PRESENTATIONS

Silicon Quantum Information Processing 2017

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Organised by the BRSG: Magnetic Resonance, Nanoscale Physics and Technology, Quantum Electronics and Photonics, Quantum Optics, Quantum Information and Quantum Control, Semiconductor Physics and Superconductivity groups

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Programme

09:30 - 10:30	Registration and refreshments
10:20 - 10:30	Welcome by conference chair

Session 1: Solid state quantum computing architectures

10:30 - 11:00	**(Invited) A crossbar network for silicon spin qubits** Menno Veldhorst, QuTech, Delft University of Technology, Netherlands
11:00 - 11:20	**Solid state quantum simulators** Abolfazl Bayat, University College London, UK
11:20 - 11:40	**Comparison of gate fidelities between different qubit architectures defined in silicon quantum dots** Marco De Michielis, CNR-IMM-Agrate Unit, Italy
11:40 - 12:00	Refreshments

Session 2: Classical control electronics for solid state quantum computing

12:00 - 12:30	**(Invited) Cryo-CMOS Electronics for Scalable Quantum Computing** Fabio Sebastiano, Delft University of Technology, Delft, Netherlands
12:30 - 12:50	**Conditional dispersive readout of a CMOS quantum dot via an integrated transistor circuit** Simon Schaal, University College London, UK
12:50 - 13:10	**Controlling electron and phonon energy fluxes in suspended semiconductor-superconductor junctions** Mika Prunnila, VTT Technical Research Centre of Finland Ltd, Finland
13:10 - 14:30	Lunch, exhibition and posters

Session 3: Quantum computing with dopants in silicon

14:30 - 14:50	**Non-destructive imaging of atomically-thin nanostructures buried in silicon** Neil Curson, University College London, UK
14:50 - 15:10	**Erbium implanted silicon for solid-state quantum technologies** Mark Hughes, University of Salford, UK
15:10 - 15:30	**Coherent superpositions of multiple eigenstates for Si:P prepared using THz radiation** Steven Chick, University of Surrey, UK
15:30 - 15:50	**An extended Hubbard model for mesoscopic transport in donor arrays in silicon** Nguyen Le, University of Surrey, UK
15:50 - 16:20	Refreshment break

Session 4: Qubit implementation and control

16:20 - 16:50 **(Invited) Electrically driven electron spin resonance mediated by spin-orbit coupling in a silicon quantum dot**
Yann-Michel Niquet, University Grenoble Alpes & CEA INAC-SPSMS, France

16:50 - 17:10 **A silicon-based single-electron interferometer coupled to a fermionic sea**
Anasua Chatterjee, University College London, UK

17:10 - 17:30 **Long decoherence time in Silicon Isolated Double Quantum Dot charge qubits at 4.2 K**
Aleksey Andreev, Hitachi Cambridge Laboratory, UK

17:30 - 17:40 Closing remarks

18:30 - 21:00 Conference dinner (Optional)

Poster programme

P:01 Continuous-time quantum computing
Vivien Kendon, University of Durham, UK

P:02 Many-body effects in 1D degenerately-doped silicon nanowire device
Muhammad M. Mirza, University of Glasgow, UK

P:03 Electron transport in top-down fabricated silicon nanowires using relaxed and scalable nanofabrication
Nivedha Radhakrishnan, University of Glasgow, UK

P:04 Quantum interference effects in degenerately doped silicon nanowire junction-less transistors
Felix J. Schupp, University of Oxford, UK

P:05 Modelling of the electronic states of silicon quantum dots through DFT & TD-DFT methods
Nicolas Iacobellis, Université Libre de Bruxelles, Belgium

P:06 A quantum interference capacitor
Anasua Chatterjee, Hitachi Cambridge Laboratory, UK

P:07 High-Q lumped-element resonators for gate-based dispersive readout
Imtiaz Ahmed, Hitachi Cambridge Laboratory, UK

