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Since 2011 **ImagineNano** has strengthened its position as one of the main events dedicated to Nanoscience and Nanotechnology (N&N) in Europe. The outstanding results of participation that have been reached and the interest created by the discussions, have laid the foundations for the upcoming edition.

ImagineNano 2021 is now an established event and is an excellent platform for communication between science and business, bringing together Nanoscience and Nanotechnology in the same place.

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Under the same roof will be held 6 International Conferences (QUANTUM, Graphene & 2DM, NanoSpain, IC2, 3DPrinting and 3PM), an exhibition showcasing cutting-edge advances in nanotechnology research and development and a brokerage event (one-to-one meetings).

ImagineNano will gather the global nanotechnology community, including researchers, industry, policymakers and investors. The latest trends and discoveries in N&N from some of the world´s leading players in the field will be discussed.

We would like to thank all participants, sponsors and exhibitors that joined us this year.

The Basque Country demonstrates its strengths in nanoscience, micro and nanotechnology, and positions itself as a major player in the "nano" world, reason why **ImagineNano** is organized for the 5th time in Bilbao.

There´s no doubt that **ImagineNano 2021** is the right place to see and be seen.

Hope to see you again in the next edition of **ImagineNano** (2023) in Bilbao.

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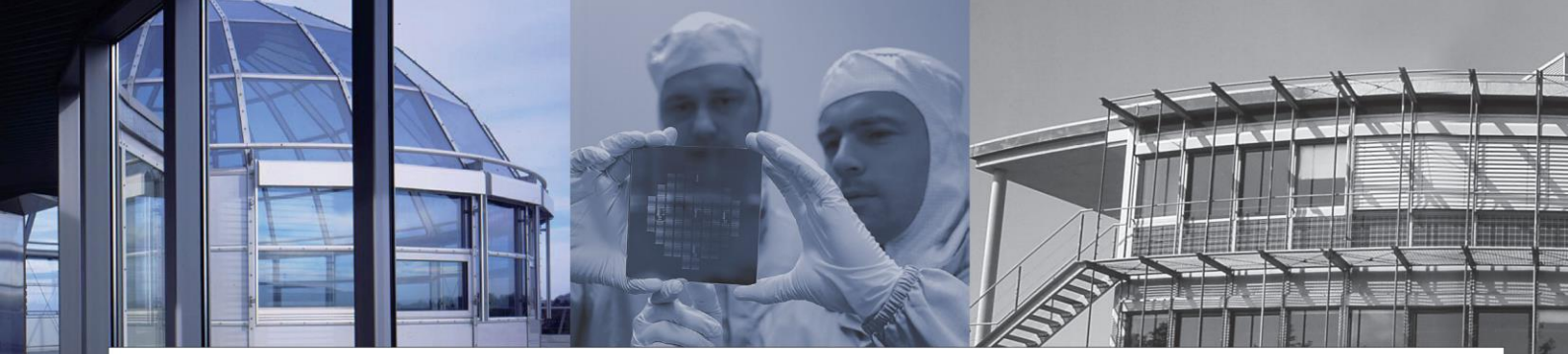

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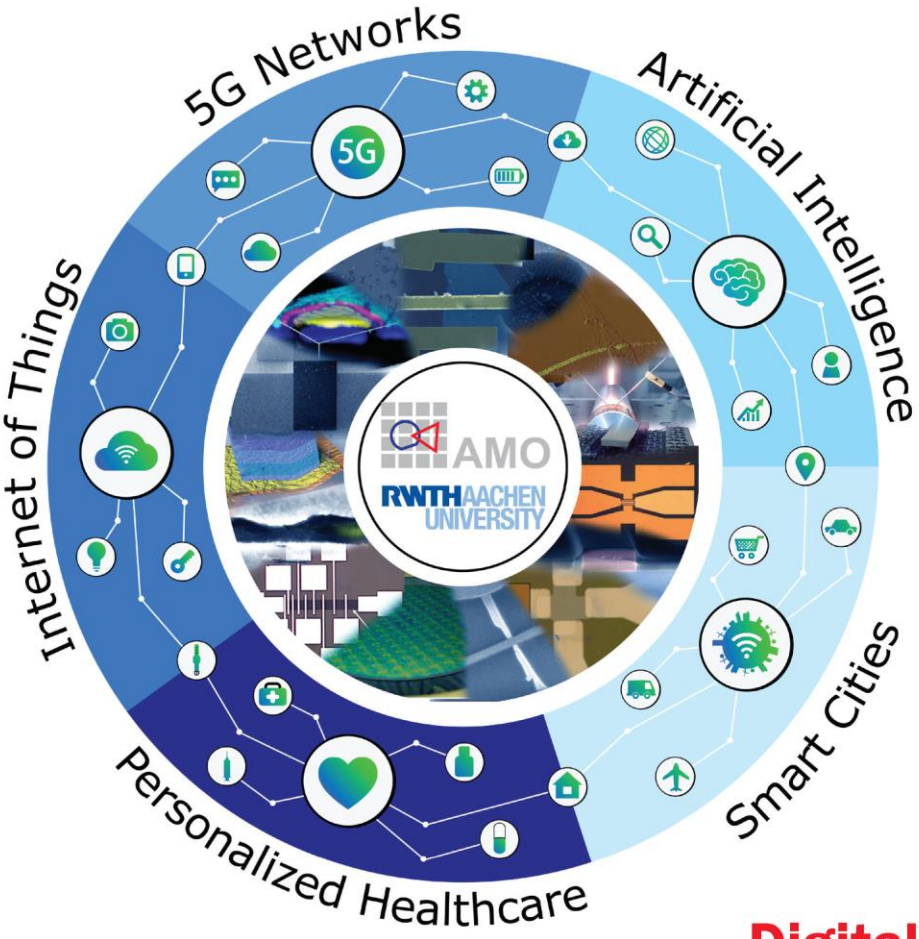

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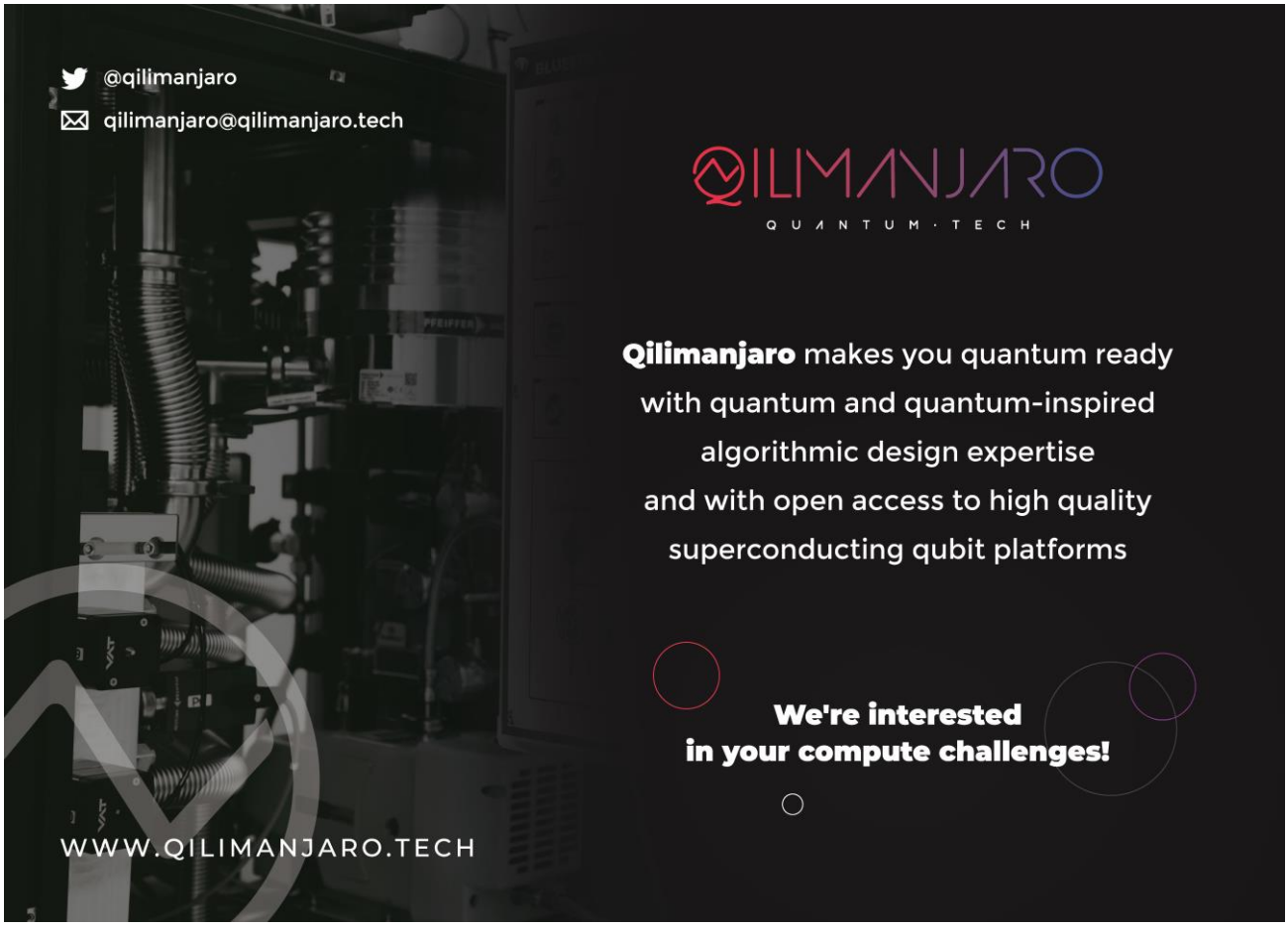

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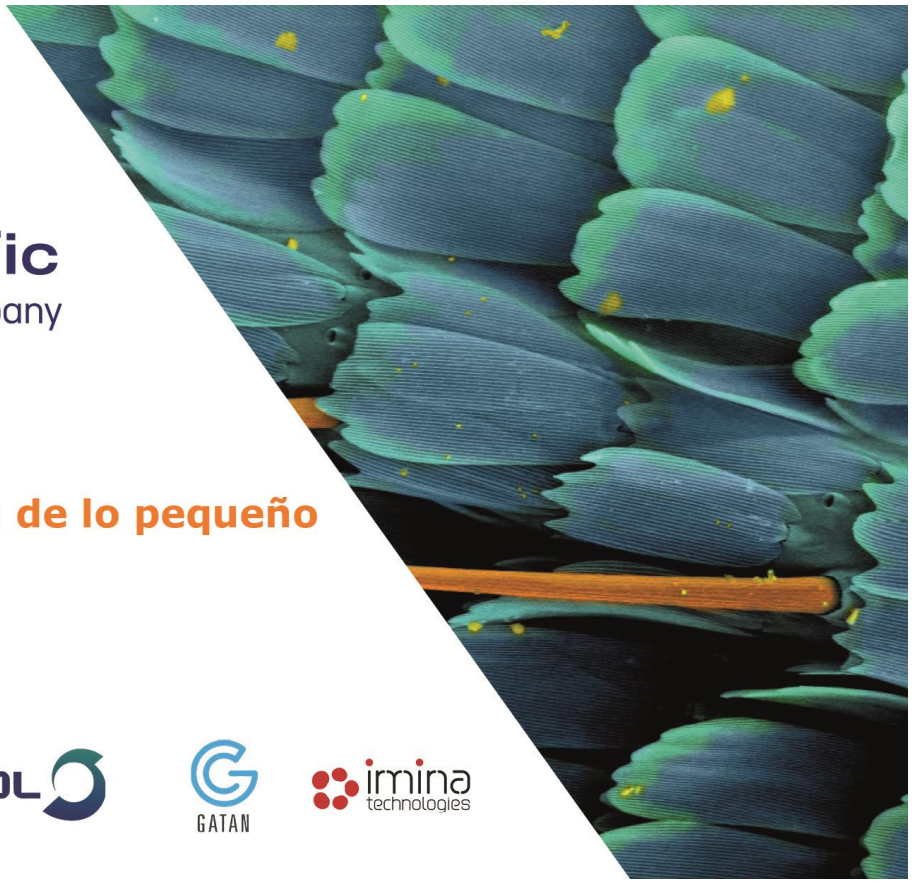

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Quantum computers and many-body systems

J. Ignacio Cirac
S. Lu and M. C. Bañuls

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Quantum many-body systems are very hard to simulate, as computational resources (time and memory) typically grow exponentially with system size. However, quantum computers or analog quantum simulators may perform that task in a much more efficient way. In this talk, I will review some of the quantum algorithms that have been proposed for this task and then explain the advantages and disadvantages of analog quantum simulators. In particular, I will describe methods to simulate the dynamics, to find ground states, or compute physical properties at finite temperatures.

References

[1] S. Lu, M.C. Banuls and J. I. Cirac, PRX Quantum 2, (2021) 020321.

Figures

Surface acoustic waves as testbed for electron flying qubits

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A surface acoustic wave (SAW) is surprisingly efficient to transport a single electron between distant quantum dots [1,2] while preserving in flight its quantum coherent properties [3,4]. The acousto-electric shuttling technique provides thus a perfect testbed to investigate the feasibility of electron-flying-qubit implementations [5]. Here we present our latest results on SAW-driven single-electron transport in a circuit of coupled quantum rails. Mastering picosecond triggering of the transfer process [6] verified via time-of-flight measurements [7], we are capable of synchronising transport along parallel quantum rails. Sending two electrons simultaneously through the coupling region, we observe distinct Coulomb-dominated repulsion – the central ingredient to realise a controlled phase gate for electron flying qubits. Discussing partitioning data of a single electron in the coupling region [5], we further point out the importance of SAW confinement for coherent in-flight manipulation. To address this critical aspect, we finally demonstrate SAW engineering via chirp synthesis enabling single-electron transport with a solitary electro-acoustic pulse. Our results lay the ground for quantum logic circuits with electron flying qubits surfing on sound.

References

[1] Hermelin *et al.*, Nature 477, 435–438 (2011)
[2] McNeil *et al.*, Nature 477, 439–442 (2011)
[3] Hermelin *et al.*, Nature 477, 435–438 (2011)
[4] Jadot *et al.*, Nat. Nanotechnol. 16, 570–575 (2021)
[5] Ito *et al.*, Phys. Rev. Lett. 126, 070501 (2021)
[6] Bäuerle *et al.*, Rep. Prog. Phys. 81, 056503 (2018)
[7] Takada *et al.*, Nat. Commun. 10, 4557 (2019)
[8] Edlbauer *et al.*, Appl. Phys. Lett. 119, 114004 (2021)

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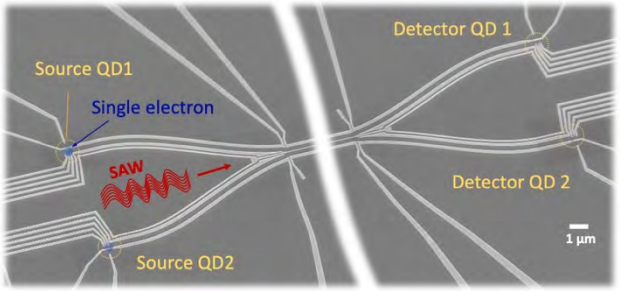

Figure 1: 2-particle collider with single electrons propelled by a surface acoustic wave (SAW). The device is composed of 2 source quantum dots (QD) and 2 detector quantum dots. In the centre region the electrons can interact through a 40-micrometre long tunnel barrier.

Design of quantum optical experiments with logic artificial intelligence

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Logic artificial intelligence (AI) is a subfield of AI where variables can take two defined arguments, True or False, and are arranged in clauses that follow the rules of formal logic. Several problems that span from physical systems to mathematical conjectures can be encoded into these clauses and be solved by checking their satisfiability (SAT). Recently, SAT solvers have become a sophisticated and powerful computational tool capable, among other things, of solving long-standing mathematical conjectures. In this work, we propose the use of logic AI for the design of optical quantum experiments. We show how to map into a SAT problem the experimental preparation of an arbitrary quantum state and propose a logic-based algorithm, called Klaus, to find an interpretable representation of the photonic setup that generates it. We compare the performance of Klaus with the state-of-the-art algorithm for this purpose based on continuous optimization. We also combine both logic and numeric strategies to find that the use of logic AI improves significantly the resolution of this problem, paving the path to develop more formal-based approaches in the context of quantum physics experiments.

References

[1] A. Cervera-Lierta, M. Krenn, A. Aspuru-Guzik, arXiv:2109.13273 [quant-ph] (2021).
[2] Code: https://github.com/albacl/klaus
[3] M. Krenn, J. S. Kottmann, N. Tischler, and A. Aspuru-Guzik, Phys. Rev. X 11 (2021), 031044.

Figures

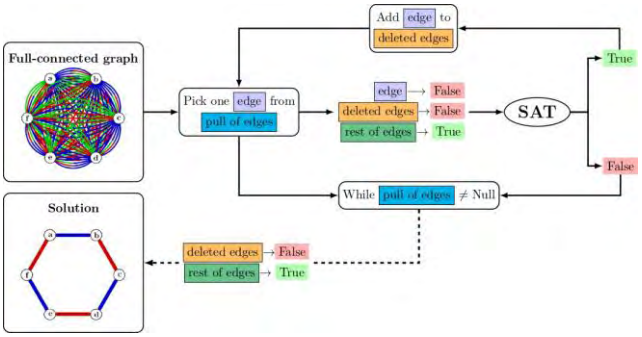

Figure 1: Diagram of Klaus algorithm.

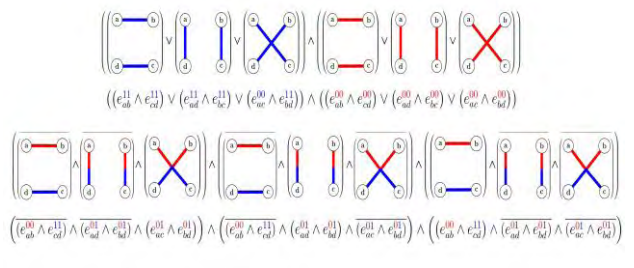

Figure 2: Example on how to encode photonic state preparation experiments into logic clauses.

Time-resolved studies of excited states in bilayer graphene quantum dots

Wister Huang

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Electrostatically defined quantum dots (QDs) in bilayer graphene [1] offer a promising platform for spin qubits with presumably long coherence times due to low spin-orbit coupling and low nuclear spin density. With recent advancements in fabrication technology, the quality of state-of-the-art BLG QDs has been raised to such a level that highly tunable QDs can now be fabricated.

Experimentally the excited state lifetime T1 was estimated with a lower bound of 0.5 µs using two level pulsed-gate spectroscopy [2]. The transport measurements are limited by signal strength and blocking processes of direct tunneling of charge carriers from the leads into unoccupied states below the bias window. By including a load phase in the pulsing scheme prohibiting direct tunneling into the ground state we can extend the measurement time scale and find a lower bound of 16 µs for the spin excited state lifetime T1 at an applied magnetic field of 1.8 T. Recent progress in fabrication technology has allowed the realization of a fully gate-defined device featuring a quantum dot with a nearby charge detector [3] which is sensitive to individual charging events. The charge sensor allows us to perform time-resolved measurements and further study the time dynamics of the excited state using Elzerman readout [4].

