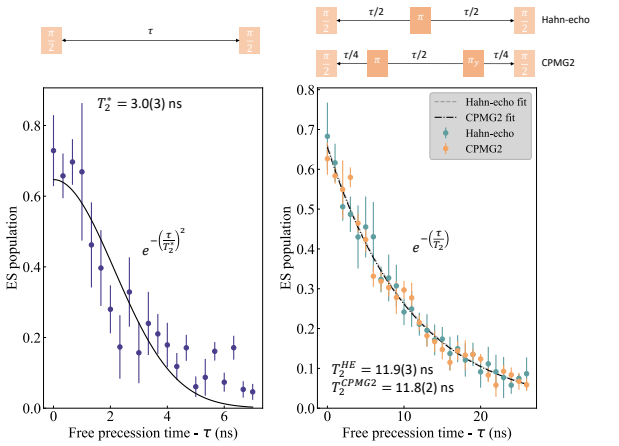


Figure 1: Inhomogeneous dephasing T_2^*(a) and coherent times T_2 (b) of the 619nm optical transition of SnV. A single rephasing pulse brings the coherent time to the theoretical limit of 2 T_1.

References

[1] Kuruma, Kazuhiro, et al. "Coupling of a single tin-vacancy center to a photonic crystal cavity in diamond." Applied Physics Letters 118.23 (2021): 230601.

[2] Rugar, Alison E., et al. "Quantum photonic interface for tin-vacancy centers in diamond." Physical Review X 11.3 (2021): 031021.Authors, Journal, Issue (Year) page

[3] Wan, Noel H., et al. "Large-scale integration of artificial atoms in hybrid photonic circuits." Nature 583.7815 (2020): 226-231

[4] Debroux, Romain, et al. "Quantum control of the tin-vacancy spin qubit in diamond." Physical Review X 11.4 (2021): 041041.

[5] Trusheim, Matthew E., et al. "Transform-limited photons from a coherent tin-vacancy spin in diamond." Physical Review Letters 124.2 (2020): 023602.

[6] Russo, Antonio, Edwin Barnes, and Sophia E. Economou. "Photonic graph state generation from quantum dots and color centers for quantum communications." Physical Review B 98.8 (2018): 085303.

[7] Michaels, Cathryn P., et al. "Multidimensional cluster states using a single spin-photon interface coupled strongly to an intrinsic nuclear register." Quantum 5 (2021): 565

Critical Behaviour and Closing Gap Issue Within Noisy Variational State Preparation

Nikita Astrakhantsev
Giuseppe Carleo

Department of Physics, University of Zurich, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland

Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

nikita.astrakhantsev@physik.uzh.ch

Abstract

Preparation of quantum state in form of a variational quantum circuit plays a crucial role in quantum computing applications such as quantum chemistry. Quality (fidelity) of the resulting state depends on, in addition to circuit architecture, the number of circuit shots N_S used on each iteration of stochastic gradient descent. In this work, within simulation of two-dimensional frustrated quantum magnets, we observe that fidelity shows critical temperature-like behavior in N_S, giving rise to the notion of *critical effective temperature*. Below this critical temperature, we observe that the resource demand of the variational optimization grows as $\sim 1/\Delta^2$ with the system gap Δ, reminding of the adiabatic theorem annealing time bound. We analyze the effect of this $N_S \sim 1/\Delta^2$ dependence on the possibility of large-scale simulations of frustrated magnets. We provide a symmetry-based approach allowing in some cases to significantly reduce the simulation costs of VQE applied to frustrated magnets.

Figures

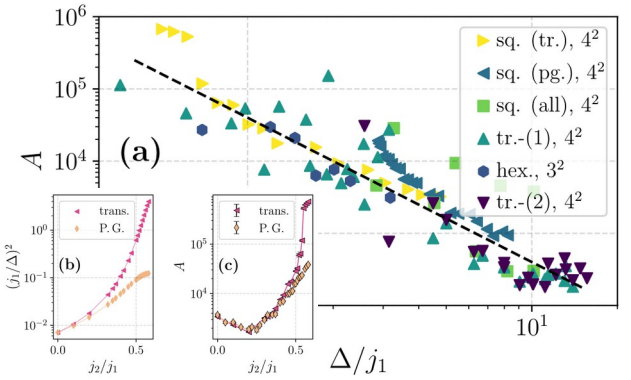


Figure 1: Resources demand A (required number of circuit shots) to reach a fixed overlap with the ground state, simulated within gradient descent VQE at various frustrated 2d magnets as the function of inverse gap. The $1/\Delta^2$ fit is shown. The inset shows that symmetry projection can vary the system gap, resulting in significant reduction of A (translational symmetry as compared to point group symmetry).

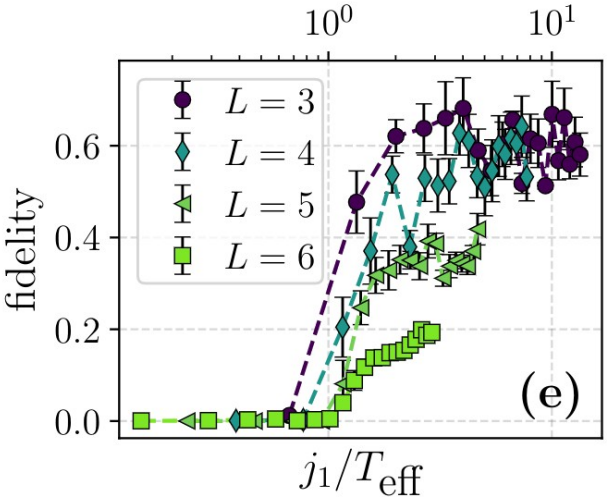


Figure 2: Fidelity as the function of number of samples (inverse effective temperature) shows critical behaviour. The critical temperature depends on the system size and is being extrapolated to thermodynamic limit.

Towards a dissipative cat qubit in a 3D circuit QED architecture

Desislava G. Atanasova[1,2]
Teresa Hönigl-Decrinis[1,2], Ian Yang[1,2], Daria Gusenkova[3]*, Ioan Pop[3], Gerhard Kirchmair[1,2]

1. Institute for Quantum Optics and Quantum Information, A-6020 Innsbruck, Austria
2. Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria
3. Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

desislava.atanasova@uibk.ac.at
* Current address: IQM, Munich, Germany

Quantum systems are fragile by nature and suffer from decoherence due to uncontrolled coupling to the noisy environment, creating a major obstacle to building a large-scale quantum computer. As most sources of decoherence are believed to originate from local fluctuations, storing the information non-locally would suppress the occurring errors exponentially[1].

This work aims to encode a quantum bit in the fundamental bosonic mode of a weakly non-linear coaxial cavity[2] and protect it from decoherence with engineered two-photon dissipation. Here, the cavity non-linearity is inherited from a fluxonium qubit[3], which allows us to tune the memory-ancilla interaction in situ. In contrast to the conventional transmon ancilla, this qubit possesses higher protection against ancilla-induced dephasing. Furthermore, the larger anharmonicity of the fluxonium allows for faster gate operations on the qubit. Together with the engineered dissipation, the setup could be utilized as an improved building block for a fully protected logical qubit. In this poster, the progress of coupling a fluxonium qubit to a high coherence cavity is presented.

References

[1] M. Mirrahimi et al., New J. Phys. 16, (2014) 045014
[2] P. Heidler, C. Schneider et al, Phys. Rev. Applied 16 (2021) 034024
[3] D. Gusenkova, M. Spiecker et al, Phys. Rev. Appl. 15 (2021) 064030
[4] O. Gargiulo, S. Oleschko et al, APL 118 (2021) 012601
[5] D. D. Bai, J. Du et al, J. Appl. Phys. 114 (2013) 133906
[6] P. Groszkowski, J. Koch, Quantum 5 (2021) 583

Figures

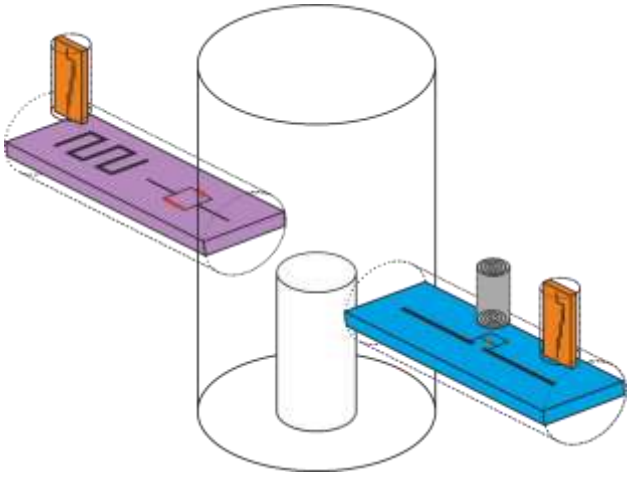


Figure 1: Setup schematic. The system consists of a coaxial cavity (white), fluxonium chip (blue), magnetic flux hose[4] (grey), a Purcell filter[5] (orange) and a 3-wave mixing element chip (violet).

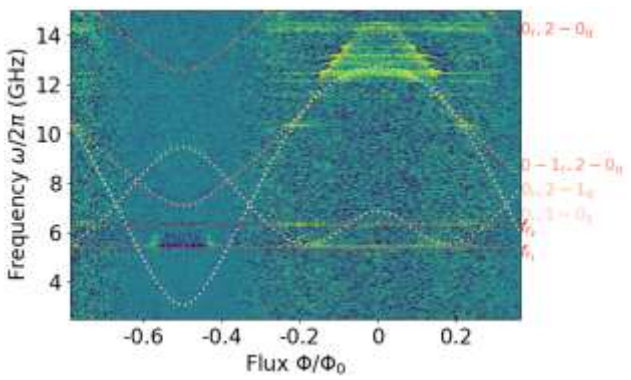


Figure 2: Two-tone spectroscopy of a fluxonium. The spectrum is fitted with the scqubits Python package[6] and includes single and multi-photon transitions.

Quantum simulator with hot atomic vapors

Azam Pierre
Kaiser Robin

Intitut de Physique de Nice, CNRS
1361 route des lucioles, Valbonne, France

pierre.azam@inphyni.cnrs.fr

Numerical resolution of complex problems remains a challenge for various applications, high performance computation centers reaching their limits in terms of speed in addition to being huge energy consumers. In recent years, important efforts are conducted to realize quantum computers and quantum simulators in order to address these limitations. Many devices presently under construction, exploit many entangled qubits, and are often based on cryogenic or ultra-cold atom techniques, in order to avoid thermal decoherence.
A alternative, though less universal development has thus emerged with the goal of realizing more specialized quantum simulators, able to solve specific problems. In this project we propose to develop a remote-controlled stand-alone device to operate as a wave simulator based on the non-linear interaction of a laser beam with a hot atomic vapor [1]. Initial problems to be addressed include hydrodynamic equations [2].

References

[1] Nonequilibrium precondensation of classical waves in two dimensions propagating through atomic vapors (2018), N. Santic, A. Fusaro, S. Salem, J. Garnier, A. Picozzi and R. Kaiser, Phys. Rev. Lett. 120, 055301 Authors, Journal, Issue (Year) page

[2] Dissipation-Enhanced Collapse Singularity of a Nonlocal Fluid of Light in a Hot Atomic Vapor (2021), P. Azam, A. Fusaro, Q. Fontaine, J. Garnier, A.
Bramati, A. Picozzi, R. Kaiser, Q. Glorieux and T. Bienaime, Phys. Rev. A 104, 013515

Figure

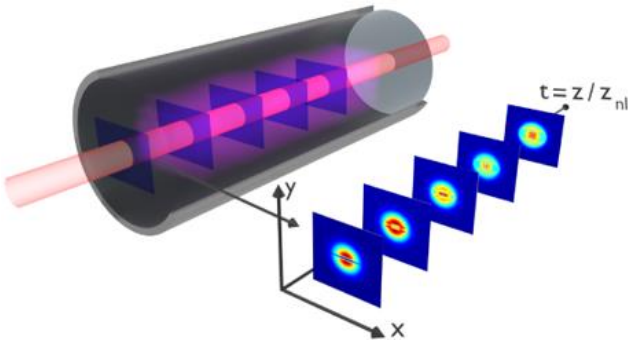


Figure 1: Scheme of laser beam propagating through atomic vapor (nonlinear medium) resulting in the simulation of a 2D fluid of light while propagation axis (z) corresponds to the time evolution of this fluid.

Single microwave photon detector with Dark count rate lower than 100 count/S

Léo Balembois
E.Flurin, P.Bertet, E.Billaud, E.Alvertinale, D. Vion, D.Estève

CEA, Orme des merisier, Gif-sur-Yvette, France

leo.balembois@cea.fr

Single photon counters are essential for detecting weak incoherent electromagnetic radiation. In the optical domain, they are widely used to detect spontaneous emission from individual quantum systems, with applications in fluorescence microscopy, and in numerous areas of quantum technologies. In the microwave domain, operational single photon counters have been developed recently using superconducting quantum circuits, offering novel opportunities for detecting spin fluorescence at microwave frequencies [1] or dark matter axions search.

The single microwave photon counter is based on a transmon qubit is irreversibly coupled to the incoming photons [2] The irreversibility of the process is provided by a 4-wave mixing interaction between the qubit, two resonators and a pump tone. The device operates at 6.98 GHz and is frequency tunable on 40 MHz around this point.

Here we demonstrate a record low absolute power sensitivity of $1 * 10^{-22}\ W/\sqrt{Hz}$, corresponding to a dark count rate of less than 100 clicks/s and an efficiency of 0.4.

References

[1] Albertinale, E., Balembois, L., Billaud, E. et al. Detecting spins by their fluorescence with a microwave photon counter. Nature 600, 434–438

[2] Raphaël Lescanne, Samuel Deléglise, Emanuele Albertinale, Ulysse Réglade, Thibault Capelle, Edouard Ivanov, Thibaut Jacqmin, Zaki Leghtas, and Emmanuel Flurin Phys. Rev. X **10**, 021038 – Published 18 May 2020

Figures

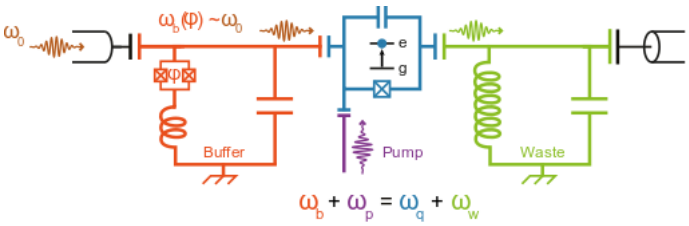


Figure 1: Working principle of the single microwave photon detector. An incident photon at frequency ω_0 is irreversibly converted in a transmon excitation thanks to a four wave mixing process

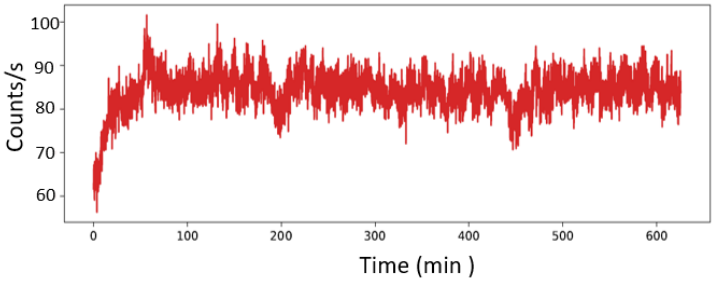


Figure 2: Dark count rate acquired over ~10 hours. After an increasing from 60 count/s to 90 count/s due to the pulses sent to the fridge, the Dark count rate stabilizes around 90 count/s

An efficient quantum algorithm for the time evolution of parameterized circuits

Stefano Barison
Filippo Vicentini
Giuseppe Carleo

Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), Route Cantonale, Lausanne 1015, Switzerland

stefano.barison@epfl.ch

Abstract

In this oral presentation I will introduce a novel hybrid algorithm to simulate the real-time evolution of quantum systems using parameterized quantum circuits.
The method, named "projected - Variational Quantum Dynamics" (p-VQD)[1] realizes an iterative, global projection of the exact time evolution onto the parameterized manifold (see Fig 1). In the small time step limit, this is equivalent to the McLachlan's variational principle [2]. The approach is efficient in the sense that it exhibits an optimal linear scaling with the total number of variational parameters. Furthermore, it is global in the sense that it uses the variational principle to optimize all parameters at once. The global nature of the approach then significantly extends the scope of existing efficient variational methods, that instead typically rely on the iterative optimisation of a restricted subset of variational parameters [3]. I will show through numerical experiments (see Fig 2) that the new approach is particularly advantageous over existing global optimisation algorithms based on the time-dependent variational principle that, due to a demanding quadratic scaling with parameter numbers, are unsuitable for large parameterized quantum circuits [4].
In the end, I will also discuss more recent findings that extend the results of the original paper [1].

References

[1] Barison S. & Vicentini F. & Carleo G., Quantum 5 (2021) 512
[2] McLachlan, A., Molecular Physics 8, (1964) 39–44
[3] Benedetti, M., Fiorentini, M. & Lubasch, M. Phys. Rev. Research, 3 (2021)
[4] Li, Y. & Benjamin, S. C., Phys. Rev. X, 7 (2017)

Figures

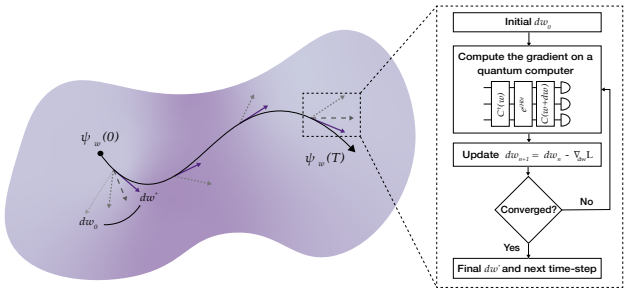


Figure 1: Sketch of the p-VQD algorithm. We follow the real time evolution of the ansatz state in the Hilbert space by optimizing the parameter variation at every time step. The optimization is performed through the gradient of the step-infidelity function L , computed using a quantum computer

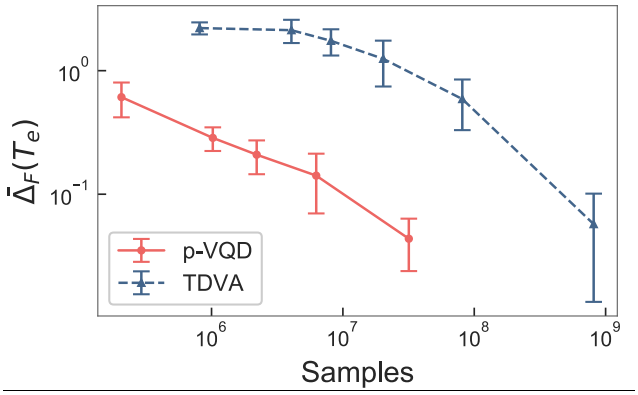


Figure 2: Mean error on fidelity accumulated over an entire time evolution for the two different methods. The plot shows, as a function of the total samples required, the fidelity error accumulated by the algorithm over an entire time evolution. TDVA refers to the method presented in [4].

Quantum algorithms for structural analysis

Presenting Author: Krisztian BENYO
Co-Authors: Antoine MALLET, Marianne SOUAIBY

Capgemini Engineering Research and Development France, Paris, France

krisztian.benyo@capgemini.com

The conception, development, and production of current airplanes is the result of decades of multidisciplinary investigation and countless improvements. From a shape and structure optimization point of view, the granularity of the problem and the extensive number of backend numerical and structural computations push even the highest performing classical machines to their limits [2]. To address this emerging issue, quantum technology has been identified as a potential candidate to bring about solutions [5].

Given the current technological state of quantum computing, the most viable route for considering such a complex and potentially high-dimensional problem is by means of hybrid algorithms [1]. Our work aims to utilise specifically such methods for finding the optimal design of the wings of an airplane.

Our wingbox optimization process can be summarized in the following 5 steps:

1. Model definition and data preparation: discretization of the wingbox model, description of the physical model of the current wingbox design, identification of the physical parameter space
2. Structural analysis of a given design: it comes down to solving the linear system of static equilibrium, a process that we implemented in a quantum computer via a novel VQE reinforced Harrow-Hassidim-Lloyd (HHL) algorithm [3]
3. Classification of the given design based on the structural integrity criteria
4. Exploring the parameter space by means of a trained quantum-enhanced support vector machine (QSVM) [6] to identify structurally sound designs
5. Searching for the minimal weight among successful designs

As of today, hybrid algorithms are relatively underrepresented in the scientific literature. Our preliminary investigations and performance analysis on the implementation of the two key quantum algorithms (HHL and QSVM) have already highlighted some key factors. An a priori eigenvalue analysis (by means of a Variational Quantum Eigensolver, VQE) allows for a close to optimal parametrization of the Quantum Phase Estimation necessary for the HHL algorithm [4], thus improving considerably its performance. It has been observed on multiple data structures that a certain degree of entanglement in the quantum circuit is positively beneficial to the training performance of a QSVM.

References

[1] Endo et. al. JPS Journal, 90 (2021)
[2] França-Garcia-Patron, Nature Physics, 17 (2021) 1221-1227.
[3] Harrow-Hassidim-Lloyd, Phys. Rev. Lett. 103 (2009)
[4] Lee et. al. Nature Scientific Reports, 9 (2019)
[5] Luckow et. al. Digitale Welt, 5 (2021), 38-45
[6] Vojtech et. al. Nature, 567 (2019), 209-212

Figures

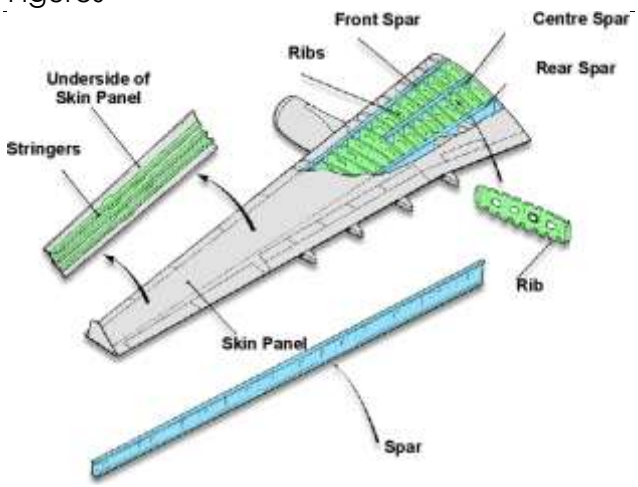


Figure 1: Illustration of problem complexity in designing the wingbox of a commercial aircraft

Experimental setup to measure superconducting flux qubits in the underground laboratory of Canfranc

Elia Bertoldo[1]
Boris Nedyalkov[1], Alba Torras-Coloma[1], Luca Cozzolino[1], Anastasiia Zolotarova[2], Emiliano Olivieri[2], Jorge Pelegrín Mosquera[3], Andrea Giuliani[2], Carlos Peña Garay[3,4], Manel Martínez[1], Pol Forn-Diaz[1]

1. Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology (BIST), Bellaterra (Barcelona), E-08193, Spain
2. Université Paris-Saclay, CNRS/IN2P3 IJCLab 91405 Orsay, France
3. Laboratorio Subterráneo de Canfranc, 22880, Estación de Canfranc, Huesca, Spain.
4. I2SysBio, CSIC-University of Valencia, 46071, Valencia, Spain.

ebertoldo@ifae.es

Abstract

The interactions of ionizing radiation with superconducting qubits is a fundamental limitation to the coherence of these devices [1]. Moreover, high energy radiation can cause chip-wide correlated errors of multiple qubits, limiting the efficacy of error correction techniques [2]. The primary source of radiation in common laboratories is constituted by cosmic rays. The cosmic ray flux can be reduced by several orders of magnitude by moving the experiment inside a deep-underground lab [3]. Enhanced performances of superconducting quantum devices have been already demonstrated in deep-underground facilities due to the suppression of ionizing radiation levels [4].
One of the suitable underground laboratories is the Laboratorio Subterráneo de Canfranc (LSC) located in the Spanish side of the Pyrenees, which ensures a strong cosmic ray suppression [5].
This work shows the preparation of an experimental setup dedicated to the measurement of superconducting flux qubits at LSC. The setup is meant to run experiments designed to understand the impact of different fluxes, energies, and types of ionizing radiation on the performance of flux qubits.

References

[1] Vepsäläinen, A.P., Karamlou, A.H., Orrell, J.L. et al., Nature 584, 551–556 (2020).
[2] McEwen, M., Faoro, L., Arya, K. et al., Nat. Phys. 18, 107–111 (2022).
[3] D.M. Mei and A. Hime, Phys. Rev. D 73, (2006).
[4] Cardani, L., Valenti, F., Casali, N. et al. Nat Commun 12, 2733 (2021).
[5] Trzaska, W.H., Slupecki, M., Bandac, I. et al. Eur. Phys. J. C 79, 721 (2019).

Figures

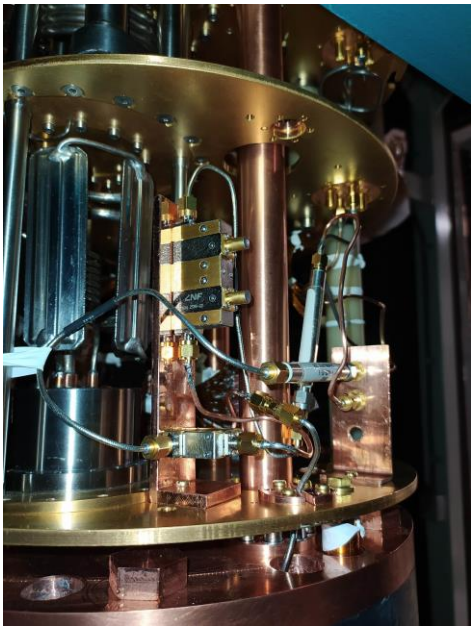


Figure 1: The mixing chamber plate of a dilution refrigerator installed in the underground laboratory of Canfranc after the preparation for the flux qubit measurement.

Rare-Earth ions spin detected with a microwave photon counter

Eric Billaud
L. Balembois, Z. Wang, D. Vion, D. Estève, E. Flurin, P. Bertet

Quantronics
SPEC, CEA Saclay
Orme des Merisiers, Gif-sur-Yvette, 91190
France

eric.billaud@cea.

Abstract:

We report the spin resonance spectroscopy of rare-earth ions using the newly developed method of spin microwave fluorescence detection at millikelvin temperature [1]. The rare-earth ion is Er3+ in a CaWO4 crystal, which behaves as an effective electron spin-½ with high gyromagnetic ratio and long coherence time [2]. The spins are magnetically coupled to a micron-size superconducting microwave resonator deposited on top of the crystal, which enhances their radiative relaxation rate via the Purcell effect [3]. The ions are excited by a resonant microwave pulse, and their radiative relaxation is detected at 10mK using a Single Microwave Photon Counter based on a transmon qubit [4].
Fluorescence detection has proven a complete spectroscopy method able to detect a large variety of spin species at various magnetic field condition. The high sensitivity of this technic allows probing the few ions close to the surface and the resonator. Those spins show a short relaxation time due Purcell effect, and have a specific resonant condition that we attribute to mechanical strain. Additionally, we have proven the possibility to measure the spin coherence with this fluorescence detection by using the appropriate excitation pulses sequence.

References

[1] Albertinale et al., Nature, 600 (2021) 434-438
[2] M. Le Dantec, ScienceAdvances, 51 (2021)
[3] A. Bienfait et al., Nature 531, (2016)
[4] Lescanne et al., Phys.Rev.X 10, 021038 (2020)

Figures

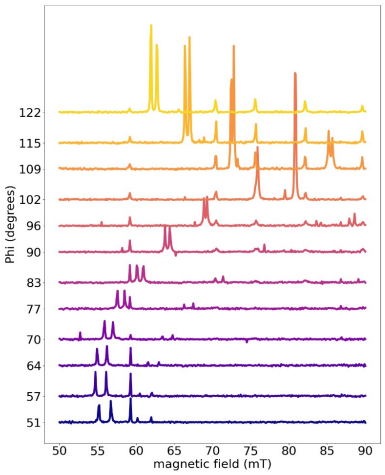


Figure 1: Fluorescence spectroscopy at various magnetic field angle and amplitude, showing many different spin signals

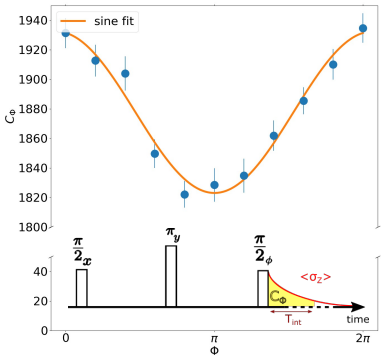


Figure 2: Coherent signal measured with fluorescence detection, with a 3 pulses sequence where we vary the last pulse angle

Information storage capacity of an open quantum Hopfield network

Lukas Bödeker[1,2]
Eliana Fiorelli[1], Markus Müller[1,2]

[1]*Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52428 Jülich, Germany*
[2]*Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany*

lukas.boedeker@rwth-aachen.de

Nowadays classical artificial Neural Networks (NNs) show their great power and versatility in information processing tasks. Early instances of NNs are given by associative NNs, which have the ability to retrieve a stored state, starting from a compromised initial one. Such dynamics can be engineered via a stochastic evolution, where stored configurations are minima of an energy landscape. One of the first examples of associative NNs is the Hopfield NN, which is an Ising-type system featuring all-to-all interactions. Motivated by the fast progress in controlling quantum systems, as well as in quantum computation, a question that is currently explored is whether a Hopfield-type associative memory could be hosted in quantum systems [1]. Our goal is to understand what role quantum effects play in such a quantum-Hopfield network with regard to store information. To this end, we calculate the maximum information storage capacity at finite temperature i.e., the maximum number of stored states given a certain system size, by generalising an approach that was previously introduced and applied to classical neural networks [2,3].

References

[1] P. Rotondo, M. C. Lagomarsino, and G. Viola, Physical review letters 114.14 (2015) 143601.
[2] E. Gardner, Journal of physics A: Mathematical and general 21.1 (1988) 257.
[3] G. M. Shim, D. Kim, and M. Y. Choi, Journal of Physics A: Mathematical and General 26.15 (1993) 3741.

Figures

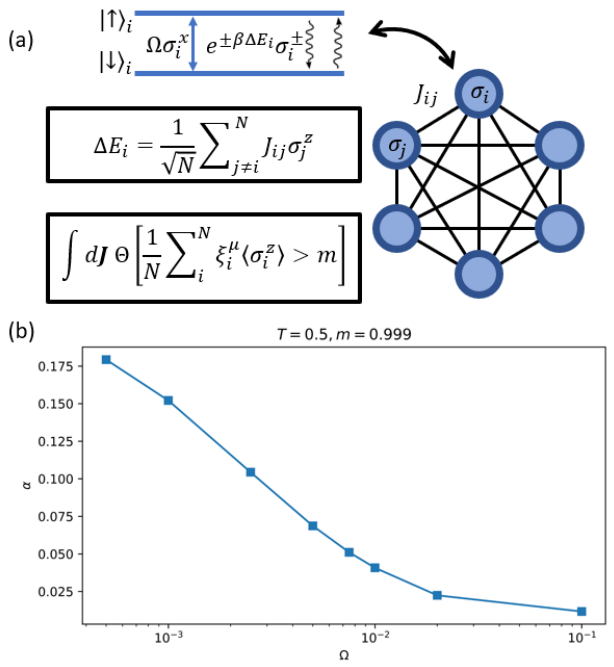


Figure 1: (a) Schematic illustration of the dissipative Hopfield model with quantum drive and the volume of attractive network configurations with regard to stored patterns. (b) Maximal capacity at finite temperature T=0.5 and large minimal overlap upon varying the quantum drive.

Advanced STEM Characterisation of SiGe/Ge Quantum Wells for Quantum Computing

Marc Botifoll[a]
Carla Borja[b], Sara Martí-Sánchez[a], Daniel Jirovec[b], Kushagra Aggarwal[b], Georgios Katsaros[b], Jordi Arbiol[a,c]

a. Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Barcelona, Catalonia, Spain
b. Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria
c. ICREA, Pg. Lluis Companys 23, 08010 Barcelona, Catalonia, Spain

marc.botifoll@icn2.cat

Quantum computing is thought to be one of the main technological revolutions to occur in the current century. It will become ubiquitous in our society providing with powerful tools to solve scientific problems in diverse fields such as chemistry and drug design, biomedical research and personalised medicine, and engineering, among others. Towards achieving quantum processing units, germanium is an outstanding platform to create well-controlled quantum dots given its high hole mobility and low effective mass. In this study, we have explored the materials science implications behind the creation of a Ge-based Josephson field-effect transistor (JoFET) [1] and a singlet-triplet hole spin qubit [2].

We proceeded with a complete electron microscopy-based study to correlate the quantum performance of the devices with their crystalline quality. HAADF-STEM was used to get atomic resolution micrographs of the misfit dislocation-free Ge quantum wells (QW) and their interfaces with the SiGe surrounding layers, and crystalline Al and Nb metallic contacts, when present. We computed the elastic strain by a correlative study between geometrical phase analysis (GPA) and quantitative-EELS and X-ray diffraction (XRD). We proved the feasibility of extracting reliable quantitative compositional information by means of core-loss EELS despite plural scattering when complementary reference values are provided (e.g. XRD). We used this precise compositional information to correlate the relative lattice displacements unveiled by GPA to the strain to which every region of the device has undergone.

In conclusion, we have applied a systematic structural-compositional correlative characterisation to state-of-the-art Ge-based devices for hole spin qubits generation in an ongoing study aiming for an optimised quantum performance.

References

[1] Aggarwal, K et al, *Physical Review Research*, **3**(2), (2021) L022005
[2] Jirovec, D. et al. *Nature Materials*, (2021) doi.org/10.1038/s41563-021-01022-2

Figures

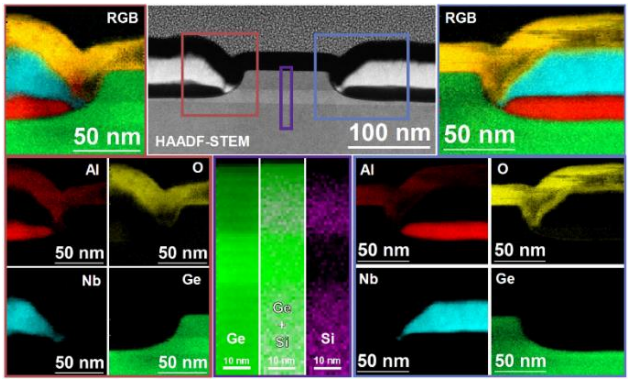


Figure 1: Electron Energy-Loss Spectroscopy (EELS) compositional maps of the JoFET device and its germanium quantum well and surrounding Al-Nb contacts. The EELS maps were taken at 200kV, with a spatial resolution of around 1nm.

An array of single atoms strongly coupled to a cavity for quantum metrology and simulation.

Pierre-Antoine Bourdel
Constance Poulain, Jakob Reichel, Romain Long.

Laboratoire Kastler Brossel, École Normale Supérieure, 24, rue Lhomond, Paris, France

pierre-antoine.bourdel@lkb.ens.fr

Strongly coupling an array of single qubits to a cavity offers the prospect of any-to-any interactions between the qubits, single qubit state read-out (fast or quantum non-demolition) and multiparticle entanglement generation.
Towards this objective, we have built a platform where cold rubidium atoms are strongly coupled to a fiber-based Fabry-Perot cavity. A high-numerical aperture lens combined with acousto-optic deflectors [1] [2] will allow to 1) generate a 1D chain of tens of single atoms, trapped in tweezers, strongly, equally and maximally coupled to the cavity mode 2) store single atoms in a 1D atomic register outside of the cavity 3) move atoms between the register and the cavity, for fast readout and entanglement generation.
With this setup, we have mapped the cavity mode with atoms trapped in the tweezers, achieved the single-atom collisional blockade regime and measured the single-atom Rabi splitting. We are now setting up the multiple-tweezer configuration to enter the regime of strong coupling CQED with a controllable number of single atoms. Our platform will then allow multi-parameter quantum metrology (e.g. measuring magnetic gradients with entanglement-enhanced precision) [3]. With our future 1D chain of spins, we will also simulate the quantum transport of an excitation in the chain in presence of disorder [4], and explore quantum information dynamic in the chain, such as scrambling [5].

References

[1] M. Endres et al.,Science 354, 1024–1027 (2016)
[2] D. Barredo et al., Science 354, 1021 (2016)
[3] M. Gessner et al., Nature Comm. 11, 3817 (2020)
[4] J. Dubail et al., Phys. Rev. A 105, 023714 (2022)
[5] G. Bentsen et al., Phys. Rev. Lett. 123, 130601 (2019)

Figures

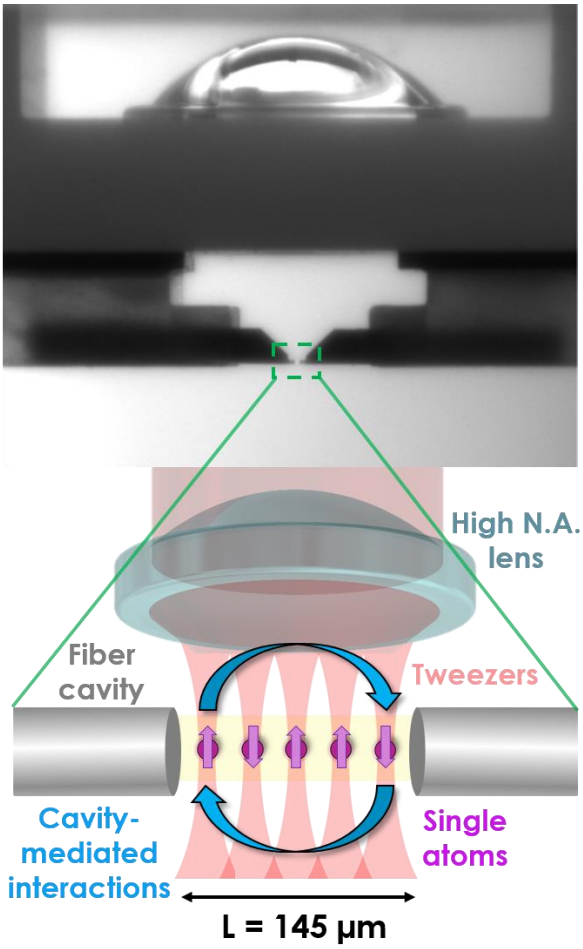


Figure 1.

Silicon Nanowires with Quantum Dots for experimentation in Quantum Technologies

J Llobet[1], J. Antoja[1], X Borrisé[2], D Bricio[1], A. del Moral[1], M Duch[1], S Durán[1], A Garcia[1], A Guerrero[1], R. Mas[1], J Sanchez[1], J Bausells[1], **F Pérez-Murano[1]**

[1] *Institute of Microelectronics of Barcelona (IMB-CNM CSIC), Bellaterra, 08193, Spain*
[2]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Bellaterra, 08193, Catalonia, Spain*

Francesc.Perez@csic.es

Abstract

Silicon Nanowires (SiNWs) are one of the building blocks for the development of semiconductor spin qubits based on quantum dots. We are developing a platform based on novel nanofabrication approaches following two mix and match routes: i) optical and electron beam lithography (EBL); ii) EBL and focused ion beam (FIB) implantation. The platform is designed for allowing rapid experimentation of novel device concepts.

The first mix-and-match approach consists of 5 lithographic steps combining optical lithography and EBL using the same negative resist. The process allows to define more than 5000 individually connected SiNW devices (figure 1).

The second approach is based on a three-step fabrication scheme [1,2] using FIB implantation as a resistless lithography process followed by wet chemical etching. It allows to obtain suspended and not suspended silicon nanowires of sub-20 nm width. By the development of an annealing step, it is demonstrated the recovery of the electrical conduction up to four orders of magnitude, the out-diffusion of gallium and the promotion of nanocrystals (sub-10nm) embedded and constricted inside the silicon nanostructures [3,4]. The nano-crystalline nature of the resulting SiNWs allowed the development of single hole transistors (SHoTs)] as depicted in figure 2.

References

[1] J. Llobet et al. J. Micro/Nanolith. MEMS MOEMS vol. 14 031207 (2015).
[2] J. Llobet et al. Nanotechnology 25, 135302 (2014). Authors, Journal, Issue (Year) page
[3] J. Llobet et al. Applied Physics Letters 107, 073104 (2015).
[4] J. Llobet et al. Nanotechnology 29, 155303 (2018).

Figures

Figure 1: Photograph of a 100 mm wafer containing more than 5,000 connected silicon nanowires

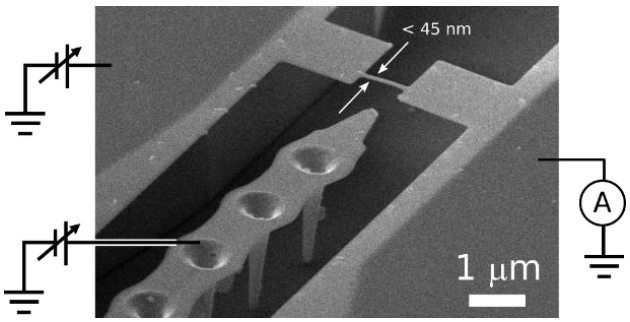


Figure 2: SEM image of a single hole transistor fabricated by a three step rapid prototyping process based on focused ion beam [4]

Quantum circuits for the preparation of spin eigenfunctions on quantum computers [1]

Alessandro Carbone [1,2]
Davide Emilio Galli, Mario Motta, Barbara Jones
[1] *Theory and Simulations of Materials (THEOS), and National Centre for Computational Design and Discovery of Novel Materials (MARVEL), École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland*
[2] *Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria 16, 20133 Milano, Italy*
alessandro.carbone@epfl.ch

The preparation of accurate and efficient approximations for Hamiltonian eigenstates on quantum computers is a crucial step for building the quantum advantage when studying many-body quantum systems. If we can describe molecules or materials with a coarse-grained spin Hamiltonian, spin eigenfunctions can be a useful starting point for simulations which aim to understand their electronic structure. On the other hand, if we do not know the spin model, the total spin eigenfunctions can be used to determine the coupling constants from first-principle calculations [2]. In particular the purpose of this work is to delve into the description of the quantum circuits which prepare total spin eigenfunctions in the case of spin-1/2 systems.

Previous approaches have typically concentrated on circuits encoding specific spin eigenstates, that have less generality, but require less quantum resources [3,4]. We investigate the balance between generality, accuracy, and computational cost in the encoding of spin eigenfunctions by quantum circuits without ancillary qubits, by pursuing two approaches: an exact recursive construction of spin eigenstates, and a heuristic variational construction of approximate spin eigenstates.

The former approach mimics the addition theorem of angular momenta. In general the circuits returned have an exponential scaling of the circuit depth with the system size. In the second approach we use the Variational Quantum Eigensolver (VQE) algorithm to minimize a suitable cost function and find the target circuits. The latter method has polynomial scaling of the circuit depth and it could lead to efficient implementations on hardware.

We have tested the described quantum circuits on the available IBM (classical) simulators and quantum devices through IBM Quantum Experience using IBM's open-source Python library for quantum computing, Qiskit [5]. In particular we show the fidelity values of several 3-spin and 5-spin quantum circuits with respect to the expected spin eigenstates, by focusing on both approaches.

References

[1] A. Carbone, D. E. Galli, M. Motta and B. Jones, arXiv: 2202.09479[quant-ph] (2022)
[2] R. Logemann, A. Rudenko, M. Katsnelson, and A. Kirilyuk, J. Phys. Cond. Mat, vol. 29, no. 33 (2017), p. 335801
[3] K. Sugisaki, S. Yamamoto, S. Nakazawa, K. Toyota, K. Sato, D. Shiomi, and T. Takui, Chem. Phys. Lett X, vol. 1 (2019), p. 100002
[4] A. Bärtschi and S. Eidenbenz, Fundamentals of Computation Theory (L. A. Gasieniec, J. Jansson, and C. Levcopoulos, eds.), Springer (2019), pp. 126–139
[5] G. Aleksandrowicz, T. Alexander, P. Barkoutsos, L. Bello, Y. Ben-Haim, D. Bucher, F. Cabrera-Hernández, J. Carballo-Franquis, A. Chen, C. Chen, et al., Zenodo, vol. 16 (2019)

Multi-level 3D device simulation approach applied to quantum-confined nanowire field effect transistors

Xavier Cartoixà[1]
Natalia Seoane[2], Antonio García-Loureiro[2]

[1] *Universitat Autònoma de Barcelona, Spain*
[2] *Universidade de Santiago de Compostela, Spain*

natalia.seoane@usc.es

While electronic devices have been continuously shrunk over the past 50+ years. In the last years, this has been possible thanks to the state-of-the-art FinFETs. However, this architecture cannot provide the required electrostatic integrity when scaled to future sub 5-nm technology nodes [1]. Hence, gate-all-around nanowire (NW) FETs are considered as a replacement thanks to their superior electrostatic integrity against FinFETs and nanosheet FETs.

Modelling of semiconductor devices via technology computer-aided design (TCAD) undoubtedly plays an essential role in the scaling of transistors. TCAD tools based on quantum-mechanical corrected classical and semi-classical transport methods can provide a good trade-off between the simulation precision and computational cost. However, when studying devices with channel cross-section dimensions below 10 nm, quantum confinement starts to play a substantial role in the band-structure [2].

We present Monte Carlo simulations of NW FETs parametrized from a tight-binding calculation of the NW band structure. These simulations show that, indeed, quantum confinement effects have a big role in devices based on NWs with diameter ~<6 nm.

NS and AGL work funded by the MICINN/Xunta de Galicia/FEDER (RYC-2017-23312, PID2019-104834GB-I00, ED431F-2020/008). XC work funded by the MCIU/AEI/FEDER (RTI2018-097876-B-C21).

References

[1] M. T. Bohr and I. A. Young, IEEE Micro, 37 (2017) 20–29.
[2] M. Luisier, A. Schenk, W. Fichtner, and G. Klimeck, Phys. Rev. B, 74 (2006) 205323.

Figures

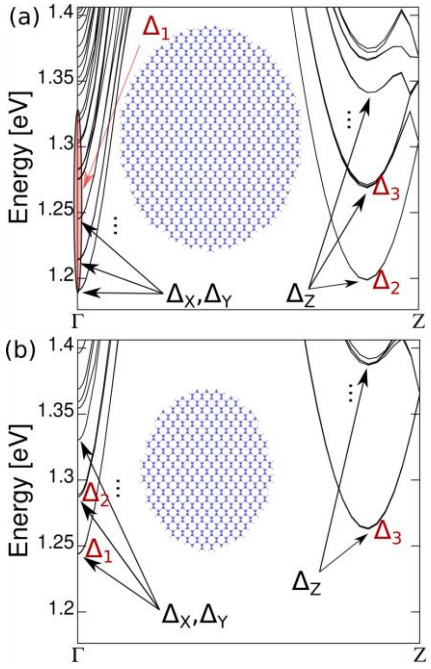


Figure 1: Tight-binding band structure of an elliptical cross-section [110] SiNW FET channel.

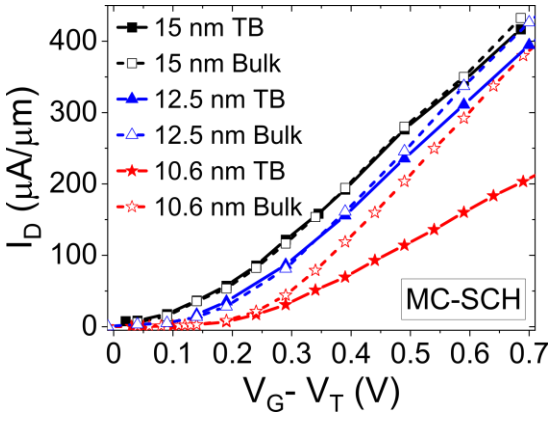


Figure 2: MC simulations of several gate length SiNW-FETs using bulk or tight-binding bands.

Robust entangling gate for capacitively coupled few-electron singlet-triplet qubits

Guo Xuan Chan[1,2]
Xin Wang[1,2]

[1]*Department of Physics, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, China*
[2]*City University of Hong Kong Shenzhen Research Institute, Shenzhen, Guangdong 518057, China*
gxchan3-c@my.cityu.edu.hk

Singlet-triplet (ST_0) qubits remain one of the leading candidates to host quantum computing devices in semiconductor quantum dots. Relative to single-spin qubits, ST_0 qubits feature fast operations, suppressed power dissipation, simplified control systems, and high-fidelity readout. Conventionally, ST_0 qubits are realized in two singly-occupied tunnel-coupled dots ("two-electron ST_0 qubit"). Such setup for ST_0 qubits is limited from performing high-fidelity capacitive gates as dipoles are introduced during the two-qubit operations. Therefore, searching a two-qubit sweet spot, locus in qubit parameters where quantum control is first-order insensitive to charge noises, is key to achieve robust entangling gates in this system.