P:08 Double-dot exchange-only qubit dynamics in presence of environmental noise
Elena Ferraro, CNR-IMM-Agrate Unit, Italy

Session 1: Solid state quantum computing architectures

(Invited) A crossbar network for silicon spin qubits

M Veldhorst

QuTech, Delft University of Technology, Netherlands

The spin states of single electrons in gate-defined quantum dots satisfy crucial requirements for a quantum computer. These include extremely long coherence times, high-fidelity quantum operation, and the ability to shuttle electrons as a mechanism for on-chip flying qubits. In order to increase the number of qubits to the thousands or millions of qubits needed for practical quantum information I will present an efficient architecture based on crossbar control, where only a limited set of control lines is needed. The qubit grid is designed to enable flexible qubit arrangement, while it crucially provides a mechanism for creating long-range entanglement, thereby opening a path towards non-planar quantum error correction protocols.

Solid state quantum simulators

A Bayat, J Gray and S Bose

University College London, UK

Quantum simulators are certain quantum systems which emulate the behavior of another system with higher controllability and precision. They are the first step towards realization of universal quantum computers. So far, cold atoms and ions have been predominantly exploited for serving as quantum simulators thanks to their high controllability and long coherence times. Nevertheless, any solid state effects cannot be easily simulated by such systems, take spin-orbit interaction as an example. Therefore, having a solid state based quantum simulator is very desirable. We propose quantum dot arrays for serving as quantum simulators. In particular, we focus on realization of the ground state of the Heisenberg spin chain in realistic experimental conditions. Furthermore, we provide an effective method for the certification of our quantum simulator via singlet-triplet measurements. Finally, we demonstrate the conformal field theory physics using our solid state quantum simulator.

Comparison of gate fidelities between different qubit architectures defined in silicon quantum dots

M De Michielis, E Ferraro and M Fanciulli

CNR-IMM-Agrate Unit, Italy

Manipulation of qubit states with high fidelity is mandatory for the exploitation of error correction codes to build logic qubits and finally to scale up the system towards a quantum processor. As a result, ranking different qubit architectures by gate fidelity when sources of manipulation errors and environmental noises arise is of great interest.

In this study, we present a comparison between fidelity of single qubit operations, in particular rotations along two independent axis in the Bloch sphere, operating on qubit architectures defined on spin states of electrons confined in silicon quantum dots (QD). We compared three different qubit architectures, namely qubit based on a single electron confined in a QD, singlet and triplet qubit held in a double QD and the hybrid qubit defined on quantum states of three electronic spins located in a double QD [1]. The inclusion of three important sources of operation error, i.e. hyperfine coupling with the nuclear spins of the silicon lattice, charge noise and time deviation of edges of qubit control signals, degrades gate fidelities in different ways. When real world values of model parameters are set, the obtained results allow us to foresee which qubit architecture is the most promising one.

[1] Z. Shi et al., Phys. Rev. Lett. 108, 140503 (2012).

Session 2: Classical control electronics for solid state quantum computing

(Invited) Cryo-CMOS Electronics for Scalable Quantum Computing

F Sebastiano

Delft University of Technology, Netherlands

A quantum computer comprises both a quantum processor cooled at cryogenic temperature and a classical electronic controller to operate and read out the quantum devices. Such controller is currently implemented at room temperature for the few qubits available today. However, due to the wiring requirements between the cryogenic quantum devices and room-temperature electronics, this approach becomes unfeasible as the number of qubits grows towards the tens of thousands required for quantum algorithms with practical applications. As an alternative, we propose a cryogenic electronic controller fabricated using CMOS technology, which is the only technology allowing the integration of the billions of transistors required to operate a very large number of qubits. This talk will address the challenges of building such CMOS controller, such as the modeling of cryo-CMOS devices for circuit simulation and design, and the co-simulation of the classical/quantum interface. By demonstrating the functionality of critical circuit components, including low-noise amplifiers for qubit read-out and signal generators for qubit control, we will conclude whether standard CMOS is a viable technology for the implementation of scalable electronic interfaces for quantum processors.