References

[1] M. Eich, et al., Phys. Rev. X 8, 031023 (2018).
[2] L. Banszerus, K. Hecker, I. Ecking, et al., Phys. Rev. B 103, L081404 (2021).
[3] A. Kurzmann, H. Overweg, M. Eich, et al., Nano Lett. 19, 5216-522 (2019).
[4] J. M. Elzerman, R. Hanson, L. H. Willems van Bevren, et al., Nature 430, 431-435 (2004).

Quantum critical behaviour in magic-angle twisted bilayer graphene

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The flat bands of magic-angle twisted bilayer graphene (MATBG) host strongly-correlated electronic phases such as correlated insulators [1,2], superconductors [3] and a 'strange metal' state [4]. The latter state, believed to hold the key to a deeper understanding of the electronic properties of MATBG, is obscured by the abundance of phase transitions; so far, this state could not be unequivocally differentiated from a metal undergoing frequent electron-phonon collisions [5]. We report on transport measurements in superconducting (SC) MATBG in which the correlated insulator states were suppressed by screening [6]. The uninterrupted metallic ground state features a T-linear resistivity extending over three decades in temperature, from 40 mK to 20 K, spanning a broad range of doping including those where a correlation-driven Fermi surface reconstruction occurs [7]. This 'strange-metal' behaviour is distinguished by Planckian scattering rates and a linear magneto-resistivity. To the contrary, near charge neutrality or a fully-filled flat band, as well as for devices twisted away from the magic angle, the archetypal Fermi liquid behaviour is recovered. Our measurements demonstrate the existence of a quantum-critical phase whose fluctuations dominate the metallic ground state. Further, a transition to the 'strange metal' is observed upon suppression of the SC order, which suggests an intimate relationship between quantum fluctuations and superconductivity in MATBG.

References

[1] Y. Cao et al., Nature 556 (2018) 80-84.
[2] Y. Cao et al., Nature 556 (2018) 43-50.
[3] X. Lu et al., Nature 574 (2019) 653-657.
[4] Y. Cao et al., Phys. Rev. Let. 124 (2020) 07680.
[5] H. Polshyn et al., Nature Physics 15 (2019) 1011-1016.
[6] P.Stepanov et al., Nature 583 (2021) 375.
[7] A. Jaoui et al. (2021) arXiv:2108.07753.

Figure

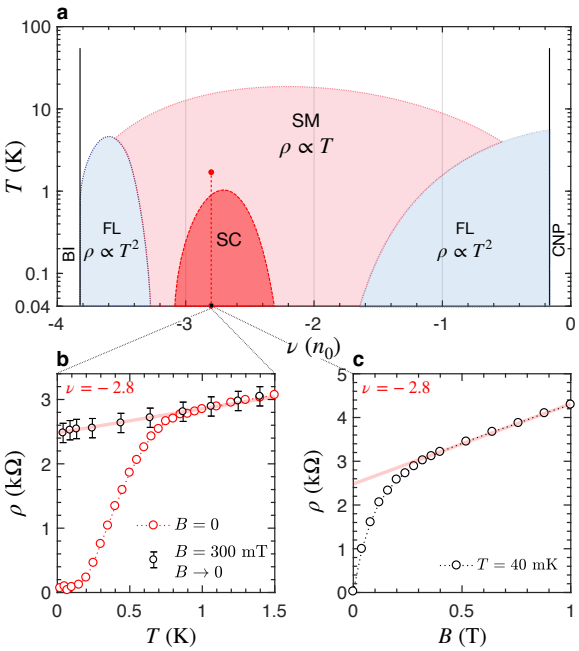

Figure 1: Quantum critical behaviour. A Schematic representation of the (ν, T) phase diagram of hole-doped MATBG. The superconducting dome is enclosed in a 'strange' metal region which is dominated by quantum fluctuations. The canonical Fermi liquid behaviour is recovered near the boundary of the flat-band region. **b** Temperature dependence of the resistivity for $B = 0$ across the SC phase transition (ν=-2.8) and the in-field corrected resistivity for the critical field 300 mT. After suppression of the SC order, the uncovered metallic state is a 'strange' metal. **c** Evolution of the resistivity at ν = -2.8 and 40 mK vs. B. The suppression of the SC order leads to a sharp increase of the resistivity, and is followed by a linear MR up to B = 1 T. The linear MR is highlighted by a solid red line.

Dynamics of hole singlet triplet qubits with large g-factor differences

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Abstract (Century Gothic 11)

Holes in SiGe/Ge quantum wells hold great promise for spin qubits as they possess several favorable qubit properties: a small effective mass, a strong spin-orbit coupling, long relaxation time and an inherent immunity to contact hyperfine interaction [1]. All these characteristics helped Ge hole spin qubits to evolve from a single qubit to a fully entangled four qubit processor in only 3 years [2]. Here, we investigate the singlet-triplet qubit approach leveraging the large out-of-plane g-factors of heavy hole states in Ge quantum dots [3]. We found this qubit to be reproducibly operable at magnetic fields as low as 1 mT and at large rotation frequencies exceeding 600 MHz. This was possible because large differences of g-factors in adjacent dots can be achieved in the out-of-plane magnetic field direction. In the in-plane direction, on the other hand, the heavy-hole g-factors are small and can be altered very effectively by the confinement potentials leading even to a sign change. The resulting g-factor difference drastically influences the dynamics of the system and produces effects typically attributed to a spin-orbit induced spin-flip term (See Figure 1).
Our work gives further insights into the possibilities of holes in Ge but also reveals important properties that need to be considered when designing future spin qubit experiments.

References

[1] Scapucci, G et al., Nature Reviews Materials (2020)
[2] Hendrickx, N. W. et al, Nature, 591 (2021) 580-585
[3] Jirovec, D. et al, Nature Materials, 20 (2021) 1106-1112

Figures

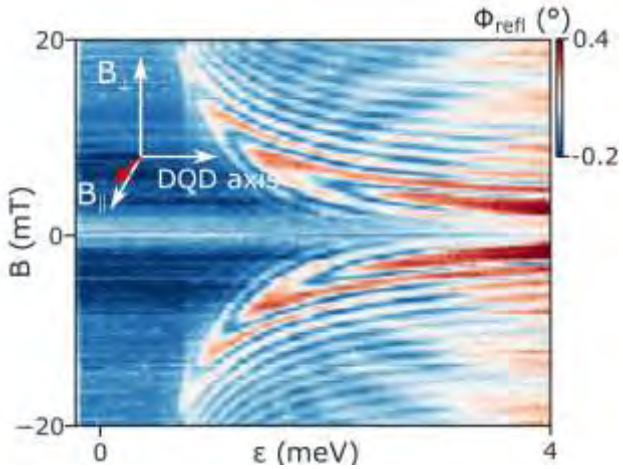

Figure 1: An intriguing butterfly shaped pattern appears when measuring the singlet-triplet degeneracy in the in-plane magnetic field direction. This pattern emerges as a consequence of a large coupling term between these two states. While typically a direct spin-orbit spin-flip term is responsible for this coupling we show that large g-factor differences are the actual cause.

Topological Phases, Electromagnetic Responses and Bilayer Semimetals

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Topological spaces have numerous applications for quantum matter with protected chiral edge modes related to an integer-valued Chern number, which also characterizes the global response of a spin-1/2 particle to a magnetic field. Such spin-1/2 models can also describe topological Bloch bands in lattice Hamiltonians. We introduce a geometrical approach on the Bloch sphere that allows us to discuss transport and electromagnetic responses. Then, we introduce interactions in a system of spin-1/2s to reveal a class of topological states with rational-valued topological numbers for each spin providing a geometrical and physical interpretation related to curvatures and quantum entanglement. We study a driving protocol in time to reveal the stability of the fractional topological numbers towards various forms of interactions in the adiabatic limit. We elucidate a correspondence of a one-half topological spin response in bilayer semimetals on a honeycomb lattice with a nodal ring at one Dirac point and a robust pi-Berry phase at the other Dirac point. These predictions can be measured in mesoscopic, atomic systems and also in bilayer systems.

[1] This work is related to our article, Joel Hutchinson and Karyn Le Hur, arXiv: arXiv:2002.11823 (*)
https://www.nature.com/articles/s42005-021-00641-0
Communications Physics 4, 144 (2021)

Quantum Optimization for Finance and Beyond

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Abstract

In this talk I will explain what id the current status of quantum optimization algorithms in different platforms, and how this can be applied to problems in finance with real data and in real conditions. In particular, I will focus on portfolio optimization problems, where quantum computers can already optimize the full SP500 index and obtain remarkable results (Fig1). I will also discuss briefly the simulation of economic and financial markets. If time allows, I may discuss further applications of quantum computing in finance as well as in other verticals.

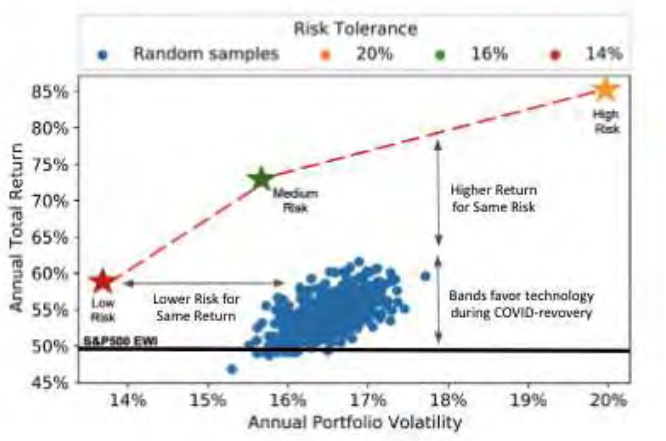

Figure 1: return vs volatility ofr optimized portfolios with real data from 2020 for the full SP500. Commercial funds are typically not much better than the best points in the random cloud (not shown).

Simulation of topological phases in quantum dot arrays

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Recent experiments demonstrate a controllable 12- quantum-dot (QD) device [1]. The fabrication and control of long semiconductor quantum dot arrays open the possibility to use these systems for transferring quantum information between distant sites. Interestingly, it also opens the possibility of simulating, in quantum dot arrays, complex hamiltonians as for instance one-dimensional topological insulators. An example of them in 1D is the Su-Schrieffer-Hegger (SSH) model, a chain of dimers. This system presents chiral symmetry and bond ordering of nearest-neighbor couplings and displays two topological phases. In a finite chain, the presence of protected edge states, allows to transfer electrons between edges, and therefore their implementation is promising for quantum information transfer. However, the SSH model does not account for long range hopping effects which should occur in real systems and which can destroy the topological properties and the edge states formation [2]. In this presentation I will first discuss how to use QD arrays with long-range hoppings (extended SSH model) as quantum simulators for new 1D chiral topological phases. I will show that, by applying a driving protocol, all hopping amplitudes can be modified at will, imprinting bond-order and effectively producing structures such as dimers chains. Importantly, our protocol allows for the simultaneous suppression of all the undesired long-range hopping processes, enhancement of the necessary ones, and the appearance of new topological phases with increasing number of edge states. I will discuss the dynamics of two interacting electrons in a 12-QD array when configurations with different number of edge states are considered. The correlated dynamics, which can be experimentally detected with QDs charge detectors, allows to discriminate between different topological phases and importantly, it opens a new avenue for quantum state transfer protocols [3].

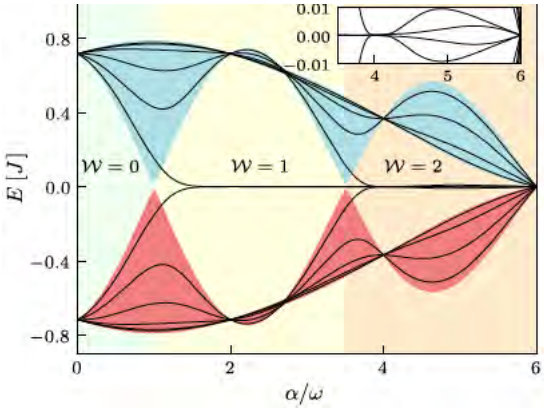

Figure 1: Quasi-energy levels of a driven 12 quantum dot array as a function of the ratio of the intensity and frequency of the driving field, including first and third neighbour hoppings. Inset: each pair of edge states for W=2 has a different energy splitting.

References

[1] D.M. Zajac et al., Phys. Rev. App., 6 (2016), 054013

[2] B. Pérez-González et al., Phys Rev. B, 99 (2019), 035146

[3] B. Pérez-González et al., Phys. Rev. Lett., 123 (2019),126401

Quantum computing beyond the gate-based paradigm

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The progress of technological capabilities has enabled recent efforts into practical realizations of quantum computation. The quest of marketable applications faces the challenge of error correction, or mitigation, while pursued within the gate-based paradigm. At Qilimanjaro Quantum Tech we pursue a platform with faster time-to-market expectations. We do this by exploiting adiabatic and diabatic approaches, which are likely to be more forgiving in terms of the impact of errors.

Topological lasers and condensates

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Topological photonics aims to replicate fermionic symmetries as feats of precision engineering. Here I show how to enhance these systems via effects such as gain, loss and nonlinearities that do not have a direct electronic counterpart. This leads to a topological mechanism of mode selection [1-4], formation of compactons in flat band condensates [5-8], as well as topological excitations [9]. The resulting effects show a remarkable practical robustness against disorder, which arises from the increased spectral isolation of the manipulated states. Common to them all are structured intensity distributions of the topological modes that correspond to an anomaly. These concepts can be applied to configure self-shielded receiver protectors [10] and directed sensors (see Fig. 1) [11].

References

[1] H. Schomerus, Topologically protected midgap states in complex photonic lattices, Opt. Lett. 38, 1912 (2013).

[2] C. Poli, M. Bellec, U.Kuhl, F. Mortessagne, H. Schomerus, Selective enhancement of topologically induced interface states in a dielectric resonator chain, Nat. Commun. 6, 6710 (2015).

[3] H. Zhao et al., Topological hybrid silicon microlasers, Nat. Commun. 9, 981 (2018)

[4] S. Barkhofen, L. Lorz, T. Nitsche, C. Silberhorn, and H. Schomerus, Supersymmetric Polarization Anomaly in Photonic Discrete-Time Quantum Walks, Phys. Rev. Lett. 121, 260501 (2018).

[5] H. Schomerus and N. Y. Halpern, Parity anomaly and Landau-level lasing in strained photonic honeycomb lattices, Phys. Rev. Lett. 110, 013903 (2013).

[6] C. Poli, H. Schomerus, M. Bellec, U. Kuhl, and F. Mortessagne, Partial chiral symmetry-breaking as a route to spectrally isolated topological defect states in two-dimensional artificial materials, 2D Mater. 4, 025008 (2017).

[7] C. E. Whittaker et al., Exciton-polaritons in a two-dimensional Lieb lattice with spin-orbit coupling, Phys. Rev. Lett. 120, 097401 (2018).

[8] M. Bellec, C. Poli, U. Kuhl, F. Mortessagne, and H. Schomerus, Observation of supersymmetric pseudo-Landau levels in strained microwave graphene, Light Sci. Appl. 9, 146 (2020).

[9] S. Malzard, E. Cancellieri, and H. Schomerus, Topological dynamics and excitations in lasers and condensates with saturable gain or loss, Opt. Express 26, 22506-22518 (2018).

[10] M. Reisner et al., Self-Shielded Topological Receiver Protectors, Phys. Rev. Applied 13, 034067 (2020).

[11] H. Schomerus, Nonreciprocal response theory of non-Hermitian mechanical metamaterials: Response phase transition from the skin effect of zero modes, Phys. Rev. Research 2, 013058 (2020).

Figures

Figure 1: Directed sensing in a nonreciprocal topological metamaterial.

Quantum magnetism and topological superconductivity in Yu-Shiba-Rusinov chains

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Chains of magnetic adatoms on superconductors have been discussed as promising systems for realizing Majorana end states. Here, we show that dilute Yu-Shiba-Rusinov (YSR) chains are also a versatile platform for quantum magnetism and correlated electron dynamics, with widely adjustable spin values and couplings. Focusing on subgap excitations, we derive an extended t-J model for dilute quantum YSR chains and use it to study the phase diagram as well as tunneling spectra. We explore the implications of quantum magnetism for the formation of a topological superconducting phase, contrasting it to existing models assuming classical spin textures.

What quantum supremacy really means

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More than a year ago, Google announced that they had reached a new milestone in quantum computing that they refer to as « quantum supremacy ». They claimed that their quantum chip had performed a task that would take thousands of years to simulate on the largest existing supercomputer. In this talk, I will first review the experimental findings. Then, I will challenge their claim and show that, while it does indeed require an exponentially large computing time to simulate a perfect quantum computer, simulating a real one with a finite fidelity is much easier. I will present how it can be done with quantum states compression techniques borrowed from many-body theory.

Mutual Reinforcement between Neural Networks and Quantum Physics

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Abstract
Quantum machine learning emerges from the symbiosis of quantum mechanics and machine learning. In particular, the latter gets displayed in quantum science as: (i) the use of classical machine learning as a tool applied to quantum physics problems, (ii) or the use of quantum resources such as superposition, entanglement, or quantum optimization protocols to enhance the performance of classification and regression tasks compare to their classical counterparts. This talk reviews examples in these two scenarios. On the one hand, a classical neural network is applied to design a new quantum sensing protocol [1]. On the other hand, the design of a quantum neural network based on the dynamics of a quantum perceptron with the application of shortcuts to adiabaticity gives rise to a short operation time and robust performance [2]. These examples demonstrate the mutual reinforcement of both neural networks and quantum physics.

References

1. Y. Ban, J. Echanobe, Y. Ding, R. Puebla and J. Casanova, Quantum Sci. Technol., 6 (2021) 045012.
2. Y. Ban, X. Chen, E. Torrontegui, E. Solano and J. Casanova, Sci. Rep., 11 (2021) 5783.

Machine-Learning Assisted Quantum Control in Random Environment

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Machine learning (ML), which enables computers to learn automatically from available task-specific data, is reshaping modern approaches in physical sciences. In quantum science, ML is one of the most useful and powerful approaches in particle physics, many-body physics, and quantum computing among others. Recently developed learning architectures such as convolution neural networks (CNN), having a considerable success in object detection and image classification, were beneficial to classify phases of matter, study non-equilibrium glasses, find hidden order in electronic-quantum-matter imaging data and identify the thermodynamic time arrow in quantum systems.

Figures

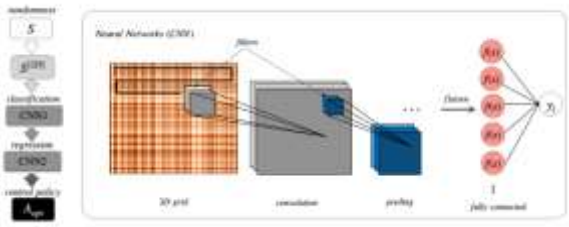

Figure 1: Schematic diagram (left) of supervised learning with two CNNs and working flow (right) of CNN.