Recent experiments have demonstrated, when a singly-occupied quantum dot is coupled to a multielectron dot, that exchange energies can depend non-monotonically on the detuning, the control parameter [1,2]. Inspired by these works, we consider ST_0 qubits allowing each dot to host more than one electron, with a total of four electrons in the double quantum dots ("four-electron ST_0 qubit"). We theoretically demonstrate, using configuration-interaction calculations, that sweet spots appear in this coupled qubit system. We further demonstrate that, under realistic charge noise and hyperfine noise, two-qubit operation at the proposed sweet spot could offer gate fidelities (~99%) that are higher than conventional two-electron singlet-triplet qubit system (~90%)

References

[1] F. K. Malinowski, et al., Phys. Rev. B X, 8 (2018) 022045
[2] F. Martins, et al., Phys. Rev. Lett., 119 (2017) 227701
[3] G. X. Chan and X. Wang, arXiv:2201.01583 (2022)

Figures

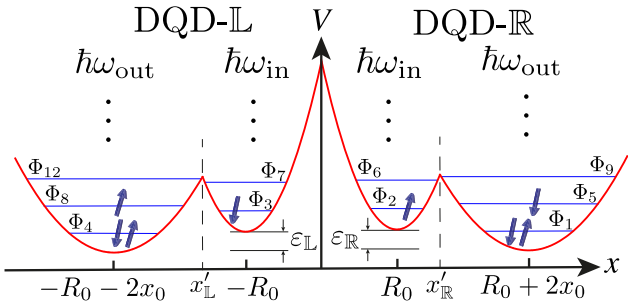


Figure 1: Schematic illustration of a double double-quantum-dot (DQD) device, where DQD-L and -R denote left and right DQD respectively, with x = 0 being the boundary between them.

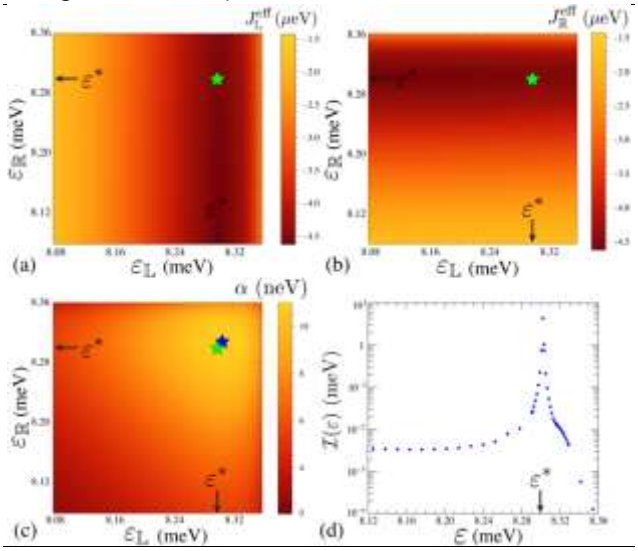


Figure 2: (a, b) Effective exchange energies and (c) capacitive coupling as functions of detunings (d) Insensitivity v.s. symmetric detunings on two DQDs

Super-Semi Interferometers based on Quantum Point Contacts

José M. Chávez-Garcia[1]
Smitha Nair[1], Constantin Schrade[1], Asbjørn Drachmann[1], Sangeeth Kallatt[1], Rasmus B. Christensen[1], Sergei Gronin[2], Geoff Gardner[2], Michael M. Manfra[2,3], Charles Marcus[1], Morten Kjaergaard[1]

1 Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark
2 Department of Physics and Astronomy, Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana 47907
3 School of Materials Engineering and School of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana 47907

jose.chavez-garcia@nbi.ku.dk

Two dimensional systems proximitized with superconductors have been demonstrated to serve as versatile platform for studying Andreev physics [1]. Here, we create several DC superconducting quantum interference devices generated by two semiconductor Josephson junctions. We probe the limits of balancing such a circuit – that is minimizing the difference of their respective Andreev energies towards creating a parity protected qubit [2]. Additionally, we inspect the quality of these super-semi proximitized modes via the transmission of superconducting quantum point contacts [3].

References

[1] J. Shabani, et al. Phys. Rev. B. 93, 155402 (2016)
[2] T.W. Larsen, et al. Phys. Rev. Lett. 125, 056801 (2020)
[3] E. Mikheev, et al. Sci. Adv. 7, 40 (2021)

Figures

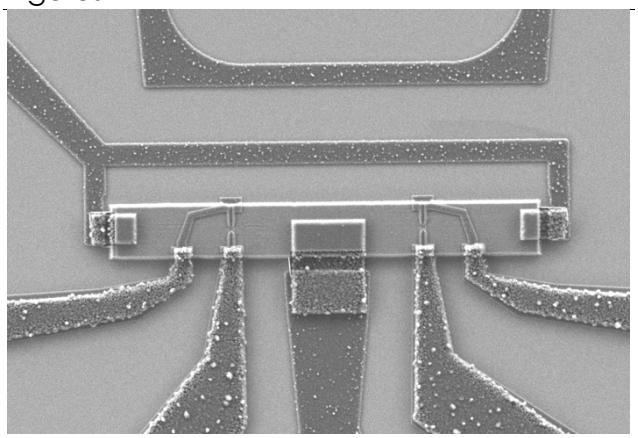


Figure 1: SEM of a hybrid interferometer with quantum point contacts and local flux control.

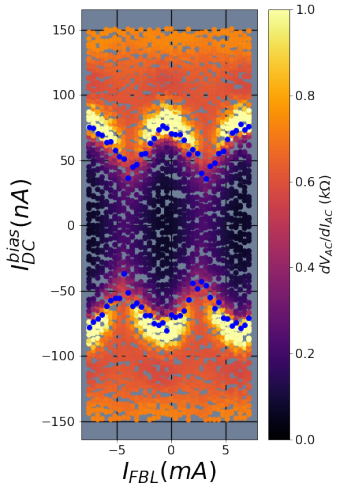


Figure 2: Oscillation of Josephson critical current as a function of local flux line current.

Magneto-Optical measurements in Weyl Semimetals

Dima Cheskis

Ariel University, Ariel Campus, Ariel, Israel

dimach@ariel.ac.il

Abstract

We present in this work is an experimental study of topological semimetals. This work was focused on studying the behavior of the type I $Co_3Sn_2S_2$ Weyl semimetals. Primarily, we are interested in magneto-optical measurements of these materials. Due to the effect of chiral anomaly, it is expected that the angle between electric and magnetic fields due to the term E*B [1] leads to the specific impacts in Weyl semimetals. In particular, it has been claimed that the chiral anomaly results in a charge imbalance between the Weyl nodes. In Weyl semimetals, the dielectric tensor receives a specific form [2] that allows observing chiral anomaly via the magneto-optical Kerr effect. Such studies have been performed for Cd_3As_2 crystals under an external magnetic field, and the outcome of the chiral anomaly was measured by magneto-optical methods. We are demonstrating our first results for $Co_3Sn_2S_2$ crystals. To the best of our knowledge, such a study was not performed in these materials.

References

[1] D. Cheskis, Symmetry, 12(9) (2020), 1412

[2] P. Hosur and X. L. Qi, Phys. Rev. B, 91(8) (2015), 081106

Figures

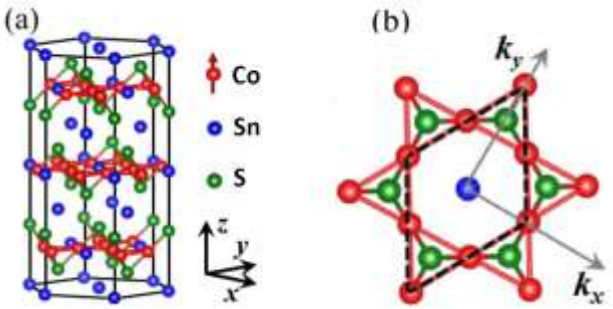


Figure 1: Lattice structure of $Co_3Sn_2S_2$ (a) 3-D view and (b) from the top.

Figure 2: Insert caption to place caption below figure (Century Gothic 10)

Microwave-activated gates between transmon and fluxonium qubits

Alessandro Ciani[1]
Boris Varbanov[2], Nicolas Jolly[2], Christian K. Andersen[2], Barbara M. Terhal[2,3,4]

[1]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum J\Jülich, 52425 Jülich, Germany
[2]QuTech, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands
[3]JARA, Institute for Quantum Information, Forschungszentrum Jülich GmbH, 52428 Jülich, Germany
[4]EEMCS, Delft University of Technology, Mekelweg 4, 2628 CD Delft, The Netherlands

a.ciani@fz-juelich.de

Abstract

We propose and analyze two types of microwave-activated gates between a fluxonium and a transmon qubit, namely a cross-resonance and a CPHASE gate. The large frequency difference between a transmon and a fluxonium makes the realization of a two-qubit gate highly nontrivial. When the inductive energy of the fluxonium is of order comparable to its Josephson energy, the fluxonium-transmon system allows for a strong cross-resonance effect mediated by the higher levels of the fluxonium over a wide range of transmon frequencies. This allows us to realize the cross-resonance gate by driving the fluxonium at the transmon frequency mitigating typical problems of the cross-resonance gate in transmon-transmon chips [1]. However, when the inductive energy of the fluxonium decreases and its fundamental frequency becomes O(10) MHz the cross-resonance effect tends to vanish. For this range of parameters, a fast microwave CPHASE gate can be implemented using the higher levels of the fluxonium [2]. In both cases, we perform numerical simulations of the gate showing that high fidelity can be obtained with gate times O(100) ns. Next to a detailed gate analysis, we consider the pros and cons of these gates in a multi-qubit surface code architecture. We provide a comparison of our architecture with the only transmon case and the recently proposed only fluxonium architecture [3].

References

[1] J. Hertzberg et al., npj Quantum Information 7: 129(2021)
[2] Q. Ficheux et al, Phys. Rev. X 11, 021026 (2021)
[3] L. Nguyen et al, arXiv:2201.09374 (2022)

Figures

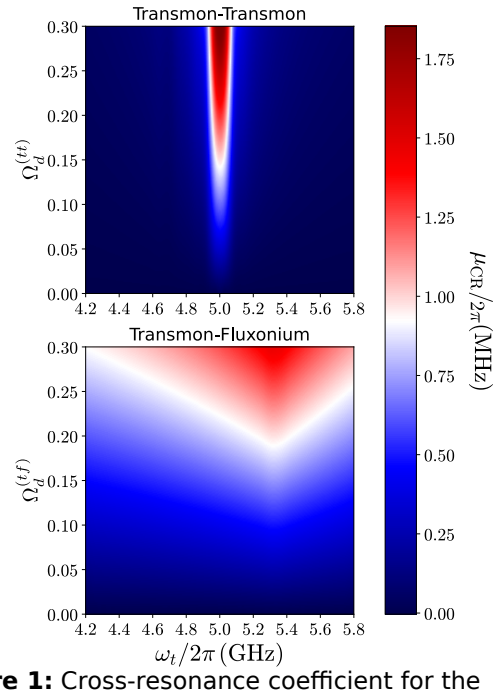


Figure 1: Cross-resonance coefficient for the transmon-transmon case (top) and transmon-fluxonium case (bottom) as a function of the frequency of the target transmon and dimensionless drive strenghts. In the fluxonium-transmon case the cross-resonance coefficient is larger for a wide range of target transmon frequency compared to the transmon-transmon case. This mitigates the problem of frequency collisions, which limits the fabrication yield in fixed-frequency transmon-transmon chips.

Coherent Four-Josephson Junction Flux Qubits For Quantum Annealing

Luca Cozzolino [1]

David López-Nuñez[1,2], Fabian Zwiehoff[1], Elia Bertoldo[1], Barkay Guttel[3], Paul Baity[5], Manel Martínez[1], Martin Weides[4], Pol Forn-Díaz[1,5]

[1] *Institut de Fisica d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, 08193 Bellaterra (Barcelona), Spain*

[2] *Barcelona Supercomputing Center, Barcelona 08034, Spain*

[3] *Weizmann Institute of Science, 7610001 Rehovot, Israel*

[4] *James Watt School of Engineering, University of Glasgow, Glasgow, G12 8QQ, UK*

[5] *Qilimanjaro Quantum Tech, 08007 Barcelona, Spain*

lcozzolino@ifae.es

In this work, we present a capacitively shunted flux qubit made out of four Josephson junctions in a superconducting loop. As part of the European FET Open project AVaQus [1], we designed and characterized a first prototype of low-impedance persistent current qubits [2] suitable for coherent quantum annealing. Here, we consider a circuit topology with four Josephson junctions in a loop to avoid unde- sired stray junctions by design. Based on progress made in the field [3], we shunt the smaller a junction with a capacitor C_{sh} = 8 to 13 fF, making the charging energy E_C more reproducible and thus the qubit gap ω_{01} more controllable, which is targeted to be between 1 to 2 GHz. Aiming at application in quantum annealing, the persistent current is designed to be small enough (I_p around ~ 100 nA) to remain high coherence while allowing for an inductive coupling between qubits in future designs [4].

Within the framework of the AVaQus project, this first generation device was fabricated by our collaborators at the University of Glasgow using a subtractive junction fabrication process [5] while the characterization of the device is carried out at IFAE.

References

1. https://www.avaqus.eu
2. J. E. Mooij et al., Science 285, 5430 (1999)
3. F. Yan et al., Nat Commun. 7, 12964 (2016)
4. S. J. Weber et al., Phys. Rev. Applied 8, 014004 (2017)
5. A. Stehli et al., Appl. Phys. Lett. 117, 124005 (2020)

Figures

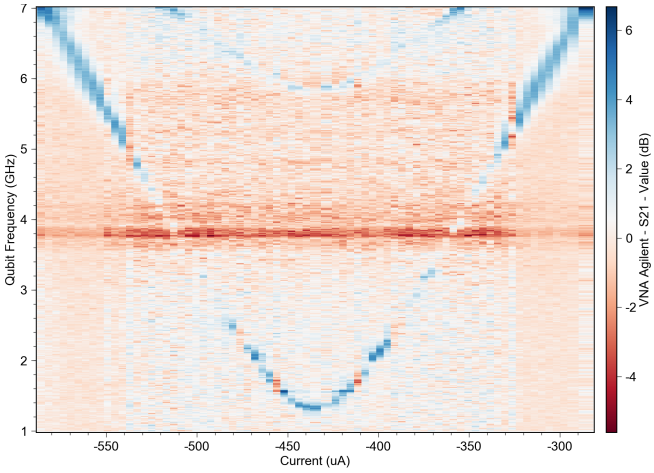


Figure 1: Measured qubit spectrum.

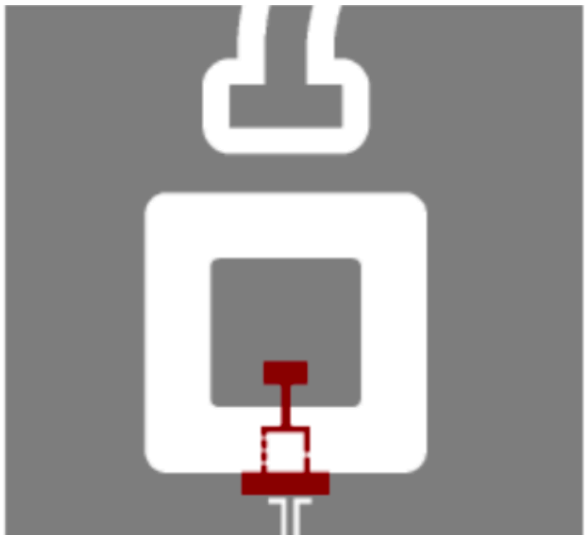


Figure 2: Grounded qubit design.

Fragmented imaginary-time evolution for intermediate-scale quantum signal processors

Thais de Lima Silva
Márcio M. Taddei, Stefano Carrazza, and Leandro Aolita

Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE

thais.delimasilva@tii.ae

Simulating quantum imaginary-time evolution (QITE), that is, implementing the operator $F_\beta(H) = e^{-\beta H}$ for a given Hamiltonian H and an imaginary time $-i\beta$, is a major promise of quantum computation. QITE is an important subroutine for many quantum algorithms, such as ground-state optimisations, partition-function estimation, and quantum Gibbs-state sampling. However, the known state-independent algorithms are either probabilistic (repeat until success) with unpractically small success probabilities or coherent (quantum amplitude amplification) but with circuit depths and ancillary-qubit numbers unrealistically large for the mid term. Our main contribution is a new generation of deterministic, high-precision QITE algorithms significantly more amenable to intermediate-scale quantum devices [1]. These are based on a surprisingly simple idea: partitioning the evolution into several fragments that are sequentially run probabilistically, as shown in Fig. 1. This causes a huge reduction in wasted circuit depth every time a run fails. Indeed, the resulting overall runtime is asymptotically better than in coherent approaches and the hardware requirements even milder than in probabilistic ones, remarkably, as exemplified in Fig. 2.
On a more technical level, we present two QITE-circuit sub-routines with excellent complexity scalings. One of them is optimal in ancillary-qubit overhead (one single ancillary qubit throughout) whereas the other one is optimal in runtime for small inverse temperature or high precision. The latter is shown by noting that the runtime saturates a cooling-speed limit that is the imaginary-time counterpart of the celebrated no fast-forwarding theorem of real-time simulations, which we prove. Moreover, we also make a technical contribution to the quantum signal processing formalism [3,4] (on which our subroutines are based) for operator-function synthesis from their Fourier expansion that is useful beyond QITE.
Our results are relevant to near-term quantum hardware. In particular, they constitute a versatile toolbox for the demonstration of experimental quantum signal processors.

Figures

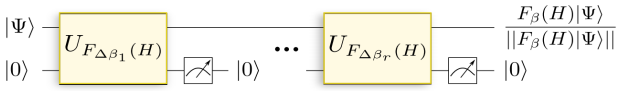


Figure 1: Schematic representation of fragmented QITE algorithm where several fragments are implemented probabilisticaly. For each $\Delta\beta$, after post-selecting the ancilla in the state $|0\rangle$ one has $\langle 0|U_{F_{\Delta\beta}(H)}|0\rangle \propto F_{\Delta\beta}(H)$.

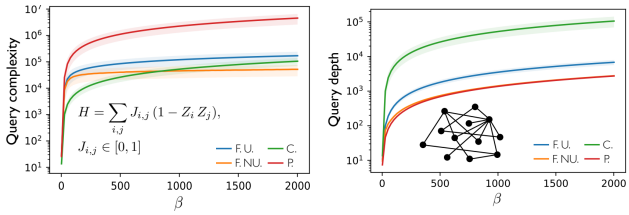


Figure 2: Results: comparison of the total number of queries to a Hamiltonian oracle and circuit depth for different algorithms for the weighted max-cut model. C. (coherent), P. (probabilistic), F.U. and F. NU (fragmented with different imaginary-time fragments).

References

[1] TLS, MMT, SC, LA; arXiv:2110. 131 80 (2021).
[2] G. H. Low and I. L. Chuang, Phys. Rev. Lett. 118, (2017), 010501.
[3] A. Gilyén et al; STOC 2019 (2019), 193.

Performance of Surface Codes in realistic quantum hardware

Antonio deMarti iOlius
Josu Etxezarreta Martinez, Patricio Fuentes, Pedro M. Crespo and Javier Garcia-Frias

Tecnun - University of Navarra, Manuel Lardizabal Ibilbidea, 13, 20018, Donostia, Gipuzkoa

ademartio@tecnun.es

Abstract

One of the main obstacles for the construction of a many qubit quantum computer is quantum decoherence. Qubits within quantum computers tend to fail and prevent us from achieving their true potential. In order to tackle quantum decoherence, Quantum Error Correction Codes (QECC) aim to detect and correct those errors. Surface codes are a class of QECC which enjoy a great popularity in the current scientific community since they do not need a large number of qubits [1]. Most of the studies on the performance of surface codes assume all qubits experience noise following an independent and identical error probability distribution (i.i.d.). In this poster, supported by experimental evidence in which individual qubits within the code present different deocherence times, we propose the independent non-identical error probability error model (i.ni.d.) [2-4]. Based on such model, we observe the change in the performance of the planar code and we try to design an algorithm which can exploit the difference in error probability of the constituent qubits in order to enhance the aforementioned performance.

References

[1] A.G. Fowler, M. Mariantoni, J.M. Martinis y A.N. Cleland, "Surface codes: Towards practical large-scale quantum computation", *Physical Review A,* vol 86, 2012.

[2] ibmWashington IBM Quantum. https://quantum-computing.ibm.com/services, 2022.

[3] ibmqBrooklyn IBM Quantum. https://quantum-computing.ibm.com/services, 2022.

[4] Wu, Y. et al. Strong Quantum Computational Advantage Using a Superconducting Quantum Processor. *Phys. Rev. Lett.* 127, 180501 (2021).

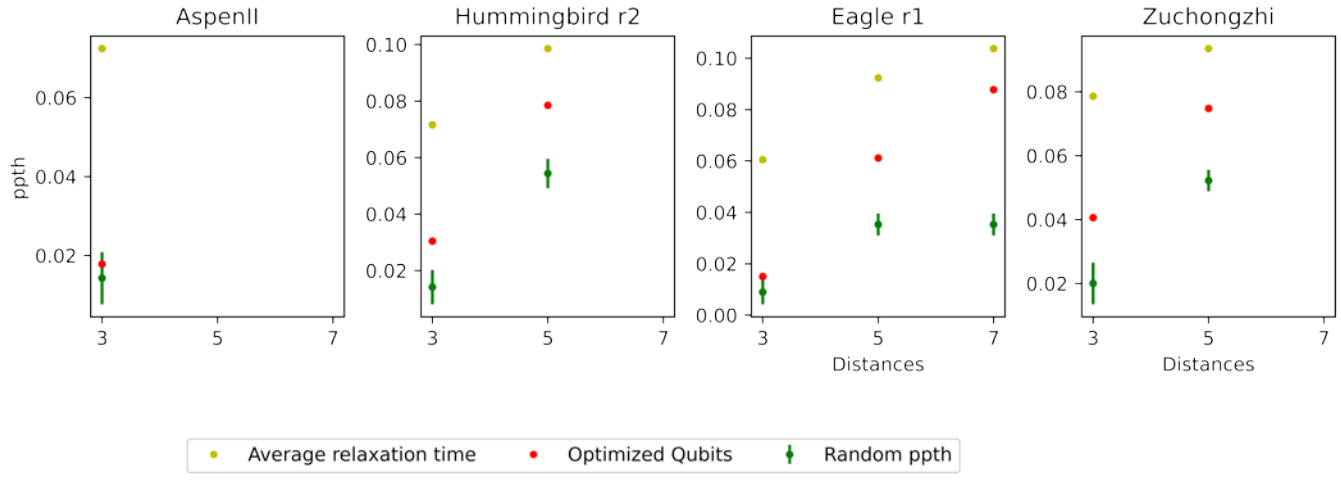


Figure 1: Pseudo-threshold for the random (i.ni.d.), optimized (i.ni.d.) and i.i.d. scenarios for 4 different quantum processors.

Stark tuning of tin-vacancy centers in diamond

Lorenzo De Santis[1,2]
Matthew Trusheim[1,3], Kevin Chen[1], Dirk Englund[1]

[1]*Massachusetts Institute of Technology, Cambridge, USA*
[2]*QuTech, Delft University of Technology, Delft, Netherlands*
[3]*CCDC Army Research Laboratory, Adelphi, USA*

ldesanti@mit.edu

Color centers in diamond are among the best performing optically accessible qubits in the solid state. Group IV-vacancy centers in particular can provide highly coherent and stable optical interfaces, a property which is attributed to their inversion symmetry [1]. In this work we investigate the effect of an external electric field on the optical transition of a single tin-vacancy (SnV) center [2].
By measuring small Stark shifts on the emitter, our study reveals a vanishingly small permanent electric dipole as well as a suppressed polarizability of the SnV, more than 4 orders of magnitude lower than for an NV center, demonstrating the inversion symmetry protection of a Group IV-vacancy defect in diamond from charge noise. At the same time, a non-zero shift suggests the Stark effect as a useful mechanism for the fine spectral tuning of the emission wavelength of these defects.
Additionally, we show that by modulating the SnV electric-field-induced dipole we can use the emitter's linewidth as a nanoscale probe for electric noise spectroscopy. The external electrodes enable to controllably tune the emitter's susceptibility to electric field, and we use the increased spectral diffusion effect on the SnV to quantify the local electric field noise at the defect location.

References

[1] C. Bradac et al., Nat. Commun. 10, 1 (2019).
[2] L. De Santis et al., Phys. Rev. Letter 127, 147402 (2021).

Figures

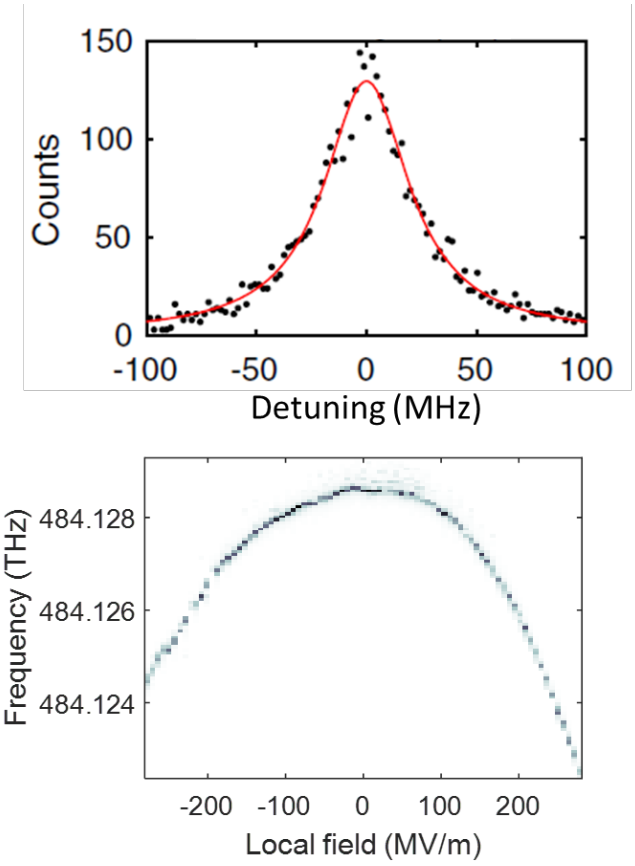


Figure 1: Top panel: PLE spectrum of the SnV center's optical transition analyzed here. Bottom panel: measurement of the SnV transition as a function of the external electric field, showing a nonlinear response.

Disordered quantum systems simulation with Potassium Bose-Einstein Condensate

Maxime DENIS
Farid MADANI, Jean-François CLEMENT, Pascal SZRIFTGISER, Jean-Claude GARREAU, Radu CHICIREANU

Laboratoire de Physique des Lasers, Atomes et Molécules (PHLAM) UMR 8523, University of Lille, 2 Avenue Jean Perrin, Villeneuve d'Ascq, France

Maxime.denis@univ-lille.fr

The kicked rotor is a paradigmatic model for classical and quantum chaos. This model displays a classical diffusive motion, where quantum interference may lead to dynamical localization [1]. This phenomenon has been shown to equivalent to Anderson localization [2] [3], a ubiquitous quantum phenomenon which governs the properties of a large class of insulator materials in condensed matter physics. Since its introduction in 1979, the kicked rotor model aroused wide interest theoretically and experimentally. Recently, theoretical studies have reported new results on periodically kicked Bose gas in the presence of interatomic interactions [4] [5]. A new experimental apparatus creating quantum degenerate gases has been recently built in our group to investigate this new physics.

Experimentally, a Bose Einstein Condensate (BEC) submitted to a periodically pulsed standing wave of light reproduces the kicked rotor model. In a BEC, interaction strength between atoms can be controlled by using Fano-Feshbach resonance. The ^{41}K BEC experiment we have built is able to generate nearly pure ^{41}K BECs of 400k atoms with high repetition rate (~16s). We have recently observed a resonance of 39mG wide at 409,17G in the $^{2}S_{1/2}$ (F=1,^{m_F}=1) state. This resonance allows us to reach several interatomic interaction regimes: repulsive, attractive and non-interacting. The last ingredient needed for the study of our system is the periodically-pulsed optical potential, which I built and characterized during my thesis. The originality of the system lies in the generation of powerful infrared pulses, converted to the near infrared domain using second harmonic generation. We are able to produce pulses at a repetition frequency between 100 kHz to 500 kHz with peak optical power up to 350W. This new laser system will allow us to explore physics of the periodically kicked Bose Einstein Condensate in the presence of tunable interatomic interactions.

References

[1] G. Casati et al, Lecture Notes in Physics, Vol. 93 (1979), p. 334
[2] P. W. Anderson, Phys. Rev, vol.109,no. 5 (1958), p.1492-1505
[3] D. R. Grempel et al, Phys. Rev. A, 29 (1984), 1639–1647
[4] S. Lellouch et al, Phys. Rev. A, 101 (2020) , 043624
[5] V. Vuatelet et al, Phys. Rev. A, 104 (2021), 043302

Quantum thermalization in closed systems through many-body Weak Values

Carlos F. Destefani
Xavier Oriols

Universitat Autònoma de Barcelona, Spain

carlos.destefani@uab.es

The main question addressed in the study of quantum thermalization in closed systems is how an initial non-equilibrium state may thermalize. The limitation due to quantum randomness and backaction, to get empirical dynamic information on the thermalization process, is overcame in our work by using Weak Values [1,2,3] for many-body scenarios in a way accessible from laboratories. We show that quantum systems satisfying the Eigenstate Thermalization Hypothesis [4,5] can simultaneously provide both thermalized ensemble expectation values (Figure 1) and non-thermalized Weak Values (Figure 2). The reason why local-in-position Weak Values of the momentum may escape Eigenstate Thermalization Hypothesis is because they are linked only to off-diagonal matrix elements in energy representation. Our model considers a harmonic trap underneath a random disorder potential typical in fermionic optical lattice experiments, and our calculations are based on the exact time-evolution of a correlated few-body Schrodinger equation of an initial non-equilibrium antisymmetric state. The same disorder model can be adapted to the study of localization, which in general works against thermalization (decoherence), and used to simulate semiconductor systems. We claim that our results provide evidence that memory, in the unitary evolution of a non-equilibrium initial state, is not effectively lost after thermalization, but it requires more sophisticated measurement protocols.

References

[1] Y. Aharonov, D. Z. Albert, L. Vaidman, Phys. Rev. Lett. 60, 1351 (1988).

[2] S. Kocsis, B. Braverman, S. Ravets, M. J. Stevens, R. P. Mirin, L. K. Shalm, A. M. Steinberg, Science 332, 1170 (2011).

[3] D. Pandey, R. Sampaio, T. Ala-Nissila, G. Albareda, X. Oriols, Phys. Rev. A 103, 052219 (2021).

[4] M. Srednicki, Phys. Rev. E 50, 888 (1994).

[5] J. M. Deutsch, Phys. Rev. A 43, 2046 (1991).

Figures

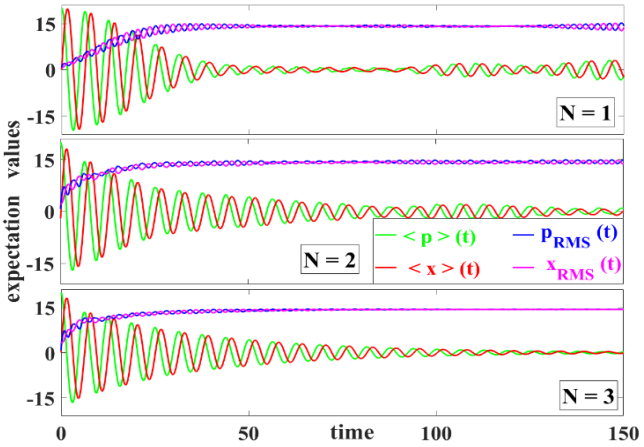


Figure 1: Thermalized expectation values. Time-evolution of position <x>(t) (red) and momentum <p>(t) (green) expectation values, as well as their respective root-mean-squares (magenta, blue) for closed systems with N=1,2,3 particles.

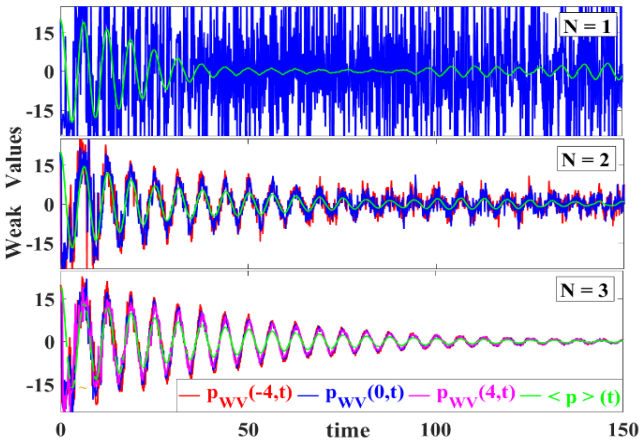


Figure 2: Non-thermalized Weak Values. Time-evolution of the local-in-position Weak Values of the momentum $p_{WV}(x_0,t)$ for closed systems with N=1,2,3 particles, from the same dynamics as in Figure 1. The initial values of x_0 are taken as the centres of the respective initial wave packets.

Quantum approximate optimization algorithm thermal-like states

Pablo Díez Valle
Diego Porras, Juan José García-Ripoll

Instituto de Física Fundamental IFF-CSIC, Calle Serrano 113b, Madrid, Spain

pablo.diez@csic.es

In this talk we present the main results of [1], where we provide analytical and numerical evidence that the single-layer Quantum Approximate Optimization Algorithm (QAOA) on universal Ising spin models creates pure, but thermal-like states with Gaussian perturbations (see Fig.1). These states resemble Boltzmann distributions that cannot be efficiently simulated on classical computers according to state-of-art techniques, and we relate these distributions to the optimization potential of QAOA.

QAOA was originally proposed as a hybrid variational algorithm suitable for solving combinatorial optimization problems on NISQ devices [2]. It has been shown that the shallowest version of the algorithm already engineers a quantum probability distribution that is classically hard to sample [3]. Our work illustrates that the sampling advantage manifests itself in pseudo-Boltzmann states with a temperature lower than can be simulated classically using state-of-art Markov Chain Monte Carlo algorithms (see Fig.2). Moreover, we connect the sampling advantage and the optimization properties, presenting that this low temperature also implies an advantage with respect to optimization. In specific, there is an algebraic (Grover-like) enhancement of the ground state probability.

References

[1] P. Díez-Valle, D. Porras, J.J. García-Ripoll, arxiv: 2201.03358 (2022)

[2] E. Farhi, J. Goldstone, S. Gutmann, arxiv:1411.4028 (2014)

[3] E. Farhi, A. W. Harrow, arxiv:1602:07674 (2019)

Figures

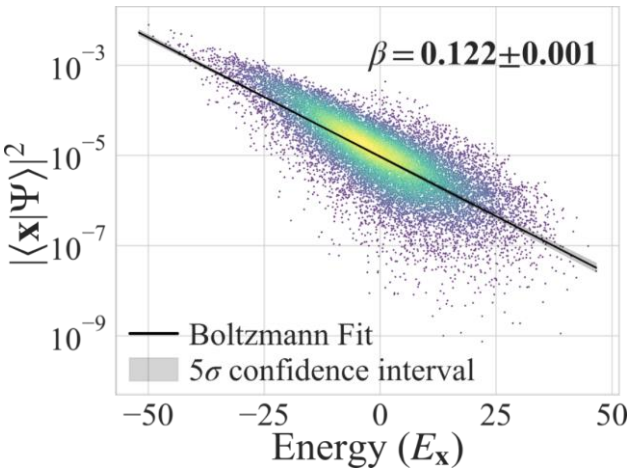


Figure 1: Eigenstate probabilities (dots) and fitted Boltzmann distribution (line) for single-layer QAOA ansatz with optimal angles.

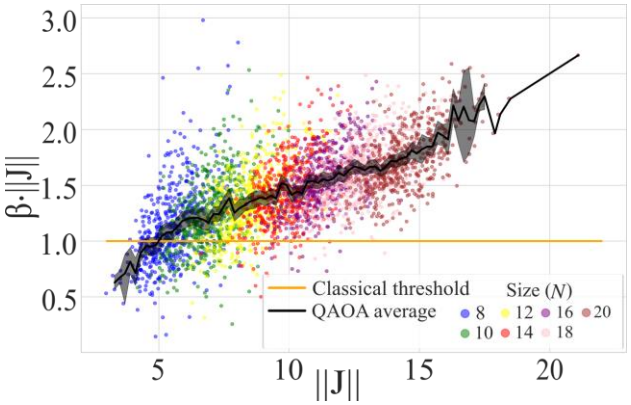


Figure 2: Effective temperatures β after single-layer QAOA with optimal angles, as a function of the interaction matrix J norm for QUBO problems. The dots display the results for 500 instances for each problem size, which grows with the J norm. We show the average of these results (black line) and the threshold given by Monte Carlo methods (orange line) which demonstrates that the distributions obtained with one-layer QAOA are hard to sample classically

Optimal quantum reservoir computing for the NISQ era

L. Domingo [1,2,3]
G. Carlo [2]
F. Borondo [1,2]

[1]*Instituto de Ciencias Matemáticas (ICMAT); Campus de Cantoblanco UAM; Nicolás Cabrera, 13-15; 28049 Madrid (Spain))*
[2]*Departamento de Química; Universidad Autónoma de Madrid; CANTOBLANCO - 28049 Madrid (Spain)*
[3]*Grupo de Sistemas Complejos; Universidad Politécnica de Madrid; 28035 Madrid (Spain)*

laia.domingo@icmat.es

Quantum reservoir computing (QRC) [1] has demonstrated to excel both in classical and quantum machine learning (QML) tasks. It exploits the quantum properties of physical systems and provides an easy training strategy, achieving excellent results. In gate-based quantum computation, QRC consists of a random quantum circuit applied to an initial state, which encodes the input data. The goal of the quantum reservoir is to extract valuable information from the input state, so that the measurements of simple local operators are useful features to predict the output. These features are then fed to a classical machine learning algorithm, typically a linear model. The design of the quantum reservoir determines the performance of the model, and thus selecting optimal quantum reservoirs is of vital importance. The majorization principle has proven to be an indicator of complexity of random quantum circuits [2]. Compared to other complexity criteria, such as the entanglement spectrum, evaluating the majorization in a quantum circuit requires significantly less operations. This makes this criterion suitable for the NISQ era, where quantum computation must be performed with limited quantum resources. In this work, the majorization criterion is used to design the optimal quantum reservoir in terms of performance in QML. The resulting quantum circuits are easily realised in noisy intermediate-scale quantum (NISQ) computers, and present a significant advantage over the commonly used Ising model. The performance of QRC is assessed using different families of quantum circuits, which have different complexity according to the majorization principle. Also, we study the number of gates needed for each family to obtain its optimal performance. In NISQ devices, the number of quantum gates used in a circuit should be as small as possible to avoid error propagation due to large error rates and short coherence times. We prove that the optimal quantum circuits provided in this work require significantly less quantum gates that the Ising model. The optimality of the quantum reservoir is illustrated by solving a quantum chemistry problem.

Figures

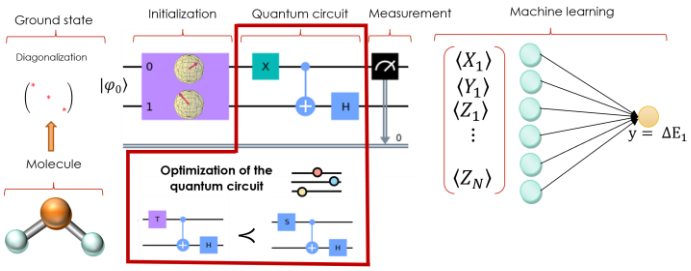


Figure 1: Pipeline used to train the quantum reservoir computing model.

References

[1] S. Ghosh, A. Opala, M. Matuszewski, T. Paterek, and T. C. H. Liew, npj Quantum Information 5, 35 (2019).
[2] R. Vallejos, F. de Melo, and G. Carlo, Phys. Rev. A 104, 012602 (2021).

Entanglement-assisted tests of general relativistic proper time

Victoria Dominguez Tubio[1]
Johannes Borregaard[1,2], Igor Pikovski[3,4]

[1]*QuTech, Department of Applied Physics, University of Delft, Delft, The Netherlands*
[2]*QMATH, Department of Mathematical Sciences, University of Copenhagen, DK-2100 Copenhagen Ø, Denmark*
[3]*The Oskar Klein Centre, Department of Physics, Stockholm University, Stockholm, Sweden*
[4]*Stevens Institute of Technology,Department of Physics, Hoboken, NJ 07030, USA*

V.DominguezTubio@tudelft.nl

The ability to control individual quantum systems at ever larger scales has opened the prospect to probe quantum theory on curved space-time. Here we show how entangled pairs of atoms can be used to probe time-dilation induced entanglement and interference modulation, a recently proposed effect at the interface between gravity and quantum physics[1,3]. Our protocol uses two atomic spin systems entangled over large distances by means of single photon emission and detection. Internal atomic levels implement a non-local quantum clock that evolves under different proper times between distant points in space. The effect is transferred onto photons which then interfere, producing an interference effect between the two different proper time evolutions. This effect can only be explained if both quantum theory and general relativity are taken into account. The proposed protocol based on entangled atoms opens the route for experimental verification even at km-scale separations.

References

[1] Zych, M., Costa, F., Pikovski, I. *et al. Nat Commun* **2,** 505 (2011).

[2] C. Wan, M. Scala, G. W. Morley, A. A. Rahman, H. Ul-bricht, J. Bateman, P. F. Barker, S. Bose, and M. S. Kim, Phys. Rev. Lett. 117, 143003 (2016).

[3] Y. Margalit, Z. Zhou, S. Machluf, D. Rohrlich, Y. Japha, and R. Folman, Science 349, 1205 (2015).

Figures

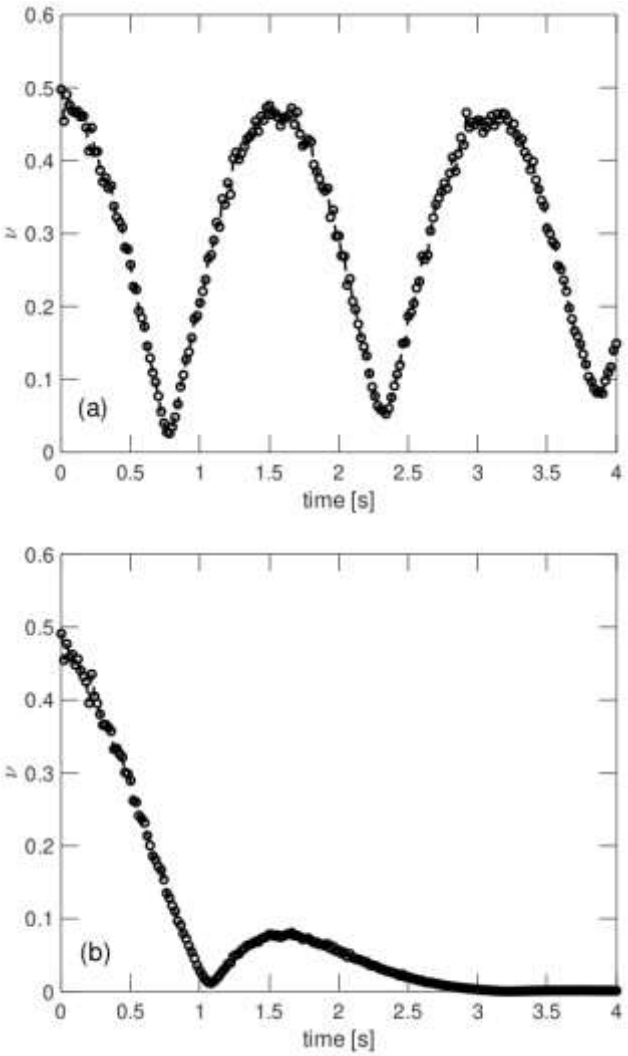


Figure 1: The visibility (v) as a function of the free evolution time for an implementation of the test with Ytterbium atoms (a) and NV-centers (b). The oscillations show the difference in proper time between the two atomic systems. (a) The separation between them in 10m, (b) the separation is 2000km.

Cavity-assisted highly efficient AFC optical memory in $Pr^{3+}:Y_2SiO_5$

Stefano Duranti
Sören Wengerowsky, Alessandro Seri, Bernardo Casabone and Hugues de Riedmatten

ICFO – The Institute for Photonic Sciences, Mediterranean Technology Park, Avinguda Carl Friedrich Gauss, 3, 08860 Castelldefels, Barcelona, Spain

stefano.duranti@icfo.eu

Abstract

In a quantum network, distributing entanglement over large distances is an essential feature in order to establish communication between different points. In this long-range regime, direct transmission is prohibitive due to losses in optical fibers; therefore, quantum repeaters are required to accomplish this task. Many schemes of quantum repeaters rely on the storage of quantum bits into quantum memories. In order for memories to be useful in practical implementations, they must exhibit multimodality, long storage time and a high storage efficiency.
In our experiment, we implemented a cavity-enhanced quantum memory using the atomic frequency comb (AFC) protocol in a $Pr^{3+}:Y_2SiO_5$ crystal [1].
The retrieval efficiency of this protocol is theoretically limited to 54%. It is known that this limit can be overcome by embedding the crystal in an impedance-matched cavity to enhance the interaction with the material [2]. So far, the highest storage efficiency with this protocol was 56% for storage of classical pulses [3] and 27% for quantum storage [4].
With the setup sketched in Figure 1, we reached 62% efficiency for storing weak coherent states with a mean photon number of 0.2 photons/pulse. At the single photon level, this is the highest efficiency achieved so far with a cavity-enhanced quantum memory.
Furthermore, we were able to store weak coherent time-bin qubits with 45% efficiency and analyze them by means of an unbalanced Mach-Zehnder based on a second AFC memory with a storage time equal to the time-bin separation. Currently the performance is limited by the intra-cavity losses and cavity bandwidth, which is dominated by the slow light effect caused by the sharp spectral features we burn inside our crystal.
In future experiments it is planned to increase these efficiencies and to extend the storage time to tens of microseconds.

References

[1] M. Afzelius et al, Phys. Rev. A, 79 (2009) 052329
[2] M. Afzelius, and C. Simon, Phys. Rev. A, 82.2 (2010) 022310
[3] M. Sabooni, et al., Phys. Rev. Lett. 110.13 (2013) 133604
[4] J. H., Davidson et al., Phys. Rev. A, 101(4) (2020) 042333

Figures

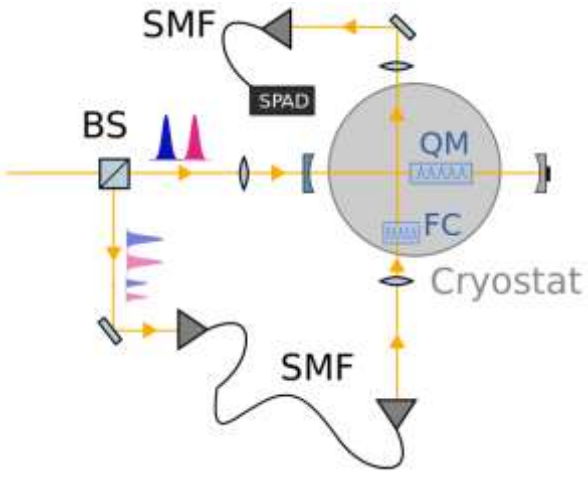


Figure 1: Sketch of our setup. The cavity is built around the cryostat vacuum chamber and has a finesse of 6. Two $Pr^{3+}:Y_2SiO_5$ crystals are sitting inside, cooled down at 3.2K: a memory crystal (QM) and a filter crystal for interfering qubits (FC).

UHV compatible hard-mask technology for superconducting qubits

Michaela Eichinger
Morten Kjaergaard, Charles Marcus

Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5 2100 Copenhagen Ø, Denmark

michaela.eichinger@nbi.ku.dk

The identification of pristine superconducting materials and low loss fabrication techniques is critical for improving superconducting qubit lifetimes and achieving scalable architectures for quantum computing [1].
We present a fabrication technique based on the concept of stencil lithography [2] that decouples mask fabrication from substrate preparation and is compatible with MBE/UHV systems. Josephson Junctions and capacitor pads are created by metal evaporation through an inorganic silicon-membrane mask, hence eliminating organic residues and nanofabrication-related contamination.
The mask is defined using advanced dry etching techniques (CORE [3]) allowing for high flexibility in the desired qubit and cQED design. The masks are reusable, easy to clean and present a scalable method for fully in-situ fabrication of superconducting devices.