Conditional dispersive readout of a CMOS quantum dot via an integrated transistor circuit

S Schaal, S Barraud, J J L Morton and M Fernando Gonzalez-Zalba

University College London, UK

Quantum computers require interfaces with classical electronics for efficient qubit control, measurement and fast data processing. Fabricating the qubit and the classical control layer using the same technology is appealing because it will facilitate the integration process, improving feedback speeds and offer potential solutions to wiring and layout challenges. Integrating classical and quantum devices monolithically, using complementary metal-oxide-transistor (CMOS) processes, enables the processor to profit from the most mature industrial technology for the fabrication of large scale circuits. In this talk I will present the integration of a single-electron charge storage CMOS quantum dot with a CMOS transistor for control of the readout via gate-based dispersive sensing using a lumped element LC resonator. The control field-effect transistor (FET) and quantum dot are fabricated on the same chip using fully-depleted silicon-on-insulator technology. A charge sensitivity of $\delta q=165\ \mu e/\sqrt{Hz}$ is obtained when the quantum dot readout is enabled by the control FET. Additionally, a single-electron retention time of the order of a second is observed when storing a single-electron charge on the quantum dot at milli-Kelvin temperatures. These results demonstrate first steps towards time-based multiplexing of gate-based dispersive qubit readout in CMOS technology and the development of an all-silicon quantum-classical processor.

Controlling electron and phonon energy fluxes in suspended semiconductor-superconductor junctions

M Prunnila, J Lehtinen, E Mykkänen, A Shchepetov, L Grönberg, D Gunnarsson, A Kemppinen and A Manninen

VTT Technical Research Centre of Finland Ltd, Finland

New tools for the engineering of electron, photon and phonon fluxes are crucial for quantum technology devices. Mastering the different energy/particle channels at the nanoscale enables control of coherence properties and realization of high sensitivity detectors and compact refrigerators. In this communication, we propose that electron and phonon flux filtering can be done virtually at single point in space by suspended semiconductor-superconductor (Sm-S) junctions and demonstrate the viability of the idea by cooling a macroscopic piece of silicon at sub-Kelvin temperatures by ~ 0.1 K by using a set of such junctions. The operation of this new electro-thermal device is based on the acoustic mismatch between the two dissimilar materials present in the suspended Sm-S (Si-Al) junction, which filters the phonons, and the non-linear Peltier effect arising from the superconductive energy gap. This operation principle is in strong contrast to the conventional superconductive electro-thermal nano-devices that operate against the electron-phonon coupling. We will discuss how the operation of our devices can be expanded to higher temperatures to enable, e.g., cooling from above 1 K to sub-1 K temperatures and how the presented idea can be utilized in quantum sensing. Possible room temperature realizations of nano-scale energy filtering devices will be also outlined.

Session 3: Quantum computing with dopants in silicon

Non-destructive imaging of atomically-thin nanostructures buried in silicon

N Curson, G Gramse, A Kölker, T Lim, T Stock, E Brinciotti, H Solanki, T Schofield, G Aeppli and F Kienberger

University College London, UK

Atomic and nano-scale structures made from dopants buried in silicon are of great interest for next generation electronics and quantum information processing applications. While great strides have been made in their fabrication and electrical characterisation, the microscopy of such nanostructures has been largely neglected. In particular, the ability to extract three-dimensional spatial information about buried nanostructures will be a crucial asset in the development of processes for the fabrication of surface code quantum computers [1]. Here we describe the use of scanning microwave microscopy (SMM) to characterise three-dimensional (3D) phosphorus nanostructures fabricated via scanning tunnelling microscope-based lithography [2]. The SMM measurements, which are completely non-destructive and sensitive to as few as 1900 to 4200 densely packed P atoms 4 to 15 nm below a silicon surface, yield electrical and geometric properties in agreement with those obtained from electrical transport and secondary ion mass spectroscopy (SIMS) for un-patterned phosphorus δ-layers containing $\sim 10^{13}$ P atoms. The imaging resolution was 37±1 nm in the lateral and 4±1 nm in the vertical direction, both values depending on SMM tip size and depth of dopant layers. Our results open up exciting opportunities for dopant nanostructure fabrication by providing a measurement capability not possible with any other technique.