Disorder in condensed matter and atomic physics is responsible for a great variety of fascinating quantum effects [1,2]. Many of these effects, being still challenging for understanding, make highly demanded dynamical control of quantum disordered systems hard, which requires novel tools to tackle the relevant issue. Particularly, as the size of the stochastic sample increases dramatically, the higher power of ML is demanding in such complexity.

To work out this problem, here we establish the ML approach for identifying and controlling dynamics of a quantum system with disorder. For this purpose, we use deep learning with two CNNs, see Fig. 1, for high-fidelity control of a quantum particle in a time-varying trapping potential embedded in a random environment.

Figures

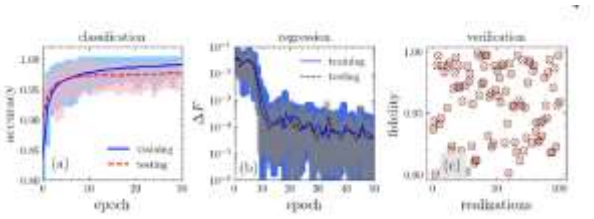

Figure 2: Performance of the accuracy in CNN1 (a) and the fidelity deviation (b) are displayed for classification and regression, where the dashed and solid lines represent the test and training batch of database. The shadow area indicates the average of every batch. (c) The outputs from two trained CNNs (red crosses) compared with the numerical results (black circles) for 100 testing realizations of random potential.

Consider a quantum particle, located at the sum of time-dependent harmonic potential and a random potential of impurities [3,4]. We show first an important result: training the CNN can efficiently preselect the relevant type of the disorder realization from tens of thousands of stochastic samples. Then, we introduce the second CNN to find the

optimal control policy such as the time-dependent potential shape, in a training regression model, see Fig. 2. To make the optimization more efficient, the randomness classification from deep learning is an essential pretraining for disordered system under control, thus removing the redundant data. Thus, the supervised learning with CNNs provides the ability to generalize to tasks beyond their original design, applicable to any realization of random potential.

Figures

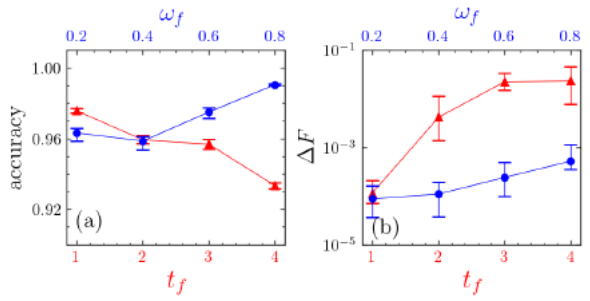

Figure 3: The average accuracy in CNN1 (a) and the average fidelity deviation in CNN2 (b) for the last ten epochs are illustrated for the different values of time and trap frequency, where the error bar represents their deviations.

To illustrate the generality of proposed method, we apply different values of time and trap frequency to the trained CNNs. Fig. 3 indicates the average accuracy in CNN1 and the average fidelity deviation in CNN2 for the last ten epochs by using the same structure and hyperparameter as before. On the one hand, when final trap frequency is increased, the random realizations are much easier to recognize, thus resulting in higher accuracy. It makes sense that the influence of random potentials on the fidelity can be negligible, when the trap potential is strong enough to localize the state near the origin. However, the more realizations as the inputs of CNN2 finally lead to the larger fidelity derivation as shown in Fig. 3. On the other hand, according to the time-energy trade-off, larger t_f (still far away from the adiabaticity) increase the area corresponding to condition for input power. The fidelity deviation in CNN2 becomes larger because of worse classification, depending on the distribution and number of the selected realizations in CNN1, see Fig. 3. In a word the combined effects of the trapping potential and disorder plays an important role in dynamical control, characterized by the fidelity and the required energy cost, e.g., the laser power for optical trap or the electrical power for quantum dots.

In practice, impurities, noise, and other imperfections are ubiquitous and unavoidable in condensate matter physics and their simulated counterparts. Our methods pave an efficient way for the robust optimal control, i.e., cooling, transporting, trapping the neutral atoms [4,5] or charged particles (ions and electrons) [6], by taking into account environmental noise and randomness.

References

[1] Aut T. Vojta, Annual Review of Condensed Matter Physics 10, 233 (2019).

[2] Sanchez-Palencia and M. Lewenstein, Nature Physics 6, 87 (2010).

[3] S. Mardonov, M. Modugno, and E. Y. Sherman, Phys. Rev. Lett. 115, 180402 (2015).

[4] X. Chen, A. Ruschhaupt, S. Schmidt, A. del Campo, D. Guery-Odelin, and J. G. Muga, Phys. Rev. Lett. 104, 063002 (2010).

[5] B. M. Henson, D. K. Shin, K. F. Thomas, J. A. Ross, M. R. Hush, S. S. Hodgman, and A. G. Truscott, Proceedings of the National Academy of Sciences 115, 13216 (2018).

[6] M. J. A. Schuetz, J. Kn¨orzer, G. Giedke, L. M. K. Vandersypen, M. D. Lukin, and J. I. Cirac, Phys. Rev. X 7, 041019 (2017).

Error mitigation and quantum-assisted simulation in the error corrected regime

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Abstract

We consider quasi-probability based error mitigation in the error corrected regime of quantum computation. In this regime, Clifford operations can be made fault-tolerant, but the Gottesman-Knill theorem tells us that they can be efficiently simulated with a classical computer [2]. In order to achieve universality one needs the addition of magic quantum states, whose fault-tolerant preparation requires complex distillation protocols, and are thus the noisiest component [3].
In this context, we develop a general framework to discuss the value of the available, noisy magic resources, relative to those ideally required. We introduce a quantity, the Quantum-assisted Robustness of Magic (QROM), which measures the overhead of simulating the ideal quantum computation with the available noisy components through quasiprobability-based methods. This extends error mitigation techniques, originally developed for Noisy Intermediate Scale Quantum (NISQ) devices [4], to the case where qubits are logically encoded. The QROM shows how the addition of noisy magic resources allows one to boost classical quasiprobability simulations of a quantum circuit and enables the construction of explicit protocols, interpolating between classical simulation and an ideal quantum computer.

References

[1] M. Lostaglio & A. Ciani, arXiv:2103.07526, (2021) (Accepted for Physical Review Letters).
[2] S. Aaronson & D. Gottesman, Phys. Rev. A, 70, (2004), 052328.
[3] S. Bravyi & A. Kitaev, Phys. Rev. A, 71 (2005) 022316.
[4] K. Temme, S. Bravyi & J. Gambetta, Phys. Rev. Lett. 119, (2017), 180509.

Figures

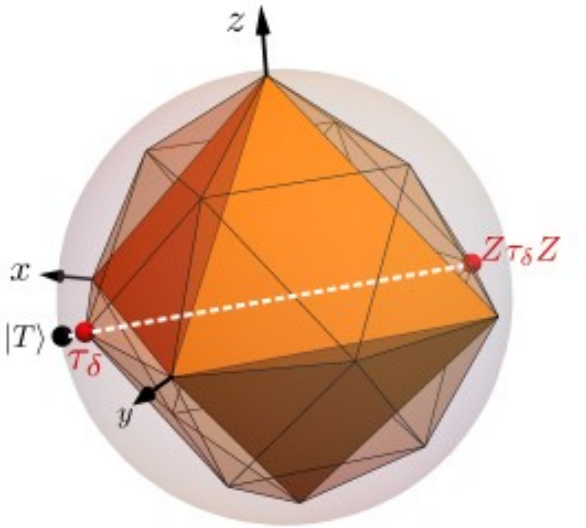

Figure 1: Graphical representation of the QROM for one qubit in the Bloch sphere.

Intraparticle entanglement in graphene

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We demonstrate the emergence and dynamics of intra-particle entanglement in massless Dirac fermions. This entanglement, generated by spin-orbit coupling, arises between the spin and sublattice pseudospin of electrons in graphene. The entanglement is a complex dynamic quantity but is generally large, independent of the initial state. Its time dependence implies a dynamical violation of a Bell inequality, while its magnitude indicates that large intra-particle entanglement is a general feature of graphene on a substrate. These features are also expected to impact entanglement between pairs of particles, and may be detectable in experiments that combine Cooper pair splitting with nonlocal measurements of spin-spin correlation in mesoscopic devices based on Dirac materials.

References

[1] BG de Moraes, AW Cummings, and S Roche, *PRB* **102**, 041403(R) (2020)

Figures

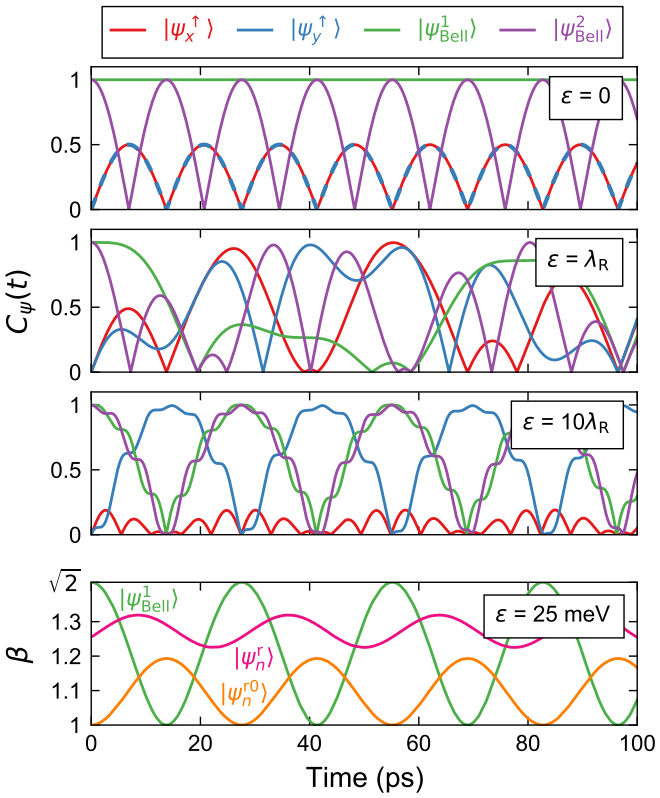

Figure 1: Entanglement dynamics of a few states at different energies. The top three panels show the concurrence of some specially-chosen states. The bottom panel shows the degree of Bell inequality violation for one Bell state and two randomly chosen states.
Image taken from Ref. [1].

Acknowledgments

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Symmetry broken Chern insulator in magic angle twisted bilayer graphene

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Flat bands in magic-angle twisted bilayer graphene (MATBG) have recently emerged as a rich platform to explore strong correlations [1], superconductivity [2–5] and magnetism [3,6,7]. However, the phases of MATBG in a magnetic field and what they reveal about the zero-field phase diagram remain relatively uncharted. Here we report a rich sequence of wedge-like regions of quantized Hall conductance with Chern numbers C=±1, ±2, ±3 and ±4, which nucleate from integer fillings of the moiré unit cell v=±3, ±2, ±1 and 0, respectively. We interpret these phases as spin- and valley-polarized many-body Chern insulators. The exact sequence and correspondence of the Chern numbers and filling factors suggest that these states are directly driven by electronic interactions, which specifically break the time-reversal symmetry in the system. We further study the yet unexplored higher-energy dispersive bands with a Rashba-like dispersion. The analysis of Landau-level crossings enables a parameter-free comparison to a newly derived 'magic series' of level crossings in a magnetic field and provides constraints on the parameters of the Bistritzer–MacDonald MATBG Hamiltonian. Overall, our data provide direct insights into the complex nature of symmetry breaking in MATBG and allow for the quantitative tests of the proposed microscopic scenarios for its electronic phases.

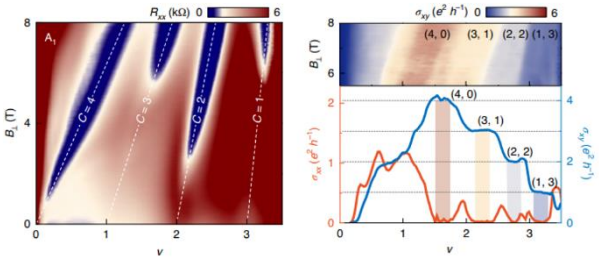

Figure1: **Emergent CCIs in MATBG.** Colour plot of R_{xx} versus v and $B_\perp$, measured at T= 1.5 K. The white lines indicate the trajectories of four different topologically non-trivial Chern gaps with (C, v) indices of (4, 0), (3, 1), (2, 2) and (1, 3). Corresponding Hall conductance σ_{xy} versus v and B⊥ (top) and line cuts showing quantized σ_{xy} and vanishing longitudinal conductance of the Chern insulators at B⊥ = 8 T (bottom).

References:

1. Cao, Y. et al. Correlated insulator behaviour at half-filling in magic-angle graphene superlattices. Nature 556, 80–84 (2018).
2. Cao, Y. et al. Unconventional superconductivity in magic-angle graphene superlattices. Nature 556, 43–50 (2018).
3. Lu, X. et al. Superconductors, orbital magnets and correlated states in magic-angle bilayer graphene. Nature 574, 653–657 (2019).
4. Stepanov, P. et al. Untying the insulating and superconducting orders in magic-angle graphene. Nature 583, 375–378 (2020).
5. Sharpe, A. L. et al. Emergent ferromagnetism near three-quarters filling in twisted bilayer graphene. Science 365, 605–608 (2019)

Magic-angle graphene superconducting nano-calorimeter

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Superconducting nano-calorimeters are currently some of the most sensitive sensors for detecting electromagnetic radiation. Two-dimensional materials, thanks to their small heat capacity are progressively evolving into a novel platform to develop a new generation of sensors that can further push the limits of detector sensitivities [1]. Specifically, magic-angle twisted bilayer graphene (MAG) exhibits a record-small heat capacity and a sharp superconducting transition that makes it suitable for superconducting calorimetry [2]. Here we investigate the thermal and optoelectronic properties of the MAG and provide precious insights towards applications. This study establishes MAG as a promising two-dimensional material for ultra-sensitive photodetection.

References

[1] Gil-Ho Lee et al., Nature, 586 (2020) 42-46
[2] Paul Seifert et al., Nano Letters, 5 (2020) 3459-3464

Figures

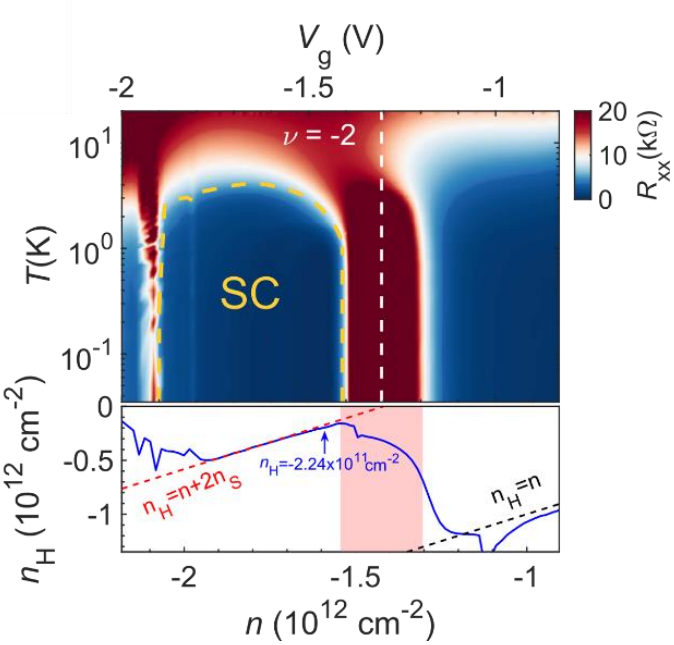

Figure 1: *Colormap of the longitudinal resistance as a function of back-gate-applied voltage V_g and device temperature T. The boundaries of the superconducting dome—indicated by the dashed yellow line—are defined by the 50% of the normal state resistance. In blue the low-field Hall effect (300 mT) for the same doping region of the top panel.*

Magnetic Josephson Junctions and Superconducting Diodes in Magic Angle Twisted Bilayer Graphene

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Abstract

The simultaneous co-existence and tunability of the superconducting[1], magnetic[2] and topological orders[3] in magic angle twisted bilayer graphene (MATBG) open up new possibilities for the creation of complex hybrid Josephson junctions. Here we report on the creation of gate-defined magnetic Josephson junctions in MATBG, where the weak link is gate tuned closed to the correlated state at a moiré filling factor of $\nu = -2$. A highly unconventional Fraunhofer pattern emerges, which is phase-shifted and asymmetric with respect to the current and magnetic field directions, and shows a pronounced magnetic hysteresis. The combination of magnetization and its currents induced switching allows us to realize a programmable zero field superconducting diode, a major building block for a new generation of superconducting electronics.

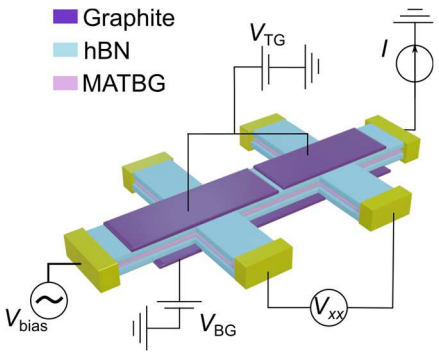

Figure 1. Device schematic and measuring circuit. The combination of the graphite back gate and split top gates allow us to realize a gate tunable Josephson junction in the MATBG.

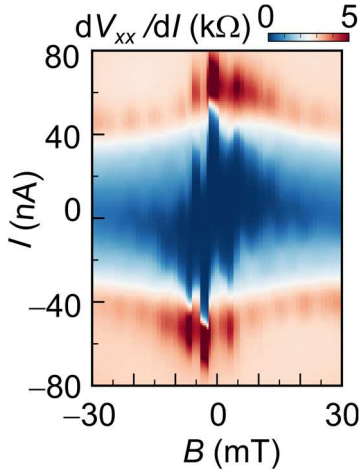

Figure 2. Fraunhofer pattern of the Josephson junction with the weak link set closed to $\nu = -2$. The pattern displays a shift from the zero-field value, and is asymmetric with respect to both the current and magnetic field directions.

References

[1] Cao, Y. *et al. Nature* **556**, 43-50 (2018)

[2] Sharpe, A. L. *et al. Science* **365**, 605-608 (2019)

[3] Nuckolls, K. P. *et al. Nature* **588**, 610-615 (2020)

Observation of superconducting Leggett modes from competing pairing instabilities in single layer $NbSe_2$

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In certain unconventional superconductors with sizable electronic correlations, the availability of closely competing pairing channels leads to characteristic soft collective fluctuations of the order parameters, which leave fingerprints in many observables and allow to scrutinize the phase competition. Superconducting layered materials[1–8], where electron-electron interactions are enhanced with decreasing thickness, are promising candidates to display these correlation effects. For example, while bulk $NbSe_2$ is essentially a conventional superconductor, recent experiments in the thin-film regime have shown evidence of competing unconventional nematic pairing[9,10]. In this work, we report the existence of a soft collective mode in single-layer $NbSe_2$, observed as a characteristic resonance excitation in high resolution tunneling spectra. This resonance is observed along with higher harmonics, its frequency $\Omega/2\Delta$ is anticorrelated with the local superconducting gap Δ, and its amplitude gradually vanishes by increasing the temperature and upon applying a magnetic field up to the critical values (T_C and H_{C2}), which sets an unambiguous link to the superconducting state. Aided by a microscopic model, we interpret this resonance as a collective Leggett mode that represents the fluctuation towards a proximate *f*-wave triplet state, due to subleading attraction in the triplet channel. Our findings demonstrate the fundamental role of correlations in superconducting 2D transition metal dichalcogenides, opening a path towards unconventional superconductivity in simple, scalable and transferable 2D superconductors.