References

[1] Devoret, M.H., and R. J. Schoelkopf, Science 339.6124 (2013): 1169-1174
[2] Gray, S., Weimer, PK., RCA Review, RCA Corporation 20 (3) (1959): 413–425
[3] Nguyen, V.T.H., et al. ECS Journal of Solid State Science and Technology 9.2 (2020): 024002

Figures

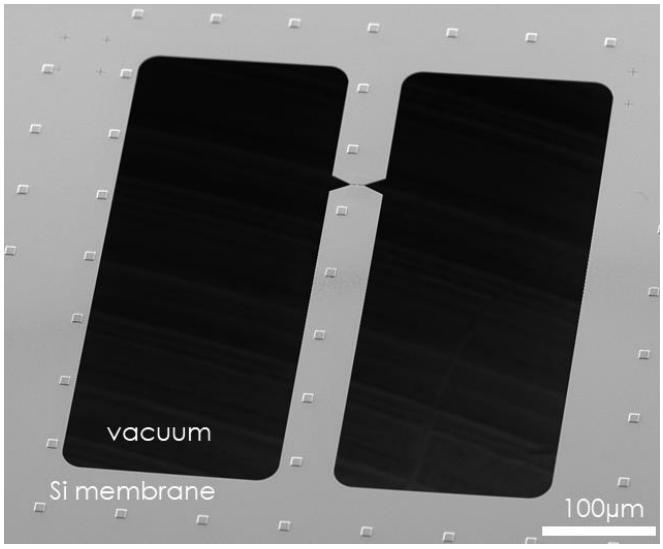


Figure 1: SEM Image of silicon stencil mask with for patterning of capacitor pads and a single Josephson junction

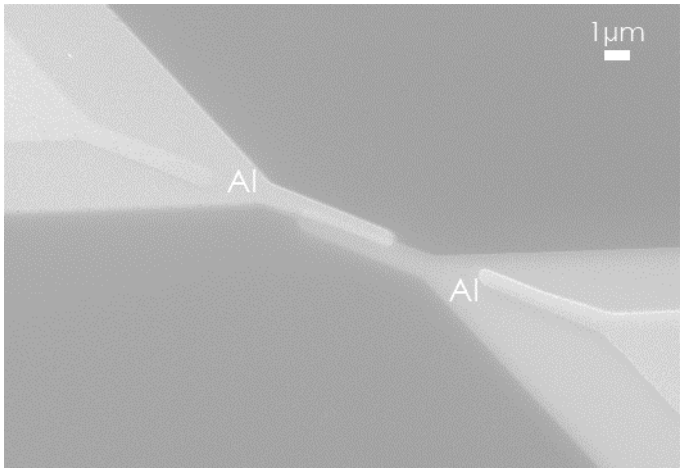


Figure 2: SEM Image of an Al/AlOx/Al junction created by shadow evaporation through a silicon stencil mask

Steered quantum annealing: improving time efficiency with partial information

Ana Palacios de Luis
Artur Garcia-Saez, Marta P. Estarellas

Qilimanjaro Quantum Tech, Passeig de Gràcia 58, 4-2 08007 Barcelona, Spain

ana,palacios@qilimanjaro.tech

Abstract

On the computational model of quantum annealing it is desirable to keep the gap between the ground and first excited states as large as possible during the annealing process, since it allows the computation to remain under the protection of the adiabatic theorem while staying efficient. We propose steered quantum annealing as a new method to enlarge the gap throughout the process, in the case of diagonal final Hamiltonians, based on the exploitation of some assumptions we can make about the particular problem instance. In order to introduce this knowledge, we propose beginning the anneal from a biased Hamiltonian that incorporates reliable assumptions about the final ground state. This is done by taking a locally rotated version of the standard initial Hamiltonian for annealing according to the guessed assignment by an angle Θ, which allows us to control the degree of confidence we have on such assignment. The approach is significantly flexible, since it allows to account for partial information about the solution and the expected quality of this information, as well as the possibility to bias against a certain subsubspace.

References

[1] Tameem Albash and Daniel A. Lidar, Rev. Mod. Phys. 90 (2018) 015002.

Figures

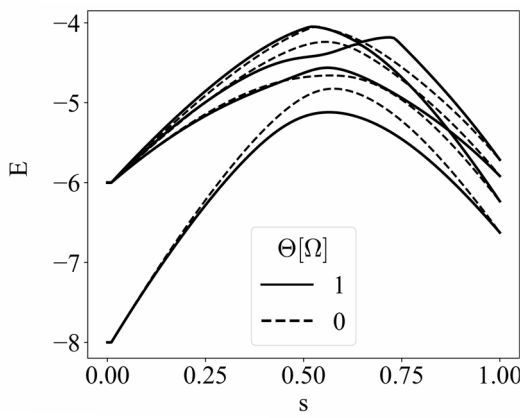


Figure 1: Comparison between spectra along the annealing process for the standard (dashed lines) and steered (solid lines) annealing process for a particular instance of a random Ising model in the spin glassy regime.

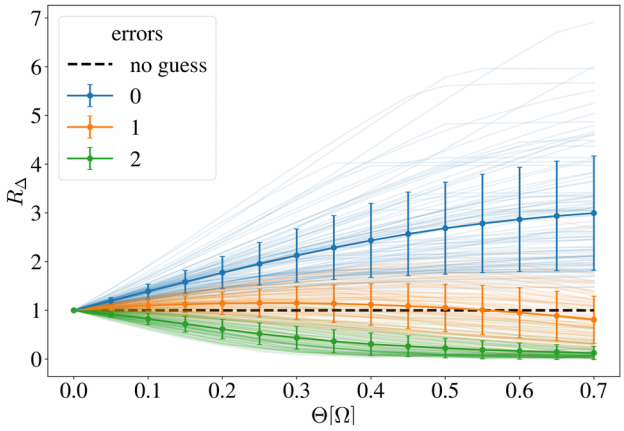


Figure 2: Comparison of the performance of the protocol for different accuracies of the initially provided information with respect to a standard anneal (dashed line). R_Δ is the ratio between the minimum gap of the steered process and that of the standard process, and Θ is normalised between 0 (no confidence on the assignment) and 1 (absolute confidence on the assignment).

Quantum Algorithms for Solving Problems in Orbital Mechanics

Rodrigo Pires Ferreira[1]
André Jorge Carvalho Chaves[1]
Willer Gomes dos Santos[2]

[1]*Group of Semiconductor Materials and Nanotechnology, Aeronautics Institute of Technology, São José dos Campos, SP, Brazil*
[2]*ITA Space Center, Aeronautics Institute of Technology, São José dos Campos, SP, Brazil*

rodrigo.ferreira@ga.ita.br

Orbital Mechanics represents the application of celestial mechanics to spacecraft motion. In this context, complex configurations (e.g., terminal Rendezvous, formation flying, N-body systems) are usually described by differential equations (DEs) [1]. Progress has been achieved in the solution of such problems, with evidence that quantum algorithms provide a substantial speedup over classical numerical methods [2]. Hence, this research focuses on solving DEs via two quantum algorithms - based on the truncated Taylor Series ("TS algorithm") [3] and variational circuits ("VC algorithm") [4], respectively.

We have applied the TS algorithm to the linearized equations of the relative motion (Hill equations) [1]. After solving the DEs analytically, we write the correspondent k-order Taylor Series and encode it into the quantum circuit implemented in Yao Quantum [5]. Our answer's convergence (compared to the exact solution) has been analyzed as a function of the truncated Taylor Series order (k) and the number of qubits in the circuit (Figure 1a).

To solve the nonlinear differential equations of the relative motion, we have used the VC algorithm implemented in Pennylane [6]. Given the initial conditions and hyperparameters (arguments of the quantum gates), the circuit is trained by classical optimizers to provide an output closer to the desired function. We then studied the model's convergence as a function of intrinsic parameters of the variational circuit and the number of qubits. Furthermore, we compare our output to the numerical solution of the problem (Figure 1b). Thus, the present work constitutes a proof of concept for modeling Orbital Mechanics problems with quantum algorithms.

References

[1] Curtis, H. Elsevier, 2009.
[2] Kyriienko, O., et al. Phys Rev. A 103 (2021), 052416.
[3] Xin, T., et al. Phys. Rev. A 101 (2020), 032307.
[4] Killoran, N., et al. Phys. Rev. Research 1 (2019), 033063.
[5] Luo, X., et al. Quantum 4, 341 (2020).
[6] Kwak, Y., et al. ICTC (pp. 416-420), IEEE (2021).

Figures

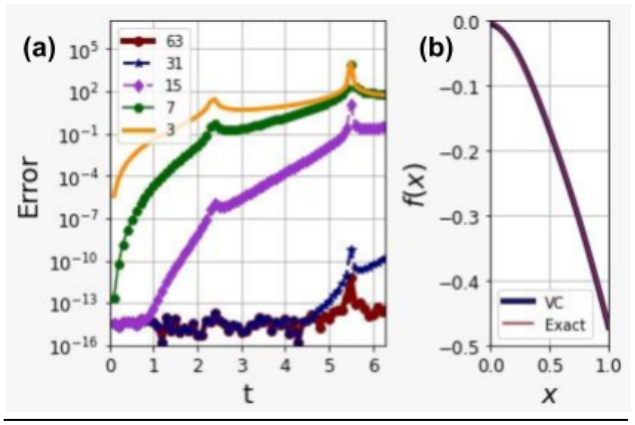


Figure 1: (a) Error as a function of the Taylor Series order (k). (b) Comparing the solutions (VC and exact) of the nonlinear DE.

Quantum non-Gaussian motion of atoms: fundamental test & force sensing

Radim Filip

Palacky University
17. listopadu 1192/12, 77146 Olomouc, Czech
filip@optics@optics.upol.cz

The talk will report recent theoretical and experimental achievements opening the door to highly non-Gaussian quantum mechanics of single atoms. This territory is challenging for investigation, both theoretically and experimentally. We will briefly present recent theoretical and laboratory activities, mainly the experimental tests of the faithful hierarchy of quantum non-Gaussianity beyond limits of optical methods [1,2], for multiphonon states of a single atom and their sensing capabilities [2]. The talk will conclude with other related results and the following challenges in theory and experiments with atoms, mechanical oscillators and superconducting circuits to stimulate discussion and further development of this field.

References

[1] Lukáš Lachman, Ivo Straka, Josef Hloušek, Miroslav Ježek, and Radim Filip, Phys. Rev. Lett. 123, 043601 (2019)
[2] Lukáš Lachman and Radim Filip, Phys. Rev. Lett. 126, 213604 (2021)
[3] Lukáš Podhora, Lukáš Lachman, Tuan Pham, Adam Lešundák, Ondřej Čip, Lukáš Slodička, Radim Filip, Quantum -Gaussianity of multi-phonon states of a single atom, arXiv:2111.10129

Figures

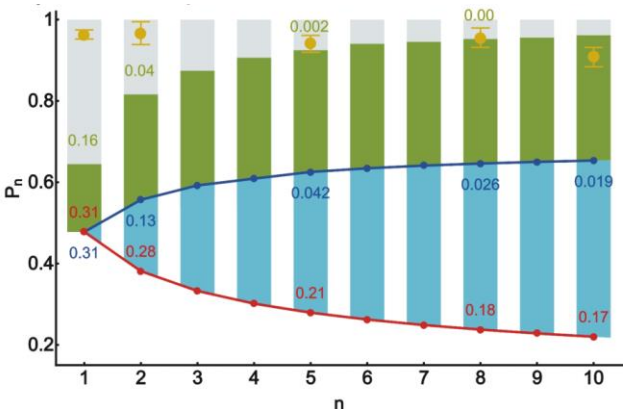


Figure 1: Experimental characterization of the Fock states of mechanical motion. The yellow points represent the measured populations Pn for experimentally generated states. Blue points represent the thresholds for a genuine n-phonon QNG. The associated blue numbers quantify the thermal depth of genuine n-phonon QNG - a maximal mean number of thermal phonons that keeps the measured states above the genuine n-phonon QNG thresholds. Similarly, the red points identify thresholds for observing the essential QNG aspects, and the associated red numbers determine their thermal depth. The green bars depict the force estimation capability of a specific model of noisy Fock states, where the probability P(n) exceeding the presented threshold values certifies a metrological advantage against the previous ideal Fock state in the force estimation. At the same time, the corresponding numbers quantify a thermal depth of this advantage for the measured states.

Benchmarking quantum error correcting codes on near-term devices

Presenting Author: Regina Finsterhölzl
Co-Authors: Guido Burkard

Department of Physics, University of Konstanz, Germany

regina.finsterhoelzl@uni-konstanz.de

Abstract

We evaluate the performance of small error-correcting codes which we implement on hardware platforms of very different connectivity and coherence: On the superconducting IBM Q system One and on a spintronic quantum register consisting of a color center in diamond. Taking the hardware-specific errors and connectivity into account, we investigate the dependence of the resulting logical error rate on the platform features such as the native gates, the native connectivity, gate times and coherence times. Using a standard error model parametrized for the given hardware, we simulate the performance and benchmark these predictions with experimental results when running the code on the IBM quantum device. The results indicate that for very small codes, IBMs hexagonal layout proves advantageous, yet for larger codes the star-like connectivity of the color centers enables lower error rates.

Figures

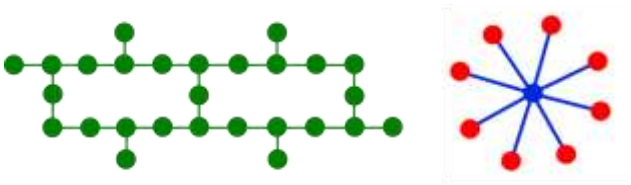


Figure 1: Quantum computing platforms of different connectivity: On the left, the coupling map of IBM Q System One is shown, while the figure on the right sketches the native connections in a spintronic system based on color centers in diamond.

References

[1] K. Georgopoulos, C. Emary, and P. Zuliani, Phys. Rev. A 104, 062432 (2021).
[2] V. O. Shkolnikov, R. Mauch, and G. Burkard, Phys. Rev. B 101, 155306 (2020).
[3] G. Waldherr et al., Nature 506 (2014) 204.
[4] J. Casanova et al., Phys. Rev. A 96, 032314 (2017).

Image distillation through modulation of an undetected beam

Jorge Fuenzalida
Marta Gilaberte Basset
Sebastian Töpfer
Fabian Steinlechner
Juan P. Torres
Markus Gräfe
Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745, Jena, Germany.
Friedrich-Schiller-University Jena, Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745, Jena, Germany.
ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Spain, and Dept. Signal Theory and Communications, Universitat Politecnica de Catalunya, 08034 Barcelona, Spain.)
jorge.fuenzalida@iof.fraunhofer.de

Induced-coherence quantum imaging takes advantage of photon pairs correlations to image an object without detecting the photons that illuminate the object [1]. The object's information is transferred from the photon that illuminates the object to the interference pattern of its partner photon, which is detected. These photon pairs are emitted by spontaneous parametric down-conversion, and are hyper-entangled in many degrees of freedom, including energy and momentum. In this way, the pair can be spectrally separated into the electromagnetic spectrum (non-degenerate case). This fact becomes relevant if we need to image at wavelengths with detection constraints, e.g., mid-infrared, hyperspectral, or terahertz wavelengths.

Quantum imaging also offers the possibility of separating a quantum image from classical noise [2]. The process called distillation is explained as follows. We have two images: a classical image and a quantum image. The classical one is considered noise. When the two images are superimposed on the camera, we can apply a post-selection detection technique to retrieve only the quantum component image.

Finally, a quantum holography technique employing undetected photons has recently been introduced [3]. In this work, we show a new distillation method based on single-photon interference. Therefore, no coincidence measurements are needed. Our method uses the same modulation that uses the quantum holography process to retrieve the object information. We can explain this considering that the statistical fluctuation of the intensity noise is lower than the intensity fluctuation of the modulation of the quantum image. In this way, our technique is resilient to high intensities of noise.

References

[1] G. B. Lemos et al., Nature, 512 (2014) 409–412.
[2] H. Defienne et al., Sci. Adv. 5 (2019) eaax0307.
[3] S. Töpfer et al., Sci. Adv. 8 (2022) eabl4301.

Figures

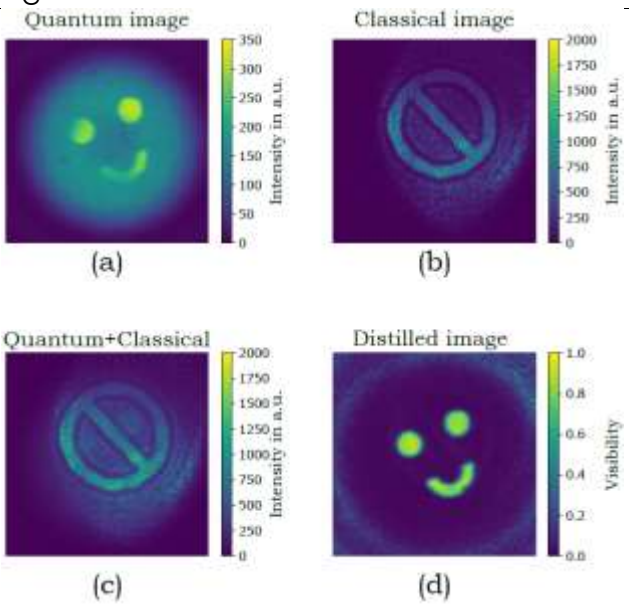


Figure 1: Distillation imaging processing.

Electrical two-qubit gates within a pair of clock-qubit magnetic molecules

Alejandro Gaita-Ariño
Aman Ullah, Ziqi Hu, Jesús Cerdá, Juan Aragó

ICMol, Universitat de València, cat. José Beltrán, 2, Paterna, Spain

gaita@uv.es

Solid-state nanoelectronic devices can now host single-qubit quantum logic operations with high fidelity and have also demonstrated quantum operations employing the spins of an electron bound to a single-donor atom, introduced in the silicon by ion implantation.[1] Molecules, being much more versatile than atoms, and yet microscopic, are claimed to be the quantum objects with the highest capacity to form non-trivial ordered states at the nanoscale, with their potential therefore deserving exploration.[2] Enhanced coherence in qubits based on Ho^{3+} spin states in a HoW_{10} molecule has been demonstrated by use of Clock Transitions (CTs) at T=5K.[3] More recently it was shown that, while operating at the CTs, it was possible to use an electrical field to selectively address HoW_{10} molecules pointing in a given direction, within a crystal that contains two kinds of identical but inversion-related molecules.[4] Herein we theoretically explore the possibility of employing electric field pulses to effect entangling two-qubit quantum gates among two neighbouring CT-protected HoW_{10} molecular spin qubits within a diluted crystal. We also estimate the thermal evolution of T_1, T_2 in this system, and find that CTs are also optimal operating points from the point of view of phonons, and that even a moderate cooling to T=2 K would significantly increase coherence times in the order of 100 µs. We find that, provided challenging initialization requirements are met, it will be possible to combine a sequence of microwave and electric field pulses to achieve coherent control within a 2-qubit operating space that is protected both from spin-bath and from phonon-bath decoherence. Finally, we found a highly protected 1-qubit subspace resulting from the interaction between two clock molecular qubits.

References

[1] Mądzik, M.T., Laucht, A., Hudson, F.E. Nat Commun 12 (2021) 181
[2] Gaita-Ariño, A., Luis, F., Hill, S., Coronado, E., Nat. Chem. 11 (2019) 301–309.
[3] Shiddiq, M. Komijani, D., Duan, Y., Gaita-Ariño, A., Coronado, E., Hill, S.. Nature 531 (2016) 348–351 .
[4] Liu, J., Mrozek, J., Ullah, A., Duan, Y., Baldoví, J. J., Coronado, E., Gaita-Ariño, A., Ardavan, A. Nat. Phys. 17 (2021) 1205–1209.

Figures

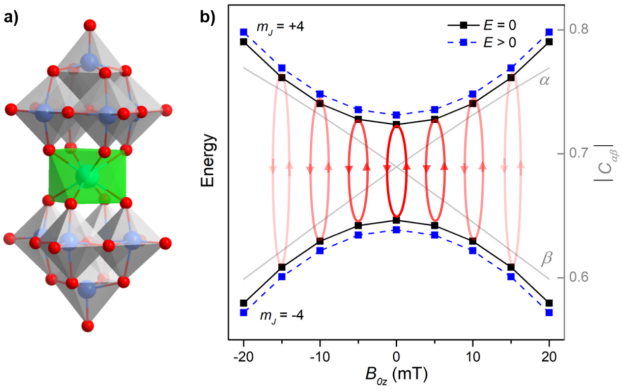


Figure 1: {a) Molecular structure of HoW_{10} b) Spin energy levels evolution (black and blue lines) and admixing of wavefunction for m_J=±4 with corresponding coefficients (gray lines) upon magnetic field. An external electric field E field affects the anticrossing, thereby regulating the qubit transition energy.

Manipulation of Spin Transport in Graphene/Transition Metal Dichalcogenide Heterobilayers upon Twisting

Jose H. Garcia
A. Pezo[1,2], Z. Zanolli[3,2], N. Wittemeier[2], P. Ordejón[2], A. Fazzio[1,4], S. Roche[2,5] and Jose H. Garcia[2]
[1]Center of Natural and Human Sciences, Federal University of ABC, Brazil. [2]Catalan Institute of Nanoscience and Nanotechnology (ICN2), Spain. [3]Dept. of Chemistry, Debye Institute for Nanomaterials Science, Utrecht University, The Netherlands. [4]Brazilian Nanotechnology National Laboratory/CNPEM, Brazil. [5]Institució Catalana de Recerca i Estudis Avançats (ICREA), Spain
josehugo.garcia@icn2.cat

Proximity effects between layered materials trigger a plethora of novel and exotic quantum transport phenomena. Besides, the capability to modulate the nature and strength of proximity effects by changing crystalline and interfacial symmetries offers a vast playground to optimize physical properties of relevance for innovative applications. In this work, we use large-scale first principles calculations to demonstrate that strain and twist-angle strongly vary the spin–orbit coupling (SOC) in graphene/transition metal dichalcogenide heterobilayers. Such a change results in a modulation of the spin relaxation times by up to two orders of magnitude. Additionally, the relative strengths of valley-Zeeman and Rashba SOC can be tailored upon twisting, which can turn the system into an ideal Dirac–Rashba regime or generate transitions between topological states of matter. These results shed new light on the debated variability of SOC and clarify how lattice deformations can be used as a knob to control spin transport. Our outcomes also suggest complex spin transport in polycrystalline materials, due to the random variation of grain orientation, which could reflect in large spatial fluctuations of SOC fields.

References

[1] Armando Pezo et al, 2D Materials, **9,** 015008M (2022)

Figures

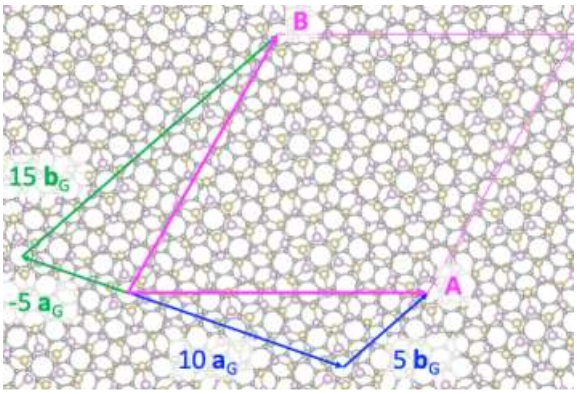


Figure 1: The Moiré periodic cell of graphene-on-$MoTe_2$, twisted by 30.00°. We use linear combinations of the primitive lattice vectors of graphene $\mathbf{a}_G$, $\mathbf{b}_G$ to write the moiré lattice vectors $\mathbf{A} = 10\mathbf{a}_G + 5\mathbf{b}_G$, $\mathbf{B} = -5\mathbf{a}_G + 15\mathbf{b}_G$

Spatial control of Andreev bound states using superconducting phase texture

Max Geier[1]
Abhishek Banerjee[1], Md Ahnaf Rahman[1], Daniel Steve Sanchez[1], Candice Thomas[2], Tian Wang[2], Michael J. Manfra[2,3], Karsten Flensberg[1], Charles Marcus[1]

[1] *Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5, 2100 Copenhagen, Denmark*

[2] *Department of Physics and Astronomy, and Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana 47907 USA*

[3] *School of Materials Engineering, and School of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana 47907 USA*

geier@nbi.ku.dk

We study planar Josephson junctions fabricated on InAs/Al heterostructure stacks, see Fig. 1 for a device micrograph. The Josephson junction is connected to a superconducting loop and is probed by tunnelling spectroscopy on both ends. When a perpendicular magnetic field is applied to the device, local and non-local differential conductance spectroscopy indicates phase-asymmetric local Andreev bound states which opposite asymmetry on both ends, see Fig. 1b and c. We interpret these results as signatures of Andreev bound states localized at a local superconducting phase difference of π, whose position and localization length is tuned by superconducting phase texture imposed by the magnetic flux through the loop and junction area, respectively. These features are captured by numerical simulations. Fig. 2 illustrates the magnetic field-controlled Andreev bound state movement from the calculated local density of states of the lowest-energy Andreev bound state.

Figures

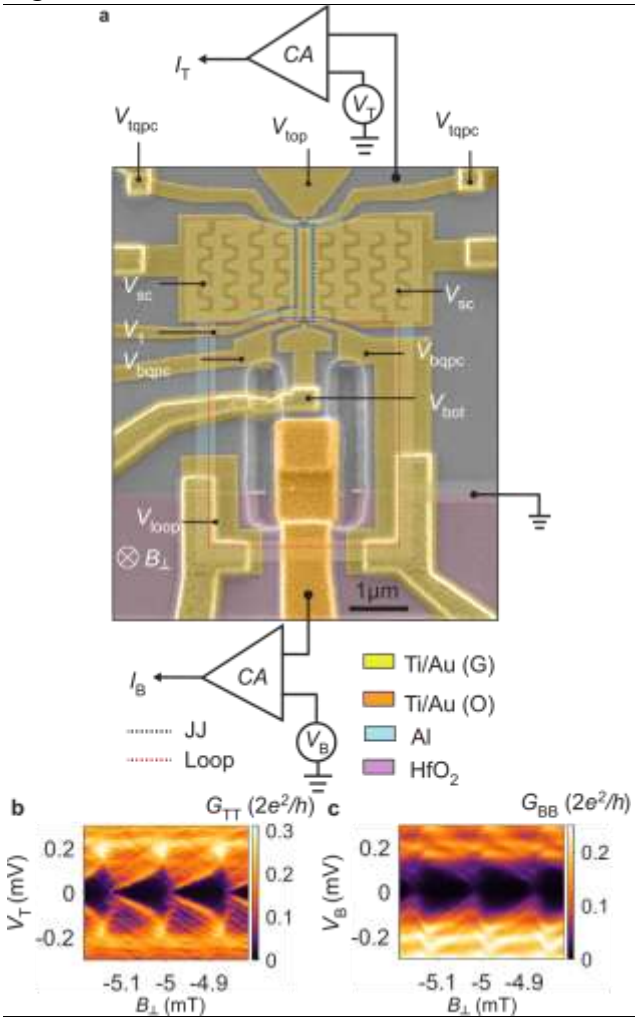


Figure 1: (a) False-colored scanning electron micrograph of a planar Josephson junction device measured in a three-terminal configuration. (b), (c) Local differential conductance spectroscopy at the top and bottom end of the Josephson junction, respectively.

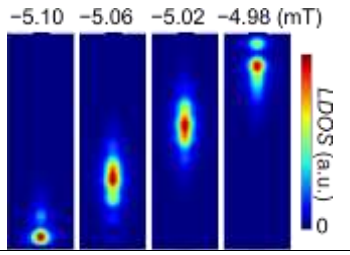


Figure 2: Calculated local density of states of the lowest-energy Andreev bound state in the junction for different values of the perpendicular magnetic field.

Interaction of a single photon with a single quantum system in ambient conditions

Maria Gieysztor[1], M. Misiaszek[1], A. Anarthe[1], K. Joarder[1], D. Chan[1,2], E. Conca[3], A. Tossi[3], F. Jelezko[4], and P. Kolenderski[1]

[1]*Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Torun, Poland*
[2]*Department of Physics and Astronomy, University of Waterloo, Waterloo, Canada*
[3]*Politecnico di Milano, Dipartimento di Elettronica, Informazione a Bioingegneria, Milano, Italy*
[4]*Institute for Quantum Optics, University of Ulm, Ulm, Germany*

margie@doktorant.umk.pl

In our work a simple, room temperature, cavity- and vacuum-free interface for photon-matter interaction is implemented. Here we report an ambient-conditions experiment in which a heralded single photon is absorbed by a single atom-like system, which is an NV center in diamond. The experimental setup is shown in Fig. 1. The NV center is pumped with a 532 nm quantum light and subsequently the fluorescence signal, registered on a single photon detector, is compared with the idler photon detection signal and fluorescence decay is collected (Fig. 2). This scheme shows a simple platform for investigating light-matter interaction with a good control on both, the number of atom-like systems and the number of photons. More control over the optical illumination can provide additional information about the interrogated sample. This can be envisioned when considering an ensemble of absorbers located at distances below the diffraction limit. After laser excitation the number of emitted photons can enable to indirectly determine the number of absorbers. However, typical single photon detectors are not photon-number-resolved, which makes this task more difficult. Illumination with a photon number state, which is well defined, could help to overcome some of these limitations.

References

[1] A. Divochiy, M. Misiaszek, Y. Vakhtomin, P. Morozov, K. Smirnov, P. Zolotov, and P. Kolenderski, Opt. Lett. 43, 6085 (2018).

[2] M. Gieysztor, M. Misiaszek, J. van der Veen, W. Gawlik, F. Jelezko, and P. Kolenderski, Optics Express, 29, 564 (2021)

Figures

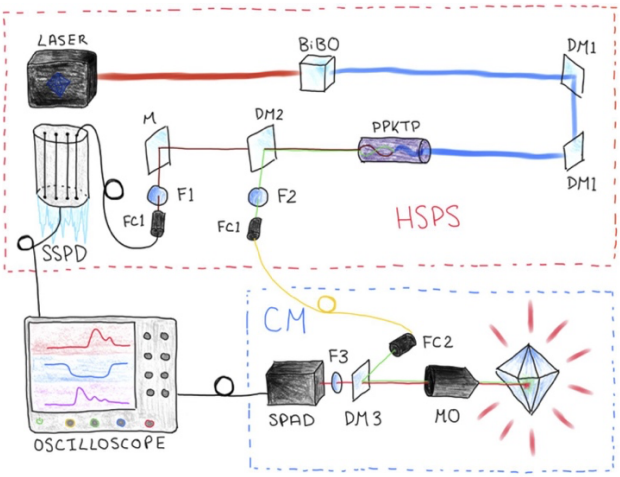


Figure 1: Experimental setup

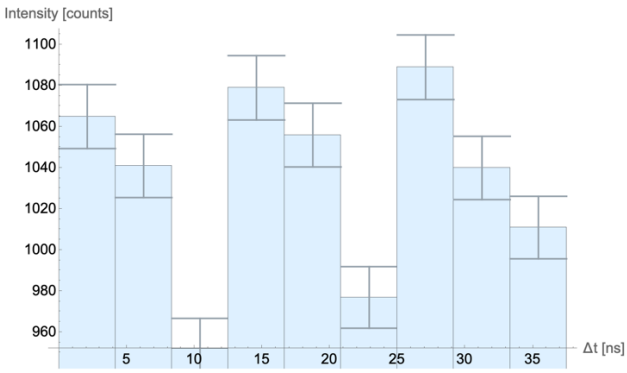


Figure 2: Fluorescence decay histogram for a single photon interacting with a single NV centre.

Machine Learning Schrödinger Equation

Joan Gómez Micó[1,*]
Arnau Rios Huguet[1]

[1] *Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona, Martí Franqués 1, E08028 Barcelona, Spain*

[*] joan.gomez.mico@ub.edu

The main objective of this work is, using the framework given by the Machine Learning methods, to solve the Schrödinger equation that governs the wavefunction of a system for different potentials in order to obtain the ground state of the system.
The problem is solved using variational methods with an Artificial Neural Network (ANN). An ANN with simple architecture is created and used as an ansatz of the ground state wavefunction. By training the ANN and minimizing its energy we will obtain an upper bond of the ground state energy of the system.
Different methods have been used in order to compute the energy integrals and compare their results. We have focused in Monte Carlo (MC) methods for integrating due to its benefits in terms of computational cost when moving from 1D to 3D and Markov Chain Monte Carlo (MCMC) methods to distribute points according to a probability distribution from which direct sampling is difficult.

Figures

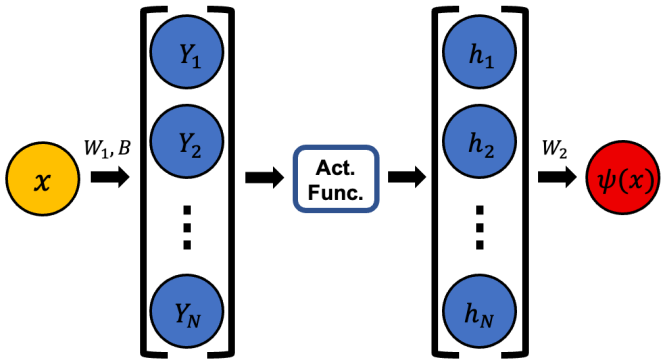


Figure 1: Architecture of the Artificial Neural Network. W_1, W_2 and B are the matrices that connect the input (in yellow), the hidden layer (in blue) and the output (in red).

References

[1] J. W. T. Keeble and A. Rios, Phys. Lett. B, 809 (2020)
[2] F. Becca and S. Sorella, Cambridge University Press, (2017) pp. 131-155
[3] K. P. Murphy, MIT Press, (2022) pp. 441-490

Quantum nonlinear optics based on 2D Rydberg atom arrays

Daniel Goncalves Romeu
Mariona Moreno-Cardoner, Darrick E. Chang.

ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

Daniel.goncalves@icfo.es

In this project [1], we explore the combination of sub-wavelength, two-dimensional atomic arrays, and Rydberg physics as a powerful platform to realize strong, coherent interactions between individual photons with high fidelity.

In particular, the spatial ordering of the atoms guarantees efficient atom-light interactions without the possibility of scattering light into unwanted directions, for example, allowing the array to act as a perfect mirror for individual photons (Fig. 1a). In turn, Rydberg interactions enable single photons to alter the optical response of the array within a potentially large blockade radius R_b, which can effectively punch a large "hole" for subsequent photons (Fig. 1b). Such a system enables a coherent photon-photon gate or switch, with an error scaling that is significantly better than the best-known scaling in a disordered ensemble (Fig. 1c, d).

References

[1] D. Goncalves, M. Moreno-Cardoner, and D. E. Chang, **Phys. Rev. Lett. 127**, 263602 (2021).

Figures

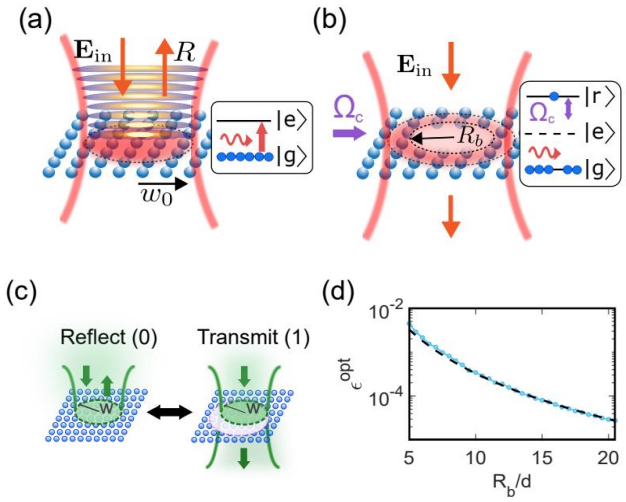


Figure 1: Illustration of a sub-wavelength 2D array of two-level atoms ($|g\rangle$,$|e_i\rangle$) reflecting a resonant input gaussian beam with beam waist w_0. (b) Next, we consider a Rydberg state $|r_i\rangle$ coupled to the $|e_i\rangle$ levels by means of a control field Ω_c. Storing a Rydberg excitation results in an energy shift that breaks the mirror resonance condition within the blockaded region of radius R_b. (c) Combining the phenomena from (a-b) we build a single-photon switch, where the transmission/reflection of a signal photon is conditioned to the storage/retrieval of a gate photon. (d) Switch error ϵ^{opt} (photon loss) as a function of R_b after optimizing the system's parameters. The scaling ($\epsilon^{opt} \sim R_b^{-4}$) and the predicted performance outperforms any current ensemble-based protocols.

Entanglement between a telecom photon and an on-demand, solid-state, multimode quantum memory

Samuele Grandi

Jelena V. Rakonjac, Dario Lago-Rivera, Alessandro Seri, Margherita Mazzera, Hugues de Riedmatten

ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

samuele.grandi@icfo.eu

Entanglement between telecom photons and quantum memories is a crucial resource towards long-distance quantum communication [1]. To this end, we are developing a system which combines a solid-state quantum memory with a source of photon pairs [2]. The memory is based on a praseodymium (Pr) doped crystal where quantum information can be stored in the ions as a collective optical excitation using the Atomic Frequency Comb (AFC) protocol. On-demand retrieval of the information is realised by transferring the excitation to a long-lived spin state. Entangled pairs of single photons are generated by parametric down conversion in a periodically poled crystal placed inside an optical cavity. This allows us to generate narrow band photons pairs, where the signal is spectrally matched to the memory for storage, while the idler is in the telecom band to allow for higher optical transmission through fibre.

We here demonstrate energy-time entanglement between the telecom idler photon and the signal photon stored as a spin-wave excitation [3]. The entanglement analysis is performed using time-bin qubit analysers made of a fibre-based Mach-Zehnder interferometer for the idler photon, and a solid-state equivalent based on AFCs with different storage times for the signal photon. We have measured entanglement between the telecom photon and the excitation in an optically excited state for 10 µs, with a fidelity high enough to violate a Bell inequality. We then moved to storage in the spin-state of the Pr ions (Fig 1), where we calculate a two-qubit conditional fidelity of 77(2)%. Taking advantage of the on-demand retrieval from the spin state we extended the total storage to up to 50 µs. Our system then features multimode operation, with an advantage of a factor of 17 over a single mode equivalent, and telecom compatibility, which could allow the ilder photon to be distributed in the commercial telecom network.

References

[1] Duan, L.-M. et al. Nature 414, 413-418 (2001)

[2] Simon, C. et al. Phys. Rev. Lett. 98, 190503 (2007).

[3] Rakonjac, J. V. et al. Phys. Rev. Lett. 127, 210502 (2021)

Figures

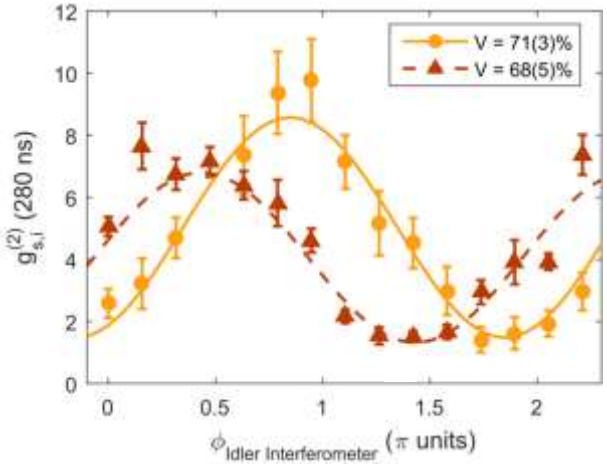


Figure 1: interference fringes for storage of energy time-entanglement in the spin wave of the quantum memory, measured through the second-order cross-correlation function of the idler and the retrieved signal photon.

Renormalization group analysis of near-field induced dephasing of optical spin waves in an atomic medium

Stefano Grava[1]
Yizun He[2], Saijun Wu[2] and Darrick E. Chang[1]

Organization, Address, City, Country (Century Gothic 10)

Stefano.grava@icfo.eu

[1]*ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Castelldefels (Barcelona) 08860, Spain*

[2]*Department of Physics, State Key Laboratory of Surface Physics and Key Laboratory of Micro and Nano Photonic Structures (Ministry of Education), Fudan University, Shanghai 200433, People's Republic of China*

Abstract

While typical theories of atom–light interactions treat the atomic medium as being smooth, it is well-known that microscopic optical effects driven by atomic granularity, dipole–dipole interactions, and multiple scattering can lead to important effects. Recently, for example, it was experimentally observed that these ingredients can lead to a fundamental, density-dependent dephasing of optical spin waves in a disordered atomic medium [1]. Here, we go beyond the short-time and dilute limits considered previously, to develop a comprehensive theory of dephasing dynamics for arbitrary times and atomic densities [2]. In particular, we make use of a novel, non-perturbative theory based on strong disorder renormalization group (RG) [3], in order to quantitatively predict the dominant role that near-field optical interactions between nearby neighbours has in driving the dephasing process. This theory also enables one to capture the key features of the many-atom dephasing dynamics in terms of an effective single-atom model. These results should shed light on the limits imposed by near-field interactions on quantum optical phenomena in dense atomic media as well as on quantum technological applications, and illustrate the promise of strong disorder RG as a method of dealing with complex microscopic optical phenomena in such systems.

References

[1] Y. He et al. (2021) arXiv:2101.10779v1
[2] S. Grava et al. (2022) *New J. Phys.* **24** 013031
[3] F. Andreoli et al. (2021) Phys. Rev. X **11** 11026

Characterization and analysis of a symmetry-breaking THz chiral metamaterial

Lorenzo Graziotto
Johan Andberger, Mattias Beck, Giacomo Scalari, and Jèrôme Faist

Institute for Quantum Electronics, ETH Zürich, Auguste-Piccard-Hof 1, 8093 Zürich, Switzerland

lgraziotto@phys.ethz.ch

Ultra-strong coupling (USC) between the cyclotron resonance of a 2D electron gas in a static perpendicular magnetic field and a cavity able to sustain chiral electromagnetic modes provides a way to break time-reversal symmetry, that is polaritonic states with opposite circular polarizations arise.
To investigate polaritons dressed by the electromagnetic vacuum in the cavity, highly subwavelength interacting volumes along with strongly polarizable materials must be employed, and to this purpose an antenna-based metamaterial coupled to electrons confined in quantum wells (QWs) in a GaAs / AlGaAs heterostructure is engineered and characterized by means of THz time-domain spectroscopy.
Classical circuit theory provides an understanding of the coupling mechanism and its limitations by cavity and material losses in an intuitive way, and may give insights on how to adapt the exact Hamiltonian approach to planar cavities.

References

[1] Li, X., Bamba, M. et al., *Nature Photonics* **2018**, 12, 324-329
[2] Maissen, C. M. et al., *Phys. Rev. B* **2014**, 90, 205309
[3] Ihn, T., *Semiconductor Nanostructures*, OUP Oxford, **2009**
[4] Hagenmüller, D., De Liberato, S., and Ciuti, C., *Phys. Rev. B* **2010**, 235303

Figures

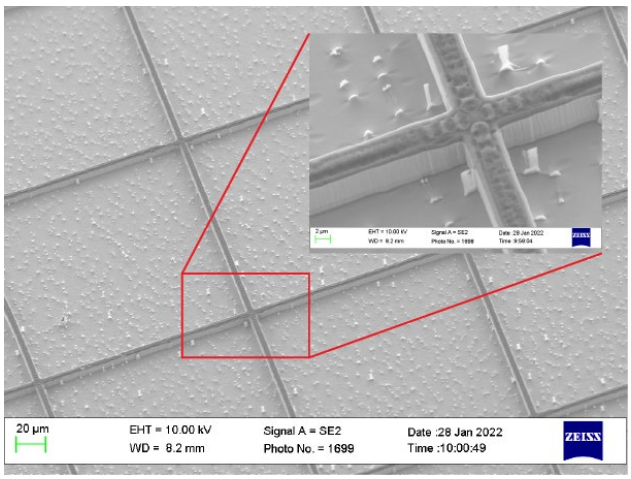


Figure 1: SEM image of the chiral metamaterial. Inset: zoom in to the antenna gap, where the field interacts with the 2DEG.

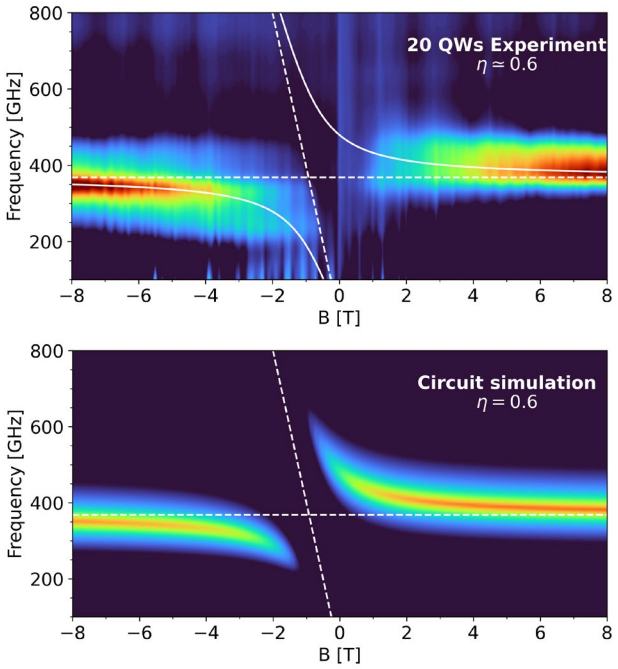


Figure 2: (top) Logarithm of transmission from metamaterial sample with 20 quantum wells, as a function of magnetic field and frequency of the excitation. (bottom) Simulation via circuital approach. The dashed lines are the cavity frequency (horizontal) and cyclotron resonance (diagonal). The estimated normalized coupling is 0.6.

A microwave photomultiplier based on inelastic Cooper pair

Joël Griesmar
Romain Albert, Florian Blanchet, Ataellah Youcef Bioud, Ulrich Martel, Max Hofheinz

Institut Quantique, Université de Sherbrooke, Sherbrooke, Québec J1K 2R1, Canada

joel.griesmar@polytechnique.edu

The detection of single photons is a fundamental quantum measurement, complementary to linear amplification. However, in the microwave domain this is a difficult task due to the low energy of the photons. We present here a photo-multiplier using the energy of a Cooper pair tunneling across a voltage-biased Josephson junction to convert one microwave photon into several photons at a different frequency. This process relies on the strong non-linearity provided by the interaction between a Josephson junction and its high-impedance electromagnetic environment. We have fabricated and measured a device composed of a low critical current SQUID galvanically coupled to two high-impedance resonators visible in Figure 1. It showed almost perfect conversion from one to one and two photons as well as a threefold multiplication with 0.75 efficiency in a 125 MHz bandwidth as shown in Figure 2. By cascading two of these multiplication stages and adding a quantum limited amplifier, it should be possible to discriminate itinerant single photon states from vacuum without dead time [1].

References

[1] J. Leppäkangas, M. Marthaler, D. Hazra, S. Jebari, R. Albert, F. Blanchet, G. Johansson, M. Hofheinz, Physical Review A, 97 (2018) 013855

Figures

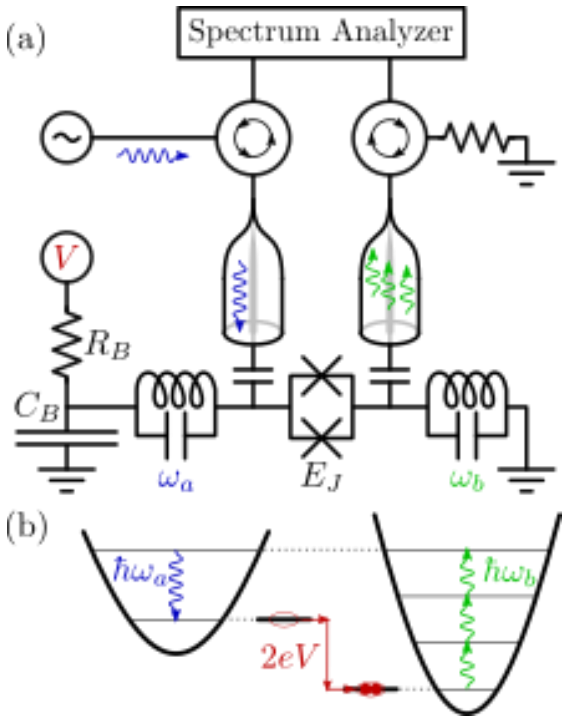


Figure 1: Microwave photon-number amplification. (a) Simplified electrical schematic. The sample consists of two buffer resonators at frequencies ω_a and ω_b. They are non-linearly coupled by a SQUID biased at a voltage V via a heavily filtered bias line. Blue input photons are sent on the left-hand microwave transmission line. They are transformed into green photons in the output line. (b) Voltage V is set such that $2eV+\hbar\omega_a = 3\omega_b$.