REFERENCES

[1] Ye, J. T. *et al*. *Science* **338**, 1193 (2012).
[2] Cao, Y. *et al. Nano Lett.* **15**, 4914 (2015).
[3] Ugeda, M. M. *et al. Nat. Phys.* **12**, 92 (2016).
[4] Xi, X. *et al. Nat. Phys.* **12**, 139 (2016).
[5] Sohn, E. *et al. Nat. Mater.* **17**, 504 (2018).
[6] Zhao, K. *et al. Nat. Phys.* **15**, 904 (2019).
[7] Rubio-Verdú, C. *et al. Nano Lett.* **20**, 5111 (2020).
[8] Cao, Y. *et al. Nature* **556**, 43 (2018).
[9] Hamill, A. *et al. Nat. Phys.* **17**, 949 (2021).
[10] Cho, C. *et al. arXiv:2003.12467* (2020)

Breakdown of the topological protection by cavity vacuum fields in the integer quantum Hall effect

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At mK temperatures we measure electron transport, Shubnikov de Haas (SdH) oscillations and Hall resistance. The platform consists of an etched GaAs two-dimensional electron gas heterostructure, forming a Hall bar geometry, combined with a 2-D metamaterial split ring resonator. Amplified vacuum fields are confined in its gap, i.e. at the position of the Hall bar (fig.1). On a chip we measure multiple samples sharing source and drain. Like this, we can directly compare effects of the cavity on longitudinal and transverse resistances with respect to the unperturbed system. In the diffusive transport regime, we observe an amplitude reduction in the SdH when coupling the electrons to amplified vacuum fields [1]. Shifting our focus to the quantized states of the integer quantum hall regime, in our latest study [2] we draw out the effect of vacuum fields breaking the topological protection of edge states: the hall quantization is lost (fig. 2), while in the very same sample much more fragile states, the fractional states, persist due to their inability to couple to optical modes as postulated by Kohn's theorem. The accompanying picture to this effect is introduced as cavity-mediated electron hopping. Conceptually it describes how electrons scatter from topologically protected edge states into bulk disordered states [3]. With a current theoretical work predicting modifications to the quantized Hall conductance as a function of the light matter coupling [4] this platform can be of major interest in studying the fundamental physics of matter coupled to vacuum fields.

References

[1] G.L. Paravicini-Bagliani et al., Nat. Phys, 15.2 (2019) 186-190
[2] F. Appugliese, J. Enkner et al., Arxiv, 2107.14145 (2021)
[3] C. Ciuti Arxiv 2107.09435v1 (2021)
[4] V.Rokaj et al., Arxiv, 2109.15075v1 (2021)

Figures

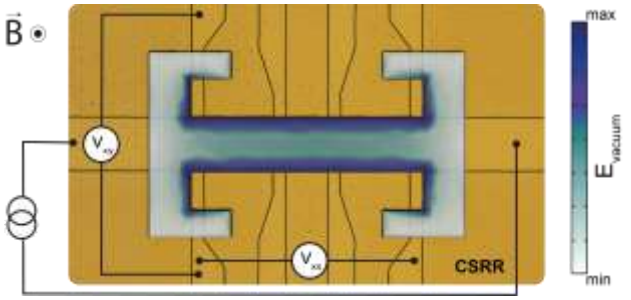

Figure 1: Visualization of cavity field distribution penetrating the Hall bar located in its gap. V_{xx} and V_{xy} indicate voltage probes for longitudinal and transverse resistivity measurements

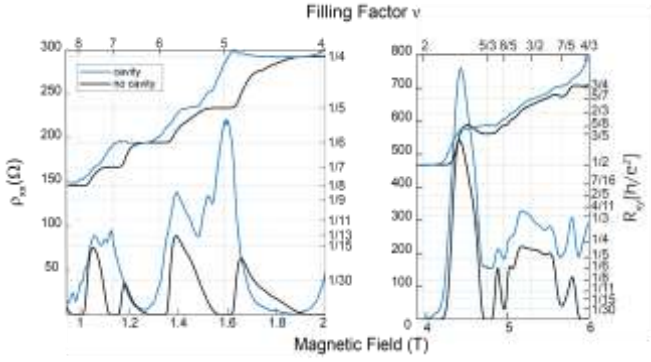

Figure 2: longitudinal and transverse resistance are shown for a cavity embedded Hall bar (blue) and a cavity-less reference Hall bar (black). The reference is well quantized, the cavity shows a collapse at filling factors 5 and 7 (left). The fractional states around 3/2 are still visible for both samples (right).

Use of SPAD arrays for quantum technology

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Thanks to their capability to detect single photons with good timing resolution, Single Photon Avalanche Diode (SPAD) can be considered as a good candidate for quantum experiments. In this work we present recent advances on the design of SPAD-based devices for quantum technology in two different projects.
The SuperTwin project [1] aimed to develop an all-solid-state super resolution microscope based on entangled photons. A quantum image sensor having a large degree of flexibility has been developed [2]. In the 60k-pixels array, each element pairs a SPAD with a reconfigurable logic block that can operate in one of the following modes: (i) photon timestamping with a fine (180 ps) or (ii) coarse (≥ 10 ns) resolution, (iii) photon counting, or (iv) high-speed binary imaging. The imager shows a high sensitivity (PDP up to 60%) and low noise (DCR of 100 Hz). Figure 1 shows the chip functionalities and the first and second-order correlation function of an SPDC source in the far field.
One of the goals of the Qrange project [3] is to develop tiny and low-cost quantum random number generator (QRNG) for IoT application. Differently from other approaches, mainly using an external source of light, we investigated on monolithic solutions [4]. The final design consists of a SPAD-based array of independent cells each integrating one central emitter and multiple detectors for random number extraction (see Figure 2). Different sources of light (Si-LED) have been also implemented. The typical bit rate generated by each cell is to few kbps. The device is now under test for validation.

We acknowledge the financial support from the European Commission through the SUPERTWIN project, ID 686731 and the Grant Agreement No. 820405 (project QRANGE).

References

[1] https://supertwin.fbk.eu/home
[2] https://www.imagesensors.org/Past%20Workshops/2020%20ISSW/Leonardo%20Gasparini%20ISSW2020.pdf
[3] https://qrange.eu/
[4] F.Acerbi et al, J. of Selected Topics in Quantum Electronics 24 (2018): 1-7

Figures

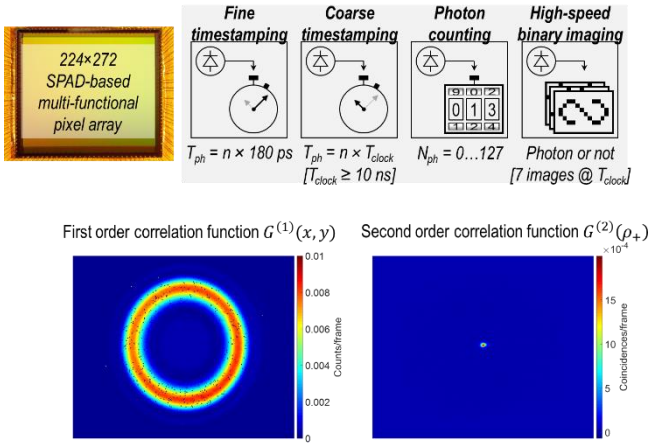

Figure 1: Micrograph and concept of the Quantum imager (top). Acquisition of SPDC photons (bottom)

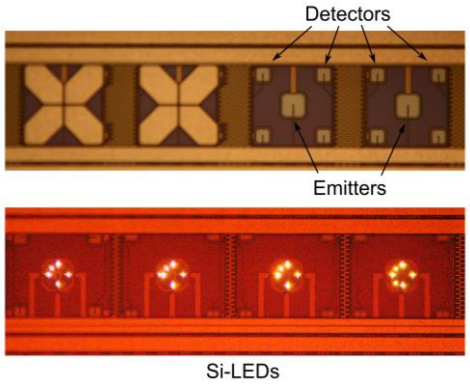

Figure 2: Implemented cell for random number generation and Si-LED.

Spin-active color centers in silicon carbide for telecom-compatible quantum devices

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Optically-active impurities with spin in crystals can realize light-matter entanglement protocols necessary for quantum-communication and sensing applications. Various transition-metal defects in SiC are unique in that they are strong emitters directly at telecom wavelength in an industrially-mature semiconductor. They have in common that a single electron of *d*-orbital origin is responsible for their electronic behaviour [1,2,3,4]. We carried out a comprehensive research line on the Mo and V defect, and report our insights into how strong spin-orbit coupling, the symmetries in SiC, and the highly anisotropic hyperfine coupling together give new and unexpected spin states and dynamics, with favourable properties for quantum technologies. We found experimentally and theoretically that spin-orbit coupling stabilizes the defect spin, leading to seconds-long spin-relaxation times and limited possibilities for microwave spin control [2]. We found, however, that strong electronic spin driving is still possible, both with magnetic and electric-microwave fields, for systems with hyperfine coupling to a central nuclear spin [3]. Our results help in understanding how macroscopic figures of merit relevant for quantum operation are related to the microscopic configuration of defect centers, and may lead to engineering of defects for specific applications. We found that these insights are also relevant for spin behaviour in a broader class of materials.

References

[1] T. Bosma *et al.*, npj Quantum Information **4**, (2018) 48
[2] G. Wolfowicz *et al.*, Scientific Advances **6**, (2020) eaaz1192
[3] C. Gilardoni *et al.*, New Journal of Physics **22**, (2020) 103051
[4] C. Gilardoni *et al.*, New Journal of Physics **23**, (2021) 083010

Figures

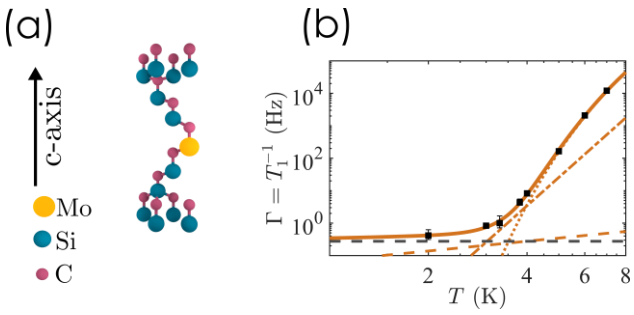

Figure 1: (a) A transition metal defect in SiC is formed as the transition metal impurity substitutes a Si in the SiC lattice. (b) Temperature dependence of the spin-relaxation rate of Mo defects in SiC, showing that for ensembles with zero nuclear spin, the spin-relaxation rate is above seconds at low temperatures despite the presence of strong spin-orbit coupling.

Quantum Annealing with Bias Fields

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Quantum annealing is a method to solve optimization problems via Hamiltonian engineering and quantum state preparation. The method requires that an energy gap protects the state of the system, as it evolves from the chosen initial state to the targeted ground state. Unfortunately, for initial states which are agnostic to the problem, this is typically not the case. However, even limited knowledge of the target state can be used to "smoothen" the evolution, and thereby, to greatly increase the efficiency of the annealing method. A concrete and simple strategy to achieve this is presented in this talk: An initial guess for the target state is incorporated in the annealing dynamics through bias fields which slightly rotate the spins/qubits towards the targeted state (see Fig. 1). If the initial guess is sufficiently close to the target state (specifically, with an error not larger than 40%), this procedure significantly increases the annealing fidelity (see Fig. 2). Iterative annealing runs can be used to generate and improve the initial guess.

We have tested this strategy via its simulation on a classical HPC cluster, and find that it significantly improves the annealing results for most instances of a NP-complete test problem. The proposed procedure can readily be implemented in present-day quantum annealers.

References

[1] Tobias Grass: Quantum annealing with longitudinal bias fields, Phys. Rev. Lett. 123 (2019) 120501

Figures

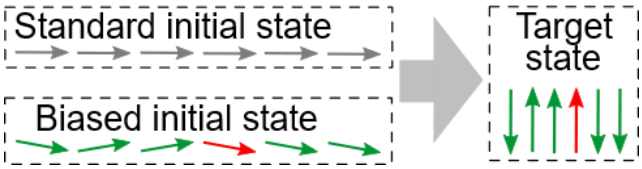

Figure 1: Standard vs. biased annealing. While standard annealing starts from a state which is agnostic to the target state, the biased annealing incorporates an (imperfect) guess of the target state into the initial state.

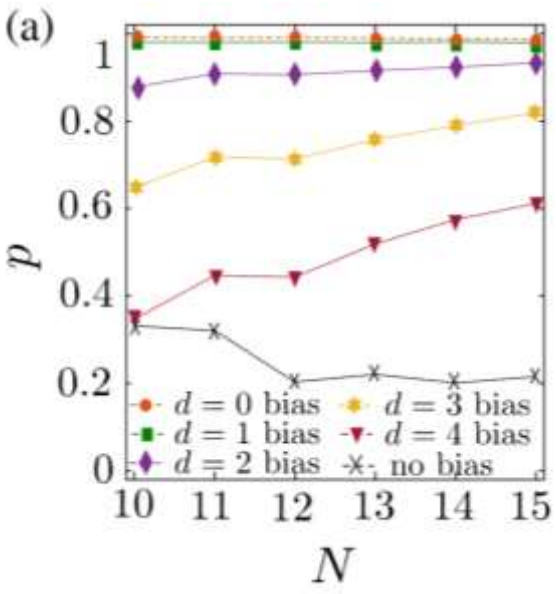

Figure 2: Annealing fidelity *p* for a problem with *N* spins/qubits when initialized in a biased state with *d* errors. If the initial guess contains less than 40% erroneous bits, the bias produces significant fidelity enhancement.

Coupling 3-Josephson junctions flux qubits for Quantum Computation

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Many platforms have been proposed to implement Quantum Simulations, from superconducting circuits to trap ions. Nevertheless, it is still not clear how to obtain general and fully tunable multi-qubits dynamics in any of those platforms. General enough qubit-qubit interactions would allow, for instance, to simulate novel quantum materials or to reproduce the dynamics of non-stoquastic Hamiltonians, the ones for which classical Monte-Carlo methods fail.
In this talk, we analyse the coupling between two 3-Josephson junctions flux qubits and present the effective Hamiltonian that controls the dynamics of the system when the two qubits are coupled via a capacitor and/or via a Josephson junction [3]. We show that those two elements allow engineering a fairly large family of qubit Hamiltonians with XX, YY and ZZ, including non-stoquastic interactions and ultrastrong coupled ones.
In addition, we discuss the capacitive coupling between a flux qubit and an LC-resonator [4], showing ultrastrong coupling in a direction perpendicular to that of the commonly studied inductive coupling.

References

[1] M. Hita-Pérez, G. Jaumà, M. Pino and J.J. García-Ripoll, "3-Josephson junctions flux qubit couplings", in preparation.
[2] M. Hita-Pérez, G. Jaumà, M. Pino and J.J. García-Ripoll, "Ultrastrong capacitive coupling of flux qubits" (2021), arXiv:2108.02549 [quant-ph].

Figures

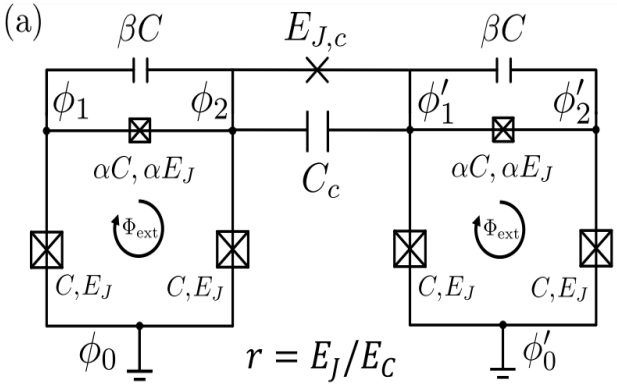

Figure 1: Example of circuit architecture for the couplings considered on the talk: two identical c-shunted 3-Josephson junctions flux qubits with ground in nodes 0 and 0' coupled through a capacitor and a Josephson junction connecting nodes 2 and 1'.

Development of the tunnelling devices with spin-split Al/EuS electrodes for superconducting spintronics and spin qubits applications

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The development of superconducting quantum circuits for quantum computing during the past two decades led to the creation of commercial quantum processors with tens of qubits [1]. With transmon being the superconducting qubit of choice in most architectures, recent quantum processors have proven to be suitable for intermediate-scale quantum computing, where coherence extends over a relatively small number of qubits. Fully-fledged quantum processors, implementing quantum error correction, require improvements in both qubit performance and downsizing. Since the latter is an issue for the transmon, a number of alternative qubits are being intensively 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, we investigate the use of superconductor — magnetic insulator interfaces for implementing single-qubit operations in spin qubits. We found that Al/EuS bilayers might be used in Andreev spin qubits to complement or even substitute the use of spin-orbit interaction and superconducting phase-phase differences across the weak link [6]. We also present results of a systematic study of Al/EuS interfaces, which led to consistent fabrication of Al/EuS bilayers featuring spin splitting of the superconducting density of states, as observed in the tunnelling spectroscopy shown in Fig 1. These devices were proposed to be used in cryogenic thermoelectric elements and diodes [7,8]. However, the fabrication process can be adapted to the needs of manufacturing of the Andreev spin qubits as well as of the superconducting spintronics in broader terms.

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] A. Hijano et al., Phys. Rev. Research, 3 (2021), 023131
[8] E. Strambini et al. arXiv:2109.01061v1

Figures

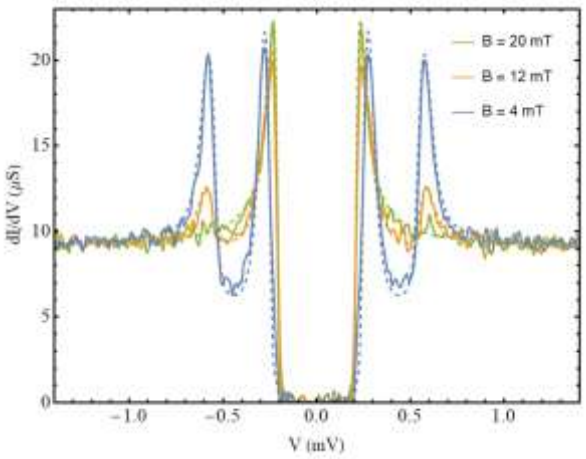

Figure 1: Tunnelling spectra demonstrating spin splitting of density of states in the second Al electrode for the Al/AlOx/Al/EuS heterostructure [7].

Quantum simulation and ground state preparation for the honeycomb Kitaev model

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Strongly-correlated magnetism represents a formidable challenge, where an efficient classical description is inapplicable due to the sign problem and long-range entanglement. The striking example is a quantum spin liquid (QSL) phase [1]. From the theoretical perspective QSL materials are often described by spin lattice models with bond-dependent Heisenberg coupling. Here, the paradigmatic model that hosts QSL is the Kitaev model of spin-1/2 arranged in a honeycomb lattice [2]. While being classically solvable at zero magnetic field, when biased it requires an exact diagonalization and its treatment is limited to small system sizes [3].