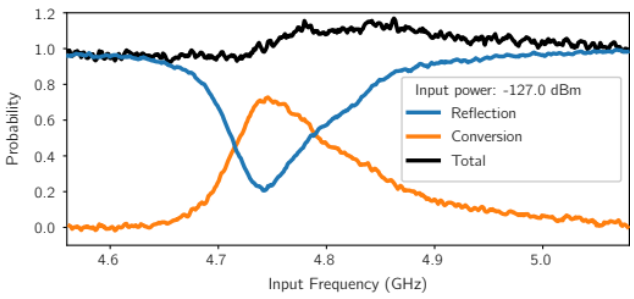


Figure 2: Measured reflection and conversion probabilities as a function of the frequency of the input photons for the 1 to 3 conversion.

Generating entangled Single-photon pairs with Rb atoms

Fenglei Gu

Lorentzweg 1, 2628 CJ Delft, The Netherlands

f.gu@tudelft.nl

Abstract:
Entangled single-photon pairs (ESPP) are essential for quantum communication. The current widely used ESPP source is the spontaneous parameter down-conversion (SPDC) source[1]. However, there is a trade-off between the emitting rate and the single-photon purity in this type of ESPP source which limits its performance for quantum communication. Here we proposed a new type of ESPP source based on a single Rubidium (Rb) atom [2, 3] strongly coupled to nanocavities which would circumvent this dilemma. By making the Rb atom emit both a telecom photon and an optical photon at the same time (Fig. 1), we devise an ESPP source with qubits encoded in time-bins. Moreover, the telecom photon is suited for low-loss propagation in optical fibers while the optical photon is directly compatible with Tm-doped-crystal quantum memories [4] (Fig. 2). Thus, no additional frequency conversion is needed. Through numerical simulations, this atomic ESPP source shows a photon purity of 96% while maintaining a tunable repetition rate up to 5MHz for realistic experimental parameters. We believe that his novel type of ESPP source is within experimental reach in the near term and that it can significantly boost the performance of quantum repeaters based on Tm-doped multi-mode memories.

References

[1] Magnitskiy, S., et al. "A SPDC-based source of entangled photons and its characterization." Journal of Russian Laser Research 36.6 (2015): 618-629.
[2] Mücke, Martin, et al. "Generation of single photons from an atom-cavity system." Physical Review A 87.6 (2013): 063805.
[3] Darquié, Benoit, et al. "Controlled single-photon emission from a single trapped two-level atom." Science 309.5733 (2005): 454-456.
[4] Askarani, Mohsen Falamarzi, et al. "Long-Lived Solid-State Optical Memory for High-Rate Quantum Repeaters." Physical review letters 127.22 (2021): 220502.

Figures

Figure 1: The optical-trapped cold Rb atom (solid red dot) that is designed to emit two entangled photons. Thus, it is coupled to two nanophotonic cavities of different resonance frequencies.

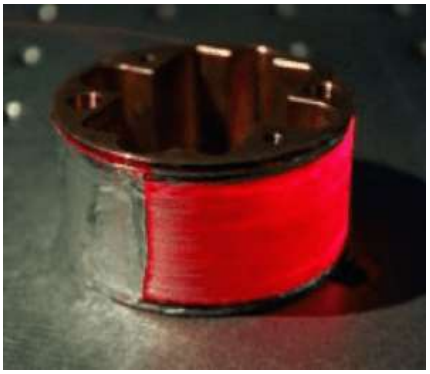


Figure 2: An experimental sample of thulium-doped yttrium gallium garnet (Tm: YGG)which could serve as a photon memory. (The picture is adapted from: https://qutech.nl/lab/tittel-lab/tittel-lab-research-overview/quantum-memory/)

Filter Functions for Quantum Processes under Correlated Noise

Tobias Hangleiter
Pascal Cerfontaine
Hendrik Bluhm

JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

tobias.hangleiter@rwth-aachen.de

While the quantum operations formalism provides a natural framework for describing the concatenation of quantum processes, it is of limited use when describing the effect of non-Markovian noise. In my talk I will address this issue with an extension of the filter-function formalism, which so far has mostly been used to model gate fidelities and the effects of dynamical decoupling sequences. Our extension allows the efficient, perturbative calculation of full quantum processes in the presence of correlated noise, e.g., the 1/*f*-like noise found in many solid-state qubit systems [1, 2]. I will then show that a simple composition rule arises for the filter functions of gate sequences. This enables the investigation of quantum algorithms in the presence of correlated noise with moderate computational resources. Moreover, it allows for singling out correlation terms between different gates in a sequence, capturing for instance the dynamical error suppression of spin echos (Figure 1). Lastly, I present a fast and easy-to-use open-source software framework [3] which facilitates the calculation of quantum processes and fidelities for arbitrary system dimensions using filter functions. Other features include the efficient concatenation of several operations, an optimized treatment of periodic Hamiltonians, as well as integration with qopt, a software package for quantum robust control [4, 5].

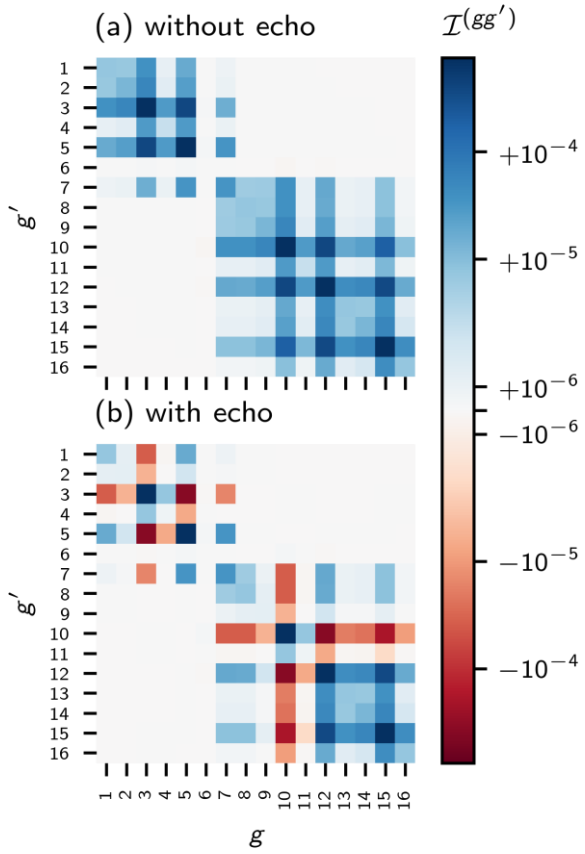


Figure 1: 'Pulse correlation infidelities' between pairs of gates executed at positions *g* and *g'* in a four-qubit Quantum Fourier Transform circuit for 1/*f* noise, once without (a) and with (b) interleaved echo pulses. The echos' effect manifests itself in negative correlation infidelity contributions, leading to a reduced overall infidelity.

References

[1] Cerfontaine, P., Hangleiter, T. & Bluhm, H., Phys. Rev. Lett., **127** (2021) 170403
[2] Hangleiter, T., Cerfontaine, P. & Bluhm, H., Phys. Rev. Research., **3** (2021) 043047
[3] github.com/qutech/filter_functions
[4] Le, I. N. M., Teske, J. D., Hangleiter, T., Cerfontaine, P. & Bluhm, H., Phys. Rev. Applied., **17** (2022) 024006
[5] Teske, J. D., Cerfontaine, P. & Bluhm, H., (2021) arXiv:2110.05873

Towards Non-Linear Interaction of Rydberg Atoms with Quantum States of Light

Lukas Heller
Jan Lowinski, Auxiliadora Padrón-Brito, Klara Theophilo, Hugues de Riedmatten

ICFO – The Institute for Photonic Sciences, Mediterranean Technology Park, Avinguda Carl Friedrich Gauss, 3, 08860 Castelldefels, Barcelona, Spain

lukas.heller@icfo.eu

A promising approach to future quantum communication & processing builds on quantum states of light and light-matter interfaces [1]. Light would act as carrier of information, while light-matter interfaces provide storage or processing capabilities.

Collective Rydberg excitations have recently sparked interest for its potential to realize deterministic two-qubit gates and efficient coupling to photons, vital for the above-mentioned applications. Due to dipole-dipole interactions present in highly-excited atoms, such Rydberg media show a non-linear response already at the single input photon level. However, to date, all demonstrations of this light-matter interaction used classical input states of light, or Rydberg media without strong non-linearity [2,3].

Here, we aim at showing the interaction of a strongly nonlinear Rydberg medium with quantum states of light. To that end, we derive single photons from a DLCZ quantum memory [4]. In a laser-cooled cloud of Rubidium, a four-wave-mixing process is driven. Pairs of signal and idler photons are emitted, where the detection of the signal projects the idler onto a single photon with sub-Poissonian statistics. The idler photon is collected and guided to a second laser-cooled cloud. Here, it is collectively absorbed in a two-photon transition (facilitated by a strong coupling pulse), creating a spin wave in a highly-excited Rydberg state. The excitation can be retrieved by switching on the coupling pulse again.

After showing the successful interaction of a single photon with a single collective Rydberg excitation, we plan to investigate several fundamental aspects of light-matter interaction & quantum optics. For example, the Rydberg media should prohibit the promotion of two excitations simultaneously to the Rydberg state. This means that if the idler photon carried a two-photon component, the Rydberg interaction should block the transmission of this second photon. Furthermore, it is expected that the atomic excitation is differently affected by the interaction with single photons compared to Poissonian light.

While both setups are already operational, we are currently implementing the improvements necessary for the upcoming experiment.

References

[1] Sangouard, Simon, de Riedmatten, Gisin, Rev Mod Phys **83**, 33 (2011)
[2] Stolz et. al., arXiv:2111.09915 (2021)
[3] Distante et. al., NatComm **8**, 14072 (2017)
[4] Duan, Lukin, Cirac, Zoller, Nature **414**, 413-418 (2001)

Figures

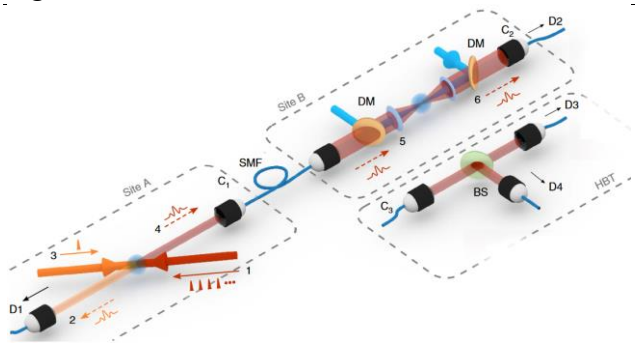


Figure 1: Sketch of the planned experiment, with the source, the Rydberg media and the detection setup. Sketch adapted from [3].

Certification of quantum non-Gaussianity and Wigner function negativity of photonic detectors

Josef Hloušek
Jan Grygar, Jaromír Fiurášek, and Miroslav Ježek.

Department of Optics, Palacký University Olomouc, 17.listopadu 12, 77146, Olomouc, Czechia.

hlousek@optics.upol.cz

Nonclassical states of light are of fundamental importance in quantum optics, optical quantum communication, quantum information processing, and quantum metrology. An important subclass of nonclassical states is represented by states with negative Wigner function and quantum non-Gaussian (QNG) states. Several criteria and witnesses for detection of QNG states have been established [1], and the quantum non-Gaussian character of various sources of nonclassical light has been demonstrated experimentally [2].

Similarly to characterization of non-classical properties of quantum states we can investigate nonclassicality of positive operator-valued measure (POVM) elements Π that describe the studied quantum measurement device. State-of-the-art methods for characterizing photonic detectors and their nonclassicality are indirect. They typically require a full detector tomography with many probing states.

We propose a new efficient procedure for direct certification of nonclassical features of photonic detectors requiring only three classical probe states – either two thermal states and the vacuum state or three thermal states [3]. We demonstrate the feasibility of the proposed certification method by experimentally verifying the quantum non-Gaussianity and the negativity of the Wigner function of a single-photon avalanche diode. Furthermore, we confirm the quantum non-Gaussian character of a photon-number resolving detector from single-photon to seven-photon measurement elements. We also find that the injection of classical background noise into the detector may reduce the measurement time required for reliable confirmation of quantum non-Gaussianity. Our results enable direct certification of the strong nonclassicality of quantum detectors.

References

[1] *R. Filip and L. Mišta, Jr., Phys. Rev. Lett. 106, 200401 (2011).*
[2] *I. Straka et al., npj Quantum Inf. 4, 4 (2018).*
[3] *J. Hloušek et al., Journal, Phys. Rev. Lett. 126, 043601 (2021).*

Figures

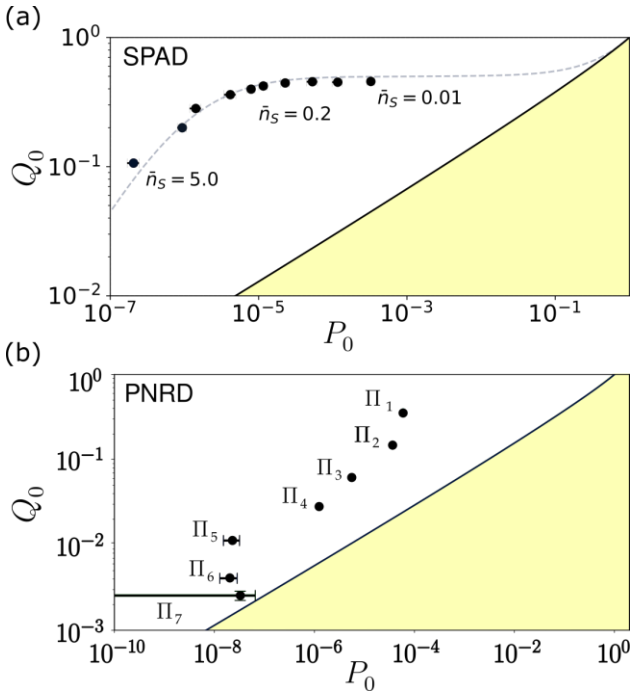


Figure 1: *Quantum non-Gaussianity certification: (a) single-photon avalanche diode for various mean photon numbers of the probe thermal states, and (b) photon-number-resolving detector for POVM elements up to 7. Quantum non-Gaussianity is certified for points lying outside the yellow area.*

Automated tuning of a quadruple quantum dot array

Simon Humpohl
Tobias Hangleiter, Sebastian Kindel, Matthias Künne, René Otten, Pascal Cerfontaine, Hendrik Bluhm

JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

simon.humpohl@rwth-aachen.de

The automatic tune-up of a controlled quantum system is a necessity for large-scale quantum computation and device fabrication characterization. Gate-defined quantum dots require careful adjustment of several voltages for dot formation, charge state control, and tunnel barrier control.
In recent years, several methods and tools for tune up automation have been proposed and published [1, 2, 3]. So far, most of the attention has focused on measurement data analysis and quantitative algorithm descriptions while benchmarks of complete tuning runs are limited.
We developed a completely defined algorithm for tuning a quadruple quantum dot array into the single electron regime. The algorithm uses the pinch-offs to calculate scan ranges and a cross capacitance model for iterative tune up similar to Volk et al. [4]. Human intervention was only required to execute defined algorithm steps that had not been implemented at the time. Importantly, our method relies solely on (virtual) single-dot charge stability diagrams. This will simplify implementing automated data analysis in the future. The algorithm was tested on a single sample utilizing sample symmetries and thermal cycles to approximate independent tuning runs.

References

[1] T. A. Baart et al., Appl. Phys. Lett. 108, (2016) 213104
[2] T. Botzem et al., Phys. Rev. Applied, 10 (2018) 054026
[3] M. Lapointe-Major et al., Phys. Rev. B, 102 (2020) 085301
[4] C. Volk et al., npj Quantum Information, 5 (2019) 29

Figures

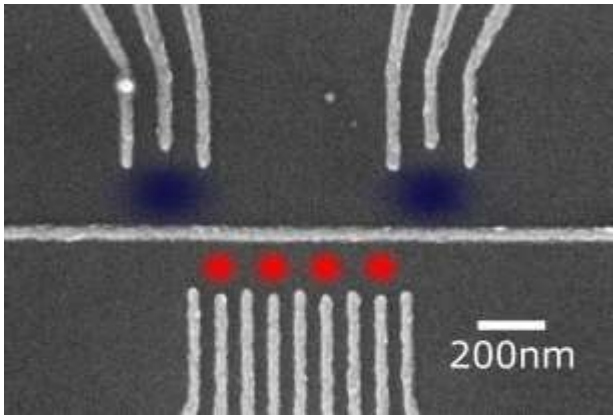


Figure 1: SEM image of gate layout for a quadruple dot system in GaAs. The intended dot positions of the four array dots for qubits (red) and the two sensor dots for charge sensing (blue) are marked.

Looking for KPZ Scaling on IBM Quantum Devices

Nathan Keenan[1, 2]
John Goold[1]

[1]*Trinity College Dublin*
[2]*IBM Quantum*

nathan.keenan@ibm.com

Abstract

Quantum simulation is the original use-case of quantum computation, and has a high chance of being the first area in which we see a quantum advantage. In this work we take inspiration from the random circuit work of [1, 2] to study hydrodynamics on IBM's quantum devices. We investigate whether there is a scalable method to study transport on current digital quantum devices. In particular, we use random circuits and Trotter evolution to study spin-transport in the XXZ model. In the poster we present some results showing that the quantum devices display super-diffusive behaviour at the isotropic point of the XXZ chain, along with the restoration of diffusion when a disordered field is added to the model.

References

[1] Richter, J., & Pal, A. (2021). Simulating hydrodynamics on noisy intermediate-scale quantum devices with random circuits. *Physical Review Letters*, *126*(23), 230501.

[2] Jin, F., Willsch, D., Willsch, M., Lagemann, H., Michielsen, K., & De Raedt, H. (2021). Random state technology. *Journal of the Physical Society of Japan*, *90*(1), 012001.

Figures

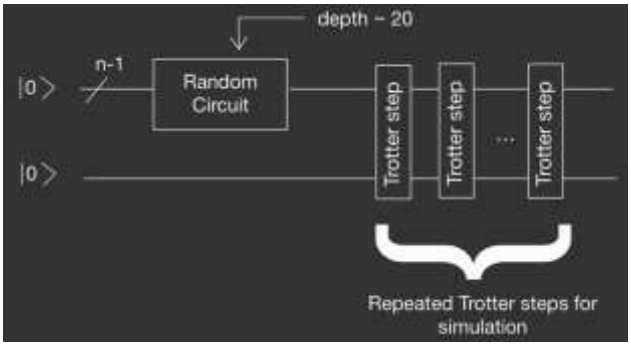


Figure 1: Heuristic of the type of circuit set-up we use for these simulations.

Harnessing environmental noise to control correlations in a quantum wire

Andisheh Khedri,
Antonio Strkalj, Alessio Chicchetta, Oded Zilberberg

Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

akhedri@phys.ethz.ch

The Tomonaga-Luttinger liquid (TLL) is one of the cornerstones of many-body quantum physics, providing a unifying low-energy description of one-dimensional systems, regardless of their nature (bosons, fermions, spins). Such ubiquitous and fascinating physics shows up in carbon nanotubes, quantum Hall systems, organic molecular crystals, ultracold atoms, Josephson-junction chains, optical waveguides in proximity to Rydberg atoms, and many other systems. However, given the one dimensional nature of the TLL, its realisations naturally involve the presence of an environment (leads) coupled to its far ends. This is not only unavoidable but also essential to realise quantum transport across the wire. The nature of these leads can be very diverse, ranging from metallic gates with unscreened Coulomb potential, and phonons, to other complex RC circuits, to superfluid Fermi gases. Accordingly, understanding the impact of leads on a TLL is imperative from an experimental as well as theoretical point of view.

We assess the impact on the TLL properties of a broad class of leads, described by different Ohmic classes. Our main result is that the TLL universality class is deeply modified by the leads. To further highlight the consequences of the above, we consider the presence of a back-scattering impurity and we address the paradigmatic Kane-Fisher physics in this context. We find that the environment with fast fluctuations (super-Ohmic) makes the effective interaction at low-energies repulsive and the renormalized back-scattering potential becomes infinitely large as if the wire is cut in half. On the other hand, for the sub-Ohmic case, the slow fluctuations of the environment overtake the many-body effects of the quantum wire and the back-scattering from the impurity becomes irrelevant. Furthermore, we present the consequences of the above on realistic transport measurements and elaborate on the temperature scaling of the impurity-induced conductance for a finite quantum wire.

Figures

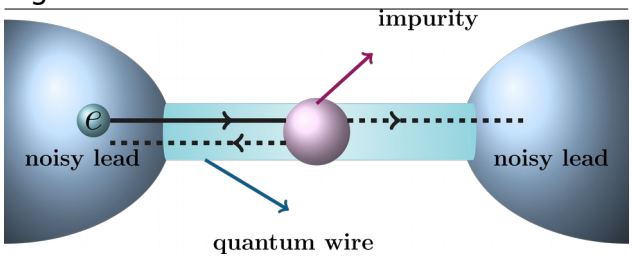


Figure 1:
Sketch of a quantum wire containing a single impurity, that back-scatters electrons. The is coupled to noisy leads at its two ends.

References

[1] T. Giamarchi, Quantum Physics in one dimension, Clarendon Press (2004)
[2] C. L. Kane and M. P. A. Fisher, Phys. Rev. Lett. 68, 1220 (1992)
[3] A. Strkalj, M. S. Ferguson, T. M. R. Wolf, I. Levkivskyi, O. Zilberberg, Phys. Rev. Lett. 122, 126802 (2019)
[4] A. Khedri, A. Strkalj, A. Chiocchetta, O. Zilberberg, Phys. Rev. Research 3, 032013 (2021)

Electrostatic exciton trap in a thin semiconductor membrane for optical coupling to a GaAs spin qubit

Sebastian Kindel
Thomas Descamps, Beata. E. Kardynal, Hendrik Bluhm

JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

sebastian.kindel@rwth-aachen.de

Interfacing stationary solid-state qubits with photonic qubits would be a major milestone towards the realization of a quantum network[1]. Here, we propose a scheme to include an electrostatically-defined and optically active quantum dot at tunnel coupling range to a gate-defined quantum dot (GDQD)[2,3]. The platform requires thinning of the double-side doped heterostructure down to 220 nm membrane without degrading the optical and transport properties. We show that mobilities over 1×10^6 $cm^2V^{-1}s^{-1}$ can be reached and that quantum point contacts and Coulomb oscillations can be observed on this structure. Besides, we demonstrate that exciton traps based on the quantum-confined Stark effect can be made provided depletion on the electron gas.

References

[1] H. J. Kimble, "The quantum internet," Nature 453, 1023–1030 (2008),
[2] M. D. Shulman et al., "Demonstration of entanglement of electrostatically coupled singlet-triplet qubits", Science 336, 202–205 (2012)
[3] R. Hanson et al., "Spins in few-electron quantum dots", Reviews of Modern Physics 79, 1217–1265 (2007)

Figures

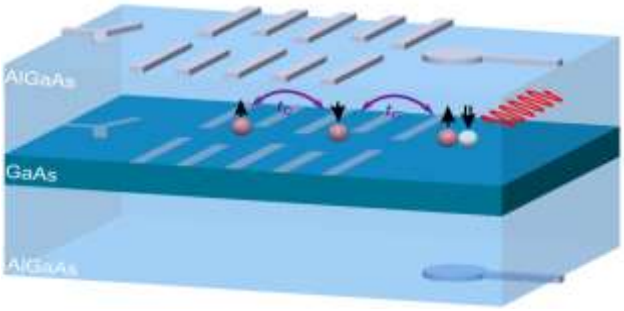


Figure 1: Sketch of an optical interface for GDQD (left side) based on an electrostatically-defined exciton trap (right side). The transfer of information is mediated by tunnel coupling t_c

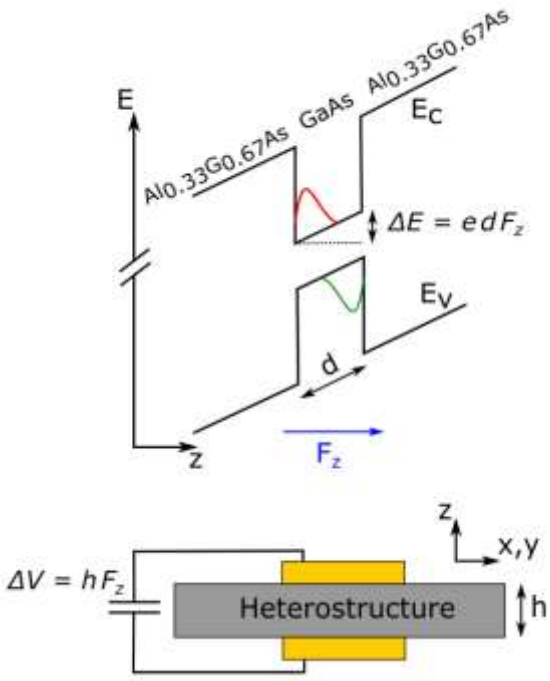


Figure 2: Quantum confined Stark effect on a $Al_{0.33}Ga_{0.67}As/GaAs/Al_{0.33}Ga_{0.67}As$ heterostructure resulting from an electric field F_z applied along the growth direction z. E_C and E_V are respectively the conduction and valence band. The electron and heavy hole ground state wave functions inside the quantum well are depicted.

Towards measuring the nonlocal Josephson effect in Andreev molecules

Mátyás Kocsis
Gergő Fülöp, Zoltán Scherübl, Péter Makk, Szabolcs Csonka

MTA-BME Nanoelectronics Momentum Research Group, Műegyetem rkp. 3, H-1111 Budapest, Hungary

matyaskocsis@edu.bme.hu

Andreev molecules – Josephson junctions positioned closely enough to each other for entangled states to arise – have received much theoretical attention recently as they could have applications in quantum information processing. [1][2] We fabricated devices based on InAs nanowries with epitaxial Al shells, and developed high-frequency experimental methods needed to detect molecular bound states. We also carried out theoretical calculations that highlight the expected experimental signature of entangled states, and help guide the exploration of the rich physics of the parameter space.

References

[1] Kornich et al., *Physical Review B* 101, no. 19 (May 20, 2020)
[2] Pillet et al., *Nano Letters* 19, no. 10 (October 9, 2019): 7138–43.

Figures

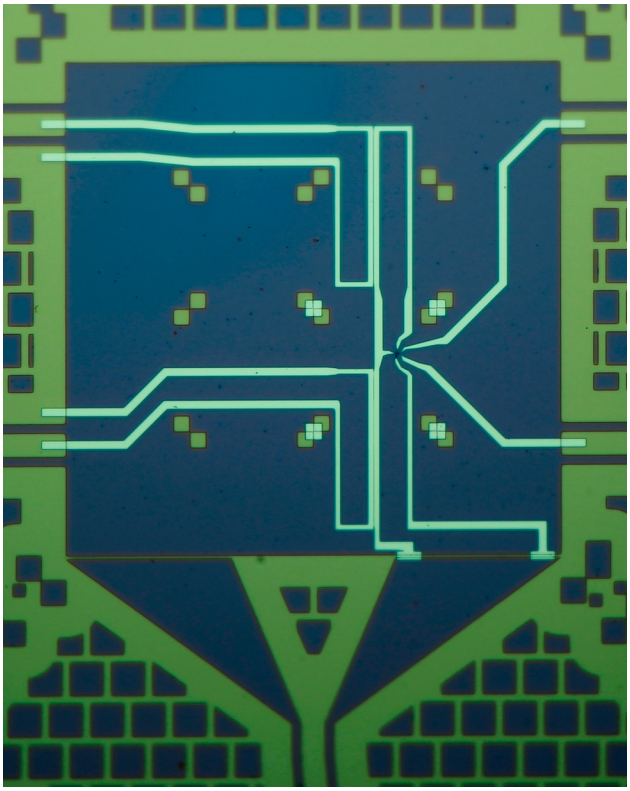


Figure 1: Device with two individually tuneable Josephson junctions coupled to a RF resonator (bottom).

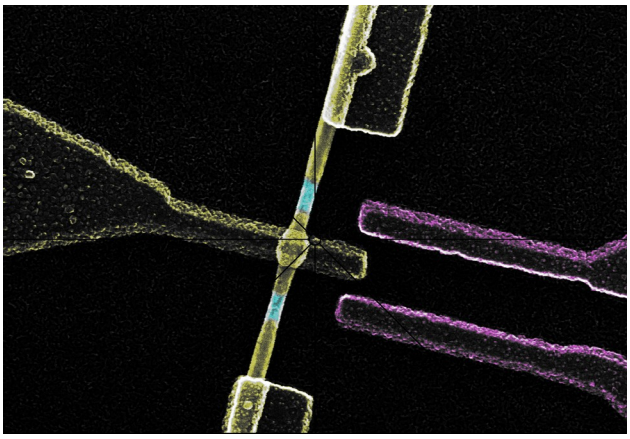


Figure 2: Two Josephson junctions (blue) etched in to the Al shell of a InAs nanowire, close enough for entangled states to arise. The phase of the superconductors (yellow) and the potential on the gates (purple) allows for precise control of the junctions.

A fast singlet-triplet qubit in planar Ge driven by a tunable g-factor difference

Josip Kukučka[1]
J.Saez-Mollejo[1], F.Martins[3], D.Jirovec[1], A.Ballabio[2], G.Tavani[2], D.Chrastina[2], G.Isella[2] and G.Katsaros[2]

[1]Institute of Science and Technology Austria, Klosterneuburg, Austria.
[2]Laboratory for Epitaxial Nanostructures on Silicon and Spintronics, Physics Department, Politecnico di Milano, Como, Italy
[3]Hitachi Cambridge Laboratory, Cambridge, UK

josip.kukucka@ist.ac.at

Exceptional properties such as long coherence times [1], fault tolerant single [2] and two-qubit fidelities [3], fast and high fidelity state read-out [4,5], together with CMOS integration capabilities [6] set spin-qubits amongst the top players in the race towards the quantum computer.

Currently, those exceptional characteristics are scattered among different spin-qubit platforms. This is where Ge kicks in. Firstly, a large spin-orbit coupling allows fast and fully electrical spin state manipulation. Secondly, holes couple only weakly to nuclear spins. Finally, the small effective mass and the low disorder in this material reduces the fabrication complexity. Recent experiments have demonstrated high-quality qubits operating in depletion mode [7], two-qubit gates [8] and a four-qubit quantum processor [9].

Here, we show our results on singlet-triplet qubit in planar Ge. Exploiting the large and tunable out-of-plane g-factors allows X-rotations of up to 600 MHz, and a quality factor exceeding 200 at a magnetic field of only 10 mT.

The reported results not only compete with state of the art spin qubits but pave also the way for on-chip co-integration with superconducting technology. Furthermore, the electrical tunability of g-factors might offer an in-situ solution for the standing problem of non-uniform spin-qubit transition frequencies, qubit addressability and crosstalk protection in dense spin-qubit arrays.

References

[1] J.T. Muhonen et al, Nature Nanotechnology, 9 (2014) 986-991
[2] Y.C.Yang et al, npj Quantum Information, 5 (2019)
[3] A.R.Mills et al, Science Advances, 14 (2022)
[4] G.A.Oakes et al, arxiv:2203.06608 (2022)
[5] E.J.Connors and J.J.Nelson et al, Phys.Rev.Applied, 13 (2022) 024019
[6] R.Maurand et al, Nature Communications, 7 (2016) 13575
[7] D.Jirovec et al, Nature Materials, 20 (2021) 1106-1112
[8] N.W.Hendrickx and D.P.Franke et al, Nature, 577 (2020) 487-491
[9] N.W.Hendrickx et al, Nature, 591 (2021) 580-585

Loophole-free Bell inequality violation with superconducting circuits

Anatoly Kulikov[1]
Simon Storz[1], Josua Schär[1], Paul Magnard[1], Philipp Kurpiers[1], Janis Lütolf[1], Theo Walter[1], Adrian Copetudo[1], Kevin Reuer[1], Abdulkadir Akin[1], Jean-Claude Besse[1], Mihai Gabureac[1], Graham J. Norris[1], Andres Rosario[1], Ferran Martin[2], José Martinez[2], Waldimar Amaya[2], Morgan W. Mitchell[3,4], Carlos Abellan[2], Jean-Daniel Bancal[5], Nicolas Sangouard[5], Baptiste Royer[6,7], Alexandre Blais[7,8], Andreas Wallraff[1,9]

[1]*Department of Physics, ETH Zurich, 8093 Zurich, Switzerland;* [2]*Quside Technologies, 08860 Castelldefels (Barcelona), Spain;* [3]*ICFO, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain;* [4]*ICREA, 08015 Barcelona, Spain;* [5]*Université Paris-Saclay, CEA, CNRS, Institut de Physique Théorique, 91191 Gif-sur-Yvette, France;* [6]*Department of Physics, Yale University, New Haven, CT 06520, USA;* [7]*Institut Quantique and Département de Physique, Université de Sherbrooke, Sherbrooke, Québec J1K 2R1, Canada;* [8]*Canadian Institute for Advanced Research, Toronto, Ontario M5G 1Z8, Canada;* [9]*Quantum Center, ETH Zurich, 8093 Zurich, Switzerland*
akulikov@phys.ethz.ch

One of the ultimate manifestations of the properties of nature as described by the laws of quantum physics is that measurements performed on entangled pairs of quantum systems can be shown to violate Bell's inequality[1,2], questioning and clashing with the principle of local realism[3]. This remarkable feature of quantum physics was first explored in seminal experiments performed with photons emitted in atomic cascade decay experiments[4,5]. Only several decades later, Bell tests with photons and nitrogen-vacancy centers have unequivocally experimentally confirmed -- in a manner free of additional assumptions called loopholes[6] -- that non-local quantum correlations cannot be described by any local realistic classical theories[7,8,9]. Here, we demonstrate a loophole-free violation of Bell's inequality with superconducting circuits. Performing such an experiment is particularly challenging due to the need of deterministically entangling qubits housed in distant cryogenic systems[10] and performing fast and high-fidelity measurements along randomly chosen bases. We address these challenges by assembling a unique 30-m-long cryogenic setup extending a prior 5-m-long one[11] and combining several state-of-the-art techniques. It allows performing a Bell test with a collective, macroscopic quantum degree of freedom using microwave frequency photons. We obtain an S-value[2] of $S_{CHSH} = 2.075$ and statistical significance (p-value) of $p = 10^{-108}$, thus violating the inequality with high certainty. Our experiment adds the resource of non-locality to the circuit QED platform, which was unavailable so far, and enables the implementation of device-independent quantum information processing algorithms.

References

[1] J. S. Bell, Physics (N. Y.), 1:195, 1964
[2] J. F. Clauser et al, Phys. Rev. Lett., 23(15):880–884, Oct 1969
[3] A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev., 47(10):777–780, May 1935
[4] S. J. Freedman and J. F. Clauser, Phys. Rev. Lett., 28:938–941, Apr 1972.
[5] A. Aspect et al, Phys. Rev. Lett., 49:91–94, Jul 1982 and 49(25) 1804–1807, Dec 1982.
[6] N. Brunner et al, Rev. Mod. Phys., 86:419–478, Apr 2014
[7] B. Hensen et al, Nature, 526:682–686, Oct 2015
[8] M. Giustina et al, Phys. Rev. Lett. 115, 250401, Dec 2015
[9] W. Rosenfeld et al, Phys. Rev. Lett. 119, 010402, Jul 2017
[10] P. Kurpiers et al, Nature, 558:264–267, 2018
[11] P. Magnard et al, Phys. Rev. Lett., 125:260502, Dec 2020

Distinguishability and mixedness in quantum interference

Shreya Kumar
Alex E Jones, Simone D'Aurelio, Matthias Bayerbach, Adrian J Menssen and Stefanie Barz

Institute for Functional Matter and Quantum Technologies, University of Stuttgart, 70569 Stuttgart, Germany
shreya.kumar@fmq.uni-stuttgart.de

Abstract

Quantum interference of photons is central to many applications in quantum technologies such as generating entangled states, quantum metrology, quantum imaging and photonic quantum computing. One of the fundamental prerequisites for these applications is that the photons are indistinguishable and have high purity. The visibility of the Hong-Ou-Mandel (HOM) interference[1] dip is usually used to deduce the nature of the photons. In case of two photons, this visibility is reduced by distinguishability, and by mixedness in the same way. However, here, we show that that when scaling up to three photons[2], despite having similar HOM interference visibilities, one can differentiate between distinguishability and mixedness of the photons by observing the count statistics after interference at a tritter[3]. This shows that the visibility alone is inadequate to discriminate between distinguishability and mixedness of the photons and that it becomes important to characterize photon state purity, in order to study interference effects at larger scales.

References

[1] C. K. Hong, Z. Y. Ou, and L. Mandel, Phys. Rev. Lett.59, 2044 (1987).
[2] A. J. Menssen, A. E. Jones, B. J. Metcalf, M. C. Tichy, S. Barz, W. S. Kolthammer, and I. A. Walmsley, Phys.Rev. Lett. 118, 153603 (2017).
[3] A. E. Jones, S. Kumar, S. D'Aurelio, M. Bayerbach, A. J. Menssen and S. Barz, arXiv:2201.04655v1.

Protocols for Trainable and Differentiable Quantum Generative Modelling

Oleksandr Kyriienko[1,2], Annie E. Paine[1,2], Vincent E. Elfving[2]

[1]1Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, United Kingdom
[2] Pasqal SAS, 2 av. Augustin Fresnel, 91120 Palaiseau, France

Quantum generative modelling (QGM) aims to exploit trainable circuits that can prepare distributions as quantum states, for instance trying to match patterns from available data. Being a subject of the emerging field of quantum machine learning (QML), QGM utilizes the Born rule inherent to quantum mechanics. This is leads to the concept of quantum circuit Born machines (QCBM) as a generator of data samples from parametrized probability distribution [1]. QCBM offers a way to fast sampling, but is ultimately limited by its learning workflow based on binary variable representation. Importantly, QCBM circuit cannot be differentiated with respect to the encoded variable.

In the talk, I will describe an approach for learning probability distributions as differentiable quantum circuits (DQC) [2] that enable efficient quantum generative modelling (QGM) and synthetic data generation. Contrary to existing QGM approaches, we perform training of a DQC-based model, where data is encoded in a latent space with a phase feature map, followed by a variational quantum circuit. We then map the trained model to the bit basis using a fixed unitary transformation, coinciding with a quantum Fourier transform circuit in the simplest case. This allows fast sampling from parametrized distributions using a single-shot readout. Importantly, latent space training provides models that are automatically differentiable, and we show how samples from solutions of stochastic differential equations (SDEs) can be accessed by solving stationary and time-dependent Fokker-Planck equations with a quantum protocol [3]. Finally, our approach opens a route to multidimensional generative modelling with qubit registers explicitly correlated via a (fixed) entangling layer. In this case quantum computers can offer advantage as efficient samplers, which perform complex inverse transform sampling enabled by the fundamental laws of quantum mechanics. On a technical side the advances are multiple, as we introduce the phase feature map, analyze its properties, and develop frequency-taming techniques that include qubit-wise training and feature map sparsification.

References

[1] M. Benedetti et al., Quantum Sci. Technol. 4, 043001 (2019).
[2] O. Kyriienko, A. E. Paine, V. E. Elfving, Phys. Rev. A 103, 052416 (2021).
[3] O. Kyriienko, A. E. Paine, V. E. Elfving, arXiv:2202.08253 (2022).

Quantum associative memory with single driven-dissipative oscillator

Adrià Labay Mora
Roberta Zambrini, Gian Luca Giorgi

Instituto de Física Interdisciplinar y Sistemas Complejos (IFISC, UIB-CSIC), Campus Universitat de les Illes Balears, E-07122 Palma de Mallorca, Spain

alabay@ifisc.uib-csic.es

Abstract

Algorithms for associative memory typically need a network of many connected systems. The prototypical example is the Hopfield model [1], whose generalisations to the quantum realm are mainly based on multipartite open quantum systems [2]. We propose a model of associative memory with a *single* driven-dissipative quantum system exploiting its infinite degrees of freedom in phase space [3]. We prove that the model is able to distinguish among *n* coherent states, which represent the stored patterns of the system. These can be tuned continuously by modifying the driving and dissipation strength, constituting a modified learning rule. We show that the associative-memory capacity is inherently related to the existence of a spectral gap in the Liouvillian superoperator, which results in a large time-scale separation in the dynamics corresponding to a metastable phase. There, a near-unit success probability is achieved, even for a single trajectory.

References

[1] Hopfield, J. J. (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the national academy of sciences*, ***79***(8), 2554-2558.

[2] Fiorelli, E., Marcuzzi, M., Rotondo, P., Carollo, F., & Lesanovsky, I. (2020). Signatures of associative memory behavior in a multimode Dicke model. *Physical Review Letters*, ***125***(7), 070604.

[3] A. Labay Mora, R. Zambrini, and G. L. Giorgi. *In preparation.*

Figures

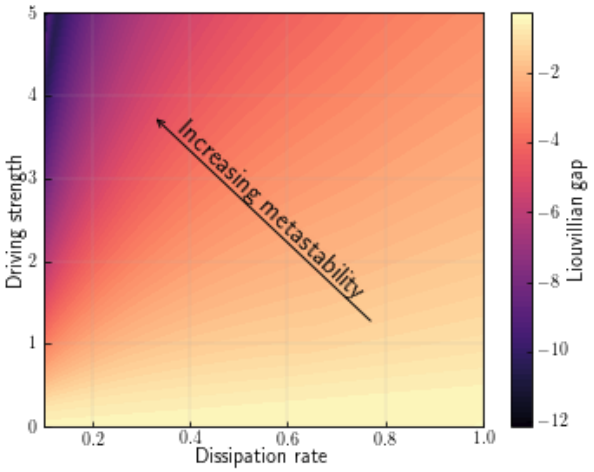


Figure 1: Liouvillian gap (logarithmic scale).

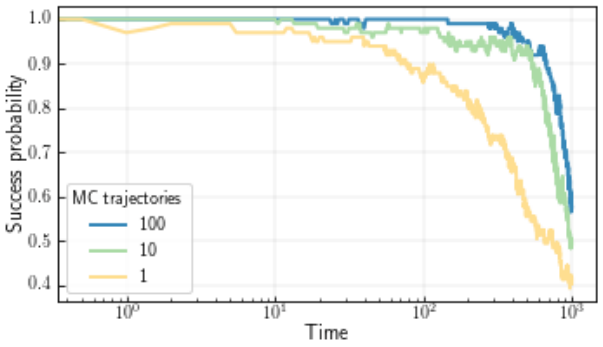


Figure 2: Probability of finding the correct pattern in time. Averaged over 100 randomly chosen initial coherent states for a different number of Monte-Carlo trajectories.

Multiplexed quantum teleportation from a telecom qubit to a matter qubit through 1 km of optical fibre

Dario Lago-Rivera
Jelena V. Rakonjac, Samuele Grandi, Hugues de Riedmatten

ICFO – Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain

dario.lago@icfo.eu

Distribution of quantum information over long distances is a basic need in the field of quantum communications. Quantum teleportation is an important capability that uses quantum entanglement as a resource to transmit arbitrary quantum bits (qubits) between distant parties [1]. A scalable implementation of quantum teleportation should feature compatibility with the telecom infrastructure and a multimode capability that allows for the decoupling of the repetition rate of the set-up from the distance between parties [2]. Moreover, the information should be transferred to a matter qubit with a storage time longer than the communication time such that the receiver can process the quantum states after they have been teleported.

In order to address all of these needs, we use a cavity-enhanced spontaneous parametric down-conversion source to create entangled photon pairs. The idler photon is created in the telecom band and the signal photon is compatible with storage in a solid-state quantum memory based on a praseodymium-doped crystal [3].

We used a source of time bin qubits to encode arbitrary states to be teleported.

We tested the system under a long distance scenario by separating sender and receiver with 1 km of optical fibre. We checked that the fidelity was the same as without the added distance (Fig. 1a). Thanks to the storage in the quantum memory, we could implement a unitary transformation on the teleported qubit conditioned on the result of the remote Bell-state measurement. Finally, we demonstrated that the teleportation repetition rate did not affect the fidelity of the teleported state (Fig. 1b, 1c).

We believe that these results represent a functional and scalable realization of long distance quantum teleportation and will inspire future implementations of long distance quantum teleportation.

References

[1] Bennett, C.H. et al. Phys. Rev. Lett. 70, 1895 (1993).
[2] Simon, C. et al. Phys. Rev. Lett. 98, 190503 (2007).
[3] Rakonjac, J. V. et al. Phys. Rev. Lett. 127, 210502 (2021)

Figures

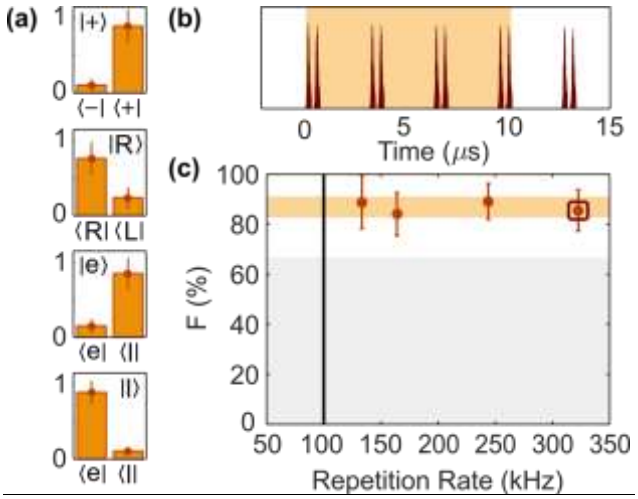


Figure 1: (a) Long distance quantum teleportation with an average fidelity of 86(4) %. Normalized coincidences for different input qubits after a qubit analyser with parallel and orthogonal settings. (b) Example of input qubit. Orange area represents the storage time in the quantum memory for that specific measurement. (c) Fidelity as a function of teleportation repetition rate. The black vertical line represents the maximum repetition rate for a single mode quantum memory after 1 km of distance in fibre. The grey area represents the classical limit of 66.7%. The orange area shows one standard deviation with respect to the average between all the measured fidelities.

A Quantum-compute Algorithm for the Exact Laser-driven Electron Dynamics in Molecules

Fabian Langkabel[1,2]
Annika Bande[1]

[1]*Helmholtz-Zentrum Berlin, Hahn-Meitner-Platz 1, 14109 Berlin, Germany*

[2]*Freie Universität Berlin, Arnimallee 22, 14195 Berlin, Germany*

fabian.langkabel@helmholtz-berlin.de

With the advent of new experimental techniques, the theoretical description of ultrafast electron dynamics in molecular systems plays an increasingly important role in understanding photo-induced processes such as energy transfer [1] or electron solvation. Unlike for solving the time-independent Schrödinger equation in "regular" quantum chemistry [2], very little thought has been given to the use of quantum computers in the field of electron dynamics.

In this work, we have investigated the capability of known quantum computing algorithms for fault-tolerant quantum computing to simulate the laser-driven electron dynamics in small molecules such as lithium hydride and performed these simulations on a quantum computer simulator. Results were compared with the time-dependent full configuration interaction method (TD-FCI). In addition to the actual wave packet propagation, which was successfully reproduced using the Jordan-Wigner transformation and the Trotter product formula, the time-dependent dipole moment was also satisfactorily determined as an example of time-dependent expectation values using the Hadamard test [3]. In order to be able to include non-Hermitian operators in the dynamics, a similar approach to the quantum imaginary time evolution (QITE) algorithm [4] was employed to translate the propagator used into quantum gates. Thus, ionization in a hydrogen molecule was also reproduced using a complex absorption potential. All these calculations were performed with the group's own program Jellyfish. While TD-FCI scales exponentially, all quantum computer algorithms used scale polynomially, which may lead to an enormous progress in the understanding of electron dynamics of increasingly large molecular systems in the future.

References

[1] F. Langkabel et al., J. Chem. Phys. 2021, 154, 045111
[2] S. McArdle, et al., Rev. Mod. Phys. 2020, 92, 015003
[3] D. Aharonov, et al., Algorithmica 2008, 55, 395-421
[4] M. Motta, et al., Nat. Phys. 2019, 16, 205-210
[5] F. Langkabel et al., Chem. Phys. 2022, 557, 111502

Figures

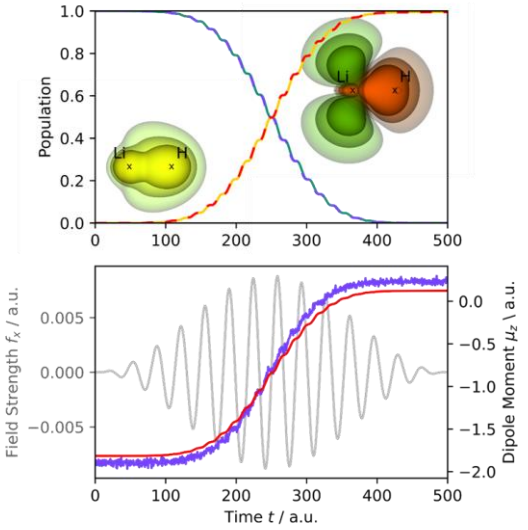


Figure 1: Comparison of population and dipole moment with TD-FCI (solid top and red bottom) and quantum computer dynamics (dashed top and purple bottom) of charge transfer in lithium hydride during a resonant π-pulse excitation (gray bottom), as well as the electron density at the beginning and the difference density [5] at the end.

Location qubits in a multi-quantum-dot system

Dayang Li [a]
Rohan Radhakrishnan [a]
Nika Akopian [a]

[a] *Department of Photonics Engineering, Technical University of Denmark, 2800 Kongens Lyngby, Denmark*

dayli@fotonik.dtu.dk

A physical platform for nodes of the envisioned quantum internet has been long-sought. Here we propose such a platform, along with a conceptually simple and experimentally uncomplicated quantum information processing scheme, realized in a system of multiple crystal-phase quantum dots. In our work [1], we introduce novel location qubits, describe a method to construct a universal set of all-optical quantum gates, and simulate their performance in realistic multi-quantum-dot structures, including the main decoherence sources. Our results from numerical studies show that location qubits can maintain coherence 5 orders of magnitude longer than single-qubit operation time, and single-qubit gate errors do not exceed 0.01%.

Crystal-phase quantum dots possess several characteristics essential for quantum internet nodes: (i) designability of individual qubits; (ii) scalability to multiple qubits; (iii) ease of incorporation with a photonic interface for long-distance communication; and, (iv) nanoscale footprint of devices — for large scale integration. Its designability is particularly remarkable — devices can be fabricated with an accuracy of a single atomic layer [2].

In our scheme, we take advantage of type-II band alignment in crystal-phase quantum dots and exploit spatially indirect excitons to construct all-optical initialization and coherent manipulation (single-qubit and two-qubit gates) of location qubits. We will also present our latest experimental results.

Our scheme paves a clear way towards constructing multi-qubit solid-state quantum systems with a built-in photonic interface, such as a multi-qubit quantum register — a key building block of the forthcoming quantum internet.

References

[1] D. Li and N. Akopian, Location qubits in a multi-quantum-dot system (2021), arXiv:2107.05960 [quant-ph].

[2] J.-C. Harmand, G. Patriarche, F. Glas, F. Panciera, I. Florea, J.-L. Maurice, L. Travers, and Y. Ollivier, Atomic step flow on a nanofacet, Phys. Rev. Lett. 121, 166101 (2018).

Figures

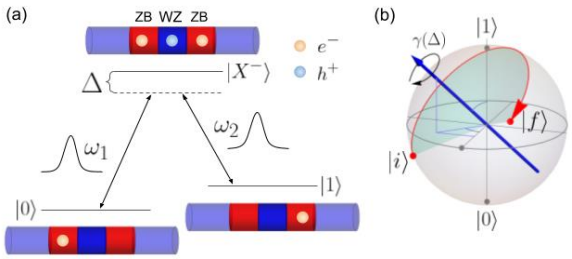


Fig. 1: (a) The all-optical manipulation scheme of a location qubit. A section of a semiconductor nanowire (GaAs or InP) in the Wurtzite (WZ, blue) phase with a pair of crystal-phase quantum dots in the zincblende phase (ZB, red). On such a structure we define a location qubit. Two laser pulses ω_1 and ω_2 of different wavelengths drive the left and right optical transitions respectively. They are both far detuned from the common excited state by Δ. (b) Equivalent representation of the coherent manipulation scheme on a Bloch sphere. Hadamard gate is shown as an example. A state rotates with respect to an axis (blue) defined by the ratio and phase between the driving pulses. The rotation angle γ is a function of the detuning Δ.

Algorithmic improvements for adiabatic state preparation

Leonard Logaric

Trinity College Dublin, Ireland

logaricl@tcd.ie

Finding the ground state of a general electronic structure Hamiltonian is one of the key problems in quantum chemistry. It is believed that quantum computers could be useful for solving this problem, due to their linear scaling with respect to the Hilbert space of a given system.
One of the first proposed methods to find good approximations to the ground state on a digital quantum computer in the gate model is adiabatic state preparation [1]. In the original implementation, the adiabatic evolution was performed using a discretisation of the time dependent Hamiltonian into sections where it is approximated as time independent, and the propagator is performed using Trotterization. The drawbacks of this method include a nonadiabatic error, which incurs due to finite simulation time, and large circuit depth due to the Trotterization of a non-local Hamiltonian.
However, since then there have been many improvements in the area of Hamiltonian simulation,
as well as our understanding of adiabatic processes. Here I will present a method which combines recent advances in Hamiltonian simulation [2], and a variational technique to counteract non-adiabatic effects [3], which has not yet been used for finding the ground state of an electronic structure problem. The former drastically improves the gate count in comparison to the more widely used Trotterization, while the latter mitigates the non-adiabatic errors.
Finally, this method is applied to hydrogen and lithium hydride molecules together with phase estimation in an emulated quantum computer in order to show the advantage of the presented method.

References

1. Aspuru-Guzik, Alán, et al. "Simulated Quantum Computation of Molecular Energies." Science,
vol. 309, no. 5741, 2005, pp. 1704–07.
2. Campbell, Earl. "Random compiler for fast Hamiltonian simulation." Physical Review Letters,
123, 2019.
3. Pieter W. Claeys, Mohit Pandey, Dries Sels, and Anatoli Polkovnikov. "Floquet-Engineering
Counterdiabatic Protocols in Quantum Many-Body Systems" Phys. Rev. Lett. 123, 2019.

Parametric single-qubit gate protocol for the Majorana-transmon.

Elena Lupo[1]
Eytan Grosfeld[2], Eran Ginossar[1]

[1]*Advanced Technology Institute (ATI) and Department of Physics, University of Surrey, Guildford, GU2 7XH, UK*
[2]*Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel*

e.lupo@surrey.ac.uk

Newly proposed hybrid qubit designs that combine novel solid-state elements with superconducting platforms promise to improve controllability and decrease sensitivity to decoherence mechanisms. Among these, the Majorana transmon [1] employs solid-state nanowires that give rise to localized, topologically-protected Majorana zero modes (MZM). It encodes the quantum information in a basis of fermion parity states originating from an additional hybridization between two MZMs through a Josephson Junction. Inevitably, the additional coupling is done at the expense of maintaining the full topological protection of the MZMs. However, when working in the "Majorana transmon" regime of high Josephson energy and low MZMs' hybridization, the high anharmonicity generated in the energy spectrum and the exponentially suppressed intra-doublet dipole coupling make it a promising tool either for the qubit manipulation and readout [2] or in general for a reliable detection method of the Majorana modes [3]. In this poster, I will present a new protocol for implementing single-qubit gates in the Majorana transmon [4], exploiting the non-linear driving term generated by a parametric modulation of the offset-charge of the system. I will argue that this protocol represents an attractive alternative to microwave control or other gate-based schemes and that it can be experimentally implemented straightforwardly via a time-dependent external gate voltage bias. In addition, I will describe the effects of wide-band 1/f charge noise on both the free and driven evolution, obtaining the system's coherence times and the loss of fidelity, using analytical and numerical methods.

For this work we acknowledge funding from the European Commission project HiTIMe.

References

[1] E. Ginossar and E. Grosfeld, Nat. Commun. 5, 4772 (2014)
[2] K. Yavilberg, E. Ginossar and E. Grosfeld, Phys. Rev. B 92 (7), 075143 (2015)
[3] K. Yavilberg, E. Ginossar, and E. Grosfeld, Phys. Rev. B 100, 241408 (2019)
[4] E. Lupo, E. Grosfeld, E. Ginossar, PRX Quantum (in press)

Quantum Enhanced Measurement of Many-Body Observables

Liubov Markovich
Attaallah Almasi, Johannes Borregaard

QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ, Delft, The Netherlands

L.Markovich@tudelft.nl

In different areas of science the problem of finding the expectation value of an operator corresponding to an observable of a system is of utmost importance. For example, in many tasks in condensed matter physics, materials science, quantum chemistry and combinatorial optimization, the goal is to find spectral properties, the ground state energy or the lowest eigenvalue of a Hamiltonian. Direct estimation of the expectation value of observable decomposed into weighted sum of N Pauli strings is not straight forward and for complex system, it deemed to be nearly impossible [1,2].

In this project we propose an alternative approach to the current method of individually measuring each Pauli string, with a further classical summation of all values (we call this approach classical method). Our idea is to sum all the Pauli strings coherently. Using the phase kickback method in quantum phase estimation (QPE) [3], each Pauli string is encoded in the phase and written into an ancilla qubit in such a way that the sum of all Pauli strings is encoded in one phase as a sum of nonlinear functions. Our circuit contains two parts (see Fig.1) : a target quantum system with a short coherent time qubits and a measurement device with a memory ancilla qubit that has a long coherent time enough to encode each Pauli string and to proceed the QPE.

As a result, our approach promises linear improvement in N comparing to the classical one.

References

[1] D. Wang, O. Higgott, and S. Brierley., Phys. Rev. Lett., 122:140504, (2019)
[2] I. Hamamura and T. Imamichi., 6:2056–6387, (2020)
[3] S. Kimmel, G. H. Low, and T. J. Yoder., Phys. Rev. A, 92:062315, (2015)

Figures

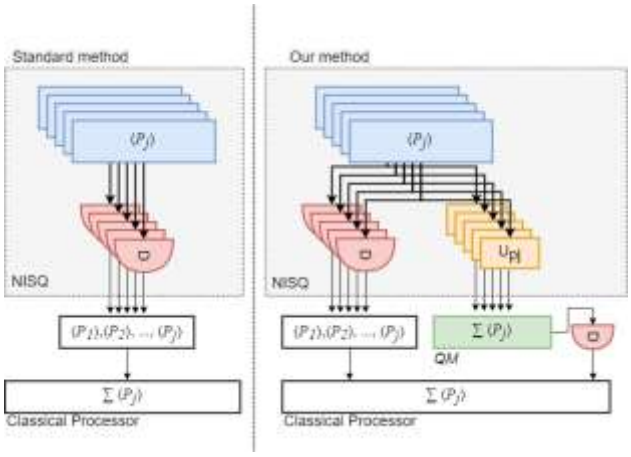


Figure 1: The comparison of standard and our method. On the left figure, the standard method, in which each Pauli circuit is prepaid in NISQ device is shown. The expectation value of each Pauli is estimated and the summation of all Pauly means is done classically. In contrast to it, in our method, shown on the right figure, we encode each Pauli string in the long coherence time memory qubit, using encoding operators U for every Pauli string. Then, we perform a single measurement on a memory qubit to estimate the desired observable.

Solving Nuclear Structure Problems with a Variational Quantum Algorithm

Antonio Márquez Romero[1,2]

J. Engel[2], Ho Lun Tang[3], Sophia E. Economou[3]

[1] *Department de Fisica Quantica i Astrofisica, Institut de Ciencies del Cosmos (ICCUB), Universitat de Barcelona, Marti i Franques 1, Barcelona, E08028, Spain*

[2] *Department of Physics and Astronomy, University of North Carolina, Chapel Hill, North Carolina 27516-3255, USA*

[3] *Department of Physics, Virginia Tech, Blacksburg, VA 24061, USA*

a.marquez.romero@fqa.ub.edu

We use the Lipkin-Meshkov-Glick (LMG) model and the valence-space nuclear shell model to examine the likely performance of variational quantum eigensolvers in nuclear-structure theory. The LMG model exhibits both a phase transition and spontaneous symmetry breaking at the mean-field level in one of the phases, features that characterize collective dynamics in medium-mass and heavy nuclei. We show that with appropriate modifications, the ADAPT-VQE algorithm [1], a particularly flexible and accurate variational approach, is not troubled by these complications. We treat up to 12 particles and show that the number of quantum operations needed to approach the ground-state energy scales linearly with the number of particles [2]. We find similar scaling when the algorithm is applied to the nuclear shell model with realistic interactions in the sd and pf shells.

References

[1] H.R. Grimsley, Sophia E. Economou, E. Barnes et al, Nature Communications 10, 3007 (2019)

[2] A. M. Romero, J. Engel, Ho Lun Tang, Sophia E. Economou, arXiv:2203.01619 (2022)

Figures

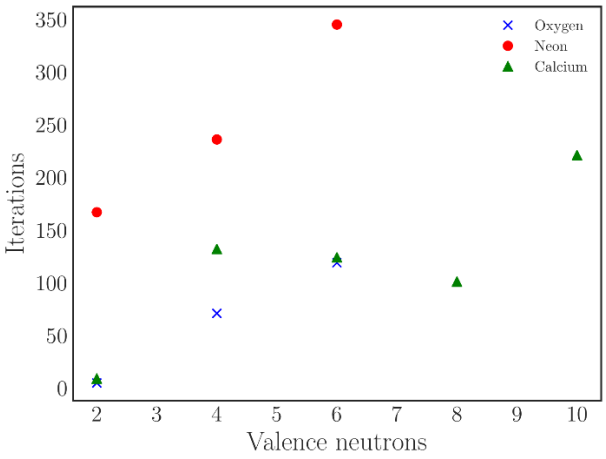


Figure 1: Number of operations needed to reach the ground-state energy of the nucleus to within 1%, 2% and 0.0001% for isotopes of calcium, neon and oxygen, respectively, as a function of the number of valence neutrons in the shell.

Towards Crystal Phase Control of Sn in Hybrid Nanowires

Sara Martí-Sánchez[1]

Sabbir A. Khan[2], Maria Chiara Spadaro[1], Peter Krogstrup[2] and Jordi Arbiol[1,3]

[1]Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Catalonia, Spain
[2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark
[3]ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Catalonia, Spain

sara.marti@icn2.cat

Hybrid systems of semiconductors connected to metals/superconductors provide interesting platforms to explore exotic topological properties for topological quantum computing purposes. In particular, Sn is a promising material as it can present two main structural phases when deposited on III-V semiconductor nanowires (NWs): semimetallic α-Sn (cubic) and metallic β-Sn (tetragonal) which also presents superconductivity below 3.7 K. In addition, α-Sn can turn into a topological insulator under strain [1] and β-Sn has the potential to turn into a topological superconductor when hybridized with a strong spin-orbit coupling 1D semiconductor [2]. However, coexistence of both phases in III-V NWs has been reported [2] and control on phase formation remains challenging.

In this work we perform a (Scanning) Transmission Electron Microscopy - based study of Sn phase dynamics based on structural parameters of the involved materials. In a first approach, examination of different growth stages of Sn on InSb (zinc blende) permits to draw a map of phase dynamics. A monophase α-Sn shell evolves to β-Sn rich shell with increasing β-Sn density with layer thickness. In a second step, poorly lattice matched NW templates of InAs (wurtzite) were employed for Sn growth, where only β-Sn presence was detected.

Our studies reveal that Sn phase control is mostly driven from structural arrangement of the nanowire template. Therefore, this work provides a key to control Sn phases on hybrid NWs to permit the tuning of the topological properties by unveiling the insights of Sn growth.

References

[1] Barfuss *et. al.*, Phys. Rev. Lett. 111 (2013), 157205
[2] Pendharkar *et. al.*, Science 372 (2021), pp. 508-511

Figures

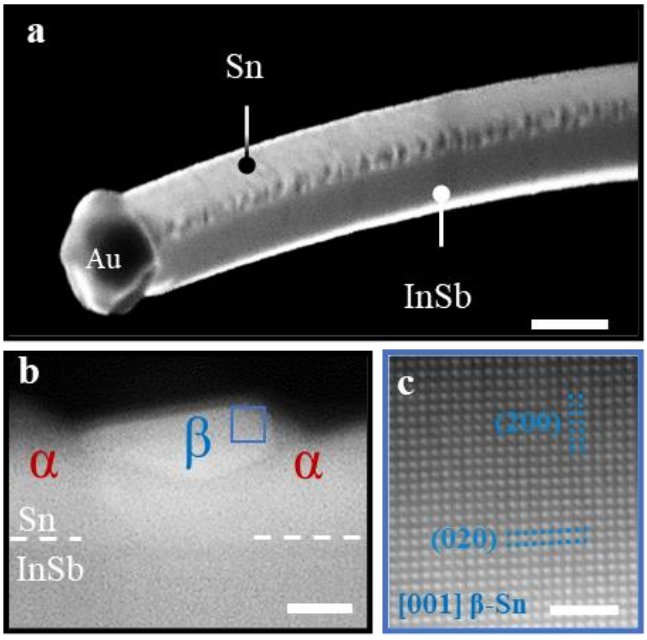


Figure 1: Electron microscopy analysis of one hybrid InSb-Sn nanowire sample of our study. **a** Tilted SEM image of the NW. **b** Low-magnification TEM micrograph of a multiphase shell. **c** Atomically resolved zoom-in of a β-Sn grain embedded in α-Sn with its orientation and plane indications. Scale bars (a-c): 100 nm, 20 nm, 2 nm.

Cyclic Einstein-Podolsky-Rosen steering

István Márton[1]
Sándor Nagy[2], Erika Bene[1], Tamás Vértesi[1]

[1]*MTA Atomki Lendület Quantum Correlations Research Group, Institute for Nuclear Research, (ATOMKI) P.O. Box 51, H-4001 Debrecen, Hungary*
[2]*Department of Theoretical Physics, University of Debrecen, P.O. Box 5, H-4001 Debrecen, Hungary*

marton.istvan@atomki.hu

Abstract

Einstein-Podolsky-Rosen (EPR) steering is a form of quantum correlation that exhibits a fundamental asymmetry in the properties of quantum systems. Given two observers, Alice and Bob, it is known to exist bipartite entangled states which are one-way steerable in the sense that Alice can steer Bob's state, but Bob cannot steer Alice's state.
In this work, we generalize the phenomenon of one-way EPR steering phenomenon from two parties to three parties and find a cyclic property of EPR steering [1]. In particular, we propose a three-qubit cyclic translationally invariant ansatz state and optimize its coefficients. As a result of a heuristic search, we find a three-qubit state with the following properties: (i) All reduced two-qubit states are one-way EPR steerable for arbitrary projective measurements, where we used numerical techniques recently developed by Nguyen et al. [2] to prove steerability. (ii) The three-qubit state has a cyclic steering property in the sense that, when the system is arranged in a triangular configuration, the neighbouring parties can only steer each other's states in one (e.g., clockwise) direction. That is, Alice can steer Bob's state, Bob can steer Charlie's state, and Charlie can steer Alice's state, but not the other way around as it is depicted in Figure 1. We have thus shown a peculiar directional feature of tripartite quantum correlations, which can neither appear in the phenomenon of quantum entanglement nor in standard Bell nonlocality.

Figures

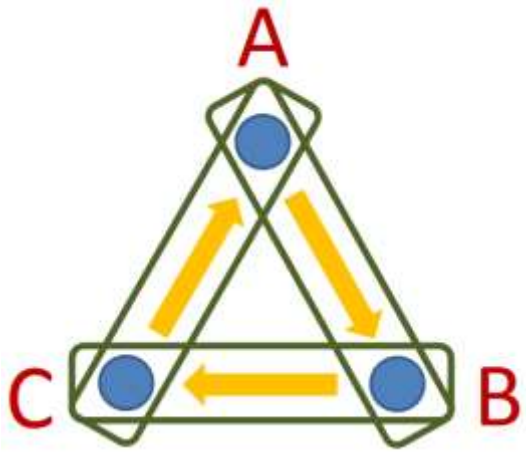


Figure 1: Setup for cyclic EPR steering. The figure depicts a three-qubit state with its two-party reduced states in green rectangles. The yellow arrows indicate that steering takes place in the clockwise direction. However, steering in the other (anticlockwise) direction is not possible, even if the untrusted party can perform arbitrary projective measurements.

References

[1] I. Márton, S. Nagy, E. Bene, T. Vértesi, Cyclic Einstein-Podolsky-Rosen steering, Phys. Rev. Research 3, 043100 (2021).
[2] H. C. Nguyen, H.-V. Nguyen, and O. Gühne, Geometry of Einstein-Podolsky-Rosen Correlations, Phys. Rev. Lett. 122, 240401 (2019).

Exotic superfluidity from correlations

Jesús Mateos[1],
Gregor Pieplow[2], Charles Creffield[1] and Fernando Sols[1]

[1]Universidad Complutense de Madrid, Plaza de las Ciencias 1, E-28040 Madrid, Spain
[2]Humboldt-Universität zu Berlin, Newtonstrasse 15, D-12489 Berlin, Germany

jesmateo@ucm.es

We study a one-dimensional Bose-Hubbard gas in a lattice whose hopping energy is made to oscilate with zero time average. Such a driving suppresses first-order particle hopping while allowing higher-order, even processes [1]. At a critical value of the driving amplitude, the system passes from a Mott insulator to an exotic superfluid phase whose cat-like ground state consist of two branches characterized by the preferencial occupation of opposite momentum eigenstates [2]. In the absence of autonomous single-particle hopping, the resulting superfluidity is exclusively driven by correlations. We discuss how such a phase differs qualitatively from conventional superfluidity. The effect is robust against variations in experimental details [3].

Figures

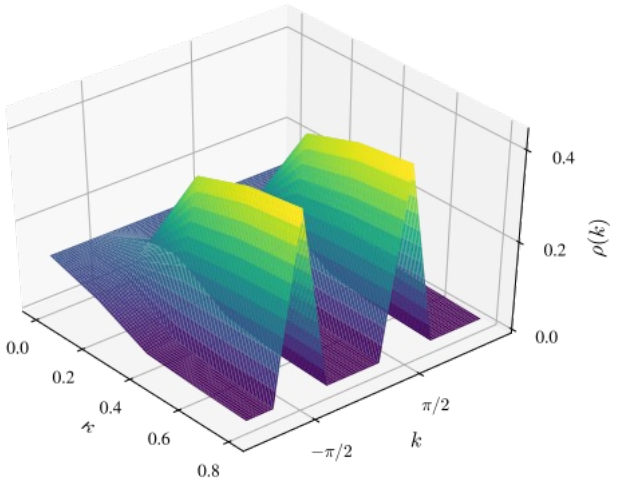


Figure 1: Momentum density vs. the driving parameter κ vs. the set of momenta of the reciprocal lattice k for the ground state of the system.

References

[1] G. Pieplow, F. Sols, C. E. Creffield, New J. Phys., 20 (2018) 073045
[2] G. Pieplow, C. E. Creffield, F. Sols, Phys. Rev. Research, 1 (2019) 033013
[3] J. Mateos, G. Pieplow, C. E. Creffield, F. Sols, Eur. Phys. J. Spec. Top., 230 (2021) 1013-1019

Simulated adiabatic cooling protocols for systems with and without topological excitations

Anne Matthies[1]
Achim Rosch[1], Mark Rudner[2] and Erez Berg[3]

[1]*University of Cologne, 50937 Cologne, Germany*
[2]*University of Washington, Seattle, WA 98195-1560, US,*
[3]*Weizmann Institute of Science, Rehovot, 76100, Israel*

anne.matthies@uni-koeln.de

Preparing the ground state of a many-body Hamiltonian on a quantum device is of central importance, both for quantum simulations of molecules and materials [1], and for a variety of quantum information task [2]. Such a Hamiltonian can be simulated physically by tuning the interaction in e.g. a cold atom system. On a quantum computer the Hamiltonian can also realized in a digital manner. Different approaches to ground state preparation have been proposed, including variational quantum simulation [3], adiabatic evolution [4] and, more recently, also simulated cooling [5,6].

We propose a simple, robust protocol to prepare a low-energy state of an arbitrary Hamiltonian on a quantum computer. The protocol is inspired by the "adiabatic demagnetization" technique, used to cool solid state systems to extremely low temperatures. The adiabatic cooling protocol is demonstrated via an application to the transverse field Ising model (see Fig.1). We use half of the qubits to model the system and the other half as a bath. Each bath spin is coupled to a system spin. In a strong magnetic field, the bath spins are prepared in the polarized ground state. By an adiabatic downward sweep of the magnetic field (see Fig. 2), we change the energy of the bath spins and allow for resonant processes that transfer entropy from the system to the bath qubits. After each cycle, the bath is reset to the ground state. We find that the performance of the algorithm in the presence of a finite error rate depends on the nature of the excitations of the system; systems whose excitations are non-local (topological) objects are more difficult to cool. Finally, we explore ways to partially mitigate this problem.

References

[1] Lloyd, S. Science, 273 (1996) 1073–1078
[2] Fahri, E. et al., arXiv:1411.4028 (2014)
[3] Peruzzo, A. et al., Nat Commun, 5 (2014) 4213
[4] Farhi, E. et al., arXiv:quant-ph/0001106 (2000)
[5] Polla, S. et al., PRA, 104 (2021) 012414
[6] Zaletel, M. et al. PRL, 126 (2021) 103401

Figures

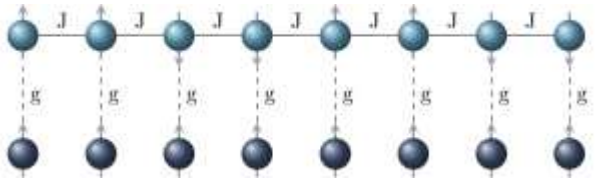


Figure 1: Model: System spins (light blue) are coupled to each other by coupling J. Each bath spin (dark blue) can be coupled to one system spin by coupling g. In the beginning of each cycle the bath is fully polarized.

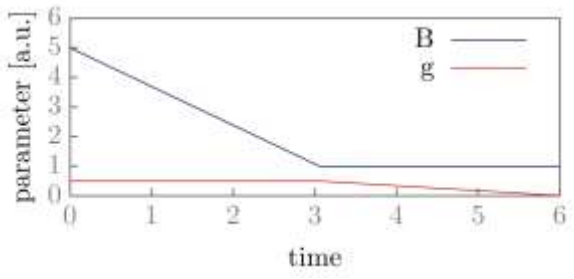


Figure 2: Adiabatic sweep: The magnetic field B of the bath spins is adiabatically decreased in each cycle. Afterwards the coupling g between system and bath slowly switched off.

Controlling photon polarisation in the Poincaré sphere through giant single-spin Kerr rotation

E. Mehdi[1,2]
M. Gundin-Martinez[1], C. Millet[1], N. Somaschi[1], A. Harouri[1], A. Lemaître[1], I. Sagnes[1], O. Krebs[1], P. Senellart[1] and L. Lanco[1,2]

[1]*Centre de Nanosciences et de Nanotechnologies, CNRS, 91120 Palaiseau France*
[2]*Université Paris-Cité, 75013 Paris, France*

elham.mehdi@c2n.upsaclay.fr

The development of a future quantum network requires an efficient interface between a flying qubit and a stationary qubit. Here we use the polarisation of a photon as the flying qubit and the spin of a charge as the stationary one. Our interface is built with a pillar microcavity in which there is an InAs quantum dot (QD), enabling the efficient coupling of incoming photons with the spin of a charge in the QD [1,2]. As shown in figure 1, the polarisation of reflected photons is rotated according to the spin state [3,4,5].

Here, we show a controlled π-phase shift rotation of the polarisation of the photon in the Poincaré sphere after its interaction with a single spin. We display in figure 2 the extrapolated Stokes vector associated to a QD in spin "up" state. The polarisation of the reflected photon depends on the detuning between the laser and the quantum dot, and on the applied magnetic field, in full agreement with the numerical simulations. In particular, the purity of the output polarisation is slightly diminished due to the effect of the hyperfine interaction between the electron and the surrounding nuclei.

This demonstration is a first step toward deterministic spin-photon and photon-photon quantum gates, exploiting the giant spin-induced polarisation rotation.

References

[1] Somaschi et al, Nature Photon. 10, (2016) 340-345
[2] Hilaire et al, PRB 102, (2020) 195402
[3] Hu et al, PRB 78, (2008) 085307
[4] Arnold et al, Nature Commun. 6, (2015) 6236
[5] Androvitsaneas et al, ACS Photonics, 6 (2019) 429-435

Figures

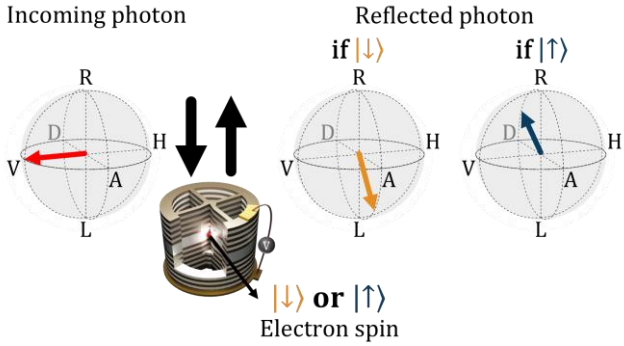


Figure 1: Scheme of an electrically contacted pillar microcavity coupled to a charged quantum dot. The polarisation of reflected photons is rotated through the interaction with the embedded spin qubit.

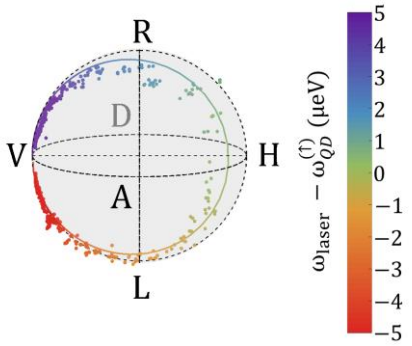


Figure 2: Extrapolated output polarisation measured in the Poincaré sphere as a function of the detuning between the laser and the QD energy, displaying a giant rotation.

Polarization entangled-photon pair source ready for full automation

M. Misiaszek-Schreyner[1], A. Czerwiński[1], T. Kocman[2], B. Olik-Gajewski[2], P. Kolenderski[1]

1. Faculty of Physics, Astronomy and Informatics, Institute of Physics, Nicolaus Copernicus University, Gagarina 11, 87-100 Toruń, Poland
2. SYDERAL Polska, Trzy Lipy 3, 80-172 Gdańsk, Poland

Contact: misiek@umk.pl

In this work we show polarization-entangled photon source that is consisted of two PPLN nonlinear crystals, mounted in the aluminum block, sandwiched between a pair of birefringent crystals [1]. Each PPLN crystal generate pair of infrared photons in specified polarization state, orthogonal to each other. Namely, one crystal produces a pair with vertical $|\updownarrow_1\updownarrow_2\rangle$, the other in horizontal $|\leftrightarrow_1\leftrightarrow_2\rangle$ polarization. That allows to obtain polarization-entangled state $|\leftrightarrow_1\leftrightarrow_2\rangle + |\updownarrow_1\updownarrow_2\rangle$.

The experimental setup of the source is presented in Figure 1. It enables characterization of a source, such as quantum-state tomography measurements, by collecting single counts (SC) and coincidence counts (CC) between detectors (D1, D2) for different sets of motorized quater-wave plates (QWP) and half-wave plates (HWP). The result of such measurement is presented in Figure 2. Figure 3 shows the electronic system that enables to automatically adjust the position of the opto-mechanical elements to the optimal position, thanks to which it is possible to maximize the achieved Bell parameter and state fidelity – measures of quantum entanglement quality. Due to the use of motorized components, the setup of such source is self-alining. All components used are commercially available.

References

[1] R. Horn, T. Jennewein, *Opt. Express,* **27** (2019) 17369

Figures

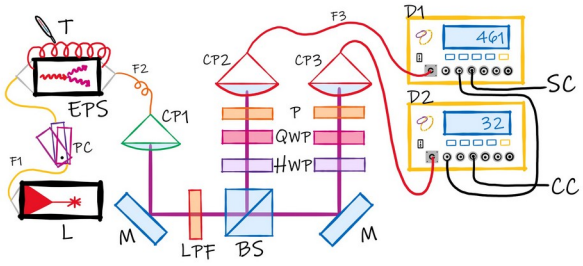


Figure 1: Experimental setup. Photon source(EPS) generates entangled states, which are characterized by coincidence measurements with InGaAs detectors (D1,D2), on different settings of motorized quater-wave plates (QWP) and half-wave plates (HWP).

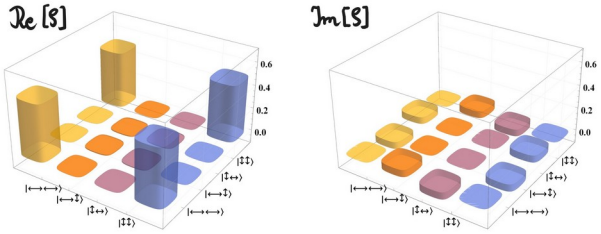


Figure 2: Real and imaginary part of the density matrix representing the entangled state produced by the source.

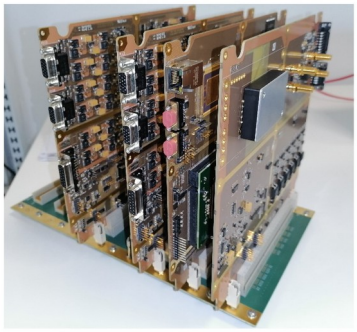


Figure 3: SECSQES electronics, responsible for controlling instruments within experiment, consisting of 6 modules: Power supply Unit, Control Unit (LEON3 space grade processor and FPGA chip, containing artificial Intelligence and steering algorithms), two Stepper Motor Units, Piezo Actuator Unit, Auxiliary Unit/Detector Interface Module (50ps resolution for input signals, automatic phase comparator and pulse generator for FPGA chip, laser current driver, laser temperature controller and PPLN crystal temperature controller.

Time-Series Processing with Quantum Measurements

Pere Mujal
Rodrigo Martínez-Peña, Gian Luca Giorgi, Miguel C. Soriano, and Roberta Zambrini

IFISC, Institut de Física Interdisciplinària i Sistemes Complexos (UIB-CSIC), UIB Campus, E-07122 Palma, Mallorca, Spain

peremujal@ifisc.uib-csic.es

Reservoir computing has a remarkable advantage over other supervised learning strategies, i.e. recurrent neural networks, since the training process is simpler and faster. The extension of this unconventional computing method to the quantum domain, firstly proposed in [1], adds benefits to this feature. Quantum systems are notorious for their large state space entailed by the principle of quantum superposition and by the possibility of displaying entanglement between their constituents. Quantum reservoir computing and related approaches harness these features and exploit the natural dynamics of quantum systems for computational purposes to perform a wide variety of machine-learning tasks, both classical and quantum [2]. In the last few years, there has been an increasing interest in this field that has led to the development of proposals suitable for various quantum platforms [2–4]. Additionally, recent theoretical studies have elucidated how to design and operate quantum reservoirs in order to maximize their performance. For instance, through the input encoding [5], by choosing an appropriate dynamical regime [6], or by analytically showing the origin of the required nonlinearities for qubits and continuous-variable systems [7]. A still challenging aspect is to consider measurement effects. Quantum systems are infamous for the crucial influence of measurements on their quantum state which could be detrimental for information processing purposes. Typically, a time-dependent input series is encoded into and processed by the quantum reservoir and the observable quantities of the system are used to produce the final output to address the task at hand. It is commonly assumed that, experimentally, the system will need to be restarted several times to be measured, or, alternatively, many copies of the system should be accessed. We propose various measurement strategies to tackle this problem which can be followed in order to obtain the expectation values of the observables at each time step [8]. Importantly, the best choice may depend on the specific features of the experimental platform or the task. We discuss this question from a fundamental point of view accounting for the backaction effect of the measurements on the system, and also from a practical perspective, i.e. with a finite number of measurements available. By means of numerical simulations, we analyze the impact of the measurement procedure into the performance of a quantum reservoir of spins in terms of memory and predictive capacity with a focus on the required experimental resources.

References

[1] K. Fuji, K. Nakajima, Phys. Rev. Applied 8, 024030 (2017).
[2] P. Mujal, R. Martínez-Peña, J. Nokkala, J. García-Beni, G. L. Giorgi, M. C. Soriano, R. Zambrini, Adv. Quantum Technol., 2100027 (2021).
[3] S. Ghosh, A. Opala, M. Matuszewski, T. Paterek, T. C. Liew, npj Quantum Inf. 5, 1 (2019).
[4] J. Chen, H. I. Nurdin, N. Yamamoto, Phys. Rev. Applied 14, 024065 (2020).
[5] J. Nokkala, R. Martínez-Peña, G. L. Giorgi, V. Parigi, M. C. Soriano, R. Zambrini, Comm. Phys. 4, 1 (2021).
[6] R. Martínez-Peña, G. L. Giorgi, J. Nokkala, M. C. Soriano, R. Zambrini, Phys. Rev. Lett. 127, 100502 (2021).
[7] P. Mujal, J. Nokkala, R. Martínez-Peña, G. L. Giorgi, M. C. Soriano, R. Zambrini, J. Phys. Complex. 2, 045008 (2021).
[8] P. Mujal, R. Martínez-Peña, G. L. Giorgi, M. C. Soriano, R. Zambrini, [In preparation, soon in arXiv] (2022).

Trapping and binding by dephasing

Kaustav Mukherjee
S. Poddar, S. Wuester

IISER Bhopal, Bhopal, Madhya Pradesh, India - 462066

kaustav16@iiserb.ac.in

Abstract

The binding and trapping of particles usually rely on conservative forces, described by unitary quantum dynamics. We will demonstrate how both can also arise solely from spatially dependent dephasing, the simplest type of decoherence. This can be based on continuous weak position measurements in only selected regions of space, for which we propose a practical realisation. For a single particle, we demonstrate a quantum particle-in-a-box based on dephasing. For two particles, we demonstrate their binding despite repulsive interactions, if their molecular states are dephased at large separations only. Both mechanisms are experimentally accessible, as we show for an example with Rydberg atoms in a cold gas background.

References

1. F. Reiter and A. S. Sorensen, Phys. Rev. A 85 (2012) 032111
2. D. W. Schoenleber, A. Eisfeld, M. Genkin, S. Whitlock, S. Wuester, Phys. Rev. Lett. 114 (2015) 123005
3. K. Mukherjee, S. Poddar, S. Wuester, Phys. Rev. A (Letters), [Accepted 2022]

Figures

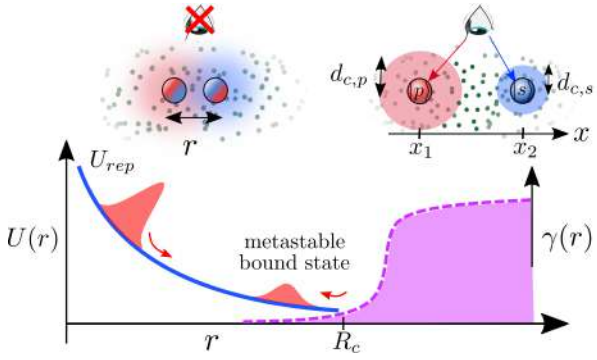


Figure 1: Formation of metastable bound states of repulsively interacting Rydberg dimer using selective relative distance measurements via Electromagnetically Induced Transparency (EIT).

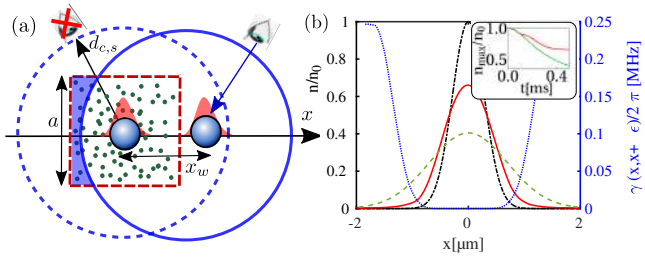


Figure 2: Trapping a single particle through dephasing. (a) Sketch of an atom trapped in a dephasing well resulting from position measurements, (b) Probability density of trapped particle at various times.

Anyonic Molecules in Atomic Fractional Quantum Hall Liquids: A Quantitative Probe of Fractional Charge and Anyonic Statistics

Alberto Muñoz de las Heras[1,2*]
Elia Macaluso[2]
Iacopo Carusotto[2]

[1]*Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain*

[2]*INO-CNR BEC Center and Università di Trento, via Sommarive 14, 38123 Trento, Italy*

[*]a.munozdelasheras@gmail.com

Abstract

We study the quantum dynamics of massive impurities embedded in a strongly interacting, two-dimensional atomic gas driven into the fractional quantum Hall (FQH) regime under the effect of a synthetic magnetic field. For suitable values of the atom-impurity interaction strength, each impurity can capture one or more quasihole excitations of the FQH liquid, forming a bound molecular state with novel physical properties. An effective Hamiltonian for such anyonic molecules is derived within the Born-Oppenheimer approximation, which provides renormalized values for their effective mass, charge, and statistics by combining the finite mass of the impurity with the fractional charge and statistics of the quasiholes. The renormalized mass and charge of a single molecule can be extracted from the cyclotron orbit that it describes as a free particle in a magnetic field. The anyonic statistics introduces a statistical phase between the direct and exchange scattering channels of a pair of indistinguishable colliding molecules and can be measured from the angular position of the interference fringes in the differential scattering cross section. Implementations of such schemes beyond cold atomic gases are highlighted, in particular, in photonic systems.

References

[1] A. Muñoz de las Heras et al., Phys. Rev. X, 10 (2020) 041058

Figures

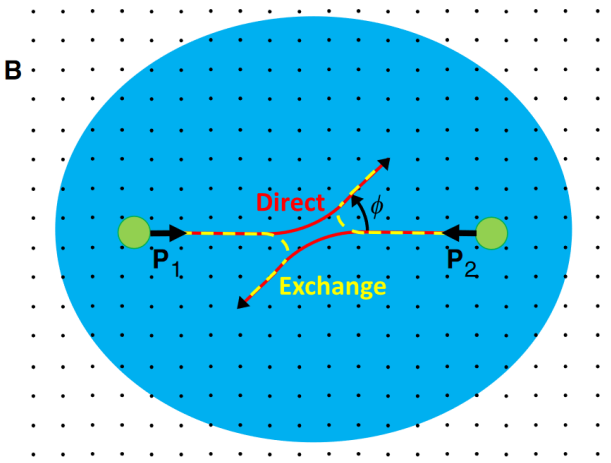


Figure 1: Scattering of two anyonic molecules (green circles) formed by the binding of the same number of quasiholes to a pair of identical impurities in the bulk of a FQH fluid (blue region). The two molecules are given momentum kicks against each other (P1 and P2, respectively). Because of their indistinguishability, two scattering channels contribute to the differential scattering cross section at an angle φ: The two channels are labeled as "direct" (red, solid trajectories) and "exchange" (yellow, dashed ones) and involve a relative phase determined by the anyonic statistics. As one can guess from textbook two-slit interference, information about the statistics can be extracted from the global position of the interference fringe pattern.

Qudit-based transpilation of quantum circuits

Anastasiia Nikolaeva[1,2,3]
E.O. Kiktenko[1,2,3], A.K. Fedorov[1,3]

[1]*Russian Quantum Center, Skolkovo, Moscow 143025, Russia*
[2]*Moscow Institute of Physics and Technology, Moscow Region 141700, Russia*
[3]*National University of Science and Technology ``MISIS'', Moscow 119049, Russia*

anastasiya.nikolayeva@phystech.edu

Recent progress in the development of quantum processors based on d-level quantum systems, qudits [1,2], makes it essential to study subtle aspects of quantum algorithms implementation on them. Since qudits provide more computational space compared to qubits, the number of possible implementations of the given circuit increases significantly. This is due to the fact that depending on a particular mapping between qubits' and qudits' computational spaces, the resulting qudit-based circuits that realise the same qubit-based circuit can be very different, e.g. in terms of the number of two-qudit operations required for algorithm's implementation. As a result, developing a method for efficient quantum circuit transpilation is crucial.

Basically, there are two main approaches to use qudits [3]. First of them is to embed several qubits in the d-dimensional space of one qudit. This technique is relevant when the number of qubits n is such that $d \geq 2^n$. It allows us to reduce the number of information carriers (e.g. atoms or ions). The second method is to substitute ancillary qubits by higher levels of qudits [4,5]. The use of qudits' upper levels as ancillas dramatically reduces the the number of two-particle gates in multiqubit gate decomposition, therefore it is especially useful for implementation of quantum circuits with multiqubit gates.

We develop a qudit-based circuit transpiler that supports a combination of two basic approaches to use qudits, while the works proposed earlier consider only one of them. Our transpiler takes as input a qubit-based quantum circuit with the concrete qubit-to-qudit mapping and creates a qudit circuit, which can be implemented on a qudit-based quantum processor as a sequence of single- and two-qudit gates. We expect our approach to provide a valuable contribution to the realisation of quantum algorithms on qudit-based quantum processors.

The work was supported by RSF grant No. 19-71-10091 and LRC program on Quantum Computing (Agreement No. 014/20).

References

[1] M. Ringbauer, M. Meth, L. Postler, R. Stricker, R. Blatt, P. Schindler, T. Monz, arXiv:2109.06903 [quant-ph] (2021)
[2] Alexander D. Hill, Mark J. Hodson, Nicolas Didier, Matthew J. Reagor, arXiv:2108.01652 [quant-ph] (2021)
[3] A. S. Nikolaeva, E. O. Kiktenko, A. K. Fedorov, arXiv211.04384 [quant-ph] (2021)
[4] A. S. Nikolaeva, E. O. Kiktenko, A. K. Fedorov, Phys. Rev. A 105, 032621 (2022)
[5] E. O. Kiktenko, A. S. Nikolaeva, Peng Xu, G. V. Shlyapnikov, A. K. Fedorov, Phys. Rev. A 101, 022304 (2020)

Dynamical Decoupling Error Mitigation on Quantum Applications

Siyuan Niu
Aida Todri-Sanial

LIRMM, University of Montpellier, CNRS, 161 Rue Ada, 34095, Montpellier, France

siyuan.niu@lirmm.fr

Today's quantum computers are prone to errors in the Noisy Intermediate-Scale Quantum (NISQ) era. Since there are not enough resources to realize quantum error correction, an alternative approach for quantum error mitigation was proposed, aiming at reducing the impact of errors to explore useful NISQ applications.

Dynamical decoupling (DD) is one of the simplest methods to suppress decoherence error without additional circuit overhead. The thrust of DD is to insert periodically a series of pulses to the idle qubits and return the qubits to their original states. Various DD strategies have been proposed, including non-universal, universal, and robust ones with different impacts. However, it has been demonstrated that the naive implementation of some of the DD techniques (inserting DD sequences to all the idle qubits) cannot always be beneficial to the circuits [1]. The state-of-the-art application-level DD insertion methods require a large overhead of tuning DD pulses by executing several additional circuits [1-2].

In our work [3], we address the following questions: (1) What are the impacts of different sequences on specific applications? (2) For a certain benchmark, does the impact of different DD sequences vary across different quantum chips. We study all the popular DD strategies, such as CPMG, XY4, UDD, KDD, and explore their performance in various quantum applications, including Bernstein-Vazirani (BV) algorithm, Hidden Shift (HS) algorithm, Quantum Fourier Transform (QFT), Graph State (GS), and QAOA. We evaluate the experiments on several IBM devices with different qubit numbers and quantum volumes.

We define application-specific metrics to evaluate the difference of each application before and after inserting DD sequences. Some of the results are shown in Figure 1. For the complete results, please refer to our paper [3]. Based on the experimental results, we found that DD techniques always show a positive impact on some benchmarks, such as BV and QAOA. Whereas for others, DD demonstrates some discouraging effects. We also provide a list of design guidelines for users to better understand different DD techniques and figure out how to improve the circuit design for various quantum applications.

References

[1] P. Das, S. Tannu, S. Dangwal, and M. Qureshi, Adapt:Mitigating idling errors in qubits via adaptive dynamical decoupling, in MICRO-54, 2021.
[2] G. S. Ravi, K. N. Smith, P. Gokhale, A. Mari, N. Earnest, A. Javadi-Abhari, and F. T. Chong, Vaqem: A variational approach to quantum error mitigation, arXiv:2112.05821, 2021.
[3] S. Niu, A. Todri-Sanial, Pulse-level noise mitigation on quantum applications, arXiv: 2204.01471, 2022.