In the talk, I will describe a quantum algorithm that allows preparing a ground state of the honeycomb Kitaev model using a variational circuit with the shallow depth. Our approach efficiently uses the underlying symmetries of the model. It is based on the stabilization procedure, the developed centralizer ansatz, and utilizes the vortex basis description being the most advantageous for qubit-based simulation [4]. We demonstrate the high fidelity preparation of quantum spin liquid ground states in the zero magnetic field Kitaev model and effective field. Specifically, we simulate the preparation of the QSL ground state with up to N=24 qubits (spins) with the depth of d=5, where the ansatz is composed of the nearest-neighbor two-qubit gates. Next, we show that the prepared ground state can be evolved in time, revealing the dynamical correlations between distant spins. Finally, we extended the variational search to prepare QSL at non-zero magnetic field. Our study points the route towards a quantum advantage for the complex material science problem.

References

[1] L. Savary and L. Balents, Quantum spin liquids: a review, Rep. Prog. Phys.80, 016502 (2017).
[2] A. Kitaev, Anyons in an exactly solved model and beyond, Ann. Phys.321, 2 (2006).
[3] C. Hickey and S. Trebst, Emergence of a field-driven U(1) spin liquid in the Kitaev honeycomb model, Nature Commun. 10, 530 (2019).
[4] T. A. Bespalova and O. Kyriienko, to be submitted.

Phonon-assisted luminescence in qubits from many-body perturbation theory

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Phonon-assisted luminescence is a key property of defect centers in semiconductors, and can be measured to perform the readout of the information stored in a quantum bit, or to detect temperature variations.
The investigation of phonon-assisted luminescence usually employs phenomenological models, such as that of Huang and Rhys, with restrictive assumptions that can fail to be predictive.
In this work, we predict luminescence and study exciton-phonon couplings within a rigorous many-body perturbation theory framework,
an analysis that has never been performed for defect centers.
In particular, we study the optical emission of the negatively-charged boron vacancy in 2D hexagonal boron nitride, which currently stands out among defect centers in 2D materials thanks to its promise for applications in quantum information and quantum sensing. We show that phonons are responsible for the observed luminescence, which otherwise would be dark due to symmetry. We also show that the symmetry breaking induced by the static Jahn-Teller effect is not able to describe the presence of the experimentally observed peak at 1.5 eV.

References

[1] F. Libbi. P. Melo, Z. Zanolli, M. J. Verstraete and N. Marzari, arXiv:2111.03518

Figures

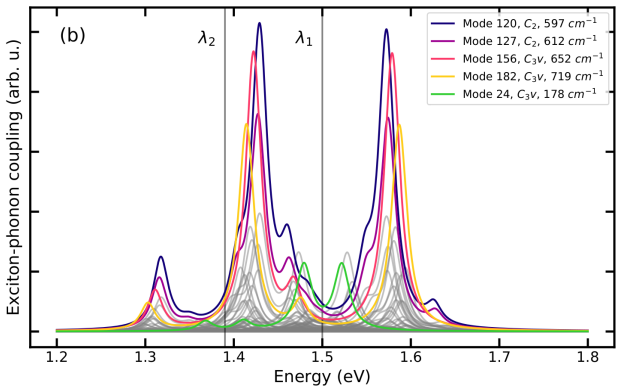

Figure 1: Exciton-phonon coupling function for the negatively charged boron vacancy in 2D hBN. The phonon modes which couple most strongly with excitons are enlightened with coloured lines and reported in the legend in decreasing order of contribution, while the other phonon modes are represented with grey lines.

PHOTODETECTION ON AN EXFOLIATED, 2D HIGH-TEMPERATURE SUPERCONDUCTOR

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2D superconductors combine the sharp superconducting properties from the bulk with ultralow heat capacity thanks to their atomic thickness [1]. In particular, 2D high-temperature superconductors are a promising platform for on-chip quantum photonics at moderate cryogenic temperatures (4 K < T < 77 K) [2]. In this work, we report ultrasensitive photodetection at telecom wavelengths using exfoliated flakes of 2D high-temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212). We use inert-atmosphere van der Waals fabrication techniques and novel non-destructive patterning methods to harness the properties of Bi2212 in the 2D limit. Our photodetectors exhibit record sensitivity at 1550 nm for moderate cryogenic temperatures [2]. Moreover, we demonstrate on-chip integration of our photodetectors on silicon waveguides. This result realizes the promise of 2D high-temperature superconductors as next-generation photodetectors for quantum technologies [3].

References

[1] Saito, Y. *et* al, Nat. Rev. Mat. **2**, (2016) 1-18
[2] Seifert, P. *et al*, 2D Materials **8**, (2021), 035053
[3] Santavicca, D. F., Supercond. Sci. Technol. **31**, (2018), 040502

Figures

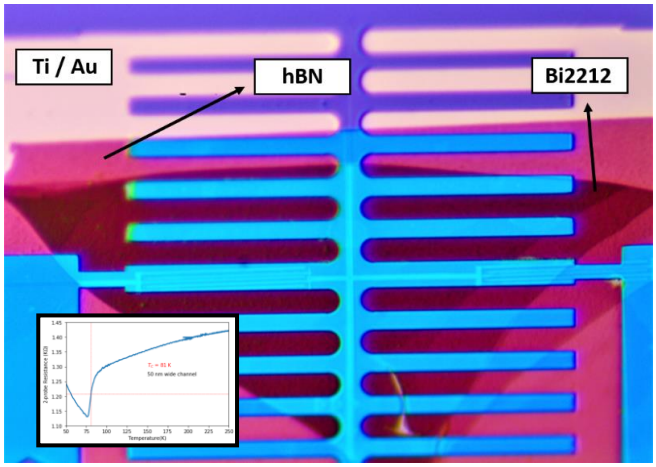

Figure 1: Nano-patterned van der Waals heterostructure for photodetection at moderate cryogenic temperatures.
Inset: Superconducting transition for a 50 nm wide nanochannel.

Quantum control of the tin-vacancy spin qubit in diamond

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Group-IV color centers in diamond are a promising light-matter interface for quantum networking devices [1,2]. The negatively charged tin-vacancy center (SnV) is particularly interesting, as its large spin-orbit coupling offers strong protection against phonon dephasing and robust cyclicity of its optical transitions towards spin-photon entanglement schemes [3,4]. Here, we demonstrate multi-axis coherent control of the SnV spin qubit via an all-optical stimulated Raman drive between the ground and excited states. We use coherent population trapping and optically driven electronic spin resonance to confirm coherent access to the qubit at 1.7 K, and obtain spin Rabi oscillations at a rate of $\Omega/2\pi$ = 3.6(1) MHz. All-optical Ramsey interferometry reveals a spin dephasing time of T_2^* = 1.3(3) μs and two-pulse dynamical decoupling already extends the spin coherence time to T_2 = 0.33(14) ms. Combined with transform-limited photons [5] and integration into photonic nanostructures [6], our results make the SnV a competitive spin-photon building block for quantum networks

Figures

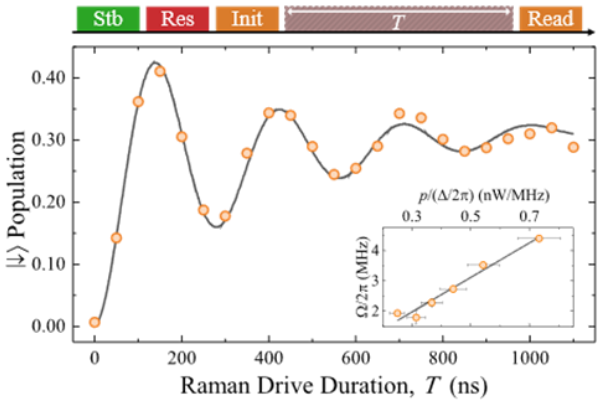

Figure 1: Coherent spin qubit control: down state population (orange circles) as a function of the Raman drive duration T with the pulse sequence shown at the top. The black curve is a fit to a 2-level model under a master equation formalism. Inset: Ω as a function of p/Δ with a linear fit to the data (solid curve).

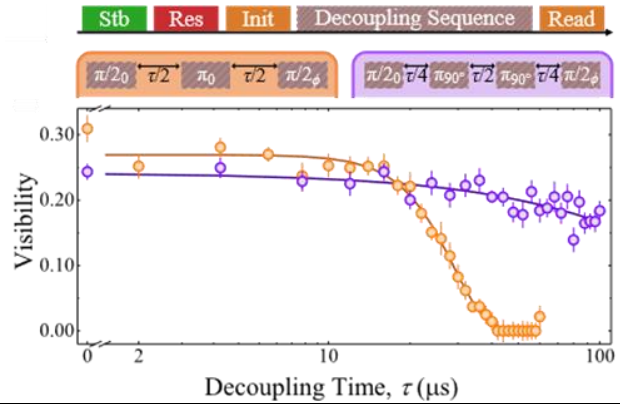

Figure 2: Dynamical decoupling: pulse sequence (top) with two implementations: (left) Hahn echo, (right) CPMG-2. The phase φ of the second π/2 pulse is variable and visibility a/b is obtained from fitting the function a cos(φ) + b at each delay time τ , plotted as a function of τ.

References

[1] M. Atatüre, et al. Nat. Rev. Mat.3, 38 (2018)
[2] C. Bradac et al. Nat. Commun.10, 5625 (2019)
[3] D. D. Sukachev et al. Phys. Rev. Lett.119, 223602 (2017).
[4] M. K. Bhaskar et al. Nature 580, 60 (2020).
[5] M. E. Trusheim et al. Phys. Rev. Lett.124, 023602 (2020).
[6] A. E. Rugar et al. Nano Lett. 20, 1614 (2020).

QFold: Quantum Walks and Deep Learning to Solve Protein Folding

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We develop quantum computational tools to predict the 3D structure of proteins, one of the most important problems in current biochemical research. We explain how to combine recent deep learning advances with the well known technique of quantum walks applied to a Metropolis algorithm. The result, QFold, is a fully scalable hybrid quantum algorithm that, in contrast to previous quantum approaches, does not require a lattice model simplification and instead relies on the much more realistic assumption of parameterization in terms of torsion angles of the amino acids. We compare it with its classical analog for different annealing schedules and find a polynomial quantum advantage, and validate a proof-of-concept realization of the quantum Metropolis in IBMQ Casablanca quantum system.

Moving electrons as spin qubits

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Quantum dots are one of the most promising physical systems for quantum computation. After reaching experimental values for single qubit manipulation fidelities of more than 99% [1] and two qubit interactions creating CNOT gates [2], the limit of universal computation is as close as ever. However, as ion traps and superconducting qubits did before, the limit of operating with short ranged interactions limits the amount of qubits that quantum computers can operate at the same time. Tackling these issues, the presented system is based on electrons as spin qubits moved by surface acoustic waves (SAWs) [3,4]. GaAs piezoelectric properties allow the creation of SAWs with patterned metallic interdigital transducers (IDTs), as well as 2D electron gases in an interface with AlGaAs, that enables it to control QDs 100 nm below the surface. Extending this experiment by placing other static dots at some known distance from the moving, one can tune the exchange interaction between the triplet and the singlet. In order to avoid the decoherences that the nuclear spin bath in GaAs may cause to spin qubits, an alternative Si/SiGe interface with piezoelectric ZnO on top is has been proposed, where isotopic purification can make spin qubits a more feasible quantum memory.

References

[1] M. Veldhorst et al., Nat Nanotechnol, 9 (2014) 981

[2] D. M. Zajac et al., Science, 359 (2018) 439

[3] C. H. W. Barnes, J. M. Shilton and A. M. Robinson, PRB, 62 (2000) 8410

[4] C. J. B. Ford, p.s.s (b), 254 (3) (2017) 1600658

Figures

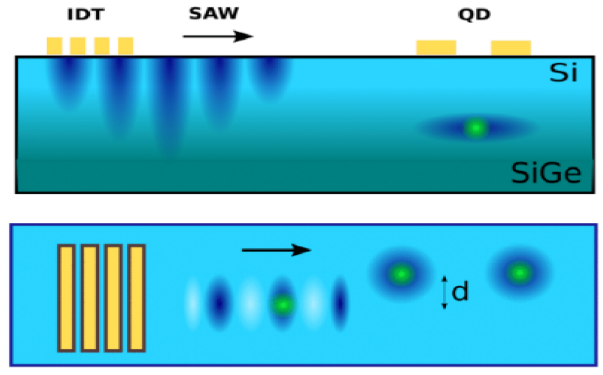

Figure 1: Side and top view of a sketch showing the working process of electron pickup and multiple particle interaction.

$$H = 2\epsilon + \begin{pmatrix} U & X & -\sqrt{2}t_{\mathrm{H}} & 0 \\ X & U & -\sqrt{2}t_{\mathrm{H}} & 0 \\ -\sqrt{2}t_{\mathrm{H}} & -\sqrt{2}t_{\mathrm{H}} & V_{+} & 0 \\ 0 & 0 & 0 & V_{-} \cdot \mathbb{I}_3 \end{pmatrix}$$

Figure 2: Hamiltonian of the interaction between two electrons, showing the singlet triplet decoupling.

Topology detection in cavity QED

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We explore the physics of topological lattice models in c-QED architectures for arbitrary coupling strength, and the possibility of using the cavity transmission as a topological marker. When the coupling between subsystems is small, the transmission can be used as a way to probe the properties of the fermionic system in a non-invasive way, while at large coupling rates, these properties are highly modified and hybrid excitations of the total system appear.
In this work, we develop an approach combining the input-output formalism with Mean-Field theory, which includes self-consistency and quantum fluctuations to first order, and allows to go beyond the small-coupling regime in the calculation of the cavity transmission. We apply our formalism to the case of a fermionic Su-Schrieffer-Heeger (SSH) chain, whose topological phase is characterized by the presence of two in-gap edge states, topologically protected against local perturbations.
Our findings confirm that the cavity can indeed act as a quantum sensor for topological phases, where the initial state preparation plays a crutial role.
Additionally, we discuss the persistence of topological features when the coupling strength increases, in terms of an effective Hamiltonian, and calculate the entanglement entropy.
Our approach can be applied to other fermionic systems, opening a route to the characterization of their topological properties in terms of experimental observables.

References

[1] B. Pérez-González, A. Gómez-León, G. Platero, "Topology detection in cavity QED", arXiv:2106.08709v2

Figures

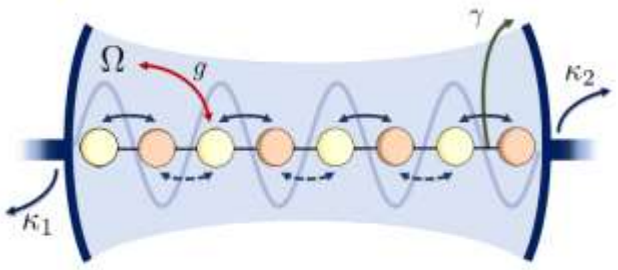

Figure 1: Schematic picture of a dimerized chain interacting the photons in a cavity. The cavity photons have frequency Ω and are connected to the input and output ports with factors κ. The fermions interact with the photons with strength *g* and γ represents the spectral broadening of the fermionic system.

Nanofabrication challenges and opportunities for the manufacturing of semiconductor spin qubits

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Abstract

The fabrication technology of semiconductor-based devices has experienced a sustained exponential growth for more than 6 decades. [1] Presently, the level of dimensional and material composition control is approaching the single atom accuracy, but it is still behind what it is needed for the realization of a practical computer based on semiconductor qubits. Recent progress on electrostatic gated quantum dot devices based on silicon and silicon related materials [2,3] shows that it is possible to obtain devices with very high coherence time [4]. However, at short term, the next generations of semiconductor electronic devices will require improved fabrication methods, that could fulfill accuracy requirements along with capability for scaling up in view of practical applications. Progress is needed in aspects like deterministic doping [5], lithography resolution, material compatibility for low-temperature operation, and interfacing with back-end electronics [6]. In this communication, we will review some recent advances in the field and we will present some explorative activities that are being carried out at IMB-CNM, covering from the development of novel lithography methods for the realization of single electron devices based on silicon nanowires (Figure 1, [7]) to the integration of single electron transistors with CMOS circuits (Figure 2, [8]).

References

[1] R Chau, IEEE International Electron Devices Meeting, (2019), 1.1.1-1.1.6
[2] M Urdampilleta et al., Nat Nanotechnol, 14 (2019) 737
[3] S Geyer et al., Appl Phys Lett,118 (2021)104004
[4] A.M.J. Zwerver, arXiv 2101.12650 (2021)
[5] DN Jamieson et al. Mater Sci Semicond Process, 62 (2017) 23
[6] M Veldhorst et al., Nat Commun 8 (2017) 1766
[7] J Llobet et al. Appl Phys Lett, 107 (2015) 223501
[8] A del Moral. PhD Thesis. Universitat Autonoma de Barcelona (2021)

Figures

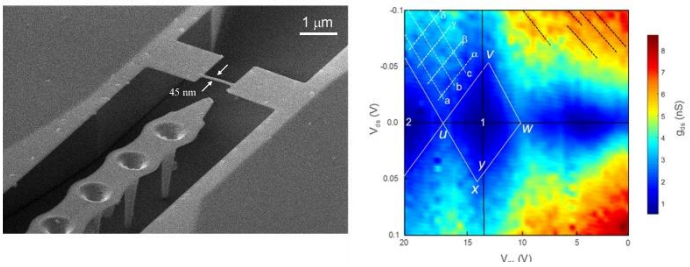

Figure 1: Suspended single hole transistor with nanocrystals embedded

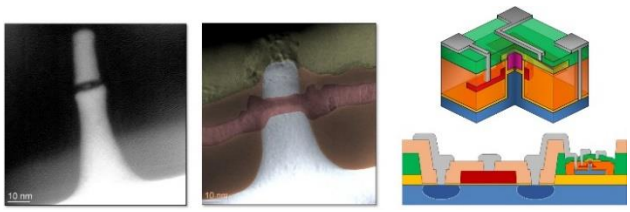

Figure 2: Single electron transistor based on a vertical silicon nanopillar with an embedded silicon nanocrystal

Optical Properties of Janus Transition Metal Dichalcogenide Monolayers WSSe and MoSSe

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Janus transition metal dichalcogenides (TMDs) lose the horizontal mirror symmetry of ordinary TMDs, leading to the emergence of additional features, such as native piezoelectricity, Rashba effect, and enhanced catalytic activity [1]. Raman, photoluminescence (PL) and second-harmonic generation (SHG) spectroscopy are essential nondestructive, phase- and composition-sensitive tools used to monitor the synthesis of materials, get insights into their excitonic properties, investigate nonlinear optical response, etc. However, comprehensive and complete study of the fundamental optical properties of Janus monolayers is still missing. Here, we discuss the Raman spectra of WSSe and MoSSe measured at room and cryogenic temperatures, near and off resonance [2]. By combining polarization-resolved Raman data with calculations of the phonon dispersion and using symmetry considerations, we identify the four first-order Raman modes and higher-order two-phonon modes (Figure 1). Moreover, we observe defect-activated phonon processes, which provide a route toward a quantitative assessment of the defect concentration and, thus, the crystal quality of the materials. Using PL spectroscopy, we study the excitonic properties of these materials. We also confirm that monolayers of WSSe and MoSSe inherit nonlinear optical response of their parent material when excited by in-plane polarized light. Furthermore, widely tuneable pulsed excitation reveals their rich electronic structure. Our work establishes a solid background for future research on material synthesis, study, and application of Janus TMD monolayers.

References

[1] Trivedi, Dipesh B., Guven Turgut, Ying Qin, Mohammed Y. Sayyad, Debarati Hajra, Madeleine Howell, Lei Liu *et al.*, **Advanced Materials 32, no. 50 (2020): 2006320.**
[2] Petrić, Marko M., Malte Kremser, Matteo Barbone, Ying Qin, Yasir Sayyad, Yuxia Shen, Sefaattin Tongay, Jonathan J. Finley, Andrés R. Botello-Méndez, and Kai Müller, **Physical Review B 103, no. 3 (2021): 035414**.

Figures

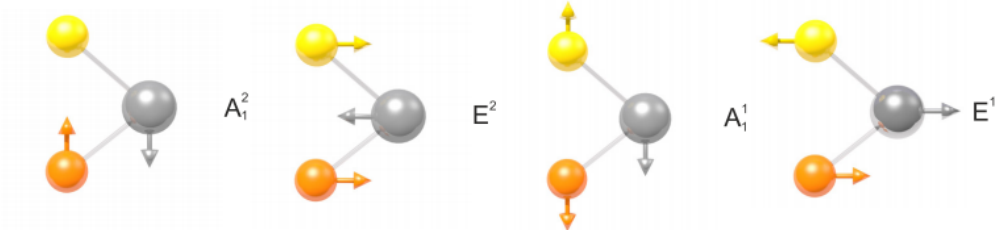

Figure 1: Schematic representation of the atomic vibrations at the center of the Brillouin Zone. Transition metal, selenium, and sulfur atoms are identified by gray, orange, and yellow, respectively.

Spin-polarized tunable photocurrents

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Circular dichroism, a distinct response to left and right-handed circularly polarized light, is an example of a phenomenon involving light-matter interaction that has been heavily exploited to control valley polarization in two-dimensional materials [1]. In most studies, light-matter interaction enters perturbatively and does not modify the electronic properties. But beyond this weak-coupling regime, Floquet engineering [2-4] has shown that we can use light to change the band-structure of a material [5-7] and even its topology [2-4, 8], generating a Hall response [9].

Light can also be used to generate directed currents even in the absence of an applied bias voltage, a phenomenon called quantum pumping, and recently it has been shown that by tailoring a selective environment one can take this to the limit of a perfect isolator effect [10], where currents flow in one direction but not the opposite.

Here, we go a step further and show how the rich interplay between electron-photon processes (and the additional synthetic dimension), stacking order, spin-orbit coupling, and the topology of a two-dimensional material can be harnessed to control spin, charge, and valley currents in two-dimensional materials, beyond the weak-coupling regime [11].

References

[1] K. F. Mak, K. He, Jie Shan, and T. F. Heinz, Nature Nanotechnology, 7 (2012) 494.
[2] T. Oka, and A. Aoki, Physical Review B 79 (2009) 081406.
[3] N. H. Lindner, G. Refael, and V. Galitski, Nature Physics 7 (2011) 490
[4] T. Kitagawa, T. Oka, A. Brataas, L. Fu, and E. Demler, Physical Review B 84 (2011) 235108.
[5] H. L. Calvo, H. M. Pastawski, S. Roche, and L. E. F. Foa Torres, Applied Physics Letters 98 (2011) 232103.
[6] Y. H. Wang, H. Steinberg, P. Jarillo-Herrero, and N. Gedik, Science 342 (2013) 453.
[7] F. Mahmood et al. Nature Physics 12 (2016) 306.
[8] L. E. F. Foa Torres, P. M. Perez-Piskunow, C. A. Balseiro, and G. Usaj, Physical Review Letters 113 (2014) 266801.
[9] J.W. McIver et al., Nature Physics 16 (2020) 38.
[10] V. Dal Lago, E. Suárez Morell, and L. E. F. Foa Torres, Physical Review B 96 (2017), 235309.
[11] M. Berdakin, E. Rodriguez-Mena, and L. E. F. Foa Torres, Nano Lett. 21 (2021), 3177.

QUANTEK - Towards consolidated Quantum Technologies in Basque Country

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Abstract
Quantum computing is a new computing paradigm, different from classical computing. It is based on the use of qubits, a special combination of ones and zeros. Classic computing bits can be either 1 or 0, but only one state at a time; while the qubits can be in *superposition*, that is, they can have the two simultaneous states. There are two main types of Quantum architectures which supports this concept: the gate-model quantum computer and the annealingbased quantum computer.
Quantum computing is not applicable for the resolution or optimization of any problem. There are real problems that require a high computational requirement, either due to the volume of information, the high number of variables to optimize or non-functional requirements (e.g. response times).
Some current application areas: logistics, simulation in chemical processes, design of new materials, communications, advanced services, etc.
QUANTEK is a project funded by the Basque Government which aims to position the Basque Country among the benchmarks in quantum computing and align with the advances of European countries. It plans to favour the generation of a Basque ecosystem in quantum technologies and their applications. The idea is to integrate and unify multidisciplinary capacities and lines of research related to quantum technologies.
Project Main Objectives are:

- Analyze the limits or restrictions that classical technology approaches imply for the great problems of Basque industry and analyze the viability and impact of quantum technologies in their resolution
- Develop technologies for the adoption of quantum approaches that allow Basque industry to facilitate its transition
- Improve the competitiveness and excellence of the agents of the Basque science and technology network around quantum technologies and adapt the needs of the industrial fabric

Project working areas are:

- Problems, challenges and limitations of quantum technologies study, and analysis of possible applications in Basque industry
- Research and Technological Development:
- Quantum Software Engineering
    - Quantum Optimization and Simulation
    - Quantum Security and Communications
    - Quantum Software Engineering
    - Quantum Computing Ecosystem
- Application of quantum technology to the problems or challenges identified
- Dissemination of applications and capacities of the Basque ecosystem around quantum technologies

Behind this project we have Tecnalia (coordinator), Ibermatica, Deusto University and UPV (with two research groups, QUTIS group and IC group) participating in the project.

Adiabatic Spectroscopy and a Variational Quantum Adiabatic Algorithm

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Preparing the ground state of a Hamiltonian is a problem of great significance in physics with deep implications in the field of combinatorial optimization. The adiabatic algorithm is known to return the ground state for sufficiently long preparation times which depend on the a priori unknown spectral gap. Our work relates in a twofold way. First, we propose a method to obtain information about the spectral profile of the adiabatic evolution. Second, we present the concept of a variational quantum adiabatic algorithm (VQAA) for optimized adiabatic paths [1]. We aim at combining the strengths of the adiabatic and the variational approaches for fast and high-fidelity ground state preparation while keeping the number of measurements as low as possible. Our algorithms build upon ancilla protocols which we present that allow to directly evaluate the ground state overlap. We benchmark for a non-integrable spin-1/2 transverse and longitudinal Ising chain with N = 53 sites using tensor network techniques. Using a black box, gradient-based approach, we report a reduction in the total evolution time for a given desired ground state overlap by a factor of ten, which makes our method suitable for the limited decoherence time of noisy-intermediate scale quantum devices.

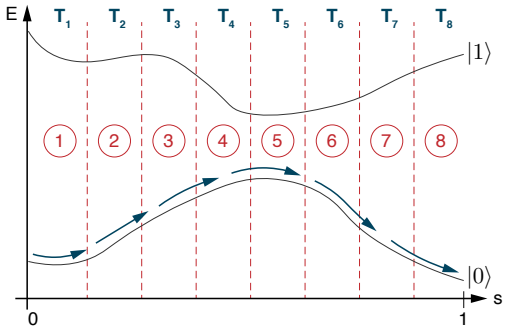

FIG. 1: Illustration of the hybrid algorithm by dividing the adiabatic path into eight chunks. The ground state and first excited state energies are shown for parametrized time $s = t/T$ from 0 to 1. For the black box optimization shown below, the adiabatic evolution time T is allocated evenly between the chunks of the adiabatic path (here $T_i = T/8\ \forall i \in \{1, 8\}$), so that the chunk positions become the variational parameters to be optimized, effectively controlling the density of adiabatic steps.

[1] B. F. Schiffer, J. Tura, and J. I. Cirac, Adiabatic spectroscopy and a variational quantum adiabatic algorithm, arXiv preprint arXiv:2103.01226 (2021).

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Modulation leakage vulnerability in continuous-variable quantum key distribution

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We address the issue of modulation leakage from the in-phase and quadrature (IQ) modulators, which are used in implementation of continuous-variable (CV) quantum key distribution (QKD). Following the previously obtained theoretical results, demonstrating the general negative effect of side-channel modulation leakage in CV QKD [1], we establish an equivalence between the unsuppressed sideband modulation and the modulation side-channel leakage. Using the set-up, incorporating a laser source, an IQ modulator, optical filters, and a homodyne detector, fed by a locally generated local oscillator (Fig. 1) and phase-referenced using pilot tones, we characterize the modulation leakage in terms of the main signal modulation. Assuming two different measurement strategies, used by an eavesdropper, namely availability of only a suppressed pilot tone or an unsuppressed desired pilot tone, we study the effect of modulation leakage on security of CV QKD. We analyse security of the scheme using a passive Trojan-horse attack model [2] in the purification-based security analysis method and incorporate additional sources of trusted noise in the sending and receiving stations. Our results show the reduction of secure key rate (Fig. 2) and, equivalently, secure regions of CV QKD in terms of tolerable channel losses and noise, when the sideband suppression is weak [3]. The effect is present in both direct and reverse reconciliation scenarios and is more pronounced for the former. On the other hand, the negative effect of modulation leakage can be removed when the sidebands are properly suppressed. We also show the positive effect of additional trusted noise in the leaking mode, particularly for the direct reconciliation. Our results reveal the importance of proper modulation sidebands suppression in practical realizations of CV QKD.

References

[1] I. Derkach, V. C. Usenko, and R. Filip, Phys. Rev. A 96 (2017) 062309
[2] J. Pereira, and S. Pirandola, Phys. Rev. A 98 (2018) 062319
[3] N. Jain, I. Derkach, H.-M. Chin, R. Filip, U. L. Andersen, V. C. Usenko, and T. Gehring, Quantum Science and Technology 6 (2021) 045001

Figures

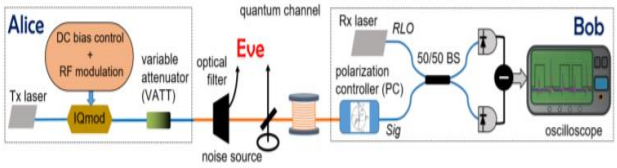

Figure 1: Experimental set-up used for studying the modulation leakage vulnerability in CV QKD.

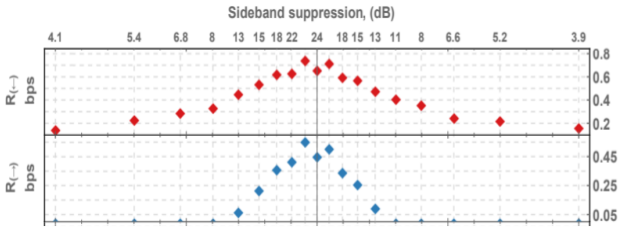

Figure 2: Effect of finite sideband suppression on secure key rate of CV QKD in reverse (top) and direct (bottom) reconciliation scenarios.

Using spatio-temporal correlations for tuning the biphoton wavefunction

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Photons are a natural choice for quantum information protocols. Among others, one technical advance that has allowed this wide range of applications of photons is the production of photonics states in nonlinear processes, such as spontaneous parametric downconversion (SPDC). The versatility of this technique resides in the fact that the generated pairs of photons can be manipulated in several degrees of freedom (DOFs). In particular, the correlations between spatial and temporal DOFs are specially important in SPDC processes. Moreover, the ability of tuning the spectro-temporal distribution is also fundamental in several applications. In this sense, several methods for shaping the spectro-temporal distribution of entangled photons have been reported in literature. In particular, when pumping with a focused beam on a nonlinear crystal and collecting them with monomode optical fibers, the spatio-temporal correlations of the generated photons can be exploited on order to tuning their spectro-temporal distribution [1,2].

Here, we will show how a typical experimental configuration of a SPDC photons source is and how we can shape its spectro-temporal distribution. In particular, we will show a versatile proposal that encompasses a straightforward experimental implementation. This method is to modify the area of the portion of the crystal from which we collect the photons, that is, the detection beam waist. In addition, we will see that the spectro-temporal distribution depends very weakly on the waist of the Gaussian pump beam. Finally, we will see that under standard experimental conditions the spectral bandwidth of the biphoton wavefunction can be tuned by approximately a factor of five [3].

References

[1] A. Büse, M. L. Juan, N. Tischler, V. D'Ambrosio, F. Sciarrino, L. Marrucci, and G. Molina-Terriza, *Phys. Rev. Lett.* 121, 173901 (2018).
[2] N. Tischler, A. Büse, L. G. Helt, M. L. Juan, N. Piro, J. Ghosh, M. J. Steel, and G. Molina-Terriza, *Phys. Rev. Lett.* 115, 193602 (2015).
[3] J.J.M. Varga, J. Lasa-Alonso, M. Molezuelas-Ferreras, N. Tischler, G. Molina-Terriza, *Optics Communications*, 127461 (2021).

Figures

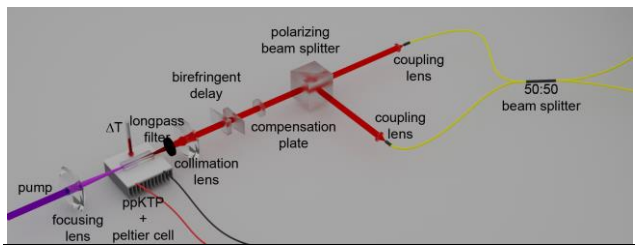

Figure 1: SPDC twin photons source.

Topological Quantum Optics for robust photon mediated interactions

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Abstract

Quantum emitters interacting with photonic band-gap materials lead to the appereance of localized and non-decaying polariton excitations that have been labeled as qubit-photon bound states [1]. These states can mediate decoherence-free tunable emitter-emitter interactions. Recently, it has been shown that when these band-gaps have a topological origin, these interactions inherit certain robustness to disorder. In this talk, I will give an overview of robust photon-mediated interactions in different photonic environments, like the photonic SSH model [2] and the extended SSH models displaying long-range hoppings [3]. I will also discussed the tunability of these interactions through non-local light-matter couplings that can be obtained with giant atoms.

References

[1] S. John et al.; Physical Review Letters (1990) ,vol. 64 no 29, p.2418
[2] M. Bello et al.; Science advances (2019), vol. 5, no 7, p. eaaw0297.
[3] C. Vega et al.; arXiv preprint, arXiv: 2105.12470 (2021).

Quantum Domain Melting in an Electronic Crystal and Its Simulation with a Quantum Computer

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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.

Proximity effects on the charge density wave order and superconductivity in single-layer $NbSe_2$

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Abstract

Collective electronic states such as the charge density wave (CDW) order and superconductivity (SC) respond sensitively to external perturbations. Such sensitivity is dramatically enhanced in two dimensions (2D), where 2D materials hosting such electronic states are largely exposed to the environment. In this regard, the ineludible presence of supporting substrates triggers various proximity effects on 2D materials that may ultimately compromise the stability and properties of the electronic ground state. In this work, we investigate the impact of proximity effects on the CDW and superconducting states in single-layer (SL) $NbSe_2$ on four substrates of diverse nature, namely bilayer graphene (BLG), SL-boron nitride (h-BN), Au(111) and bulk WSe_2. By combining low-temperature (340 mK) scanning tunneling microscopy/ spectroscopy (STM/STS) and angle-resolved photoemission spectroscopy (ARPES), we compare the electronic structure of this prototypical 2D superconductor on each substrate. We find that, even when the electronic band structure of SL-$NbSe_2$ remains largely unaffected by the substrate except when placed on Au(111), where a charge transfer occurs, both the CDW and SC show disparate behaviors. On the insulating h-BN/Ir(111) substrate and the metallic BLG/SiC(0001) substrate, both the 3x3 CDW and superconducting phases persist in SL-$NbSe_2$ with very similar properties, which reveals the negligible impact of graphene on these electronic phases. In contrast, the electronic phases of SL-$NbSe_2$ are severely weakened and even absent on the bulk insulating WSe_2 substrate and the metallic single-crystal Au(111) substrate. Our results provide valuable insight into the fragile stability of such electronic ground states in novel 2D materials.

Single-Electron Transport with Acousto-Electric Chirp Pulses for Quantum Applications

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Abstract

A surface acoustic wave (SAW) can transfer a single-electron between distant quantum dots [1,2], resulting in a promising platform for the implementation of electronic flying qubits [3-6]. The inconvenience in these experiments is that a relatively long SAW train (~100 minima) is generated, but only a single minimum is required for the electron transfer [7]. These additional SAW minima make the exact location of the electron during the transfer ambiguous and lead to unwanted perturbation of the quantum state of the electron [6]. Here we demostrate the generation of a single moving SAW minimum using a chirp interdigital transducer with a single-electron transfer efficiency above 99.5%. Owing to the simplicity to synchronise several single-electron sources and the high transfer efficiency, our results represent a paradigm shift for SAW-driven quantum-transport experiments.

References

[1] S. Hermelin et al., Nature 477, 435–438 (2011)
[2] R. P. G. McNeil et al., Nature 477, 439–442 (2011)
[3] S. Takada et al., Nat. Commun. 10, 4557 (2019)
[4] Bäuerle et al., Rep. Prog. Phys. 81, 056503 (2018)
[5] B. Jadot et al., Nat. Nanotechnol. 16, 570–575 (2021)
[6] B. Bertrand et al., Nat. Nanotechnol. 11, 672-676 (2016)
[7] H. Edlbauer et al., APL 119, 114004 (2021)

Figures

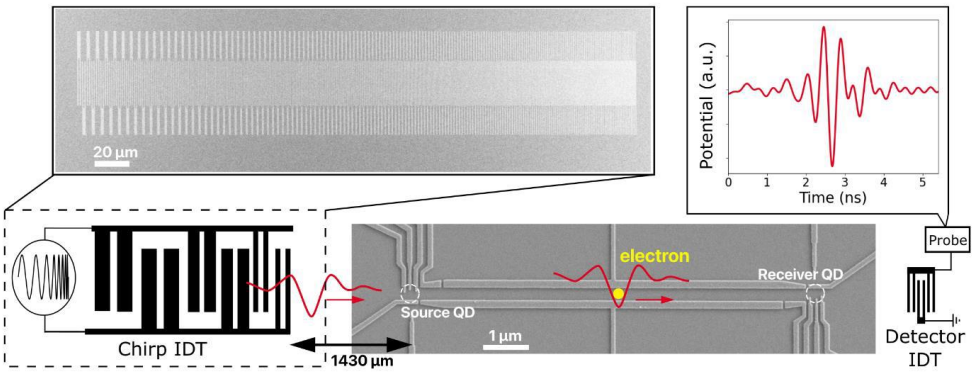

Figure 1: SEM image of the SAW-driven single-electron circuit with a chirp interdigital transducer (IDT). The engineered SAW comprises a single minimum which transfers a single electron from the source quantum dot (QD) to the receiver quantum dot. Top right: measured shape of the SAW from the wideband detector IDT.