Figures

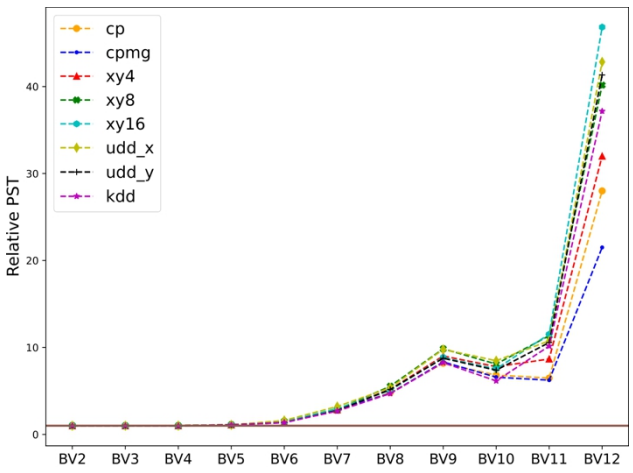


Figure 1: Relative PST results for BV circuits on IBM Q 27 Montreal. Higher is better.

Unraveling Quantum Scrambling with Neural Networks

Jan Olle
Jeff Murugan, Dario Rosa, Ruth Shir

Max Planck Institute for the Science of Light, Erlangen, Germany.

Institut de Fisica d'Altes Energies (IFAE)
The Barcelona Institute of Science and Technology (BIST), Campus UAB, Bellaterra (Barcelona) Spain.

Center for Theoretical Physics of Complex Systems, Institute for Basic Science (IBS), Daejeon, Korea.

jan.olle@mpl.mpg.de

Abstract

Quantum scrambling is the process by which quantum information is spread within the degrees of freedom of many-body quantum systems. As such, understanding what are the features of a quantum system that maximise this information spreading has become a recent topic of interest of crucial importance. Graph theory provides a natural mathematical framework to encode the interactions of a quantum many-body system, and we thus employ it to study the properties of quantum scrambling as we vary the underlying graph of interactions.
Predicting when a particular quantum many-body system features either strong quantum scrambling (chaotic system) or not (integrable system) is a delicate issue where sophisticated computationally expensive methods are needed. Using the adjacency matrix of the underlying graph of interactions we set up a supervised classification problem that we solve using (i) A standard 2D Convolutional Neural Network, and (ii) A Graph Neural Network. We show that well-known graph-theoretic quantities such as clustering coefficients control the quantum scrambling properties of the system. This suggests that far simpler quantities than previously thought might be needed in order to understand quantum scrambling.
While very much a work in progress, we believe our results pave the way for a better understanding of how to maximize the spreading of quantum information.

References

1. J.Murugan, J.Olle, D.Rosa, R.Shir, To appear.
2. J.Kim, J.Murugan, J.Olle, D.Rosa, Phys.Rev.A 105 (2022) 1, L010201

Figures

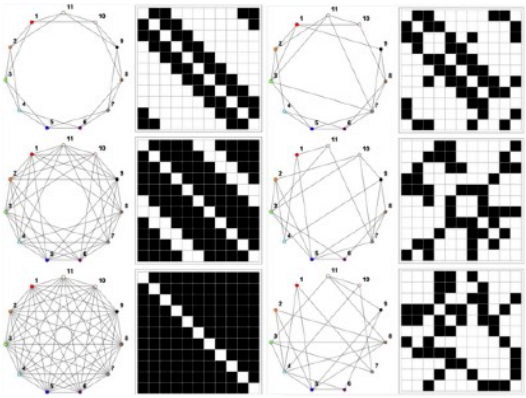


Figure 1: Examples of graphs with their associated adjacency matrix, here represented by an N × N array coded black where a connection exists and white otherwise.

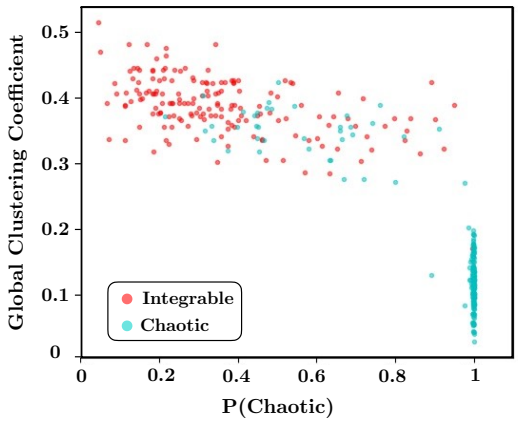


Figure 2: Global clustering coefficient as a function of the probability to be chaotic as predicted by the NN. Different colors correspond to the different labels used in the supervised training.

Effect of dilute impurities on short graphene Josephson junctions

Francesco M.D. Pellegrino[1,2,3]
Giuseppe Falci[1,2,3] and Elisabetta Paladino[1,2,3]

1 Dipartimento di Fisica e Astronomia "Ettore Majorana", Università di Catania, Via S. Sofia 64, I-95123 Catania, Italy.
2 INFN, Sez. Catania, I-95123 Catania, Italy.
3 CNR-IMM, Via S. Sofia 64, I-95123 Catania,

francesco.pellegrino@dfa.unict.it

Within the Dirac-Bogoliubov-de Gennes approach [1], we study the effect of a dilute homogeneous spatial distribution of nonmagnetic impurities on the equilibrium supercurrent sustained by a ballistic graphene Josephson junction, in the short junction limit [2,3]. We find a modification of the current-phase relation with a reduction of the skewness induced by the disorder, and a nonmonotonic temperature dependence of the critical current. Moreover, we investigate the power spectrum of the supercurrent, used as a tool for spectroscopic analysis of the disordered impurities.

References

[1] M. Titov and C. W. J. Beenakker., Phys. Rev B, 74 (2006) 041401.
[2] F. M. D. Pellegrino, G. Falci, and E. Paladino, Communications Physics, 3,(2020) 6.
[3] F. M. D. Pellegrino, G. G. N. Angilella, and R. Pucci, Phys. Rev. B, 80 (2009) 094203.

A quantum-circuit algorithm for simulating artificial graphene

Adrián Pérez-Salinas
Axel Pérez-Obiol, Sergio Sánchez-Ramírez, B. G. Moraes, Artur Garcia-Saez

Barcelona Supercomputing Center (BSC), Barcelona 08034, Spain

adrian.perezsalinas95@gmail.com

In this work, a quantum algorithm for attaining the ground state and energy of free moving electrons in an artificial graphene (AG) lattice is developed. This work thus lies in the intersection of condensed-matter physics and quantum computing, and makes use of HPC resources to perform simulations.

The AG is modeled via the 2D Fermi-Hubbard Hamiltonian including hopping, Coulomb and spin-orbit terms. The algorithm to obtain this ground state is carried in three steps. First, the lattice is mapped to a quantum computer using the Jordan-Wigner mapping. Second, an easy-to-prepare initial state is created in the quantum computer. This initial state does not consider any interacting electrons [1]. Finally, adiabatic evolution is performed to include all elements in the model of interest. The exact implementation is based on previous works for square lattice [2], adapted and improved to this problem. The algorithm is efficiently performed, requiring a linear number of operations with respect to the system size both for the initial state preparation and for each step in the adiabatic evolution.

The algorithm is simulated using simulators quantum circuits build upon exact statevector [3] and Matrix Product States (MPS) [4]. Calculations are made in supercomputer MareNostrum 4 at BSC. Exact simulation is performed for systems up to 32 qubits, while MPS methods permit to arrive up to 36 qubits with fidelities over 99%. With a sufficient amount of resources, the errors in the final energy can be bounded below 1% with respect to the initial one, see Fig. 1. Future extensions of this work aim to use distributed computing to increase the size of addressable systems.

References:
[1] Jiang, Zhang, et al., *Physical Review Applied* 9.4 (2018): 044036.
[2] Cade, Chris, et al., *Physical Review B* 102.23 (2020): 235122.
[3] Efthymiou, Stavros, et al., *Quantum Science and Technology* 7.1 (2021): 015018.
[4] Sánchez-Ramírez, Sergio, et al., *IEEE/ACM Second International Workshop on Quantum Computing Software* (2021).

Figures:

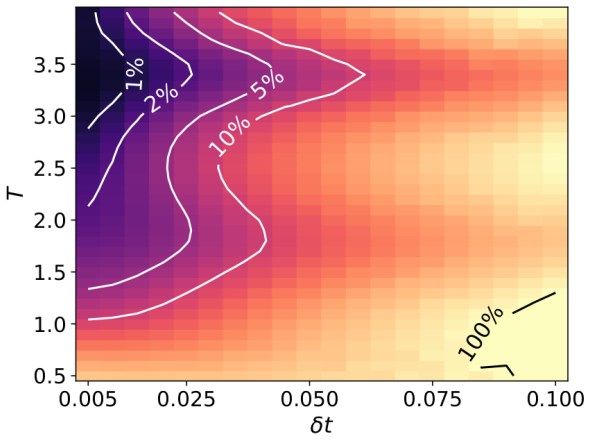


Figure 1: Error in the obtained energy with respect to the initial one for a sample system depending on adiabatic evolution time (T) and time steps (δt).

Many-body quantum phases in ultracold dipolar gases

C. Politi[1,2]
L. Klaus[1], E. Casotti[1], M. J. Mark[1,2] and F. Ferlaino[1,2]

[1]*Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria*

[2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

claudia.politi@uibk.ac.at

In the last decades, ultracold atomic gases proved to be an ideal platform for simulating many-body quantum phenomena thanks to the ability of adding complexity in a controlled way. Recently, ultracold gases made of magnetic atoms brought to the discovery of new phenomena and exotic states of matter arising from the long-range and anisotropic dipole-dipole interactions, as roton modes and supersolidity [1].

We present here the latest results from our dipolar quantum gas experiment, which uniquely combines two highly magnetic atomic species, erbium (Er) and dysprosium (Dy) [2]. Our quantum mixture merges for the first time the field of heteronuclear mixtures with the one of ultracold dipolar gases. After the investigation of their interspecies interactions [3], we proved two-dimensional supersolidity with dysprosium [4], paving the way to the study of vortices, persistent currents, and phases with exotic geometry.

As a future step in the experiment, we present our concept for quantum gas microscopy of dipolar systems, designed to manipulate the two species at the single-atom level within a highly-controlled magnetic field environment, where complex phases arising from the spontaneous orientation of the dipoles can appear.

References

[1] M. A. Norcia and F. Ferlaino, Developments in atomic control using ultracold magnetic lanthanides, Nat. Phys. 17, 1349 (2021).
[2] A. Trautmann, P. Ilzhöfer, G. Durastante, C. Politi, M. Sohmen, M. J. Mark, and F. Ferlaino, Dipolar Quantum Mixtures of Erbium and Dysprosium Atoms, Phys. Rev. Lett. 121, 213601 (2018).
[3] C. Politi, A. Trautmann, P. Ilzhöfer, G. Durastante, M. J. Mark, M. Modugno, and F. Ferlaino, Interspecies interactions in an ultracold dipolar mixture, Phys. Rev. A 105, 023304 (2022).
[4] M. A. Norcia, C. Politi, L. Klaus, E. Poli, M. Sohmen, Manfred J. Mark, R. N. Bisset, L. Santos and F. Ferlaino, Two-dimensional supersolidity in a dipolar quantum gas. Nature 596, 357–361 (2021).

Figures

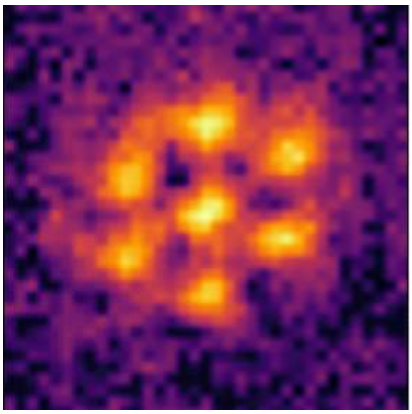


Figure 1: Experimental realization of two-dimensional supersolidity with dysprosium atoms

Nonlocal conductance spectroscopy of Andreev bound states in 2DEG-based nanowires

Andreas Pöschl[1]*
Alisa Danilenko[1], Deividas Sabonis[1], Kaur Kristjuhan[1], Tyler Lindemann[2], Candice Thomas[2], Sergei Gronin[2], Geoffrey C. Gardner[2], Michael J. Manfra[2], Charles M. Marcus[1]

[1]*Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5, 2100 Copenhagen, Denmark*
[2]*Purdue University, Birck Nanotechnology Center, West Lafayette, Indiana 47907, USA*

andreas.poschl@nbi.ku.dk

We present experimental measurements of local and nonlocal tunneling spectroscopy of Andreev bound states in a hybrid superconductor-semiconductor three-terminal device based on a gate-defined InAs two-dimensional electron gas (2DEG) with an epitaxial Al layer. Andreev bound states in a nanowire with 0.6 micrometers between probes are investigated as a function of parallel magnetic field. At magnetic fields of order 2 T, we observe low-energy Andreev bound states, which oscillate around zero bias as a function of gate voltage, revealing in the non-local signal the oscillating electron-hole character of the bound state, consistent with theoretical predictions [1,2]. An improved device geometry that allows for spatially resolved control of the electrostatic confining potential is presented.

Figures

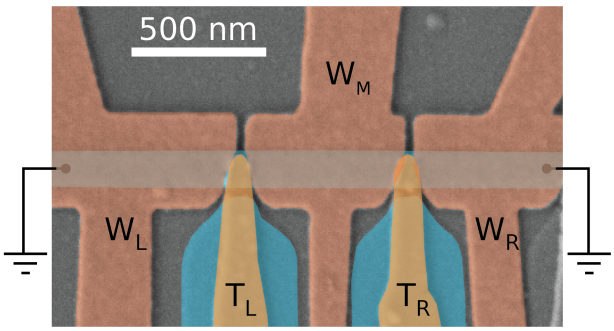


Figure 1: Three-terminal device based on Al-InAs superconductor-semiconductor hybrid heterostructure.

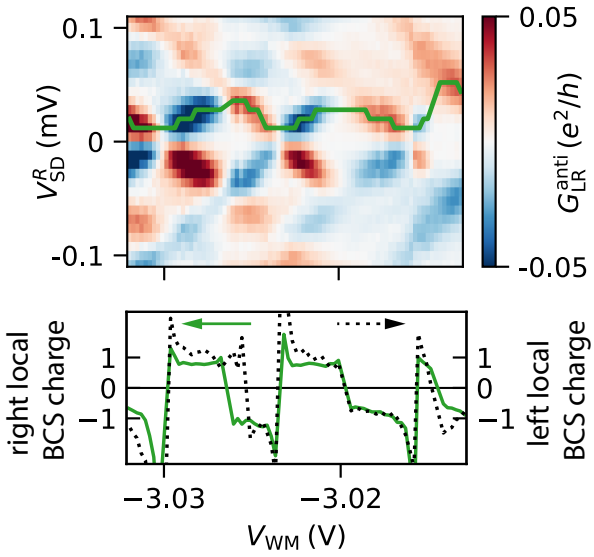


Figure 2: Nonlocal conductance of Andreev bound states at 2 T magnetic field parallel to the nanowire and extracted local Bardeen-Cooper-Schrieffer (BCS) charge.

References

[1] J. Danon et al., Phys. Rev. Lett. 124 (2020) 036801
[2] G.C. Ménard et al., Phys. Rev. Lett. 124 (2020) 036802

Experimental proposal to probe the extended Pauli principle

Nika Akopian [a]

Lucas Fabian Hackl [b, †]
Dayang Li [a,†]
Matthias Christandl [c]

[a] *Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark*
[b] *School of Mathematics and Statistics & School of Physics, The University of Melbourne, Melbourne, Australia*
[c] *QMATH, Department of Mathematical Sciences, University of Copenhagen, Copenhagen, Denmark*
[†] *Equal contribution*

dayli@fotonik.dtu.dk

Fundamental principles in Physics — such as the well-known Pauli exclusion principle — lie at the core of the entire discipline with far-reaching implications: from the electron shell structure of atoms to the stability of matter itself, including neutron stars. The extended Pauli principle is not an exception — it too provides a fundamental constraint on the natural occupation numbers of any pure fermionic state. It is, for instance, an important benchmark for the simulation of fermionic quantum matter.

So far, however, it has never been accessed experimentally. Here, we propose an experiment [1] in a multi-quantum-dot system capable of producing the highly entangled fermionic states necessary to reach the regime, where the inequalities of the extended Pauli principle become relevant. Our proposal combines recent theoretical results revealing an onion-like structure of barriers limiting the allowed entanglement and experimental advances that enable us to transcend these barriers by carefully controlling the quantum states. The multi-quantum-dot system and coherent fermionic operations in our proposal are recently developed by us in [2]. We simulate our state preparation procedures in realistic structures, including all main decoherence sources, and find fidelities above 0.97. All highly entangled states comply with the extended Pauli constraints well within error margins.

The extended Pauli constraints are present in every fermionic system. Our proposal therefore opens up a standardized pathway for experimental exploration of the extended Pauli principle.

References

[1] L. Hackl, D. Li, N. Akopian, and M. Christandl, Experimental proposal to probe the extended pauli principle (2021),arXiv:2107.05961 [quant-ph].

[2] D. Li and N. Akopian, Location qubits in a multi-quantum-dot system (2021), arXiv:2107.05960 [quant-ph].

Figures

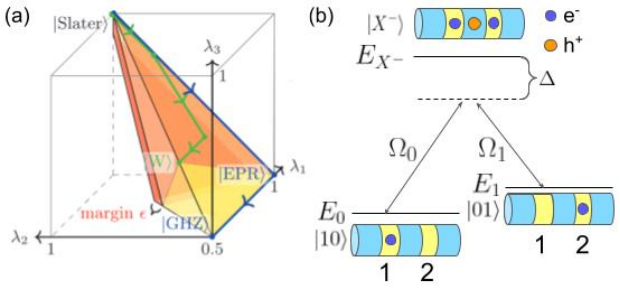


Fig. 1: (a) The all-optical manipulation scheme of our multi-quantum-dot system. A section of a semiconductor nanowire (GaAs or InP) in the Wurtzite (WZ, blue) phase with a pair of crystal-phase quantum dots in the zincblende phase (ZB, yellow). There is a localized spin-orbital for electrons (dark blue dots) on each quantum dot that share a common excited state with a hole (orange dot) in the WZ region. Two laser pulses Ω_0 and Ω_1 of different wavelengths drive the left and right optical transitions respectively, both far detuned from the common excited state by Δ. By exploiting the dynamics of such a system, we coherently manipulate the fermionic states. (b) Our simulation results show that the representative highly entangled fermionic states (EPR, GHZ & W state) can be prepared with high fidelity. Both merit functions $F_1=\lambda_1+\lambda_2-\lambda_3$ and $F_2=\lambda_1+\lambda_2+\lambda_4$ satisfy the extended Pauli constraints $F_1\leq 1+\varepsilon$ and $F_2\leq 2+\varepsilon$ for all three states, taking into account the error margins due to the slightly impure nature of the prepared states.

Covered-gold-nanorod-dimer for optical and electrical hybrid applications

Andres A. Reynoso[a,b]
Iván A. Ramos[a,c], L. M. Leon Hilario[c] and María L. Pedano[a]
[a]*Centro Atómico Bariloche & INN, CNEA-CONICET, Av. Bustillo 9500, Bariloche, Argentina*
[b]*Departamento de Física Aplicada II, Universidad de Sevilla, Av. de la Reina Mercedes, 2, E-41012 Sevilla, Spain*
[c]*Facultad de Ciencias, Universidad Nacional de Ingenieria, Apartado 31-139, Av. Tupac Amaru 210, Lima, Peru*
E-mail: reynoso@cab.cnea.gov.ar

Illuminated gapped-gold-nanorod dimers hold surface plasmon polaritons (SPPs) that can be engineered, by an appropriate choice of geometrical parameters, to enhance the electromagnetic field at the gap, allowing applications in molecular detection via surface-enhanced Raman spectroscopy (SERS) [1]. Envisioning hybrid devices in which the SERS spectroscopy of molecules in the gap is complemented by electrical measurements, it arises the question of designing efficient geometries to contact the nanorods without decreasing the enhancement factor (EF) of the nanoantenna, i.e., the figure of merit for SERS spectroscopy. We show [2] that covering with gold the far-from-the-gap areas of the dimer can produce enhancement factors larger than the best achieved in the uncovered dimer. This paves the way towards the use of these devices both for hybrid electrical and optical applications in sensing and detection of target molecules. Here, we explore the response of the system inside a cavity, a situation that can be useful for coupling the dimer´s plasmons to the cavity field enabling potential quantum applications.

References

[1] S. Li, M. L. Pedano, S.-H. Chang, C. A. Mirkin and G. C. Schatz, Nano Lett., 10(2010), 1722–1727.
[2] Iván A. Ramos, L. M. León Hilario, María L. Pedano, Andres A. Reynoso, RSC Adv.,11(2021), 9518-9527.

Figures

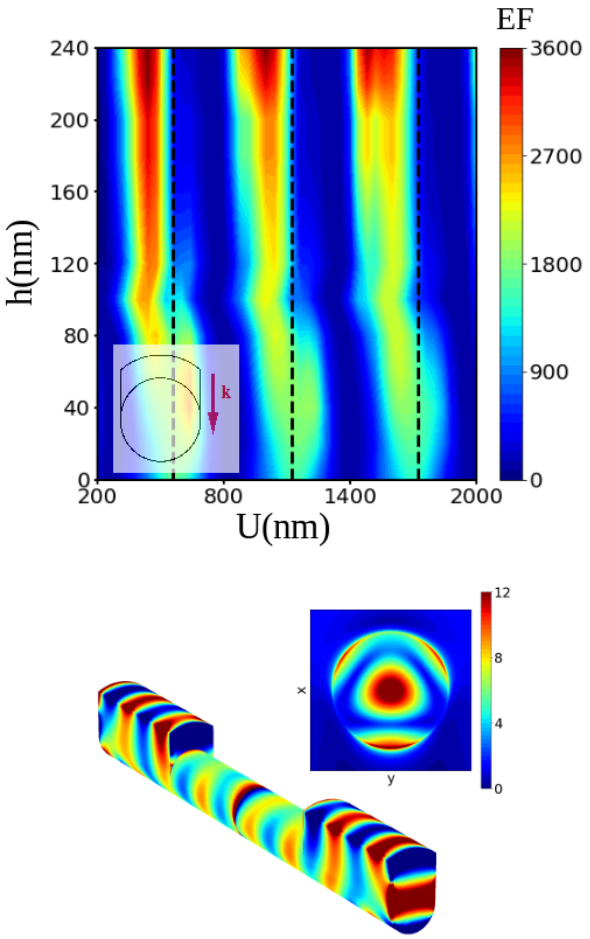


Figure 1: (top) Enhancement Factor in function of *U* and *h* lengths for a covered gold dimer of *C* = 1200nm. (bottom) Surface charge density of the dimer and |E| distribution in the x-y plane near the gap (2nm inside the gap).

Quantum Intranets for Scalable Multi-Core Quantum Computing

Santiago Rodrigo [1]
Sergi Abadal [1]
Medina Bandiç [2]
Hans van Someren [2]
Sebastian Feld [2]
Carmen G. Almudéver [3]
Eduard Alarcón [1]

[1] *N3Cat, Universitat Politècnica de Catalunya - BarcelonaTech*
[2] *QuTech, TU Delft, The Netherlands*
[3] *Universitat Politècnica de València,*

srodrigo@ac.upc.edu

The unprecedented power of Quantum Computing (QC) has been lately accelerating its endeavour from the theory to the experimental demonstration [1]. However, the complexity and resource-intensive nature of current quantum processors make every qubit count, and scaling up to the qubit numbers that are needed to unlock the full potential of QC is proving to be a considerable obstacle to surmount [2]. Together with research on improving qubit isolation and control, multi-core quantum processors have been proposed as a solution to these scalability issues [3]: interconnecting current quantum chips with dozens of qubits each (Fig. 1) with experimentally demonstrated chip-to-chip quantum state transfers (using e.g. ion shuttling or qubit teleportation)[4] in a quantum intranet is envisioned to be the"quantum leap" that will unleash QC performance. Nevertheless, coordinating several independent quantum processors comes with its own share of challenges. Communicating quantum data, which cannot be copied and is steadily corrupted, implies an environment where latencies play a leading role, thus affecting the overall computation performance. Because of this, we postulate that to lay firm foundations for multi-core quantum computing architectures, a deeply entangled design between quantum communication and computation is essential. Much work is being done on large-scale quantum communications and the Quantum Internet [5], yet a gap exists covering chip-scale quantum communications for QC. In our oral presentation, we propose a double full-stack layered vision combining communications with single-chip quantum computer designs (Fig. 1). This approach lets us perform thorough design explorations of these systems in order to derive the minimum requirements for the quantum-coherent inter-core interconnect that will ultimately unlock QC scalability.

Figures

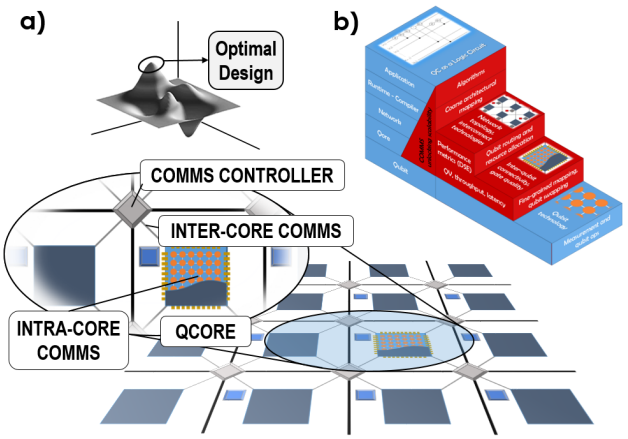


Figure 1: Multi-core quantum platform vision.
a) 3D diagram of a multi-CORE architecture
b) Double layered full-stack architecture

References

[1] F. Arute et al. Nature, vol 574, no. 7779 (2019) pp. 505-510
[2] J. Preskill, Quantum, vol. 2, (2018) p. 79
[3] K. R. Brown et al., npj Quantum Information, vol. 2, no. 1, (2016) pp. 1-10
[4] D. Llewellyn et al., Nature Physics, vol. 16, no. 2 (2020) pp. 148–153
[5] S. Wehner et al., Science, vol. 362, no. 6412 (2018) p. eaam9288
[6] S. Rodrigo et al., IEEE Micro, vol. 41, no. 5 (2021), pp. 48-56

Simulating quantum systems with Neural Networks

Javier Rozalén Sarmiento[1,2]
Arnau Rios Huguet[1,2], James W.T Keeble[3]

[2]*Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona, Martí Franquès 1, E08028 Barcelona, Spain*
[3]*Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*

[1] jrozalsa7@alumnes.ub.edu

The Schrödinger equation is the main pillar of Quantum Mechanics, yet an analytical solution exists solely for some simple cases. As a consequence of this, numerical solutions are in order, and indeed computational approaches tackling this very problem have been around for the last few decades. However, it is widely known that as systems become more complex, even the most powerful supercomputers available fall short.

Motivated by the opportunity to find a solution to this, our work is along a line that is gaining momentum in the Physics community, which is the usage of Machine Learning methods, namely Artificial Neural Networks (ANNs), that are capable of "learning" the wave function of a system without previous exposure to a solution (not to be confused with supervised learning). Our approach is variational: we have an ANN represent the wave function and we train it to minimise the energy expectation, which is an upper bound of the exact ground state energy. This is a well-established method, first published in 2017 [3].

Our contribution is twofold. First, by building a simple ANN we are able to model a nuclear ground state wave function to within 2 keV of the exact energy; this can be seen in Figure 2. Second, we build four different neural networks and we train them to solve the same problem, with the ultimate goal of understanding in a deep level the effect of changes in the network architecture. Whereas this discussion is typically omitted in the literature, we believe that if Machine Learning is to compete against the solid, classical computation methods, a thorough understanding of each element of our model (the Neural Network in this case) is indispensable.

References

[1] J.W.T Keeble and A. Rios, Phys. Lett. B, 809 (2020).
[2] H. Saito, Journal of the Phys. Society of Japan, 87(7) (2017).
[3] G. Carleo and M. Troyer, Science, 355(6325) (2017)

Figures

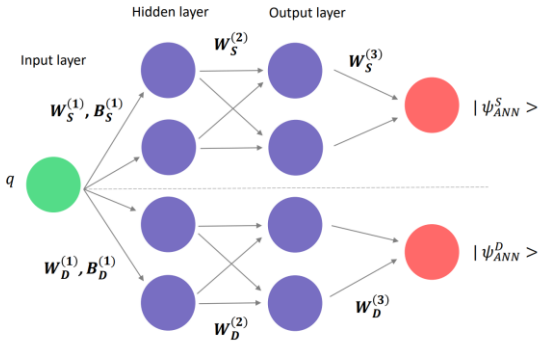


Figure 1: Architecture of a Neural Network used to find the ground state wave function of the deuteron (nuclear bound state).

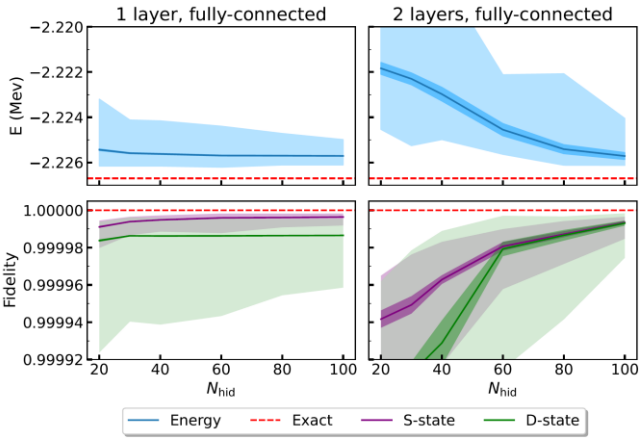


Figure 2: Energy and fidelity (computed with the exact wave function) vs. number of neurons, represented for two distinct models.

Phase-flip repetition code with realistic noise

Áron Rozgonyi
Gábor Széchenyi

Eötvös Loránd University, Budapest, Hungary
aaron9605@student.elte.hu

During computation on a quantum hardware the data is subject to noise hence its lifetime is limited.
To preserve information, quantum error correction must be implemented [1]. QEC relies on encoding of data into specific multi-qubit states and stabilizer measurements.
Specific code-stabilizer operators are chosen whose eigenstate is the preferred encoded state. Thus the post measurement state remains identical.
By syndrome extraction we are able to detect errors by kind and apply an appropriate recovery operation to re-establish the noise-free state.
The simplest QEC code is repetition code [2] which consists of data-qubits in row and ancillary-qubits are plugged in between them. If an error occurs in any of the data qubits, it will be indicated by ancillas.
We investigate the optimal code-length by considering a realistic noise such that relaxation, dephasing. Noises are charaterized by coherence times. Our theoretical results would support the quantum computer engineers by what the reasonable code-length is as a function of engineering parameters.

References

[1] Joschka Roffe. "Quantum error correction: an introductory guide". In: Contemporary Physics
[2] Manuel Rispler et al. "Towards a realistic GaAs-spin qubit device for a classical error-corrected quantum memory". In: Phys. Rev.

Figures

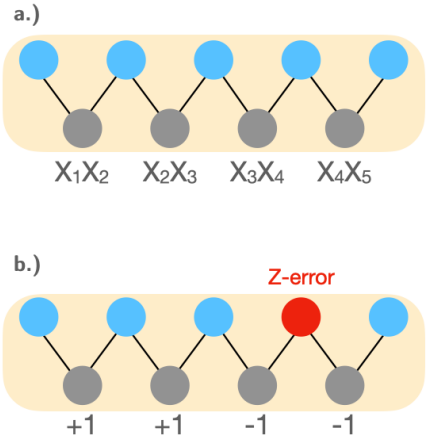


Figure 1: Schematic model of phase-flip repetition code for code distance d=5. In the chain of qubits the blue and grey dots are representing the data and ancillary qubits respectively. Under the ancillary qubits a.) the corresponding measuring operators b.) yielded syndrome are subscribed.

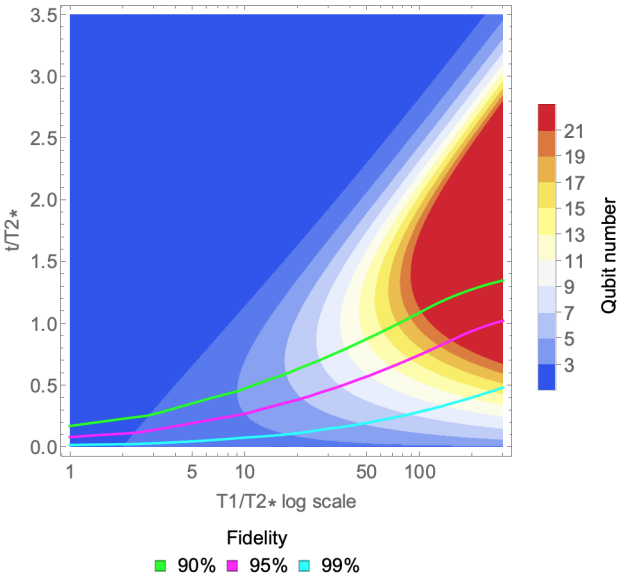


Figure 2: Optimal code-length diagram as a function of the T1,T2* coherence times and t idling time.

Benchmarking portfolio optimization with integer simulated annealing

Álvaro Rubio García
Juan José García Ripoll, Diego Porras Torre

Instituto de Física Fundamental (IFF), CSIC, Calle Serrano 113b, 28006 Madrid, Spain

alvaro.rubio@csic.es

Abstract

The discrete portfolio optimization problem [1] is a combinatorial optimization problem that selects an optimal set of financial assets which tries to maximize expected returns, while keeping risks low. As such, many algorithms have been developed to tackle this problem, with quantum algorithms and machine learning approaches being proposed in recent years. In this work we show that the convexity of the problem makes it very well suited to be studied with a simple integer classical simulated annealing algorithm. We show how it is able to find optimal portfolios even for Hilbert spaces of dimension $\sim 2^{1000}$ and how it scales polynomially with the number of available assets and total budget P_0 by measuring the Time To Target (TTT) needed to compute optimal solutions [See Fig.1].
When we take into account transaction fees, such as linear costs t_l associated to the traded amount, the convexity of the problem is usually maintained and our algorithm keeps its polynomial scaling. However, transaction fees such as fixed costs t_f make the problem non convex. We show how, in the limit of low non convexity, which is the relevant regime in the financial sector, our algorithm is versatile enough to still find optimal portfolios. Taking these costs into account is specially relevant in the portfolio rebalancing problem, where we start with an initial portfolio and we seek to optimize it in periodical time windows. We show in Fig. 2 the result of rebalancing a portfolio each month within a year and compare the relative annual return when we compute the portfolios using simulated annealing against a greedy approach that is not able to take non convex transaction fees [2]. This also shows that our algorithm is competitive in an out-of-range real setup.

References

[1] H. Markowitz, Portfolio selection, The Journal of Finance 7, 77 (1952).a
[2] Martin, R. A.. PyPortfolioOpt: portfolio optimization in Python. Journal of Open Source Software, 6(61), 3066 (2021)

Figures

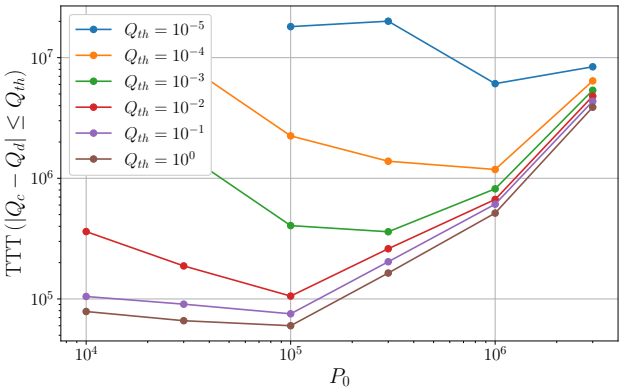


Figure 1: Time To Target for computing an optimal portfolio with quadratic utiliy below certain thresholds (different colors) against the total available budget P_0.

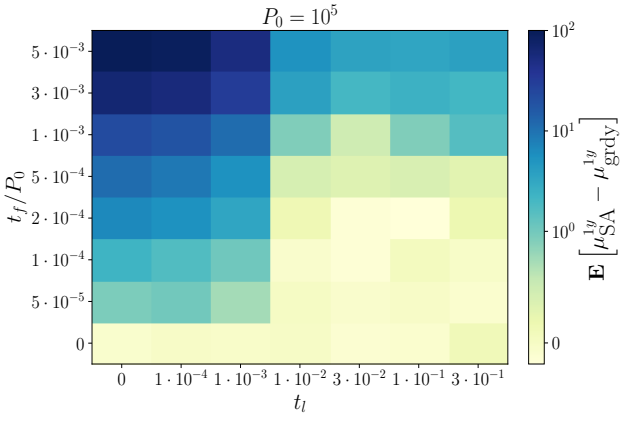


Figure 2: Absolute relative annual return of a portfolio monthly-rebalancing problem with different linear and fixed transaction costs using an integer simulated annealing computation against a greedy algorithm approach.

Localisation, quantum phase transitions and graph theory for adiabatic quantum computing

Matthias Werner*
Marta P Estarellas*
Artur Garcia Saez* **

** Qilimanjaro Quantum Tech, Carrer dels Comptes de Bell-Lloc 161, 08014 Barcelona, Spain*

*** Barcelona Supercomputing Center, Plaça d'Eusebi Güell 1-3, 08034 Barcelona, Spain*

matthias.werner@qilimanjaro.tech

In the context of adiabatic quantum computation (AQC), it has been argued that first order quantum phase transitions (QPTs) due to localisation phenomena will always cause adiabatic quantum computation (AQC) to fail by exponentially decreasing the minimal spectral gap of the Hamiltonian along the annealing path [1]. However this notion has been subject to some debate in the community [2], since more recent findings suggest the existence of methods to avoid this by carefully designing the involved Hamiltonians. It remains a challenge to formulate a comprehensive theory on the effect of the various parameters and the conditions under which QPTs make the AQC algorithm fail. In this work we investigate the conditions under which localisation causes first order QPTs. As a consequence of this analysis and using methods from spectral graph theory, we here examine both analytically and numerically the role of the connectivity of the driver Hamiltonian in the mitigation of such effects in different AQC algorithms and show that in the limiting case of full connectivity, first order QPTs due to localisation are avoided entirely.

References

[1] B. Altshuler, H. Krovi, J. Roland, Proceedings of the National Academy of Sciences, Vol. 107 No. 28 (2010)
[2] V. Choi, Proceedings of the National Academy of Sciences, Vol. 108 No. 7 (2011)
[3] M. H. S. Amin, V. Choi, Phys. Rev. A 80, 062326 (2009)

Figures

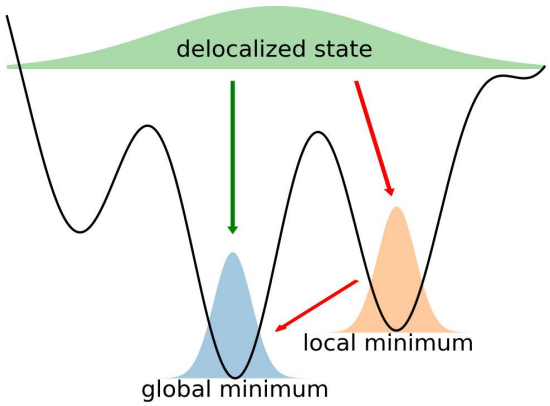


Figure 1: Illustration of the ground state transitioning from a delocalised to a localised state in the global minimum directly (green arrows); the ground state transitioning to a localised state in a local minimum with subsequent localised-localised transition to the global minimum (red arrows)

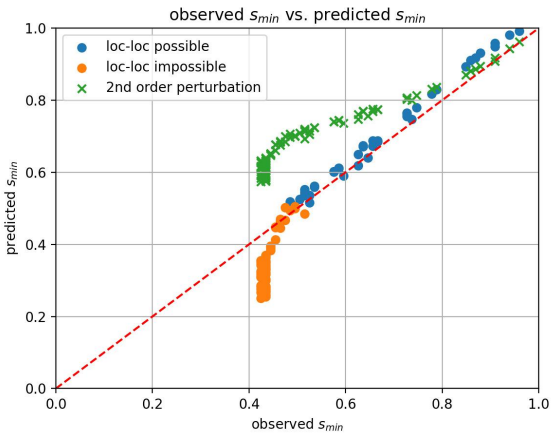


Figure 2: Predicted over observed location of the minimal gap along the annealing path on a toy model with localised-localised transition (blue dots) and without localised-localised transition (orange dots) using our conductance bound; same predictions using perturbation theory from [3]

High-Q Nanomechanical Resonators as Force Sensors and Synthetic Two Level Systems

Deividas Sabonis

ETH Zurich, Department of Physics, Otto Stern Weg 1, Zurich, Switzerland

dsabonis@phys.ethz.ch

Abstract

In the first half of this contribution [1], we demonstrate that soft-clamped silicon nitride strings with large aspect ratio can be operated at mK temperatures. The quality factors (Q) show consistent dependency on the cryostat temperature, with soft-clamped mechanical modes reaching $Q > 10^9$ at 80 mK. For low optical readout power, Q is found to saturate, indicating good thermalization between the sample and the stage it is mounted on. Our best device exhibits a force sensitivity of 12.6 zN/√Hz and a thermal decoherence time of 0.22 s which bode well for future applications such as nanomechanical force sensing and beyond. We also elaborate on potential next steps on performing force sensing using high-Q perimeter mode resonators with integrated optical cavities.

In the second half [2], we study the Kerr Parametric Oscillator as an approximation to a synthetic two-level system. In the presence of strong noise, the system switches between two states via a fluctuating trajectory in phase space, instead of following a straight path. The presence of such fluctuating trajectories makes it hard to establish a precise count, or even a useful definition, of the ``lifetime'' of the state. Addressing this issue, we compare several rate counting methods that allow to estimate a lifetime for the levels. In particular, we establish that a peak in the Allan variance of fluctuations can also be used to determine the levels' lifetime. Our work provides a basis for characterizing KPO networks for simulated annealing where an accurate determination of the state lifetime is of fundamental importance.

References

[1] arXiv:2112.03730
[2] arXiv:2112.03357

Figures

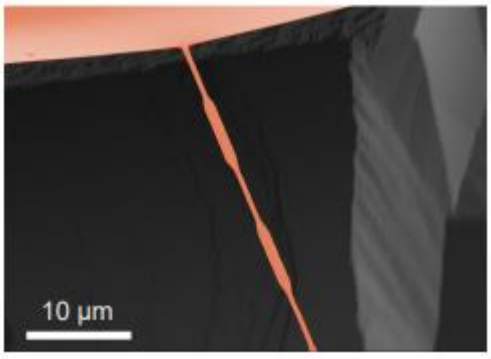


Figure 1: A false-colored SEM image of a high-Q nanomechanical string device. Shown is one clamping point and two unit cells.

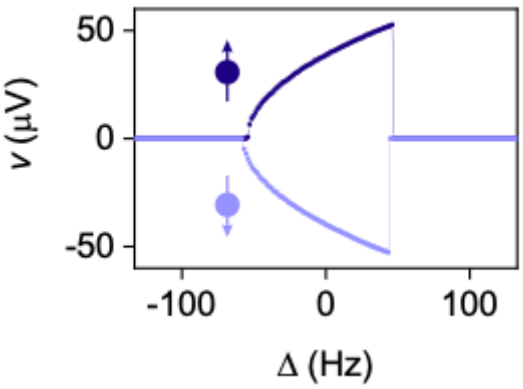


Figure 2: Measured out-of-phase response *v* of the resonator to parametric driving as a function of detuning.

Avoiding barren plateaus using classical shadows

Stefan H. Sack[†]
R. A. Medina[†], A. A. Michailidis[†,*], R. Kueng[+], M. Serbyn[†]

[†]*Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria*
[*]*University of Geneva, 24 quai Ernest-Ansermet, 1211 Geneva, Switzerland*
[+]*Johannes Kepler University Linz, Altenberger Straße 69, 4040 Linz, Austria*

stefan.sack@ista.ac.at

Variational quantum algorithms (VQAs) are promising algorithms for achieving quantum advantage on near-term devices. The quantum hardware is used to implement a variational wave function and measure observables, whereas the classical computer is used to store and update the variational parameters. The optimization landscape of expressive variational ansätze is however dominated by large regions in parameter space, known as barren plateaus (BPs)[1-3], with vanishing gradients which prevents efficient optimization.

In this work, we propose a general algorithm to avoid BPs in the initialization and throughout the optimization. To this end, we define a notion of weak barren plateaus (WBP) based on the entropies of local reduced density matrices. The presence of WBPs can be efficiently quantified using recently introduced shadow tomography[4] of the quantum state with a classical computer.

We demonstrate that avoidance of WBPs suffices to ensure sizable gradients in the initialization. In addition, we demonstrate that decreasing the gradient step size (controlled by the learning rate η), guided by the entropies allows avoiding WBPs during the optimization process. This paves the way for efficient BP free optimization on near-term devices.

References

[1] McClean et al., Nat Commun **9**, 4812 (2018)
[2] Cerezo et al., Nat Commun **12**, 1791 (2021)
[3] Holmes et al., PRX Quantum **3**, 010313 (2022)
[4] Huang et al., Nat Phys **16**, 1050-1057 (2020)

Figures

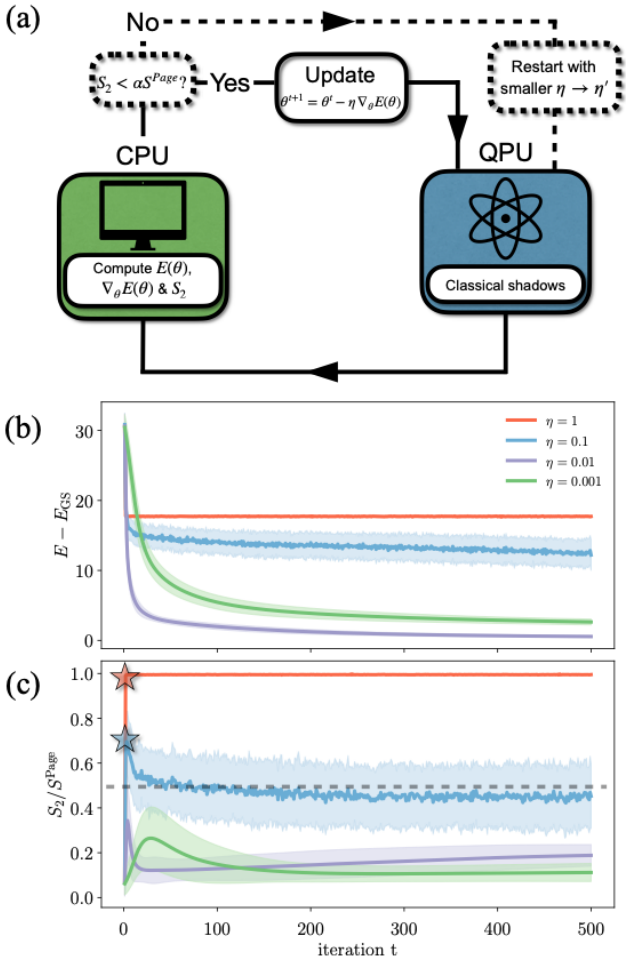


Figure 1: (a) Schematic illustration of the WBP avoidance procedure using classical shadows in VQAs. (b) Energy expectation value during the VQA optimization for different learning rates η. (c) Large learning rates lead to fast growth in entanglement entropy. A nearly maximal value (Page value) coincides with a WBP and poor optimization performance. Once a WBP is encountered, we restart the VQA with a smaller learning rate.

High fidelity quantum science with arrays of Strontium Rydberg atoms

Pascal Scholl
Adam Shaw, Ran Finkelstein, Joonhee Choi, Daniel Mark, Soonwon Choi, Manuel Endres

California Institute of technology, Pasadena, CA 91125, USA

pscholl@caltech.edu

Here we show our ability to manipulate and benchmark with high fidelity a many-body quantum system. Our apparatus relies on the individual trapping of Strontium atoms in optical tweezers [1] (see Figure 1), excited to their Rydberg states [2]. We first uncover the signatures of universal random statistics emerging from both temporal evolution and projective measurement [3]. In particular, we observe the so-called Porter-Thomas distribution, a phenomenon which we find is universal across a wide variety of quantum computers and simulators. The presence of these random statistics allows us to further develop recent protocols for quantum device benchmarking, which we use to demonstrate (i) in situ Hamiltonian learning, and (ii) the measurement of highly-entangled states fidelity (see Figure 2). We finally highlight possibilities for scaling this protocol to hundreds of qubits, and discuss prospects for realizing quantum advantage with near-term quantum simulators.

References

[1] J. Covey, I. Madjarov, A. Cooper, and M. Endres, PRL, 17 (2019) 173201
[2] I. Madjarov, J. Covey, A. Shaw, J. Choi, A. Kale, A. Cooper, H. Pichler, V. Schkolnik, J. Williams, and M. Endres, Nature Physics, 16 (2020) 857-861
[3] J. Choi, A. Shaw, I. Madjarov, X. Xin, J. Covey, J. Cotler, D. Mark H.Y. Huang, A. Kale, H. Pichler F. Brandao, S. Choi, and M. Endres arXiv:2103.03535

Figures

Figure 1: Array of Strontium atoms in optical tweezers

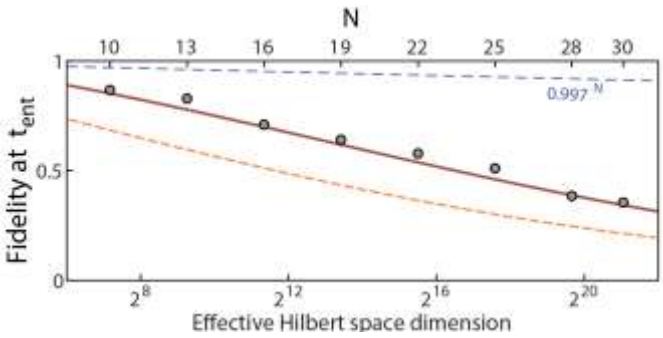


Figure 2: Evolution of the fidelity at entanglement entropy saturation time, as a function of the number of qubits N. The markers and the red line represent the experimental results and the ab-initio calculation including all known imperfections, respectively.

Distinguishing Andreev modes from Majorana modes via quasi-particle poisoning

Jens Schulenborg[1]
Svend Krøjer Møller[1], Michele Burrello[1], Martin Leijnse[2], Karsten Flensberg[1]

[1] *Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Universitetsparken 5, 2100 Copenhagen, Denmark*

[2] *Solid State Physics and NanoLund, Lund University, Box 118, S-221 00 Lund, Sweden*

jens.schulenborg@nbi.ku.dk

Substantial effort in recent years went into identifying and probing signatures of Majorana modes in superconductors that distinguish them from other zero-energy subgap states. However, many of these signatures have subsequently been shown to be explicable by physics unrelated to Majorana modes.[1]

This theoretical work shows how a continuous, time-resolved measurement of quasi-particle-poisoning induced parity flips of subgap states — via quantum-dot based parity-to-charge conversion and a capactively coupled sensor dot[2] — can directly expose the property of Majoranas being an equal superposition of a particle and a hole. For the example of two separate Majorana- or Andreev type subgap modes coupling to the detector, we provide the key distinguishing features of the charge detector signal, and discuss how their measurability is constrained by charge- and flux noise, non-equilibrium and thermal excitations, as well as detector shot noise.

References

[1] Flensberg et al.: Nat. Rev. Mat **6**, 944–958 (2021)
[2] Munk et al.: Phys. Rev. Research **2**, 033254 (2020)

Figures

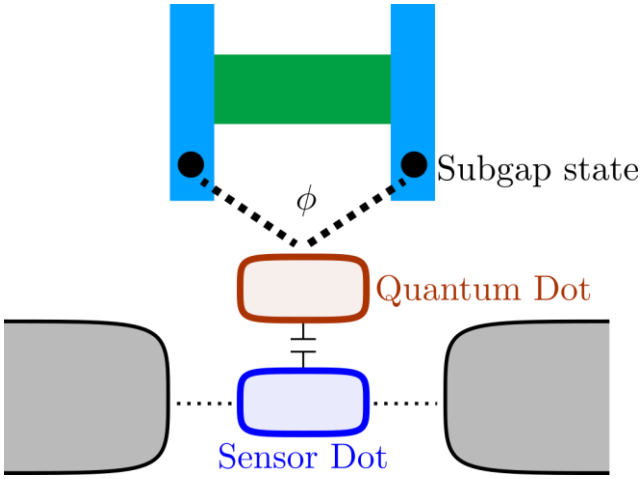


Figure 1: Parity of subgap states in superconducting wires converted to a charge in a tunnel coupled quantum dot, continuously measured by a capacitively coupled sensor.

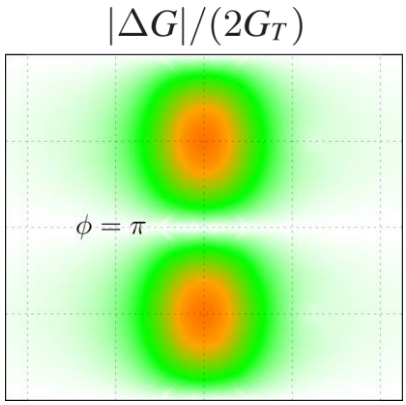


Figure 2: For Majorana modes, the sensor signal becomes independent of subgap parity for a specific coupling phase but otherwise arbitrary parameters.

Performances and limitations of variational quantum algorithms under realistic noise models

Marco Schumann
Frank Wilhelm-Mauch
Alessandro Ciani

Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich, 52425 Jülich, Germany

ma.schumann@fz-juelich.de

Abstract

We are entering an era where we can achieve increasing control of quantum systems which may pave the way toward many new technologies, like quantum computing. An intriguing question is if the currently available NISQ devices, despite their lack of error correction, can be used to obtain a quantum advantage over classical computation. While in 2019 quantum supremacy for a specific task was shown by Google [1], it remains an open question if the current NISQ devices can deliver a quantum advantage for practical applications. In this regard, promising candidates are the so-called Variational Quantum Algorithms (VQAs). They proceed by using a parametrized quantum circuit to compute a cost function that gets minimized by a classical optimizer. Recently it was shown that a quantum state undergoing a variational quantum circuit with general Pauli noise approaches the completely mixed state with increasing circuit depth [2]. This phenomenon is called "Noise-induced Barren Plateau" and limits the performance of VQAs under noise.
In this ongoing project, we study the question of how variational quantum circuits behave under more realistic noise models, like dephasing or amplitude damping noise. We use the Quantum Approximate Optimization Algorithm (QAOA), which is a specific VQA, to solve combinatorial optimization problems. Considering the problem of MaxCut on d-regular graphs, we run the circuit for many instances of randomly chosen circuit parameters, which means we do not use the optimizer. We find that for weak amplitude damping or dephasing noise the average purity of the output state of the circuit approaches the purity of the completely mixed state while the variance of the purity approaches zero with increasing circuit depth. The decrease of the average purity is well described by an exponential decay, where the decay rate is approximately linear in the noise strength λ. We check this for different d-regular graphs with different qubit numbers.

References

[1] Frank Arute et al., Nature, 574 (2019) 505-510
[2] Samson Wang et al., Nature Communications, 12 (2021),6961

Figures

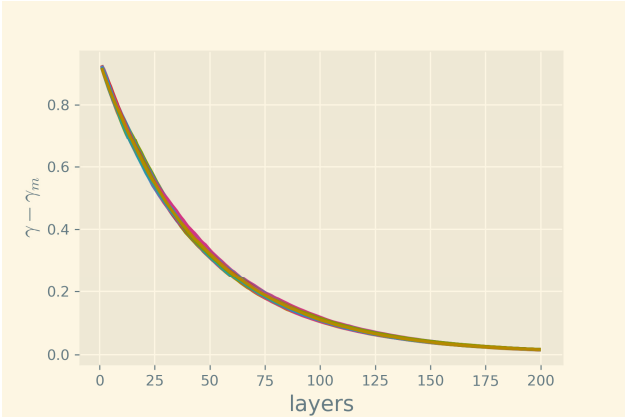


Figure 1: Purity difference between the purity of the output state of the circuit and the purity of the completely mixed state. Here we consider a 3-regular graph with 4 qubits under amplitude damping of strength λ=0.001. We show data for 100 samples of randomly chosen circuit parameters.

Studying the Limiting Behaviour of Qubit Hamiltonians Using Graphons

Amy Searle[1]
Joseph Tindall[1], Abdulla Alhajri[1]
[1]*Clarendon Laboratory, The University of Oxford, Oxford, OX13PU, United Kingdom*
amy.searle@physics.ox.ac.uk

Although qubit Hamiltonians are usually studied on lattice structures, recently there has been interest in studying the behaviour of such systems on top of more general graph structures [1,2](see Figure 1), such as random graphs. Usually it is properties in the thermodynamic limit which are of interest, so that the behaviour of the system on graphs of increasing size, or a graph sequence, is studied in order to discern its limiting behaviour. These calculations are necessarily limited by current state-of-the-art many body simulations [3]. On the other hand, the graph sequence itself is known to have a unique limit, known as a *graphon* [4].

Here, we define a system of qubits with XXZ Hamiltonian on the graphon directly. We find that Hamiltonians resulting from different graph sequences can be identical, up to a rescaling. For example, the Erdös Renyi graphon (see Figure 2) has the same Hamiltonian as the fully symmetric graphon, and for the latter it can be analytically shown that all qubits behave as a single collective unit and no many-body physics arises. More generally, the automorphism group of the graphon constrains the possible ground states, so that systems with graphons with relatively few spatial symmetries can display more interesting and complex behaviour. This furthers results obtained in [5] by the present authors using tensor network simulations.

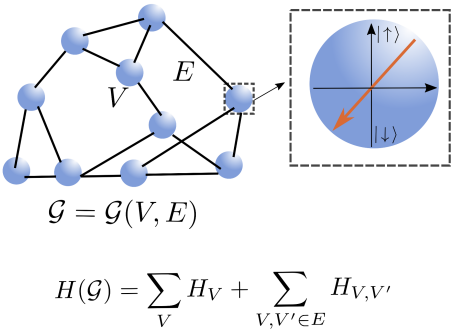


Figure 1: Defining a system of interacting qubits over a graph with vertex set V and edge set E. Each node represents a qubit and qubits share an interaction term $H_{V,V'}$ in the Hamiltonian if and only if the graph has an edge between vertices V and V'. (reproduced from [5])

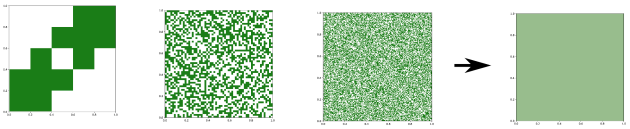


Figure 2: The graphon as a graph limit. The large squares, from left to right, correspond to a sequence of adjacency matrices of Erdös Renyi graphs for increasing N and $p = 0.5$; the rightmost square corresponds to the graph limit, the graphon, $W(x, y) = 0.5$, for $x, y \in [0, 1]$.

References

[1] P. Hauke, L. Tagliacozzol, Physical Review Letters, Vol. 111 Iss. 20 (2013)
[2] M. Dupont and N. Laflorencie, Physical Review B, Vol. 103 Iss. 17 (2021)
[3] R. Orús, Nature Review Physics, 1, 538-550 (2019)
[4] L. Lovász, B. Szegedy, Journal of Combinatorial Theory, Series B (2012)
[5] J. Tindall, A. Searle, A. Alhajri and D. Jaksch, Quantum Physics in Connected Worlds, Under Review, 2022.

Ergodicity breaking and quasiparticle dispersion in the PXP quantum cellular automaton

Kevissen Sellapillay, Alberto Verga, Giuseppe Di Molfetta

Aix-Marseille Université, Campus de Luminy, 13288 Marseille, France

kevissen.sellapillay@univ-amu.fr

Abstract

Thermalization in quantum many body systems is a main theme is physics. We study a Quantum Cellular Automaton (QCA) inspired by the PXP model [1]. This model, realizable on Rydberg atoms [3], has two interesting limits: the PXP model and the rule 201 classical automaton. We look at the entanglement spectrum of the dynamics close to the automaton limit. Quasiparticle excitations evolve towards chaotic states characterized by Wigner-Dyson statistics, whereas a state without quasiparticle excitation evolves towards a Poisson statistics. This ergodicity breaking mecanism in a QCA, which could be of interest for quantum information application, is reminiscent of the scarring phenomenon and the Z2 emergent symmetry of the PXP model [2]. We relate the thermalizing behaviour of the state containing a quasiparticle with the dispersion observed and we find that entanglement grows in the wake of the quasiparticles. We compute the dispersion relation to first order in the chiral and collision-free sector.

References

[1] Iadecola, Thomas, et Sagar Vijay. « Nonergodic quantum dynamics from deformations of classical cellular automata ». *Physical Review B* 102, n° 18 (6 novembre 2020)

[2] Serbyn, Maksym, Dmitry A. Abanin, et Zlatko Papić. « Quantum Many-Body Scars and Weak Breaking of Ergodicity ». *Nature Physics* 17, n° 6 (juin 2021)

[3] Morgado, M., et S. Whitlock. « Quantum simulation and computing with Rydberg-interacting qubits ». *AVS Quantum Science* 3, n° 2 (juin 2021)

Figures

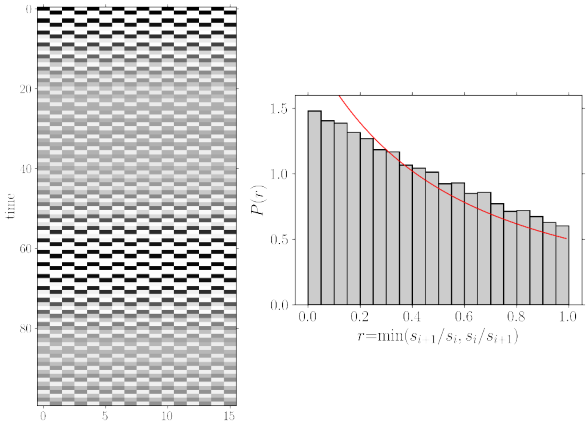


Figure 1:
QCA near the automaton limit, for a state without quasiparticle which displays the revival phenomenon (left) and associated entanglement spectrum spacings statistics (right).

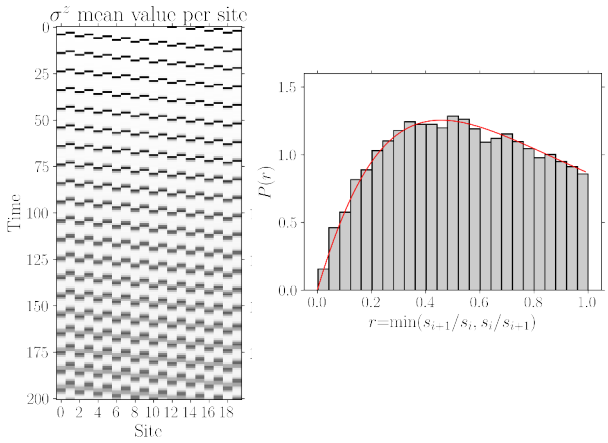


Figure 2: Dispersion of chiral quasiparticle (left) and associated entanglement spectrum spacings statistics (right).

Approaching the thermodynamic limit of a first-order dissipative quantum phase transition in zero dimension

Riya Sett[1]
Farid Hassani[1], Duc Phan[1], Shabir Barzanjeh[1,2], Andras Vukics[3], Johannes M. Fink[1]

[1]*Institute of Science and Technology Austria, 3400 Klosterneuburg, Austria*
[2]*Institute for Quantum Science and Technology, University of Calgary, Calgary, Alberta, Canada*
[3]*Wigner Research Centre for Physics, H-1525 Budapest, P.O. Box 49., Hungary*

riya.sett@ist.ac.at

Abstract

In this work, we show a detailed experimental study of the photon blockade breakdown (PBB) process as a dissipative first order quantum phase transition (QPT) in a circuit QED system containing a single transmon qubit and a single cavity mode. Here, we show the key feature of such a QPT – coexistence of two states of the system [1] with a time domain bistable signal, similar to the one observed in a previous work [2]. However, it is also necessary that the two states – dim and bright – in such an observable be macroscopically distinct from each other. In our work we show such a regime, the "thermodynamic limit", where both the timescale and the amplitude of the bistable signal [Figure 1], as also predicted theoretically [3], approaches infinity, resulting in long-lived and macroscopically distinct dim and bright phases. We approach this thermodynamic limit of infinite coupling strength (g→infty) by controlling the cavity linewidth (κ) in situ, hence increasing the ratio of coupling versus resonator loss. For the smallest κ value, the blinking timescale reaches 6 seconds, which is at least four orders of magnitude higher than the slowest timescale of the system. Also, we show experimental phase diagram [Figure 2] in the drive detuning (Δ) - drive strength (η) plane for the first time for the PBB phase transition.

References

[1] H. J. Carmichael, Phys. Rev. X 5, 031028 (2015).
[2] J. M. Fink, A. Dombi, A. Vukics, A. Wallraff, P. Domokos, Phys. Rev. X 7, 011012 (2017).
[3] A. Vukics, A. Dombi, J. M. Fink, P. Domokos, Quantum 3, 150 (2019).

Figures

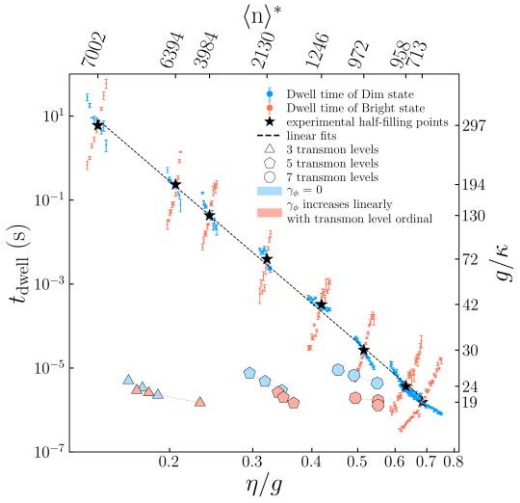


Figure 1: Measured dwell times and the mean intracavity photon numbers at different g/ κ values, being compared with the numerical simulations for 3,5 and 7 transmon levels at lowest three g/ κ cases.

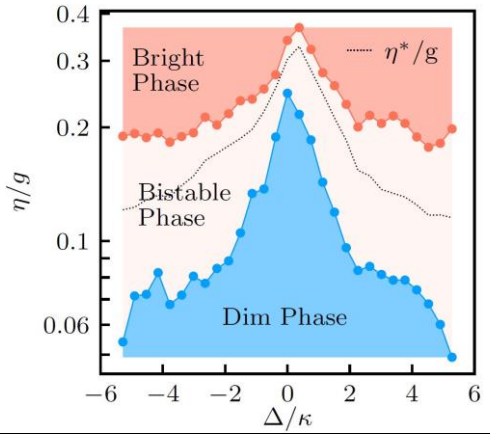


Figure 2: Experimentally obtained phase diagram.

Flame & EntropyHub: Open-source stack for scalable, heterogeneous and distributed quantum workflows

Presenting Author

Nikola Šibalić

Co-authors: Maxim Dobrokhvalov, Guy Kerem, Sergey Grishin, Kladnitsky Danil,
Sofia Nagavkina, Irina Garmatina, Gal Winer

Quantum Machines, Yigal Alon St 126, Tel Aviv, Israel

nikola@quantum-machines.co

Abstract

Writing control software for quantum experiments in a scalable and modular manner is crucial for successful creation of complex quantum workflows. This is challenging since such experiments tightly incorporate experiment control and classical processing, using potentially heterogeneous hardware and software. We present an open-source software stack for creating modular and scalable workflows required for the evolving quantum ecosystem. Our architecture, Flame, allows creation of testable program nodes, written in a language of choice. Nodes are independent processes which are orchestrated into the final solution by writing a workflow that specifies communication between nodes, using expressive Python syntax. Using asynchronous, direct node-to-node communication, workflows can span in scalable manner multiple hosts, joining heterogeneous languages and operating systems. The underlying actor based processing model allows easy access to scalable performance thanks to implicit parallelism. Uniting this low-level experiment creation with high-level management is EntropyHub: a web based interface providing facilities for experiment authoring and result management. Together Flame & EntropyHub provide infrastructure for building solutions needed for both complex quantum experiments as well as remotely deployed and controlled quantum processing units.

Cold Atoms Plus Photonics for Quantum Simulation

A. Simonsen
J. T. Hansen, J. B. Mathiassen, B. Martinez de Aguirre, J. H. Müller, E. S. Polzik & J.-B. Béguin

University of Copenhagen, Blegdamsvej 17, Copenhagen, Denmark

asimonsen@nbi.ku.dk, jbeguin@nbi.ku.dk

We present an experimental apparatus for quantum simulations that combines cold atoms with 2D photonics. The setup follows the proposal in [1] and is illustrated in fig. 1. The photonic structure enhances light-atom coupling by confining optical fields to sub-wavelength dimensions near the atoms. The structure also guides photons that can mediate strong and long-range interactions between atoms according to the Hamiltonian $H = \sum_{ij} J^{ij} \sigma_{eg}^{i} \sigma_{ge}^{j}$, where $\sigma = |e\rangle\langle g|$ refers to atomic states and J^{ij} is a coupling constant that depends on the photonic design. Fig. 2 shows J^{ij} for a structure with a photonic bandgap. More many-body Hamiltonians may be engineered by further customizing the interactions with optical driving and magnetic fields that manipulate internal atomic states.[2]
Our setup uses Cs atoms cooled to μK temperatures, trapped in an array of optical tweezers in the collisional blockade regime, and delivered into the near-field of the photonic structure. The approach is inspired by [3]. The photonic structures are fabricated in silicon nitride membranes as proposed in [4]. We will report progress on construction of the optical tweezer array for delivery of atoms, development of fabrication recipes, and numerical simulation (fig. 2) and optimization of future atom-photonic devices.

The work is part of Quantop and the Novo Foundation consortium *Quantum for Life*.

References

[1] A. González-Tudela, C. L. Hung, D. E. Chang, J. I. Cirac, H. J. Kimble, Nat. Photon., 9 (2015) 320-325

[2] C.L. Hung, A. González-Tudela, J. I. Cirac, H. J. Kimble, PNAS 34 (2016) E4946-55

[3] J.-B. Béguin, A. P. Burgers, X. Luan, Z. Qin, S.-P. Yu, H. J. Kimble, Optica 1 (2022) 1-2

[4] S.-P. Yu, J. A. Muniz, C.-L. Hung, H. J. Kimble, PNAS 26 (2019), 12743-51

Figures

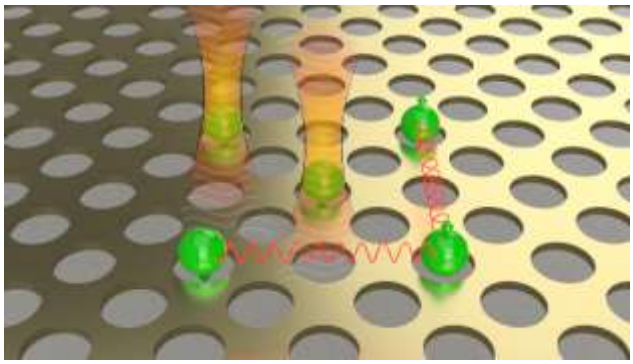


Figure 1: Atoms (green balls) trapped in optical tweezers (orange shaded area) near a membrane perforated with a photonic pattern. Guided photons (wiggly lines) connect atoms by pairwise interaction.

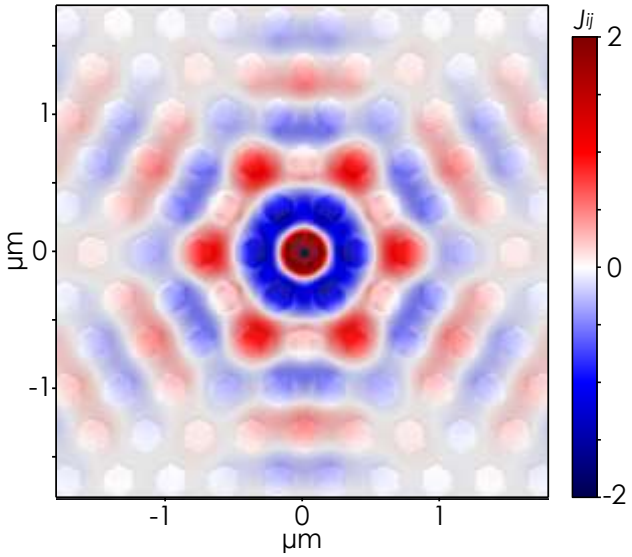


Figure 2: Spin-exchange rate, J^{ij}, normalized to the dissipation rate for an atomic emitter at the center of a hexagonal lattice.

Enhancing the mobility of scalable quantum networks based on InAs nanowires with a double buffer approach

Maria Chiara Spadaro[1*], Sara Martí-Sánchez[1*] Daria V. Beznasyuk[2], Jung-Hyun Kang[2], Thomas Sand Jespersen[2,3], Peter Krogstrup[2] and Jordi Arbiol[1,4] ***equal contribution**

1Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, Barcelona, Catalonia, Spain
2 Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark
3 Department of Energy Conversion and Storage, Technical University of Denmark, Fysikvej, Building 310, 2800 Lyngby
4 ICREA, Passeig de Lluís Companys 23, 08010 Barcelona, Catalonia, Spain

sara.marti@icn2.cat, mariachiara.spadaro@icn2.cat

One dimensional high mobility and so coupling semiconductors have potential to be a base of next generation quantum devices, and particularly, InAs nanowires present outstanding properties that make them suitable for this application. So far, high crystal quality NWs have been achieved by VLS growth, but scalable growth techniques should be explored to ultimately fabricate commercial devices.

Recently, InAs NW networks on GaAs have been successfully grown by the scalable selective area growth (SAG) technique[1], but the inherent strain between substrate and nanowire (NW) is responsible of dislocation formation acting as scattering centres negatively affecting the material's mobility. Other studies have proven that the addition of a buffer layer can potentiate elastic strain contributions, reduce dislocation formation and thus, improve electronic transport of the devices [2].

In this study, we performed strain engineering based on a double buffered approach to minimize strain fields within the InAs channel and we improved the nanowire-substrate interface quality also by substituting conventional thermal annealing for atomic hydrogen during the GaAs substrate preparation, for native oxide removal.

Our results reveal that a two-fold optimization of growth temperature (Fig. 1a, steps iii and iv) can effectively trap dislocations away from the InAs channel (Fig. 1b) while keeping high compositional purity on the InAs channel (Fig. 1c). As a result, we achieve a doubling of field-effect mobility compared to similar nonoptimized SAG counterparts[3].

References

[1] P. Aseev et al., Nano letters 19 (2018), 218-227
[2] F. Krizek et al., Physical review materials 2 (2018), 093401
[3] D. Beznasyuk et al., Phys Rev Materials 2022, 6, 034602

Figures

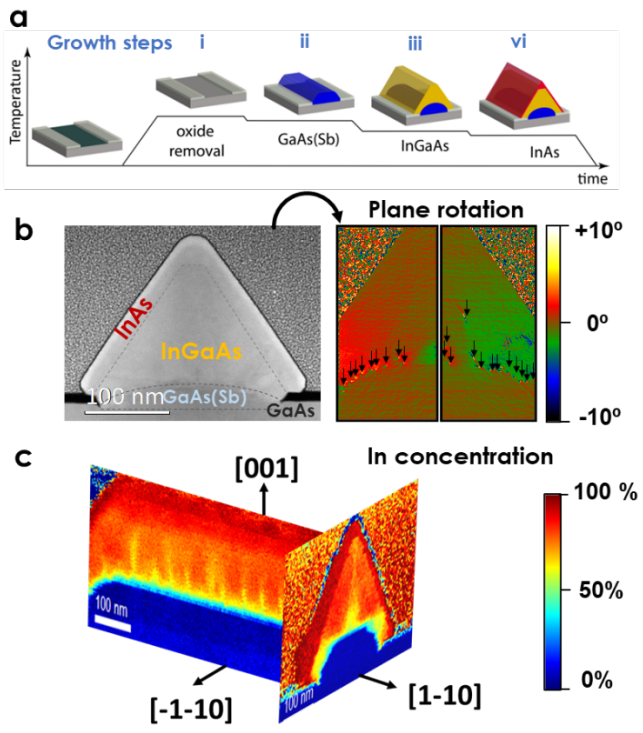


Figure 1: a Growth steps of double buffered InAs NWs. **b** STEM image and plane rotation map on a

NW cross section showing dislocations confined away from the InAs interface (arrows). **c** EELS compositional map of In relative atomic composition (vs. Ga).

Hybrid Kernel Polynomial Method

Alessandro Summer
Cecilia Chiaracane, John Goold

School of Physics, Trinity College Dublin, Dublin 2, Ireland

summera@tcd.ie

The evaluation of spectral quantities and correlation functions of large entangled systems is a core problem in computational physics today. As technology progresses, classical computers struggle to keep pace with the growing size of the quantum systems to be described. Quantum computers appear to be the solution to keep advancing in the field of quantum simulations.
However, currently available machines are still prone to errors and noise when dealing with long, dense, wide, and ultra-connected algorithms. So far, what appears to be the primary benefit of using them is the creation of random (pseudo-) circuits (as in Google's recent Sycamore processor experiment).
Decades of scientific research on quantum simulation techniques have resulted in sophisticated classical algorithms. A well-known example is the kernel polynomial method (KPM) [1], which is used to obtain the density of states (DOS), local-DOS and correlation functions through their Chebyshev expansion. The bottleneck of the algorithm resides in the computation of the Chebyshev moments, namely $\mathrm{Tr}[H^n A]$ for different n, where A is an observable and H the Hamiltonian of the system. Our goal is to use quantum computers to solve this last step.

We are building a hybrid algorithm that uses a set of random states to perform a stochastic evaluation of trace to calculate the moments of the expansion. The powers of the Hamiltonian are implemented as derivatives of the time-evolution operator, in the manner of Ref.[2]. The trace is evaluated using a DQC1-like circuit, with a random state in place of the identity state, which cannot be directly built on a digital quantum computer. We are currently applying Richter's technique to create a random state [3], which we checked to be extremely performing in the simulation of Haar distribution and with the Trotterisation in high-dimensional Hilbert spaces. We are using the XXZ model as testing Hamiltonian, but the algorithm can be generalized to a broader class of systems.

References

1. A. Weiße, G. Wellein, et al., Rev. Mod. Phys. 78, 275 (2006)
2. K. Seki, S. Yunoki, PRX Quantum 2, 010333 (2021)
3. J. Richter, A. Pal, PRL 126, 230501 (2021)
4. Authors, Journal, Issue (Year) page

Measurement-induced entanglement transitions and Anderson localization

Marcin Szyniszewski
Oliver Lunt
Arijeet Pal

Department of Physics, University College London, Gower Street, London, WC1E 6BT, UK

mszynisz@gmail.com

Generically, quantum mechanical systems exhibit thermalization, where the properties can be easily described by standard statistical mechanics. However, one also loses the access to quantum information, which is smeared-out throughout the system and becomes inaccessible to local measurements. To combat this, many non-equilibrium scenarios have been proposed in the recent decades, such as the recently intensely researched topic of *measurement-induced entanglement transitions* [1], where measurements are used to induce quantum Zeno effect in a quantum circuit in order to stop the growth of entanglement and the ballistic smearing of information. Such non-equilibrium phases have high prospects of usability in quantum computing, as they have tight connections to the topic of quantum error correction.

We review the topic of entanglement transitions and give a brief overview of our current knowledge of the universality class landscape in systems exhibiting this novel behavior. We then focus our discussion on a quantum circuit where the unitary evolution is governed by the Anderson model Hamiltonian. This system exhibits two phases [2]: area-law phase – where the quantum trajectory gets pinned by the measurement and by the disordered field, and the log-law critical phase – where the pinning does not occur (see Figure 1).

We find that the Anderson localization is destroyed for small disorder strengths as one introduces measurements in the circuit. This leads to a sudden emergence of the entanglement phase transition. We explain this behavior by considering nonunitary circuits, which generically favor the critical phase [3]. We also find a non-monotonic shift of the transition point at low disorder, where small random field stabilises the critical phase by coupling to the fermion modes. The universality class of the phase transition (believed to lie within the Berezinskii–Kosterlitz–Thouless class) seems to survive the introduction of a random field term. Our results shed further light on the monitored free-fermion circuits and the stability of the critical phase within these models.

References

[1] Y. Li, et al., Phys. Rev. B 98, 205136 (2018); A. Chan, et al., Phys. Rev. B 99, 224307 (2019); B. Skinner, et al., Phys. Rev. X 9, 031009 (2019); M. Szyniszewski, et al., Phys. Rev. B 100(6), 064204 (2019).

[2] O. Alberton, et al., Phys. Rev. Lett. 126, 170602 (2021).

[3] X. Chen, et al., Phys. Rev. Research 2, 033017 (2020).

Figures

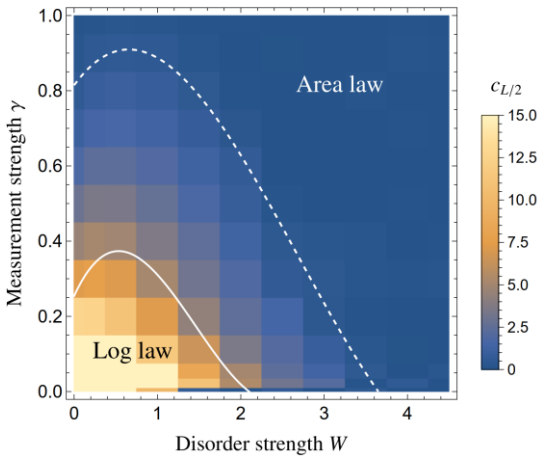


Figure 1: Phase diagram of the monitored circuit with Anderson model unitary evolution. Density map shows the central charge estimate.

Photon-mediated interactions between spin 1 atoms

Cristian Tabares
Alejandro González-Tudela

Institute of Fundamental Physics (IFF-CSIC), Calle Serrano 113b, Madrid, Spain.

cristian.tabares@csic.es

Quantum simulators are highly controllable devices that exploit quantum effects to answer questions about another system. They can be built using different platforms, such as ultracold atoms in optical lattices, superconducting circuits or atoms interacting with nanophotonic structures [1]. This last system is particularly interesting because the nanophotonic environment can be tailored to generate exotic photon-mediated interactions between atoms [2], with both dissipative and coherent evolutions, opening the door for the exploration of a wide range of physical models. However, these atoms have been typically considered as two-level systems, which limits the type of models that can be explored [3,4]. Our work considers the full hyperfine structure of the atoms to go beyond this and study effective spin-1 interactions between the quantum emitters, where Raman-assisted transitions allow a mapping to well known models such as the Ising or the XX spin-1 interactions. These results could be interesting both in quantum simulation (where they could be applied to study spin chains or even simulating some lattice gauge theories [5,6]) and quantum computation (as a way to obtain quantum gates between qutrits [7]).

References

[1] E. Altman et al., PRX Quantum 2, 017003 (2021).
[2] D. E. Chang et al., Rev. Mod. Phys. 90, 031002 (2018).
[3] A. González-Tudela et al., Nature Photonics, 9 (2015) 326-331.
[4] J. S. Douglas et al., Nature Photonics 9 (2015) 326-331.
[5] E. Zohar et al., Phys. Rev. A 95, 023604 (2017).
[6] T. Armon et al., Phys. Rev. Lett. 127, 250501 (2021).
[7] Y. Wang et al., Front. Phys., 10 (2020).

Figures

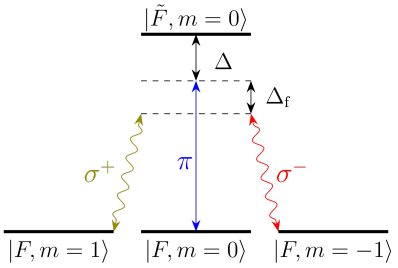


Figure 1: Different types of transitions between the ground hyperfine levels and an hyperfine excited state of a driven real atom.

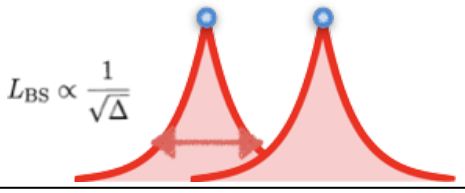


Figure 2: Atom-photon bound states for atoms coupled close to a waveguide. The range of the effective interaction between them can be tuned modifying the system's parameters and it can go beyond nearest neighbours.

Anyonic local elements of reality

Nicetu Tibau Vidal
Lucia Vilchez Estevez

Clarendon Laboratory, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom

anicet.tibauvidal@physics.ox.ac.uk

Abstract

We study non-abelian anyon theories from an information theory perspective. Following [1] and [2] we study the notion of subsystem in anyon theories and prove that any anyon theory satisfies the no-signalling principle.

We find the local algebra of observables for any anyon theory. Following [3] we identify the generators of the local algebra of observables as the local elements of reality for anyons: local elements that fully describe the global system.

We comment on the possible uses of our work to find error-correction protocols for anionic quantum computation.

References

[1] G. Chiribella, Entropy, 20(5), 358. (2018)
[2] P. Bonderson, K. Shtengel, and J. K. Slingerland. Annals of Physics, 323(11). (2008) 2709-2755
[3] P. Raymond Robichaud. arXiv preprint arXiv:1710.01380 (2017)

Figures

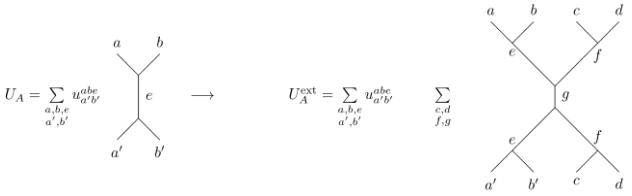


Figure 1: Local anyonic operators in local subspace (left) and in the global system (right)

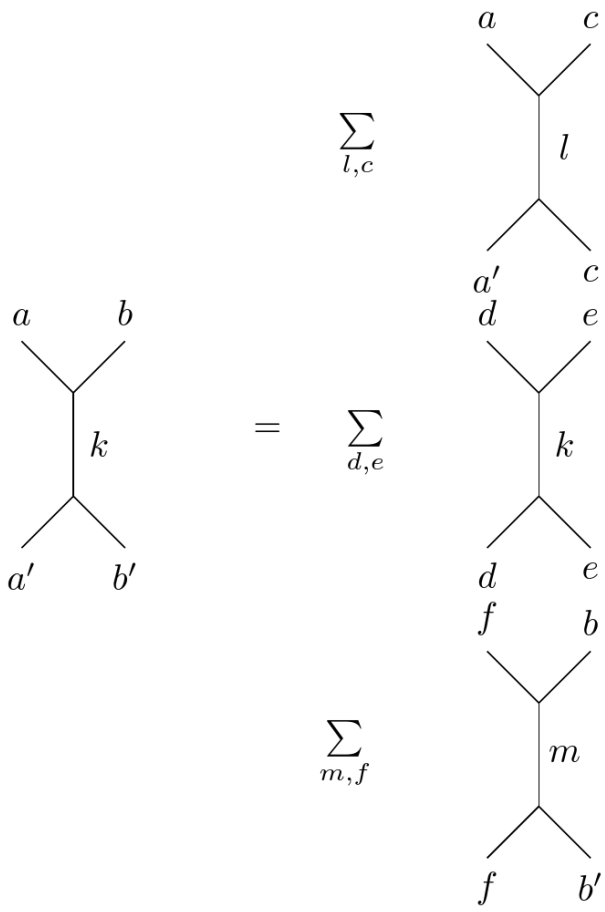


Figure 2: Decomposition of a global operator as a product of three local operators.

Non-Hermitian topology in monitored quantum circuits

Apoorv Tiwari

KTH, Sweden

apoorvt@kth.se

We demonstrate that genuinely non-Hermitian topological phases and corresponding topological phase transitions can be naturally realized in monitored quantum circuits, exemplified by the paradigmatic non-Hermitian Su-Schrieffer-Heeger model. We emulate this model by a 1D chain of spinless electrons evolving under unitary dynamics and subject to periodic measurements that are stochastically invoked. The non-Hermitian topology is visible in topological invariants adapted to the context of monitored circuits. For instance, the topological phase diagram of the monitored realization of the non-Hermitian Su-Schrieffer-Heeger model is obtained from the biorthogonal polarization computed from an effective Hamiltonian of the monitored system. Importantly, our monitored circuit realization allows direct access to steady state biorthogonal expectation values of generic observables, and hence, to measure physical properties of a genuine non-Hermitian model. We expect our results to be applicable more generally to a wide range of models that host non-Hermitian topological phases

Towards a mechanical qubit in a double quantum dot in a carbon nanotube-based device

Roger Tormo Queralt
C. B. Møller[a] , C. Samantha[a] , S. L. De Bonis[a,b], D. Czaplewski[c] , A. N. Cleland[d] , F. Pistolesi[e], A. Bachtold[a]

a. *ICFO – The Institute of Photonic Sciences, Barcelona, Spain.*
b. *C12 Quantum Electronics, Paris, France.*
c. *Argonne National Lab, Illinois, USA.*
d. *University of Chicago, Illinois, USA.*
e. *University of Bordeaux, Bordeaux, France.*

Roger.tormo@icfo.eu

Mechanical resonators are systems which present high quality factors and can easily couple to a wide range of forces. For this reason, they are excellent candidates for sensing and quantum information. While their qualities as sensors have been exploited for many years, it is only recently that their potential use as quantum bits (qubits) have been proposed.
To enable a mechanical qubit, the resonator may be coupled to an external force which induces anharmonicity in the energy dispersion curve of the harmonic oscillator. While they exist some theoretical proposals [1][2], inducing non-linearities on the energy spacing of a mechanical resonator has not yet been achieved experimentally.
In this context, the force exerted by single electron tunnelling on the mechanical vibration of quantum dots embedded in carbon nanotubes has been shown to induce such anharmonicity [2]. In practice this effect necessitates operation in the so-called strong coupling regime. In this regime, the mechanical motion of the carbon nanotube couples to the single electron tunnelling on the quantum dot leading to a ladder of charge-mechanical energy states.
In our work, we present data that evidences the ultra-strong coupling for the single quantum dot case and preliminary data for a double quantum dot system (DQD). In the latter, an electronic two-level system (eTLS), based on the delocalisation of an electron over the two quantum dots, can efficiently couple to the second flexural mode of the carbon nanotube. In the above mentioned ultra-strong coupling regime, the system presents an energy difference between its ground and first excited states significant enough to be used as a basis for a qubit.
The qubit decoherence of the charge-mechanical hybrid system is expected to display a sizeable improvement with respect to current state-of-the-art charge qubits [2]. In our project, we aim to show how to implement such a system experimentally including: our novel nanofabrication techniques for high quality DQDs and cavity read-out of the qubit states.

References

[1] F. Pistolesi, A. N. Cleland, and A. Bachtold. Proposal for a nanomechanical qubit. Phys. Rev. X 11, 031027, 2021.
[2] S. Rips and M. J. Hartmann. Quantum information processing with nanomechanical qubits.Physical Review Letters, 110, 3 2013.

Figures

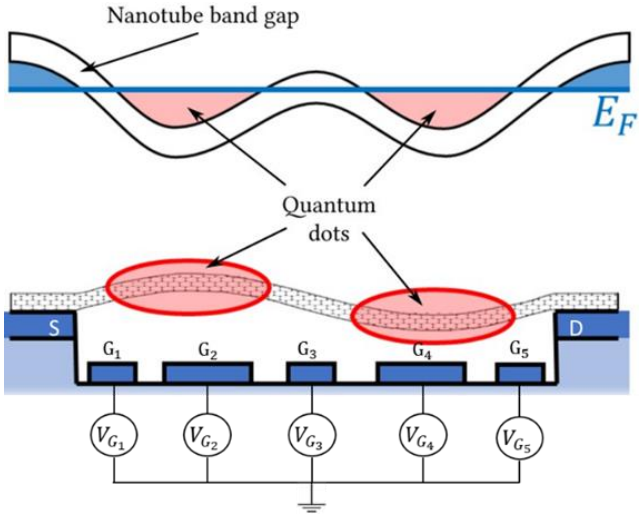


Figure 1: Scheme of a double quantum dot system defined on a suspended carbon nanotube over five gate electrodes.

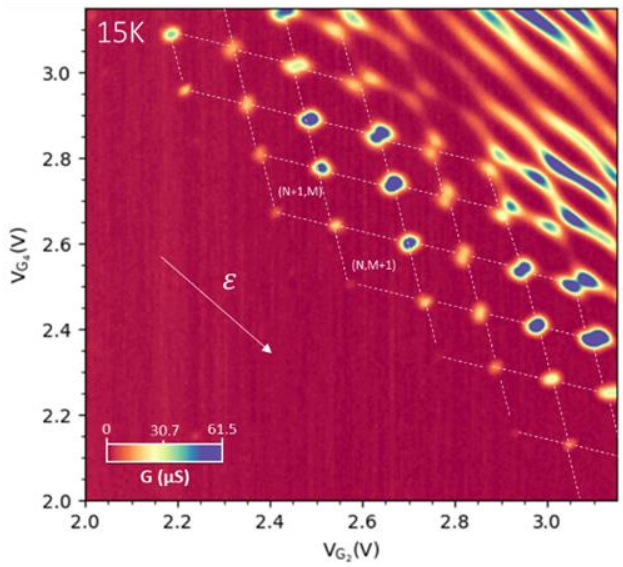


Figure 2: Double quantum dot charge stability diagram of one of our devices at 15K.

Ultrastrong coupling regime in superconducting circuits using superinductor materials

Alba Torras-Coloma
David López-Núñez, Elia Bertoldo, Luca Cozzolino, Fabian Zwiehoff, and Pol Forn-Díaz

Institute of High Energy Physics (IFAE), Edifici Cn Campus UAB, Bellaterra (Barcelona), Spain.

atorras@ifae.es

Superconducting circuits offer a versatile platform to control and study light-matter interaction beyond the strong coupling regime. In this context, qubits play the role of artificial atoms, LC resonators act as cavities and the shared capacitance or inductance between elements define the level of coupling [1].

From a circuit design point of view, the coupling coefficient can be engineered to take values of the order of the bare frequencies of the qubit and the resonator ($0.1 < g/\omega < 1$), allowing the study of the so-called ultrastrong coupling (USC) regime. The challenge of obtaining large inductive couplings can be overcome by using either shared Josephson junctions or superinductor materials showcasing large kinetic inductances such as granular aluminium [2, 3].

In this study we report the first experimental steps towards the exploration of novel phenomena and the characterization of the dynamics and coherence of the USC regime [4]. Particularly, we propose a circuit layout composed of a flux qubit galvanically coupled to an LC lumped-element resonator where each element can be probed with an independent feedline (Figure 1). Contrarily to previous studies, our design integrates superinductor materials to reach couplings within the range of the non-perturbative USC regime ($0.3 < g/\omega < 1$).

References

[1] Forn-Díaz, P., Lamata, L., Rico, E., Kono, J. and Solano, E., Rev. Mod. Phys. 2 (2019) p. 025005.
[2] Grünhaupt, L., Spiecker, M., Gusenkova, D., Maleeva, N., Skacel, S.T., Takmakov, I., Valenti, F., Winkel, P., Rotzinger, H., Wernsdorfer, W. and Ustinov, A.V., Nature Materials, 18 (2019) p. 816.
[3] Maleeva, N., Grünhaupt, L., Klein, T., Levy-Bertrand, F., Dupre, O., Calvo, M., Valenti, F., Winkel, P., Friedrich, F., Wernsdorfer, W. and Ustinov, A.V, Nature Communications, 9 (2018) p. 3889.
[4] Magazzù, L., Forn-Díaz, P., Grifoni, M., Phys. Rev. A 5 (2021) p. 053711.

Figures

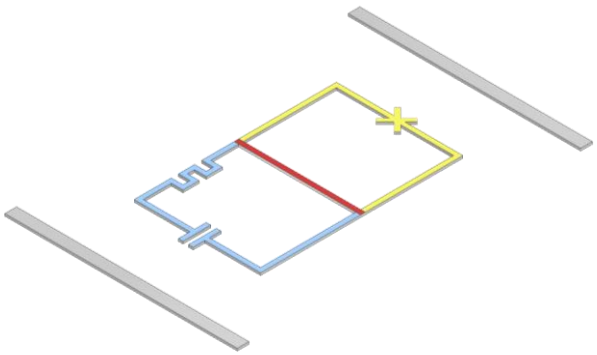


Figure 1: Schematics of the chip design. The qubit (yellow) is coupled to an LC resonator (blue) by means of a shared portion of the circuit (red). Two feedlines are designed to independently probe the qubit and the resonator.