Dispersively Probed Microwave Spectroscopy of a Silicon Hole Double Quantum Dot

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Owing to ever increasing gate fidelities and to a potential transferability to industrial CMOS technology, silicon spin qubits have become a compelling option in the strive for quantum computation. In a scalable architecture, each spin qubit will have to be finely tuned and its operating conditions accurately determined. In view of this, spectroscopic tools compatible with a scalable device layout are of primary importance.
Here we report on a two-tone spectroscopy technique providing access to the spin-dependent energy-level spectrum of a hole double quantum dot defined in a split-gate silicon device, see Figure 1. A first gigahertz-frequency tone drives electric dipole spin resonance enabled by the valence-band spin-orbit coupling. A second lower-frequency tone (approximately 500 MHz) allows for dispersive readout via rf-gate reflectometry, see Figure 2. We compare the measured dispersive response to the linear response calculated in an extended Jaynes-Cummings model and we obtain characteristic parameters such as g factors and tunnel and spin-orbit couplings for both even and odd charge occupation.

References

Ezzouch et al. Phys. Rev. Applied 16, 034031 (2021)

Figures

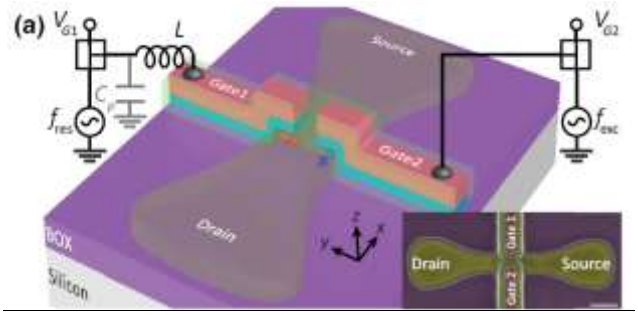

Figure 1: (a) Simplified 3D schematic of a split-gate, silicon-on-insulator field-effect transistor. An LC resonator wired to gate 1 is used for reflectometry readout while a spectroscopy tone in the GHz range is applied to gate 2 (f_{exc}). The inset shows a false color scanning electron micrograph of the device (scale bar is 100 nm)

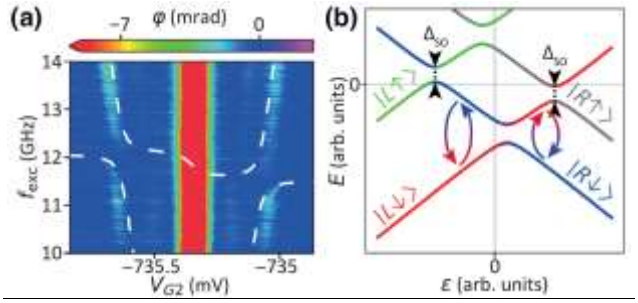

Figure 2: (a) Photon assisted spectroscopy at finite magnetic field for an odd-parity interdot charge transition. The dispersive shift of an LC resonator as a function of DQD detuning and spectroscopy tone (f_{exc}) is plotted. (b) Energy diagram of an odd charge configuration in a DQD at finite magnetic field.

Quantum kernels to learn the phases of quantum matter

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Classical machine learning has succeeded in the prediction of both classical and quantum phases ofmatter. Notably, kernel methods stand out for their ability to provide interpretable results, relatingthe learning process with the physical order parameter explicitly. Here, we exploit quantum kernels instead. They are naturally related to thefidelityand thus it is possible to interpret the learning process with the help of quantum information tools. In particular, we use a support vector machine (SVM) (with a quantum kernel) to predict and characterize quantum phase transitions. The general theoryis tested in the Ising chain in transverse field. We show that for small-sized systems, the algorithm gives accurate results, even when trained away from criticality. Besides, for larger sizes we confirmthe success of the technique by extracting the correct critical exponentv. The characterization is completed by computing the kernel alignment between the quantum and ideal kernels. Finally, we argue that our algorithm can be implemented on a circuit based on a varational quantum eigensolver.

Figures

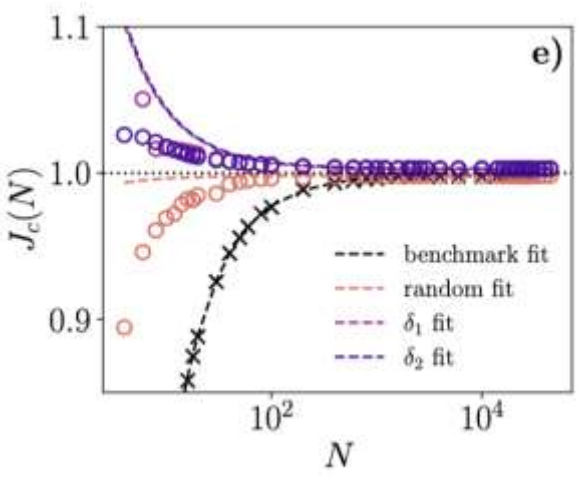

Figure 1: Prediction of a quantum phase transition using quantum machine learning. We show that a SVM can learn the phase transition and its critical exponents.

References

[1] T Sancho-Lorente, J Román-Roche, D.Zueco , arXiv:2109.02686

Ab Initio Description of the Photoionization of Graphene Under Laser Pulses

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Graphene (Gr) is the archetype of a 2D material. With a zero-gap and excellent mechanical properties, Gr seems to be an endless source of research topics, with a huge range of potential applications. However, most of the theoretical works on Gr are based in models (e.g. tight binding) or in regular Density Functional Theory (DFT) calculations. With such approaches, the time evolution of the electrons in the material is rarely considered. Thus, several ultrafast processes, in the range from attoseconds up to a few femtoseconds, cannot be studied with standard calculations.

However, using our methodology [1], based on the Wave Packet Propagation (WPP) technique, we are able to describe the electron dynamics taking into account the full atomistic structure, thanks to the inputs of high-level ab initio DFT calculations.
This methodology, which has been used to follow the dynamics of electrons attached to molecules adsorbed on metal surfaces [2] and on metal surfaces decoupled with ultrathin insulator layers [3], allows the inclusion of time-dependent potentials, such as ultra-short and/or ultra-intense laser pulses.

Here, we present a WPP study of the photo-excitation and photo-ionization of Gr under the action of infrared (IR) laser fields. Our results show a strong relation of the coordinate of the Brillouin zone of the initial state and the probability of the photoionization.
Also, we observe the transition from the multiphoton to the strong field regime when intense IR laser sources are applied to the material.

References

[1] F. Aguilar-Galindo et al. Journal of Chemical Theory and Computation, 17 (2021), 639
[2] F. Aguilar-Galindo et al. Applied Surface Science, 554 (2021), 149311
[3] F. Aguilar-Galindo et al., ACS Photonics, Accepted (2021)

Figures

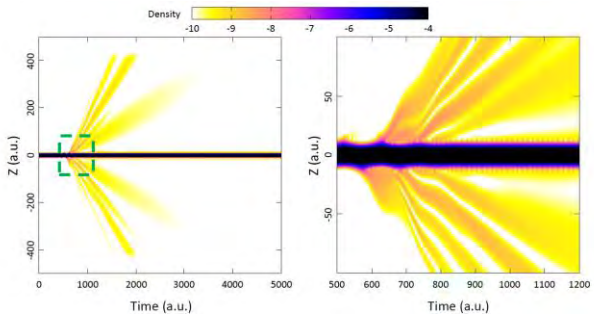

Figure 1: Density of the emitted electrons as function of time under the action of the laser pulse. Graphene is located at z=0.

Integer quantum Hall effect modified by a tunable cavity

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Quantum Hall effects and cavity quantum electrodynamics are two pillars of modern quantum physics. We recently proposed an experimental platform [1], which allows studying the transport of charged particles strongly coupled to cavity vacuum fields.
By measuring at mK temperatures the linear transport regime, we showed that the amplitude of the Shubnikov de Haas oscillations is modified by the presence of a cavity [1], even without external illumination. We also studied the effects of vacuum field fluctuations on the integer quantum Hall effect, showing a breakdown of most quantized odd plateaus [2] due to cavity-mediated electron hopping [3].
We present here an experiment where we modulate the cavity field by means of a movable metallic plate (Fig.1). This allows to modify the electromagnetic environment and the enhancement of the vacuum fields without changing the properties of the 2D electron gas.
We show (Fig. 2) that the longitudinal resistance exhibits a change at odd integer filling factors for the hall bar immersed in the cavity vacuum fields. The transport properties of a reference hall bar, measured at the same time, on the same chip are not modified.
This platform, offering a more direct way of controlling the vacuum field distribution sensed by the Hall bar, paves the way to experimentally test predictions on the cavity modification of the quantization of the integer Hall effect[4].

References

[1] G.L. Paravicini-Bagliani et al., Nat. Phys, 15.2 (2019) 186-190
[2] F. Appugliese et al., Arxiv, 2107.14145 (2021)
[3] C. Ciuti, Arxiv, 2107.09435 (2021)
[4] V.Rokaj et al., Arxiv, 2109.15075v1 (2021)

Figures

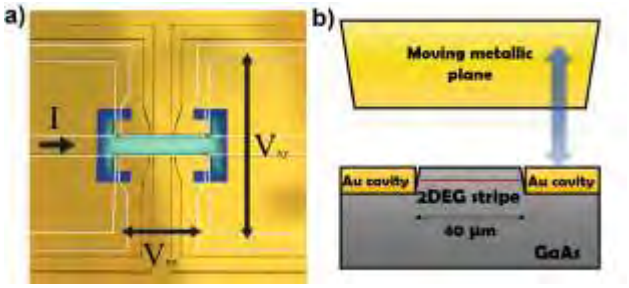

Figure 1: a) representation of the hall bar immersed in the field of a complementary split ring resonator. b) Schematics of the experiment where a movable mirror modifies the properties of the split ring resonator without modifying the 2D electron gas

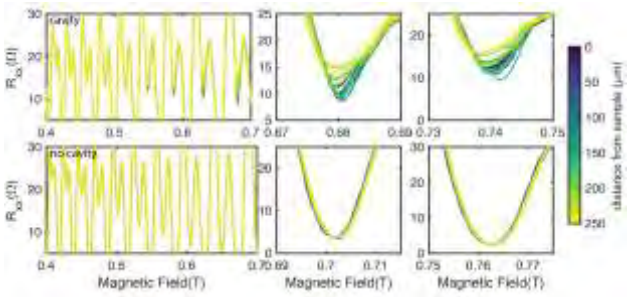

Figure 2: Longitudinal resistance for different positions of the metallic plane. While the reference Hall bar shows no response, a change at odd integer filling factors is visible in the cavity embedded Hall bar.

Magnetic Josephson Junctions and Superconducting Diodes in Magic Angle Twisted Bilayer Graphene

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The gate-tuneability of magic angle twisted bilayer graphene (MATBG) as well as its superconducting (SC), magnetic and topological states [1], allow for the creation of Josephson junctions (JJ) in a single device [2-4]. Here we report on the creation of gate-defined, magnetic JJ in MATBG, where the weak link is gate-tuned close to the correlated state at a moiré filling factor of ν=−2. A highly unconventional Fraunhofer pattern emerges, which is asymmetric with respect to the current and magnetic field directions, and shows a pronounced magnetic hysteresis. We find that these features are explained by a valley polarized ν=−2 state. Finally, we demonstrate how the switching of current, induced in this state by magnetization, enables us to realize a programmable zero field superconducting diode, which represents a major building block for a new generation of superconducting quantum electronics.

References

[1] Cao, Y. *et al.*, Nature 556, 43–50 (2018).
[2] Díez-Mérida, J., Díez-Carlón, A. *et al.*, Preprint arXiv:2110.01067 (2021).
[3] de Vries, F. K. *et al.*, Nature Nanotechnology 16, 760–763 (2021).
[4] Rodan-Legrain, D. *et al.*, Nature Nanotechnology 16, 769–775 (2021).

Figures

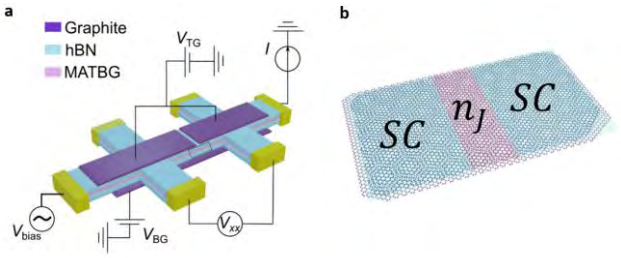

Figure 1: Scheme of the device (a), where the three gates are used to keep the sides in the SC state and to gate-tune the central region (b), creating a JJ.

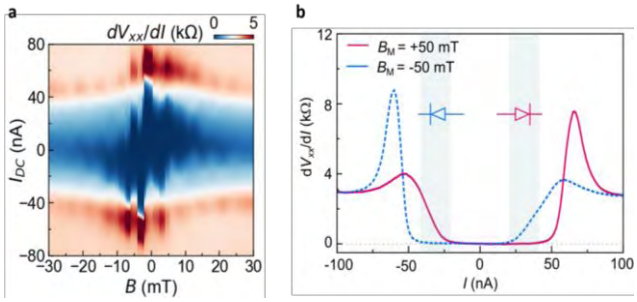

Figure 2: When the weak link of the JJ is set close to ν=−2, the oscillations of the resulting Fraunhofer pattern are asymmetric with respect to current and field (a). By reversing the magnetization of this state, we can switch the current direction of a superconducting diode at zero field (b).

Towards a graphene-based Quantum Resistance Standard for metrological applications

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Since the changes brought by the Système International d'unités (SI) in 2018, the basic units of measurement are redefined from universal constants of nature. Specifically, redefinitions for the mass (kg) and current (A) in this new quantum SI are obtained from the relation between Planck's constant (h) and the electron charge (e). The Quantum Hall Effect[1] (QHE) is a quantum macroscopic phenomenon in 2DEG systems where, in the presence of high magnetic fields, the Hall resistance is quantized in multiples of h/e^2. Nowadays the QHE in AlGaAs/GaAs heterostructures is used as the quantum resistance standard (QRS) defining the relation between e and h with extremely high precision. Recently, it has been shown that the electronic properties of single layer graphene[2] (SLG) allow the observation of the QHE in more relaxed experimental conditions (temperature, magnetic field and current) as compared to AlGaAs/GaAs making graphene an attractive candidate for the development of QRS that could have a broader use beyond national metrology institutes[3]. However, one disadvantage of graphene is its susceptibility for degradation with time. We have fabricated epitaxial SLG Hall bars and characterized the electronic transport and QHE as a function of temperature. We have performed preliminary studies of aging effects when the devices are stored in vacuum for a long time.

References

[1] T. J. B. M. Janssen et al. Rep. Prog. Phys. 76, 104501(2013).
[2] A. H. Castro et al. Rev. Mod. Phys. 81, 109, (2009)
[3] R. Ribeiro-Palau et al. Nat Nano,10, 965 (2015)

Figures

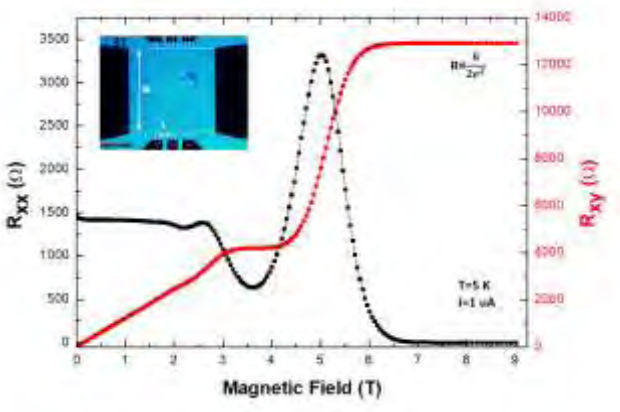

Figure 1: Quantum Hall effect in graphene at 5 K, 1 μA. Insert: Optical image of graphene Hall bar.

One qubit as a Universal Approximant

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Abstract

A single-qubit approximant is a quantum circuit with only one qubit capable to mimic the behavior of any complex function, which is useful in the field of Quantum Machine Learning.
We implement the single-qubit universal approximant in a superconducting qubit circuit cooled to the base temperature of a dilution refrigerator (20mK). The qubit is a 3D transmon geometry located inside an aluminum three-dimensional cavity. Coherence times greatly exceed typical gate time, thus allowing to perform several layers of approximation. Final results show an overall agreement with the theoretical predictions and noise in the system seems to set a lower bound on the cost function.

References

[1] G. Cybenko, Approximation by superpositions of a sigmoidal function, Mathematics of Control, Signals, and Systems 2, 303 (1989).
[2] A. Pérez-Salinas, J. Cruz-Martinez, A. A. Alhajri, and S. Carrazza, Determining the proton content with a quantum computer, Physical Review D 103 034027 (2021).
[3] M. Schuld, R. Sweke, and J. J. Meyer, Effect of data encoding on the expressive power of variational quantum-machine-learning models, Physical Review A 103 032430 (2021).

Figures

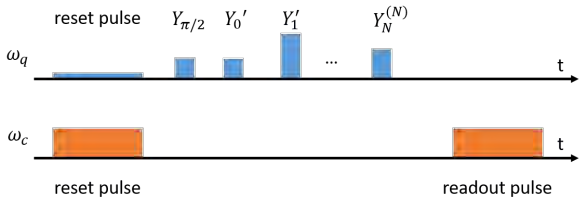

Figure 1: Pulse sequence of the N layers Universal Approximant algorithm. Upper (blue) row corresponds to the qubit pulses and lower (orange) one to the cavity pulses. Prior to the control pulse an active reset is performed to the system. Afterwards, a sequence of Y and Z gates is applied to the qubit. Z gates are virtual and correspond to axis variation in subsequent Y pulses. Finally, a readout tone measures the state of the qubit by probing the cavity.

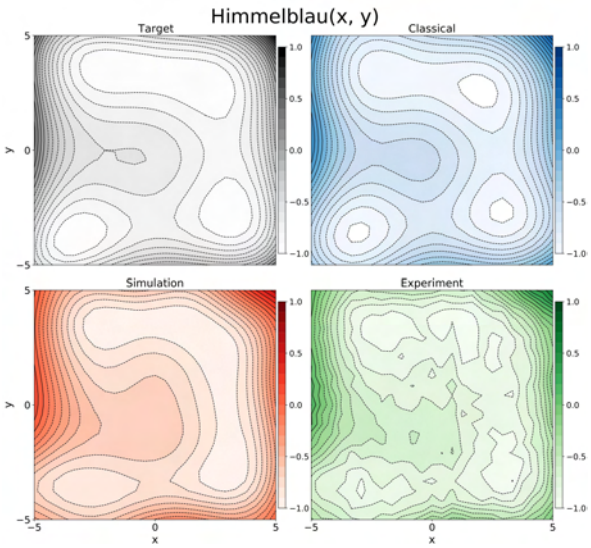

Figure 2: Top left picture shows the target Himmelblau two-dimensional function to be approximated. Classical optimization is seen in the top right corner. Optimization of the system by classically simulating a qubit is shown on the bottom left corner while the experimental realization with the parameters obtained in the classical simulation is located in the bottom right of the figure.