Uncertainty relations with the variance and the quantum Fisher information based on convex decompositions of density matrices

Géza Tóth[1,2,3,4]
Florian Fröwis[5]

[1]*Department of Theoretical Physics, University of the Basque Country UPV/EHU, Bilbao, Spain*

[2]*Donostia International Physics Center (DIPC), San Sebastián, Spain*

[3]*IKERBASQUE, Basque Foundation for Science, Bilbao, Spain*

[4]*Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary*

[5]*Group of Applied Physics, University of Geneva, Geneva, Switzerland*

toth@alumni.nd.edu

We present several inequalities related to the Robertson-Schrödinger uncertainty relation [1]. In all these inequalities, we consider a decomposition of the density matrix into a mixture of states, and use the fact that the Robertson-Schrödinger uncertainty relation is valid for all these components. By considering a convex roof of the bound, we obtain an alternative derivation of the relation in Ref. [2], and we can also list a number of conditions that are needed to saturate the relation. We present a formulation of the Cramér-Rao bound involving the convex roof of the variance. By considering a concave roof of the bound in the Robertson-Schrödinger uncertainty relation over decompositions to mixed states, we obtain an improvement of the Robertson-Schrödinger uncertainty relation. We consider similar techniques for uncertainty relations with three variances. Finally, we present further uncertainty relations that provide lower bounds on the metrological usefulness of bipartite quantum states based on the variances of the canonical position and momentum operators for two-mode continuous variable systems. We show that the violation of well-known entanglement conditions in these systems discussed in Refs. [3,4] implies that the state is more useful metrologically than certain relevant subsets of separable states. We present similar results concerning entanglement conditions with angular momentum operators for spin systems

References

[1] G. Tóth and F. Fröwis, *Uncertainty relations with the variance and the quantum Fisher information based on convex decompositions of density matrices*, Phys. Rev. Research 4, 013075 (2022).

[2] F. Fröwis, R. Schmied, and N. Gisin, *Tighter quantum uncertainty relations following from a general probabilistic bound*, Phys. Rev. A 92, 012102 (2015).

[3] L.-M. Duan, G. Giedke, J. I. Cirac, and P. Zoller, *Inseparability Criterion for Continuous Variable Systems*, Phys. Rev. Lett. 84, 2722 (2000).

[4] R. Simon, Peres-Horodecki *Separability Criterion for Continuous Variable Systems*, Phys. Rev. Lett. 84, 2726 (2000).

Multicopy metrology with many-particle quantum states

Róbert Trényi[1,2,3]
Árpád Lukács,[4,1,3] Paweł Horodecki,[5,6] Ryszard Horodecki,[5] Tamás Vértesi, [7] and Géza Tóth[1,2,8,3]

[1]*Department of Theoretical Physics, University of the Basque Country UPV/EHU, Bilbao, Spain*
[2]*Donostia International Physics Center (DIPC), San Sebastián, Spain*
[3]*Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary*
[4]*Department of Mathematical Sciences, Durham University, Durham, United Kingdom*
[5]*International Centre for Theory of Quantum Technologies, University of Gdańsk, Gdańsk, Poland*
[6]*Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdańsk University of Technology, Gdańsk, Poland*
[7]*MTA Atomki Lendület Quantum Correlations Research Group, Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary*
[8]*IKERBASQUE, Basque Foundation for Science, Bilbao, Spain*

robert.trenyi@ehu.eus

The main goal of quantum metrology is to estimate the unknown phase shift Θ in an interferometer with the smallest possible uncertainty. Using separable quantum states, one can have the precision of $(\Delta\Theta)^2 \sim 1/N$, at best, where N is the number of particles. This can only be overcome with the help of entangled states, in which case, the so-called Heisenberg scaling $(\Delta\Theta)^2 \sim 1/N^2$ can be achieved, which, for our case, represents the maximal metrological usefulness [1].

We say that a quantum state is useful for metrology if it can outperform the precision limit for separable states for phase estimation. It is remarkable, that, entanglement is required for metrological usefulness, however, there are entangled states that are not useful for metrology.

In Ref. [2], we consider the idea of activating the metrological usefulness by taking several copies of bi- and multi-partite quantum states. In doing so, we identify a large class of states that can become maximally useful in the limit of infinite number of copies in such a way that the Heisenberg scaling is attained exponentially fast in the number of copies.

We show that, on the other hand, pure entangled states with even a small amount of white noise do not become maximally useful even in the limit of infinite number of copies. Moreover, we also provide numerical evidence that for some of these states, adding further copies cannot increase their metrological usefulness.

Finally, we also show that the non-useful multi-qubit entangled states presented in [3] can be made useful if we embed the qubits locally in qutrits.

Our scheme for activation can be relevant for Noisy Intermediate-Scale Quantum (NISQ) technology as we also consider the case of moderate number of copies [4].

References

[1] L. Pezzé *et al.*, Rev. Mod. Phys. 90, 3 (2018).
[2] R. Trényi *et al.*, arXiv:2203.05538 (2021).
[3] P. Hyllus *et al.*, Phys. Rev. A 82, 012337 (2010).
[4] J. Preskill, Quantum 2, 79 (2018).

Hardware requirements of option pricing with the quantum Monte Carlo method

Zoltán Udvarnoki
Gábor Fáth

Department of Physics of Complex Systems, Eötvös Loránd University, Budapest, Hungary

zoltan.andras.udvarnoki@ttk.elte.hu

Abstract

One of the promising future applications of quantum computers is the quantum Monte Carlo method, leading to a quadratic speed-up above the classical approach. However, it is impossible to run the Monte Carlo algorithm with reasonable error on current devices because of the decoherence, which is the most crucial limiting factor for the practical usage of quantum computers. In our work, we quantify the necessary hardware requirements for a quantum Monte Carlo simulation - namely financial option pricing [1] - by utilizing noisy simulations and theoretical error bounds on maximum likelihood quantum amplitude estimation [2]. We do that in terms of quantum volume - a universal single number metric to measure the power of quantum hardware - and noise strength. This can be done by measuring the quantum volume of a simulated quantum device with a specific noise model and estimating the error of the given algorithm in parallel. To validate the methods and our results, we used IBM quantum processors.
Our estimates show relatively high requirements for such an easy task even if the type of the noise model is assumed to be known and the likelihood function is modified accordingly. Nonetheless, it can be compared to the roadmap of manufacturers to get an insight into the future of the field.

References

[1] Stamatopoulos, Nikitas, et al. "Option pricing using quantum computers." Quantum 4 (2020): 291.
[2] Tanaka, Tomoki, et al. "Amplitude estimation via maximum likelihood on noisy quantum computer." Quantum Information Processing 20.9 (2021): 1-29.

Figures

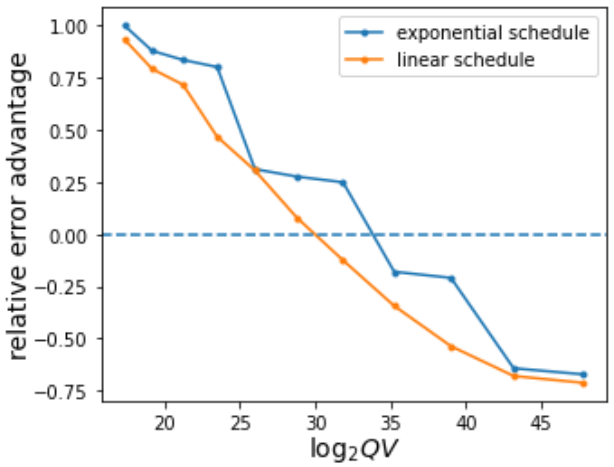


Figure 1: The relative difference between the standard deviation of the classical method and QAE with specific schedules at different quantum volume values. The simulations assumed depolarizing noise model with two-qubit gate error rate 20x larger than one-qubit gate error. Quantum advantage is seen from 2^{30} quantum volume.

Noisy squeezing in continuous-variable quantum communication

Vladyslav C. Usenko[1]
Akash nag Oruganti, Ivan Derkach

[1]*Department of Optics, Faculty of Science, Palacky University, 17. listopadu 12, 77146 Olomouc, Czech Republic*
usenko@optics.upol.cz

We address the role of anti-squeezing excess noise in continuous-variable (CV) quantum communication using Gaussian quadrature modulation and homodyne detection, motivated by advantages offered by the use of squeezing in continuous-variable quantum key distribution (QKD) [1]. Anti-squeezing noise unavoidably appears in the process of generation of squeezed states due to intrinsic losses in an optical parametric oscillator, which reduce squeezing and lead to higher anti-squeezing variance than that of a pure state. We study the role of such phase-sensitive anti-squeezing noise in CV QKD, assuming trusted and untrusted preparation scenarios.

In the case of trusted anti-squeezing noise being a part of the trusted preparation, which is the typical assumption in CV QKD, and a channel with fixed transmittance (typical for fiber links), the noise is even slightly helpful for the trusted parties and allows analytical derivation of the Holevo bound, upper bounding the information leakage, in the limit of infinitely strong anti-squeezing noise. If the channels are fluctuating, however (which is typical for the atmospheric channels where turbulence effects lead to transmittance fluctuations also referred to as fading), presence of even trusted anti-squeezing noise leads to appearance of untrusted channel noise, concerned with fading [2], and limits applicability of squeezed-state CV QKD, requiring squeezed states with high purity or even reduced squeezing [3].

In the stricter assumption of untrusted anti-squeezing (meaning that an eavesdropper controls the squeezer), the presence of such noise significantly limits the achievable key rates, secure distances and robustness to channel noise, the latter shown in Fig. 1. Therefore, for a squeezing source to be untrusted, high level of purity of squeezed states is required.

We also consider finite-size effects concerned with the estimation of parameters in CV QKD [4] and show that the parameter estimation is undermined by the presence of anti-squeezing noise even if it is trusted, hence limiting the efficiency of the protocols.

Our results set the bounds on anti-squeezing noise for practical squeezed-state CV QKD and represent a challenging task of high squeezed-state purity requirement for practical implementation of the protocols.

References

[1] R García-Patron, N.J. Cerf, Phys. Rev. Lett., 102 (2009) 130501; L.S. Madsen, V.C. Usenko, M. Lassen, R. Filip, U.L. Andersen, Nature Communications, 3 (2012) 1083; V.C. Usenko, R Filip, New Journal of Physics, 13 (2011) 113007

[2] V.C. Usenko, B. Heim, C. Peuntinger, C. Wittmann, C. Marquardt, G. Leuchs, R. Filip, New J. Phys. 14 (2012) 093048Authors, Journal, Issue (Year) page

[3] I. Derkach, V.C. Usenko, R. Filip, New J. Phys. 22 (2020) 053006

[4] L. Ruppert, V.C. Usenko, R. Filip, Phys. Rev. A 90 (2014) 062310

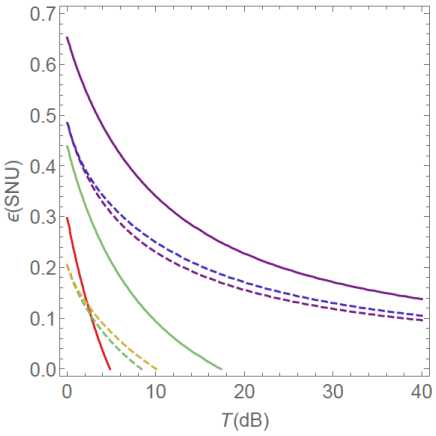


Figure 1: Maximum tolerable channel noise for strong (-10 dB, solid) and weak (-3 dB, dashed) pure squeezing (purple) and with untrusted anti-squeezing noise of 0.5 shot-noise units (SNU, green) and 1 SNU (red). Blue line: 10 SNU trusted anti-squeezing noise.

Few-boson systems with spin-orbit coupling in the presence of strong interaction

Ayaka Usui[a]
Abel Rojo-Francàs[a]
James Schloss
Bruno Juliá Díaz[a]

[a]*Universitat de Barcelona, Martí i Franqués, 1, E08028 Barcelona, Spain*

ayaka.usui@icc.ub.edu

We consider a few spin-1/2 bosons with strong contact interactions and spin-orbit coupling in one dimension and investigate the ground state and the energy spectrum. Some of us have reported that, in two particle systems with spin-orbit coupling, the ground state contains a significant amount of the anti-symmetric spin state in the presence of strong interactions [1]. Without spin-orbit coupling, spin-1/2 bosons keep the symmetry and are composed of only symmetric spin states. For instance, this fact enables one to use symmetrised collective spin operators. However, our two-particle results have indicated that is not the case if spin-orbit coupling is induced due to the emergence of the anti-symmetric spin state. We will show the properties of three- and four-particle systems in the presence of strong interactions. They disagree with some previous reports [2,3], and we will explain why.

References

[1] A. Usui, Th. Fogarty, S. Campbell, S. A. Gardiner, and Th. Busch, New J. Phys. 22 013050 (2020).
[2] C. Hamner, C. Qu, Y. Zhang, J. J. Chang, M. Gong, C. Zhang, and P. Engels, Nature Comm. 5, 4023 (2014).
[3] J. Lian, L. Yu, J.-Q. Liang, G. Chen, and S. Jia, Sci. Rep 3, 3166 (2013).

Imbalance in one-dimensional quantum droplets

Jofre Vallès Muns[1, 2]
Ivan Morera[1, 2], Bruno Juliá-Díaz[1, 2]

[1]*Departament de Física Quàntica i Astrofísica, Facultat de Física, Universitat de Barcelona, E–08028 Barcelona, Spain*

[2]*Institut de Ciències del Cosmos, Universitat de Barcelona, ICCUB, Martí i Franquès 1, Barcelona 08028, Spain*

jofrevalles@ub.edu

Abstract

Recently a whole new class of ultra-dilute quantum droplets has been produced in ultracold atomic laboratories with dipolar bosonic atoms [1] and bosonic mixtures [2]. These quantum droplets originate from a compensation between mean-field and quantum fluctuations [3]. Moreover it has been shown that by loading bosonic mixtures in an optical lattice a new type of strongly correlated paired quantum droplets can be formed [4].
We study strongly correlated droplets in a one-dimensional optical lattice for an imbalance bosonic mixture. In this situation not all bosons are paired and we encounter an interplay between pairs and individual atoms that leads to intriguing phenomena. For small imbalances, the quantum droplet is able to support a finite imbalance in density, thus showing an effective magnetization. As the imbalance increases, a critical point is reached at which the droplet expels the excess of particles and the magnetization is locked in the bulk, see Fig. 1.

References

[1] D. S. Petrov, Phys. Rev. Lett., 155302 (2015) 115.
[2] C. R. Cabrera et. al, Science 359 (2018) 301.
[3] I. Ferrier-Barbut et. al, Phys. Rev. Lett., 215301 (2016) 116.
[4] I. Morera et al., Phys. Rev. Res., 022008(R) (2020) 2.

Figures

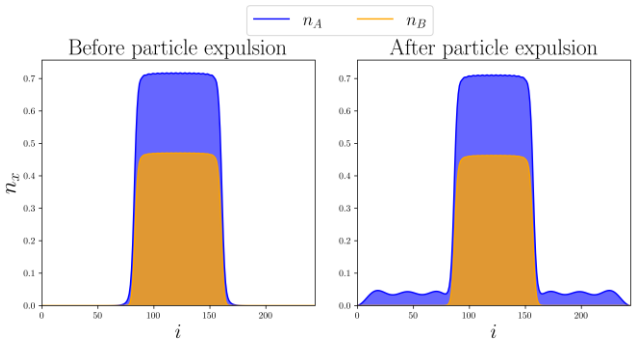


Figure 1: Particle densities as a function of the lattice site. Both plots show an imbalance between the number of particles of each specie. In the right, the imbalance is larger than the critical value and thus we observe an expulsion of particles outside the droplet.

Bidirectional optimal quantum control boosted by deep learning: A use case of polarization in liquid crystals

Dominik Vašinka
Martin Bielak, Michal Neset, and Miroslav Ježek

Department of Optics, Palacký University Olomouc, 17. listopadu 12, 77146, Olomouc, Czechia

VasinkaDominik@seznam.cz

Quantum devices share the common aspect of being controlled by classical analog signals, related nontrivially to the device operation. The control signals need to be optimally adjusted to provide a high-fidelity operation of the device. A common approach to predicting control signals required to prepare the target quantum state, i.e., the inverse control model, minimizes an ad hoc selected distance metric in the classical control space. However, the values of control signals are given by the technical implementation and are often ambiguous. We propose and experimentally test a novel idea for constructing the inverse control model. We develop an unsupervised-like deep learning approach combining the inverse and direct control models, as depicted in Fig. a). The classical control signals play the role of latent variables with no required quantification in the latent space. By minimizing the error in the space of quantum states, various models and devices, even with a different number of control signals, can be optimized and compared. We demonstrate our approach in a use case of polarization state transformation using twisted nematic liquid crystals controlled by several voltage signals. Furthermore, the method is used for local preparation and remote preparation of polarization-encoded qubits with unprecedented accuracy, both shown in Fig. b).

References

[1] D. Vašinka, M. Bielak, M. Neset, and M. Ježek, Bidirectional deep learning of polarization transfer in liquid crystals with application to quantum state preparation, arXiv:2109.12436, accepted for publication in Phys. Rev. Appl. (2022).

Figures

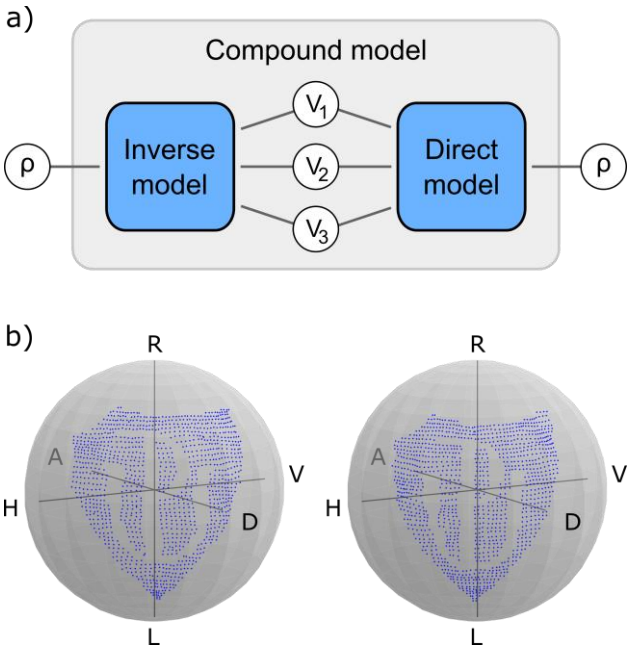


Figure: a) Representation of the compound model created by connecting the inverse model to the pre-trained fixed direct model. b) Visualization of the single-photon polarization qubits from local preparation (left) and remote preparation (right) forming the Palacký University logo on the Bloch sphere.

Valley-Polarized Quantum Anomalous Hall Phase in Bilayer Graphene with Layer-Dependent Proximity Effects

Marc Vila[1,2,3]
Jose H. Garcia[1], Stephan Roche[1, 4]
[1] Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Campus UAB, Bellaterra, 08193 Barcelona, Spain
[2] Department of Physics, University of California, Berkeley, California 94720, USA
[3] Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
[4] ICREA--Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain
marcvila@berkeley.edu

Realizations of some topological phases in two-dimensional systems rely on the challenge of jointly incorporating spin-orbit and magnetic exchange interactions. Here [1], we predict the formation and control of a fully valley-polarized quantum anomalous Hall effect in bilayer graphene, by separately imprinting spin-orbit and magnetic proximity effects in different layers. This mechanism contrasts with other proposals of this effect where both interactions are needed in both layers and as such poses challenges for experimental realizations. Our model results in varying spin splittings for the conduction and valence bands, which gives rise to a topological gap at a single Dirac cone [see Figure 1(a)]. The topological phase can be controlled by a gate voltage and switched between valleys by reversing the sign of the exchange interaction. By calculating the valley-resolved Hall conductivity [see Figure 1(b)] together with quantum transport simulations in disordered systems, the chirality and resilience of the valley-polarized edge state are demonstrated. Our findings provide a promising route to engineer a topological phase that could enable low-power electronic devices and valleytronic applications as well as putting forward layer-dependent proximity effects as a way to create versatile topological states of matter.

References

[1] Marc Vila, Jose H. Garcia, Stephan Roche, Phys. Rev. B, 104 (2021) L161113

Figures

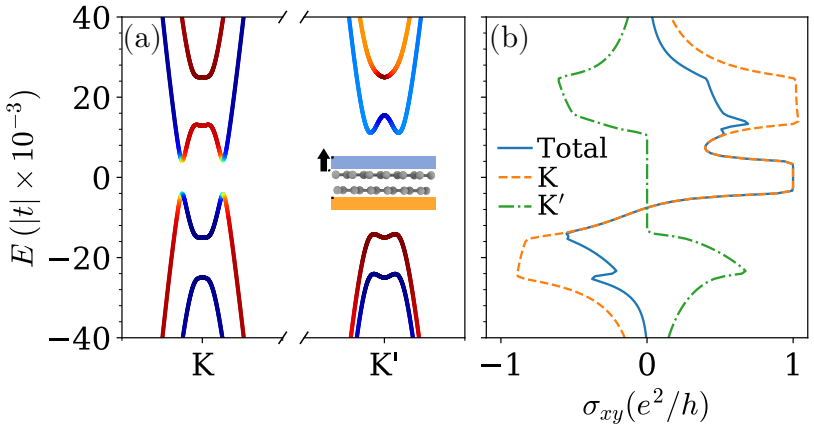


Figure 1: (a) Low-energy band structure of bilayer graphene proximitized with exchange interaction in one layer, and spin-orbit in the other layer. The gap at the K (K') valley is topological (trivial). (b) Valley-resolved Hall conductivity of the system in (a). The plateau of the Hall conductivity in the bulk band gap region demonstrates the presence of a valley-polarized quantum anomalous Hall effect.

Error correction for Fibonacci quasiparticle poisoning

Lucia Vilchez Estevez
Nicetu Tibau Vidal

Clarendon Laboratory, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom

lucia.vilchezestevez@physics.ox.ac.uk

Abstract

Topological quantum computers encode information in global and topological properties of quantum systems that are resistant to local perturbations [1]. This makes this type of information processing very promising in the future. However, it is possible that the effects of finite temperature can introduce some inevitable errors. This event is known as quasiparticle poisoning.

We consider a quasiparticle pair creation error process where a particle and its antiparticle are created from the vacuum. One of them might interact with the anyons in our system by fusing with them. Such interaction is described by a unitary operation accounting for all the possible fusion outcomes.

We use the diagrammatic algebra for anyonic theories [2] to study different types of quasiparticle poisoning on Fibonacci anyons. We find the concrete description of the error as a quantum channel. We see that the channels are non-unitary, implying that the process is not reversible. However, the error can be corrected.

Within our set of physically available anyons we identify a qudit subspace that will serve as the code space. We explore different possible encodings that guarantee the shielding against the error or its recoverability.

We focus on the implementation of stabilizer codes [3] as one of these recoverability schemes.

References

[1] Nayak, C., Simon, S. H., Stern, A., Freedman, M., & Sarma, S. D. *Reviews of Modern Physics*, *80*(3), 1083 (2008).
[2] P. Bonderson, K. Shtengel, and J. K. Slingerland, Annals of Physics, 323(11), 2709-2755 (2008).
[3] Gottesman, D., Caltech Ph.D. thesis, https://arxiv.org/abs/quant-ph/9705052 (1997).

Figures

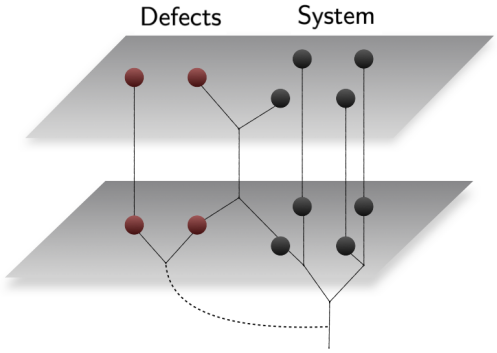


Figure 1: Illustration of the quasiparticle pair (red dots) production and poisoning process in a four-anyon (black dots) system.

Quantum Domain Melting in a Quantum Annealer

Jaka Vodeb[1,2]
Michele Diego[1], Yevhenii Vaskivskyi[1], Leonard Logaric[1], Yaroslav Gerasimenko[1], Viktor Kabanov[1], Benjamin Lipovsek[3], Marko Topic[3] and Dragan Mihailovic[1,2,4]

[1]*Department of Complex Matter, Jozef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia*
[2]*Department of Physics, Faculty for Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia*
[3]*Faculty for Electrical Engineering, University of Ljubljana, 1000 Ljubljana, Slovenia*
[4]*CENN Nanocenter, Jamova 39, 1000 Ljubljana, Slovenia*

jaka.vodeb@ijs.si

The ordering of systems emerging through non-equilibrium symmetry breaking transitions is commonly accompanied by domain formation which strongly modifies the bulk materials' properties. The underlying microscopic physics that defines the system's energy landscape for tunneling between domain configurations is of interest in many different areas [1-8]. Domains may reconfigure by thermally-driven microscopic processes[9, 10], or - in quantum systems - by macroscopic quantum tunneling (MQT). Here, we report quantum domain melting in two embodiments: an electronic crystal 1T-TaS_2, and its matching simulation on a quantum computer. We use scanning tunneling microscopy to measure the time-evolution of electronic domain reconfiguration dynamics, and compare this with the time evolution of domains in an ensemble of entangled correlated electrons in simulated quantum domain melting. The domain reconfiguration is found to proceed by tunneling in an emergent, self-configuring energy landscape, with remarkable correspondence between a quantum charged lattice gas model and experiment exhibiting characteristic ragged time evolution and temperature-dependence observed macroscopically. Understanding the quantum processes involved in electronic domain melting opens the way to experimental observation and modelling mesoscopic emergent behaviour in non-equilibrium interacting many-body quantum systems at the microscopic level.

References

[1] M. Turner, F. Wilczek, *Nature* 298 (1982) 633–634.
[2] B. M. Roberts, G. Blewitt, C. Dailey, M. Murphy, M. Pospelov, A. Rollings, J. Sherman, W. Williams, and A. Derevianko, Nature Communications 8 (2017) 1.
[3] S. Coleman, Physical Review D 15 (1977) 2929.
[4] S. Kustov, I. Liubimova, and E. K. H. Salje, Physical Review Letters 124 (2020) 016801.
[5] L. Thomas, F. Lionti, R. Ballou, D. Gatteschi, R. Sessoli, and B. Barbara, *Nature* 383 (1996) 145–147.
[6] E. M. Chudnovsky and J. Tejada, Cambridge Studies in Magnetism (1998) pp. 8-28.
[7] A. Kandala, A. Mezzacapo, K. Temme, M. Takita, M. Brink, J. M. Chow, and J. M. Gambetta, Nature 549 (2017) 242.
[8] D. D. Awschalom, J. F. Smyth, G. Grinstein, D. P. Di- Vincenzo, and D. Loss, Physical Review Letters 68 (1992) 3092.
[9] L. P. Pitaevskii and E. M. Lifshitz, Physical Kinetics: Volume 10 (2012).
[10] A. Baldan, Journal of Materials Science 37 (2002) 2171.

Persistent spectral hole burning and atomic frequency comb at microwave frequency in Er^{3+} : $CaWO_4$

Zhiren Wang
M. Le *Dantec*, M. Rancic, E. Billaud, L. Balembois, E.Flurin, P. Bertet, D. Vion, D. Estève

CEA, Orme des merisier, Gif-sur-Yvette, France

zhiren.wang@cea.fr

The interaction of electron spins with neighboring nuclear spins in a host crystal leads to rich physics and dynamics, as observed in semiconducting quantum dots, color centers in diamond and donors in silicon. Here, we report a new phenomenon, using a crystal of $CaWO_4$ containing Erbium ions, at millikelvin temperature.

Erbium has a doublet ground state with a large magnetic moment behaving as an effective electron spin-1/2. In CaWO4, Er^{3+} couple to the magnetic moment of neighboring ^{183}W nuclear spins (14% abundance). Under a field of 450 mT, the Erbium spin is brought in resonance with a superconducting resonator at 7.8 GHz used for detection. By applying a microwave tone, we observe spectral holes created in the absorption of Er and these holes exist over 20 hours, which is much longer than the Er^{3+}:$CaWO_4$ spin-lattice relaxation time (0.2s). We interpret the holes as being caused by dynamic nuclear polarization of the nearby W nuclear spin leading to an Overhauser field seen by the Er^{3+}, while its persistent existence demonstrates the stability of polarization within W nuclear spins at low temperature. Furthermore, by applying repeated double-pulse sequence, we are able to generate an atomic frequency comb in the spin ensemble, which persists for at least 120 hours at 10mK.

References

[1] Putz, Stefan, et al. "Spectral hole burning and its application in microwave photonics." Nature Photonics 11.1 (2017): 36-39.
[2] Le Dantec, Marianne, et al. "Twenty-three–millisecond electron spin coherence of erbium ions in a natural-abundance crystal." Science advances 7.51 (2021): eabj9786.

Figures

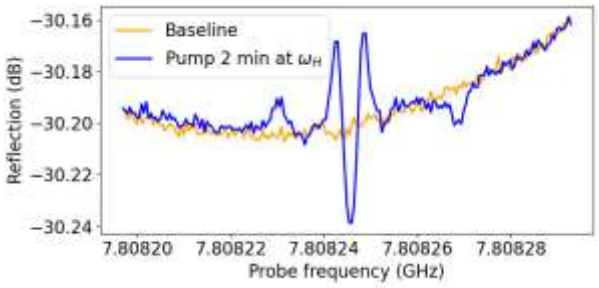


Figure 1: Refection spectrum of spin ensemble before and after applying microwave at the frequency ω_H, where the ω_H is the summation of resonator frequency ω_0 and tungsten nuclear Larmor frequency ω_I

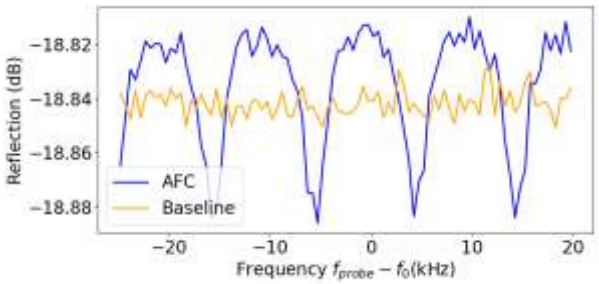


Figure 2: Atomic frequency comb created in the spin ensemble absorption spectrum after applying the following pulse sequence with a repetition of 18000 times: two square pulses separated by 100 µs and waiting time of T_1(Er) 0.2 s

Quantum Algorithms with Superconducting Qubits coupled to High Q Coaxial Cavities

Ian Yang Yen Wei
Desilava Atanasova, Teresa Hoenigl-Decrinis, Arman Alizadeh, Seyed Iman Mirzei, Gerhard Kirchmair

University of Innsbruck, Department of Experimental Physics, Technikerstrasse 25, 6020 Innsbruck, Austria

ian.yang@uibk.ac.at

Abstract

High Q coaxial cavities have shown high single photon quality factors of 0.5×10^9 [1]. Such a low-loss cavity is especially useful as a common quantum bus for multiple qubits or for encoding quantum information, using it as a bosonic qubit. Here, we present our platform for coupling transmon qubits to a high Q cavity.

We use high purity niobium in a $\lambda/4$ coaxial seamless design [2]. We use electro-discharge machining and buffer chemical polishing for a smooth surface that reduces losses in the cavity.

A flux hose allow us to apply magnetic field inside the superconducting coaxial cavity [3]. The flux hose also allows for fast flux tuning. Our in-house assembled hoses are ideally suited for fast flux bias lines in 3D superconducting architectures.

We are also incorporating a bandpass filter that will act as a modular Purcell filter replacing the readout SMA pin.

By combining these ingredients, we build a platform for interacting mutli-qubit systems for quantum information processing. Additionally, the multi-dimensional Hilbert space of the cavity is a suitable for hardware efficient encoding for quantum error correction.

References

[1] P. Heidler et al., *Phys. Rev. Appl.*, vol. 16, no. 3 (2021) p. 034024
[2] M. Reagor *et al.*, *Phys. Rev. B*, vol. 94, no. 1 (2016) p. 014506
[3] O. Gargiulo et al., *Appl. Phys. Lett.*, vol. 118, no. 1 (2021) p. 012601

Figures

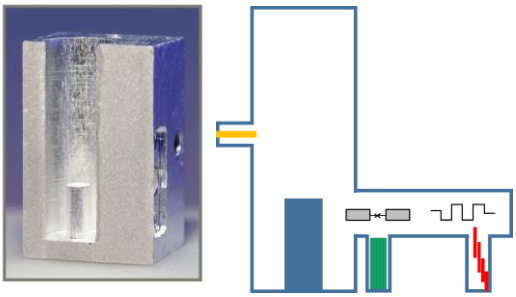


Figure 1: (left) Cut picture of a Coaxial cavity. (right) Schematic representation of the setup. SQUID transmons are capacitively coupled to the High Q Coaxial Niobium cavity. The SQUIDs are tuned with a Flux Hose and protected by a Purcell Filter, which is integrated into the readout pin.

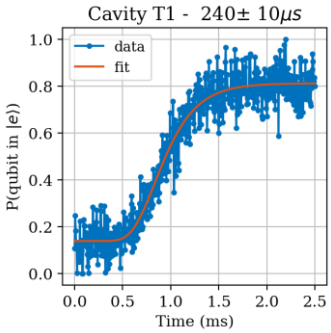


Figure 2: High Q Cavity T1 Measurement – A displacement pulse puts the cavity into a coherent state with high average photon number. The coherent state then decays back to the cavity ground state with characteristic time T_1, which is probed by a selective π pulse on the qubit transition for the cavity ground state.

Rare-earth ions in nanocavities as a quantum information platform

Yong Yu

Delft University of Technology, Delft, The Netherlands

y.yu-7@tudelft.nl

Rare-earth ions doped in solids have unique, appealing properties of long optical and spin coherence time. These properties make them excellent candidates for quantum information processing. Its ability has been shown in numerous amounts of successful quantum memory [1] and remote quantum entanglement experiments [2].

With the development of nanofabrication technology, accessing single rare-earth ions becomes feasible by using high quality factor nanocavities [3][4]. The strong light-matter interaction opens a new door for the rare-earth ions, enabling single-photon generation and light-matter gates.

Here, I want to discuss our recent efforts to realize a rare earth ion-nanocavities system and share our preliminary results.

References

[1] De Riedmatten H, et al. Nature, 2008, 456(7223): 773-777.
[2] Lago-Rivera D, et al. Nature, 2021, 594(7861): 37-40.
[3] Raha, Mouktik, et al. Nature communications 11.1 (2020): 1-6.
[4] Kindem J M, et al. Nature, 2020, 580(7802): 201-204.

Figures

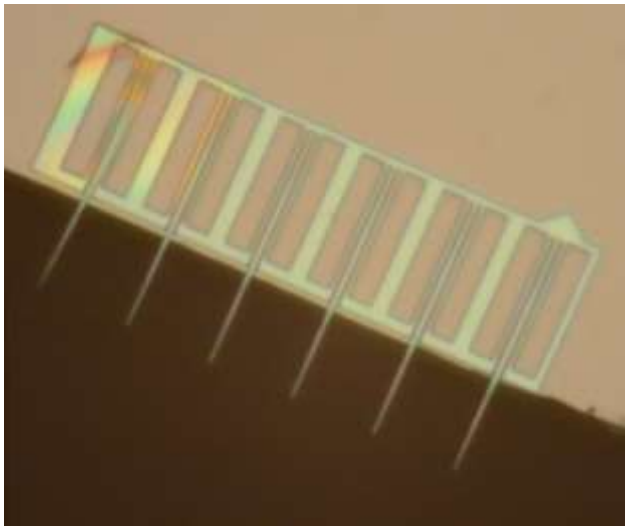


Figure 1: Nanocavities on the Er:$LiNbO_3$

Quantum transfer between arbitrary pairs of protected states in a topological ladder

Juan Zurita,
Charles Creffield and Gloria Platero

Instituto de Ciencia de Materiales de Madrid (CSIC), Cantoblanco, 28049, Madrid, Spain

Universidad Complutense de Madrid, 28040, Madrid, Spain

juzurita@ucm.es

In recent years, the number of proposed quantum protocols which use the protected end states of topological insulators has increased steadily [1-4]. Most of them, however, are constrained by two limitations: the transfer can only happen between the ends of the system, and the time it takes to be completed scales exponentially with distance.

We explore solutions to these issues by proposing a family of quantum transfer protocols between any two topological states in a quasi-1D topological insulator: the multi-domain Creutz ladder.

This model can have an arbitrary number of topological modes. Each of its domain walls holds two such states, which can be tuned with a control parameter [5]. This is possible due to the interference created by the magnetic field, which is also responsible for the flat bands of the model. In our work [6], we describe its topological subspace in detail, propose the transfer protocols mentioned above, and discuss some applications in the field of quantum information.

References

[1] N. Lang, H. Büchler, npj Quantum Information, **3** (2017) 47.

[2] P. Boross, J. K. Asbóth, G. Széchenyi, L. Oroszlány, A. Pályi, Physical Review B, **4** (2019) 045414.

[3] F. Mei, G. Chen, L. Tian, S.-L. Zhu, S. Jia, Physical Review A, **98** (2018), 012331.

[4] M. P. Estarellas, I. D'Amico, T. P. Spiller, Scientific Reports, **7** (2017), 42904.

[5] J. Jünemann, A. Piga, S. J. Ran, M. Lewenstein, M. Rizzi, A. Bermúdez, Physical Review X, **7** (2017), 031057.

[6] J. Zurita, C. Creffield, G. Platero, *In preparation* (2022).

Figures

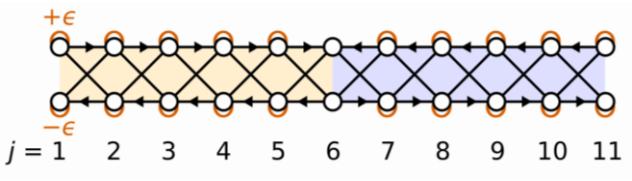


Figure 1: Two-domain Creutz ladder with an energy imbalance of 2ϵ. The two non-equivalent topological domains are defined by the magnetic field values of $\phi = \pi$ (yellow) and $\phi = -\pi$ (blue).

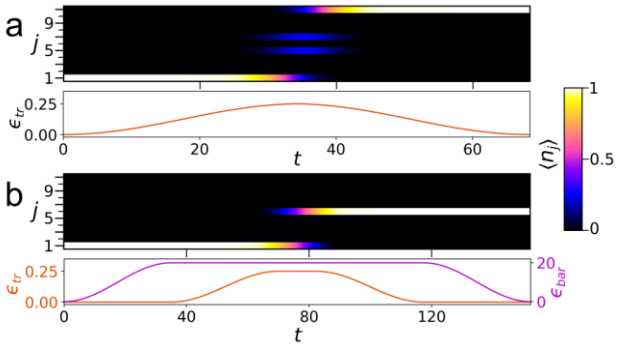


Figure 2: Topological transfer protocols in a two-domain Creutz ladder. The occupation number per rung is represented as a function of rung number *j* and time *t*. The energy imbalances of the model, which act like control parameters, are represented below the transfer picture. (a) Left-to-right transfer. (b) Left-to-center transfer.

Quantum sensing for deep tissue magnetic resonance imaging

Analia Zwick

G. A. Alvarez, D. Suter, G. Kurizki

Bariloche Atomic Center, Institute of Nanoscience and Nanotechnology – Conicet - CNEA, Balseiro Institute, Bariloche Argentina

analia.zwick@gmail.com

The development of quantum technologies is an area expected to revolutionize medical diagnosis by taking advantage of quantum information processing to improve devices, such as sensors. Quantum sensors will serve applications ranging from thermometry to diagnostic imaging with sub-micrometer resolutions [1-4]. The current spatial resolution of non-invasive in-vivo magnetic resonance imaging (MRI) is limited to a scale of millimeters in conventional imaging modalities. However, relevant tissue microstructure details and processes linked to disease occur at molecular and microstructural scales governed by the laws of quantum physics. We use nuclear spins of molecules intrinsic to biological systems (e.g. water protons) as quantum sensors of their environment and control them with magnetic resonance techniques to characterize quantitatively the underlying microstructure efficiently in time and precision (Figure 1) [1,4-7]. We exploit fundamental concepts of quantum mechanics developed within the area of quantum information sciences, as quantum-control and -information theory tools to non-invasively quantify deep tissue-microstructure parameters such as cell-sizes or axon diameters [4-5]. This allows us to resolve structures with length scales that are about 100 times smaller than the actual imaging resolution.

References

[1] A. Zwick, G. A. Álvarez, G. Kurizki, Phys. Rev. Applied 5, 014007 (2016).

[2] V. Mukherjee, A. Zwick, A. Ghosh, X. Chen, Commun. Phys. 2, 162 (2019).

[3] M. Kuffer, A. Zwick and G. A. Álvarez. PRX Quantum 3, 020321 (2022).

[4] A. Zwick, D. Suter, G. Kurizki, G. A. Álvarez, Phys. Rev. Applied 14, 024088 (2020).

[5] M. Capiglioni, A. Zwick, P. Jiménez and G. A. Álvarez, Proc. Intl. Soc. Mag. Reson. Med. 29, 2036 (2021).

[6] M. Giménez, P. Jiménez, L. Pedraza, D. Betancourth, A. Zwick, and G. A. Álvarez, Proc. Intl. Soc. Mag. Reson. Med. 29, 3418 (2021).

[7] M. Capiglioni, A. Zwick, P. Jiménez and G. A. Álvarez, Phys. Rev. Applied 15, 014045 (2021)

Figures

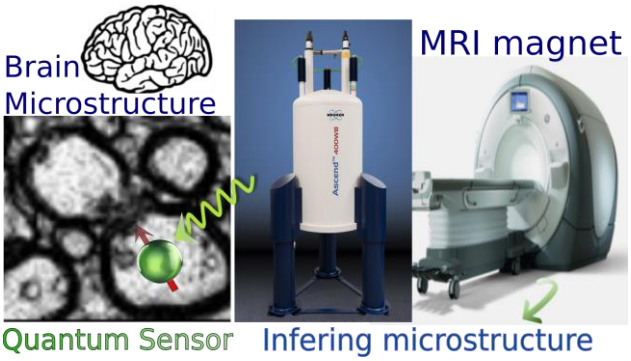
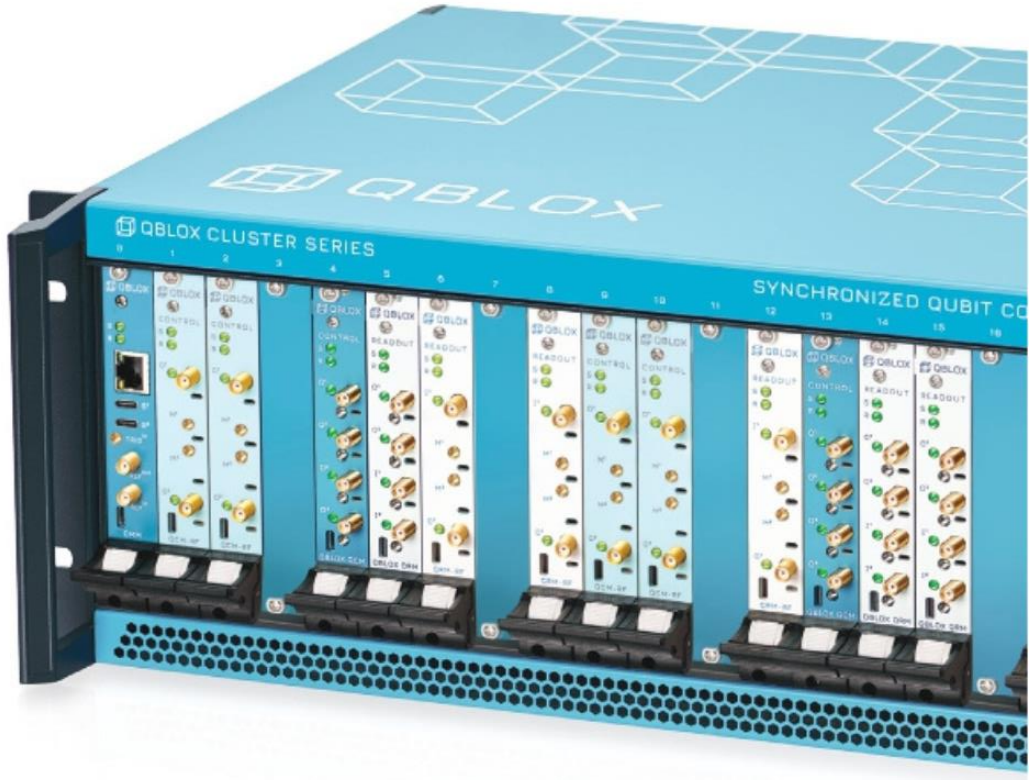


Figure 1: Schematic quantum sensing for improving tissue microstructure resolution by Magnetic Resonance Imaging

QBLOX

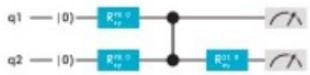
Control The Quantum Future

Fully-integrated Quantum Control Stacks
Modular + Synchronized
Analog Excellence
DC to 18.5 GHz

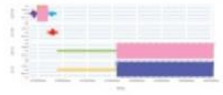


quantify

Intuitive Scheduling



Pulse Sequence Visualization



SYNQ

LINQ

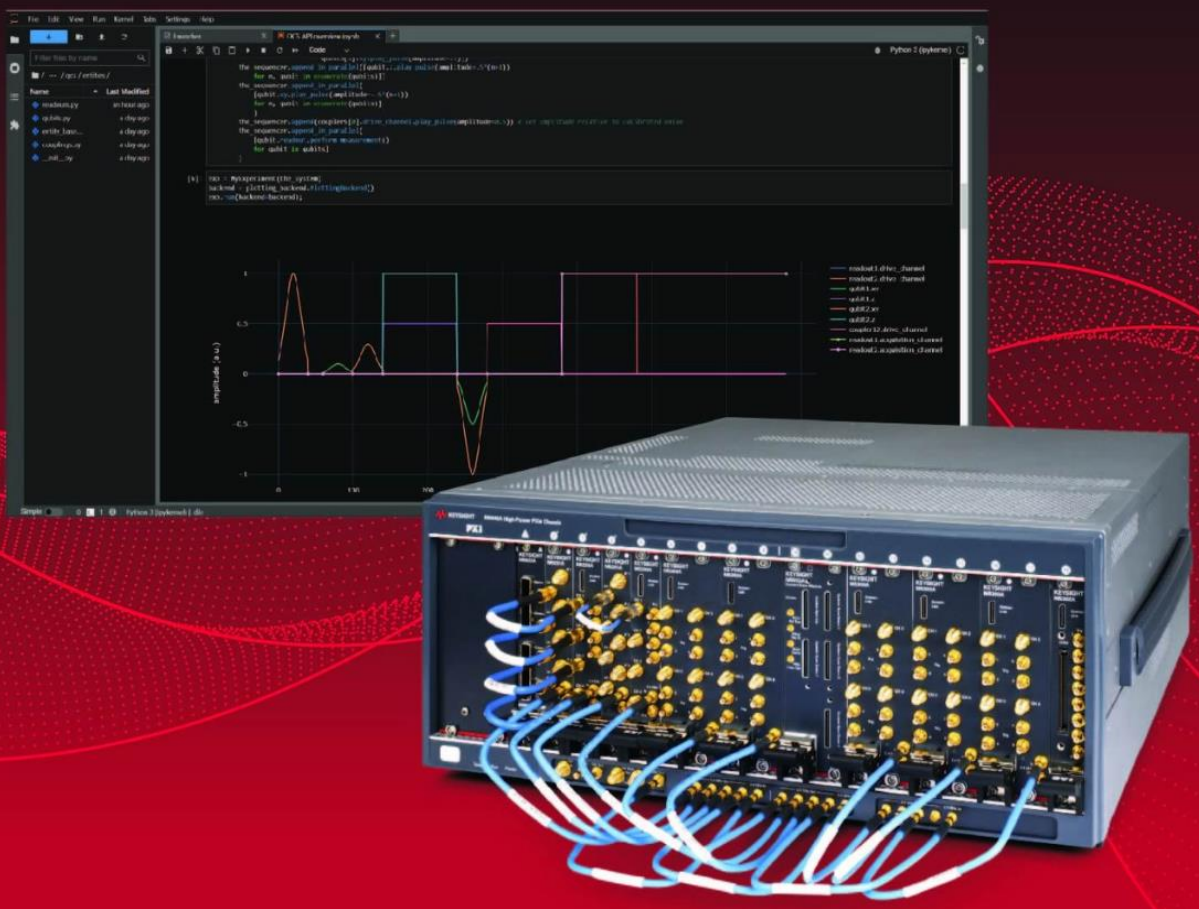
SIGNALS 0-300 MHz

SIGNALS 2-18.5 GHz

Join our **keynote** session or visit **our booth** at QuantuMatter 2022 | www.qblox.com

KEYSIGHT

Introducing the world's first **fully digital** Quantum Control System



Visit the Keysight booth to learn more