Yu-Shiba-Rusinov states in 2D superconductors with arbitrary Fermi contours

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Abstract

Magnetic impurities on a superconductor induce sub-gap Yu-Shiba-Rusinov (YSR) bound states, localized at the impurity site, and fading away from it for distances up to several nanometers [1,2]. In this article, we present a theoretical method to calculate the spatial distribution of the YSR spectrum of a two-dimensional superconductor with arbitrary Fermi contours (FCs) in the presence of magnetic impurities. Based on the Green's Function (GF) formalism, we obtain a general analytical expression by approximating an arbitrary contour shape to a regular polygon. This method allows us to show the connection between the spatial decay (and, hence, the extension) of YSR states and the shape of the FC of the host superconductor. We further apply this formalism to compute the evolution of YSR states in the presence of a nearby impurity atom [3] and compare the results with Scanning Tunneling Microscopy (STM) measurements on interacting manganese dimers on the β-Bi_2Pd superconductor. The method can be easily extended to any arbitrary number of magnetically coupled impurities, thus providing a useful tool for simulating the spectral properties of interacting YSR states in artificial atomic nanostructures.

References

[1] H. Kim, L. Rózsa, D. Schreyer, E. Simon, and R. Wiesendanger, Nat. Commun. (2020) 11, 1.

[2] G. C. M´enard, S. Guissart, C. Brun, S. Pons, V. S. Stol-yarov, F. Debontridder, M. V. Leclerc, E. Janod, L. Cario,D. Roditchev, P. Simon, and T. Cren, Nat. Phys. (2015) 11, 1013.

[3] D. J. Choi, C. G. Fernández, E. Herrera, C. Rubio-Verdú, M. M. Ugeda, I. Guillamón, H. Suderow, J. I. Pascual, andN. Lorente, Phys. Rev. Lett. (2018) 120, 1.

Figures

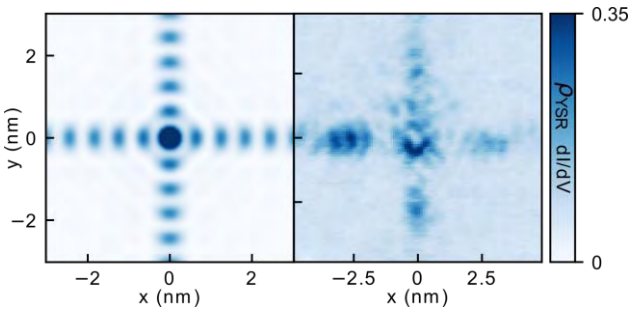

Figure 1: Calculation of the extension of the YSR states for a square-shaped FC (left panel) and dI/dV map of the extension of the YSR of an V adatom on the β-Bi_2Pd surface (right panel).

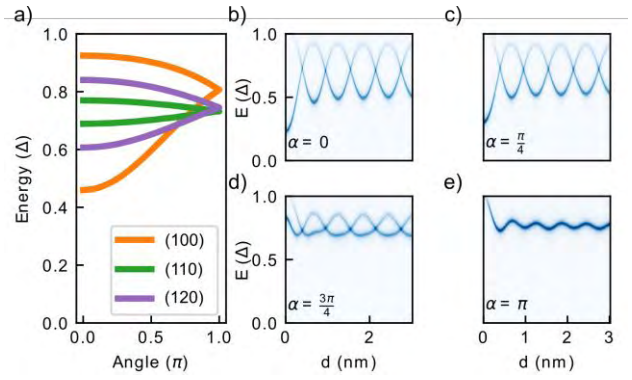

Figure 2: Multiple calculations of the splitting of the YSR states for adatom dimers. (a) Angular dependence of YSR states splitting for the (100), (110) and (120) directions. (b-e) Dependence of the splitting on the relative distance between adatoms for the (100) direction and several relative angles.

Towards Measurements of the Optical Coherence of the SnV in Diamond

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Recently the tin-vacancy (SnV) centre in diamond was demonstrated as a competitive spin-qubit with a spin-coherence time of 0.33ms and MHz Rabi rates [1]. This is particularly promising as these demonstrations were achieved in nanostructured diamonds, without any surface passivation engineering, in standard closed-cycle He cryostats; overcoming the charge instability and phonon-limited dephasing at these temperatures inherent to the other major defect centres in diamond: the nitrogen and silicon vacancies respectively.

However, despite this promise, in order to realise quantum-networking applications the intrinsic, optical, coherence of the SnV is yet to be shown through Hong-Ou-Mandel (HOM) spectroscopy. In this work, we report on the excited state coherence of the SnV and show that the $T_2 = 2T_1$ limit is easily reached given simple Hahn-Echo rephasing protocols. This result further highlights that the SnV is a promising candidate for quantum-networking applications as the maximum achievable HOM visibility is not intrinsically limited. Furthermore, we describe steps towards measuring the HOM visibility to confirm these findings. As such, these preliminary results highlight that the SnV is a realistic platform on which to build photonic cluster states, and similar photonics-based quantum resources, for high fidelity, error-tolerant, quantum communication.

References

[1] Debroux, R., Michaels, C.P., Purser, C.M., Wan, N., Trusheim, M.E., Martínez, J.A., Parker, R.A., Stramma, A.M., Chen, K.C., de Santis, L. and Alexeev, E.M., 2021. Quantum control of the tin-vacancy spin qubit in diamond. arXiv preprint arXiv:2106.00723.

Figures

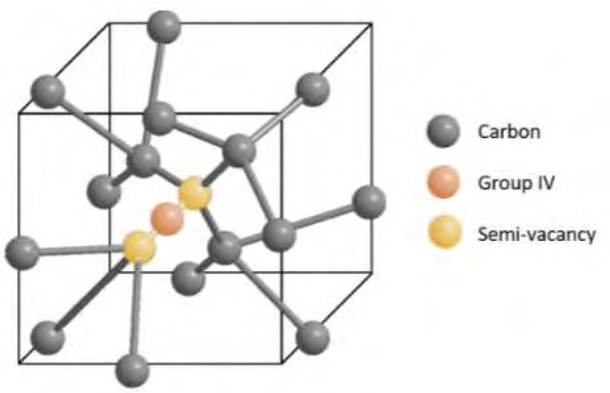

Figure 1: The inversion symmetric SnV centre in diamond

Predictive simulation of gate coupling strengths in a spin qubit device

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Abstract

Spin qubit device community explores various semiconductor heterostructures and gate designs to build a fault-tolerant quantum computer. Characterizing a semiconductor heterostructure experimentally is a demanding task, with the full development cycle taking at least months of work. While numerical simulations are more time-efficient, their predictive power is limited due to the unavoidable disorder and device variations [1]. In the current work, we develop a spin-qubit device simulation that predicts the coupling strengths between the electrostatic gate potentials and the effective device Hamiltonian. By comparing our simulation results with the experimental data from Ref. [2], we demonstrate that the gate couplings to the dot chemical potential and the interdot coupling are correctly predicted even in presence of disorder. To demonstrate the flexibility of our approach, we also analyse an alternative non-planar geometry inspired by FinFET devices.

References

[1] P. Barthelemy and L. M. K.Vandersypen, Annalen der Physik 525 (2013) 808.

[2] T.-K. Hsiao et al., Phys. Rev. Applied 13 (2020) 054018.

Figures

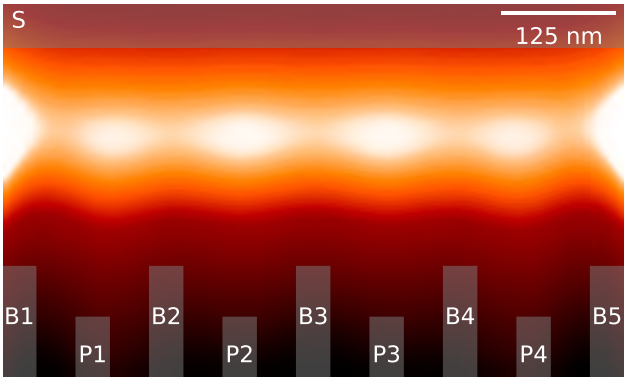

Figure 1: Confinement potential of four quantum dots in the plane of 2DEG. Plunger gates (P1, P2, P3, P4) are used to tune the chemical potential of each dot and barrier gates (B2, B3, B4) are used to tune the interdot tunnel couplings. Screening gate (S) forms a tunnel barrier between the qubit dots and sensor dots (not shown in the image). Gates B1 and B5 control the electron tunnelling rate between a corner dot and neighbouring electron reservoir.

EMPIR project COMET: Two dimensional lattices of covalent- and metal-organic frameworks for the Quantum Hall Resistance Standard

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The widespread adoption of graphene devices as Quantum Hall Resistance Standard (QHRS) in metrology, and industrial end-users, is currently limited by the inability to grow large areas of high-quality graphene with uniform, reproducible and stable electric properties (conductivity, doping and mobility). To alleviate these issues, the COMET project will assess and benchmark a new family of graphene-like analogues for realizing the QHRS: two-dimensional lattices of covalent- and metal-organic frameworks [1,2]. These novel Dirac materials can be defined in an atomically precise and scalable manner, holding promise for replacing graphene in metrology and other applications where the "uniqueness" of graphene properties are exploited. The COMET consortium is formed by six European National Metrology Institutes (NMIs) and four academic research institutions. The complementary expertise of the involved NMIs and the academic partners covers theoretical modelling, synthesis, characterization and device engineering.

References

[1] R. Dong et al., Nature Materials, 17 (2018) 1027
[2] Y. Jing and T. Heine, J. Am. Chem. Soc., 141 (2019) 743

Figures

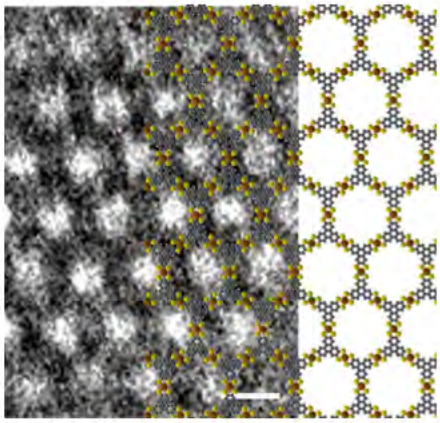

Figure 1: *HRTEM of a graphene-like honeycomb structure for an iron based 2D metal organic framework [1]*

Pseudospin resonances reveal synthetic spin-orbit interaction

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The interplay between interference and interaction produces several effects in degenerate quantum systems, including spin torques [1], dark states formation [2] and multilevel coherences [3]. In this context, a spin resonance without spin splitting has been first predicted for a single quantum dot spin valve [4]. We investigate a spinful double quantum dot coupled to leads in a pseudospin valve configuration. We predict in the stability diagram a rich variety of current resonances which are modulated by the system parameters [5]. In the presence of ferromagnetic leads and pseudospin anisotropy, those resonances split, turn into dips, and acquire a Fano shape, thus revealing a synthetic spin-orbit interaction induced on the double quantum dot. A set of rate equations derived for a minimal model captures those features. The model accurately matches the numerical results obtained for the full system in the framework of a generalized master equation and calculated within the next to leading order approximation.

References

[1] M. Braun et al., Phys. Rev. B 70 (2004), 195345
[2] A. Donarini et al., Nature Comm. 10 (2019), 381
[3] M. Maurer et al., Phys. Rev. Research 2 (2020), 033440
[4] M. Hell et al., Phys. Rev. B 91 (2015), 195404
[5] C. Rohrmeier et al., Phys. Rev. B 103 (2021), 205420

Figures

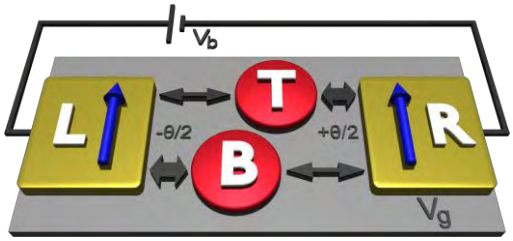

Figure 1: Schematic setup of a double quantum dot in a pseudospin valve configuration

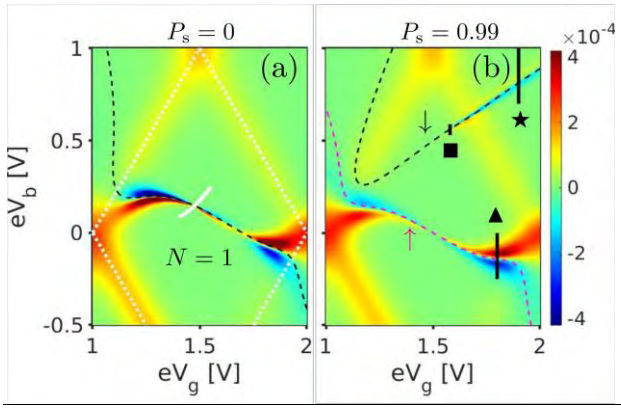

Figure 2: Differential conductance of a double quantum dot shows pseudospin resonances tuned by spin polarization P_s

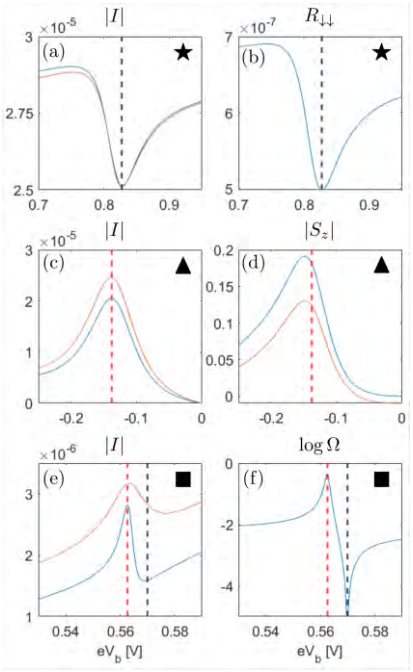

Figure 3: Bias traces from Fig. 2 b)

Magnetic Interaction Between Mn atoms on β-Bi_2Pd Revealed by their Yu-Shiba-Rusinov States

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Jon Ortuzar[1], Javier Zaldivar[1], Nacho Pascual[1], E. Herrera[2], I. Guillamón[2], H. Suderow[2]

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Abstract

In the last decade, the interest in studying the coupling between magnetic atoms arranged in linear chains on superconducting surfaces increased.[1,2,3] This is due to proposals suggesting emergence of Majorana bound states (MBS) in condensed matter systems, that have potential applications in topological quantum computing.[4] A powerful way to investigate the coupling is looking at how it modifies the Yu-Shiba-Rusinov (YSR) states inside the superconducting gap. These states are generated by the exchange coupling between a magnetic impurity and the Cooper pair condensate of the superconductor.[5] The coupling mechanism can be investigated by monitoring the sub gap YSR fingerprint during the construction of atomically precise structures.[6,7] By means of a low temperature scanning tunneling microscope (STM) working at 1.3K, we perform atomic manipulation of Mn atoms on β-Bi_2Pd superconductor (T_c=5.4K, Δ=0.78mV). A major advantage is achieved doing atomic manipulation directly with superconductive tips, studying the coupling with high energy resolution in Mn dimers, trimers, cross like structures, chains, and other more complex structures. Depending on the distance and crystallographic directions different coupling effects occurs, with signatures of ferromagnetic and antiferromagnetic coupling. In linear chains, there is evidence of collective behavior that lowers the overall energy of the YSR states, effect that saturates for lengths that exceed 6-7 atoms.

References

[1] Nadj-Perge, S., Drozdov, I. K., Bernevig, B. A. & Yazdani, A., Phys. Rev. B 88, (2013), 020407
[2] Nadj-Perge, S. et al. Science 346, (2014), 602–607
[3] Kim, H. et al. Sci. Adv. 4, (2018), 5251
[4] Alicea, J., Oreg, Y., Refael, G., von Oppen, F. & Fisher, M. P. A. Nat. Phys. 7, (2011), 412–417
[5] Heinrich, B. W., Pascual, J. I. & Franke, K. J. Prog. Surf. Sci. 93, (2018), 1–19
[6] Lucas Schneider, Philip Beck et. al.,Nature Physics, 17, (2021), 943–948
[7] Eva Liebhaber et al. Arxiv, (2021) https://arxiv.org/abs/2107.06361

Figures

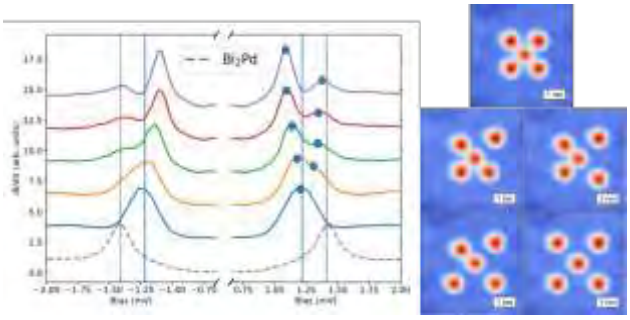

Figure 1: Intra-gap density of states of Mn nanostructures built on β-Bi_2Pd by atomic manipulation. The spectra are measured on the central atom and an increasing splitting is observed upon adatom addition.

IKUR STRATEGY AT A GLANCE

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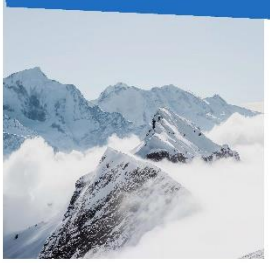
1 What it is



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

... with opportunities for industrial, business and institutional development

2 Its objectives

- Development of Advanced Capabilities
- "Tractor effect" of Research in the Basque Country
- Reference in Europe
- Economic and Social Impact

3 Flagship Areas

- Neurobiosciences
- Quantum Technologies (QT)
- NeutriOnics

High Performance Computing & Artificial Intelligence (HPC-AI)

4 Expected impact

- **Research personnel**: +400
- **Publications**: +4.000
- **EPO Patents**: +30
- **Spin offs**: +20
- **Turnover**: +350 M€
- **Employment**: +3.200

5 Governance

- ikerbasque Basque Foundation for Science — Recruitment and attraction of research personnel
- Management of IKUR funds
- EUSKO JAURLARITZA GOBIERNO VASCO — HEZKUNTZA SAILA / DEPARTAMENTO DE EDUCACIÓN
- Fundación Biofísica Bizkaia / Biofisika Bizkaia Fundazioa — Neurobiosciences
- DIPC — QT + HPC-AI
- MPC Materials Physics Center — NeutrIOnics
- euskampus FUNDAZIOA — Monitoring and evaluation the impact of the IKUR Strategy

Scientific Direction of IKUR's Flagship Areas