[1] C. D. Hill, E. Peretz, S. J. Hile, M. G. House, M. Fuechsle, S. Rogge, M. Y. Simmons, C. L. Hollenberg, A surface code quantum computer in silicon. Sci. Adv. 1, e1500707 (2015).

[2] G. Gramse, A. Kölker, T. Lim, T. J. Z. Stock, H. Solanki, S. R. Schofield, E. Brinciotti, G. Aeppli, F. Kienberger, N. J. Curson, Nondestructive imaging of atomically thin nanostructures buried in silicon. Sci. Adv. 3, e1602586 (2017).

Erbium implanted silicon for solid-state quantum technologies

M Hughes, N Panjwani, M Urdampilleta, I Wisby, J D Carey, K Homewood, T Lindström and J Morton

University of Salford, UK

There are currently no quantum technology (QT) platforms with telecommunications and integrated circuit (IC) processing compatibility, and long coherence times. Rare-earth ions are a promising QT platform components: they possess a partially filled 4f shell which is shielded from the environment by the outer 5s and 5p shells. Er transitions can be optically addressed at telecoms wavelengths which allow transfer of quantum information over distance. Er and O co-implanted Si (Er:Si) is compatible with both telecoms and IC processing and has previously been observed to produce sharp electron paramagnetic resonance (EPR) lines and 1.5 μm photoluminescence lines. We used a tuneable 1.5 μm laser to modulate the Er-related narrow EPR lines to show that they must originate from Er.

We also present coherence and superconducting resonator coupling measurements for Er:Si. The electron spin coherence time of Er implanted Si has been measured to be as long as 20 μs at 5 K and the spin echo decay profile displays strong modulation due to the super-hyperfine interaction with ^{29}Si nuclei; analysis indicates Er can couple to the closest ~60 lattice sites. This interaction could be utilised for gate operations in potential two qubit controlled NOT (c-NOT) gate schemes. The collective coupling strength between a superconducting resonator and Er implanted Si was ~ 1MHz. Our study demonstrates the potential of Er:Si for both hybrid and non-hybrid quantum computation and communication schemes.

Coherent superpositions of multiple eigenstates for Si:P prepared using THz radiation

S Chick, B Murdin, N Stavrias, K Saeedi, B Redlich, T Greenland, G Matmon, M Naftaly, C Pidgeon and G Aeppli

University of Surrey, UK

Orbital eigenstates of shallow donors in silicon promise the ability to control entanglement between relatively remote donors by application of coherent terahertz laser light. The coherent excitation and control of the eigenstates is therefore crucial, but so far only simple 2-eigenstate control has been demonstrated. More complicated control over the spatial distribution of the wavepacket may be achieved by involving multiple eigenstates. We present a study of pulsed laser excitation of three orbital eigenstates of Si:P, observing a beating behaviour typical of three-state superpositions and which is tuneable by Zeeman splitting under a small magnetic field. We discuss how the observation, consistent with appropriate theory, implies that we may control the spatial extent of the electron wavefunction and thus control a qubit’s interaction with its neighbours. It is proposed that this technique could be used to implement a surface code network, which requires spatially controlled interaction between atoms.

An extended Hubbard model for mesoscopic transport in donor arrays in silicon

N Le, A Fisher, and E Ginossar

University of Surrey, UK

Arrays of dopants in silicon are promising platforms for the quantum simulation of the Fermi-Hubbard model. We show that the simplest model with only on-site interaction is insufficient to describe the physics of an array of phosphorous donors in silicon due to the strong inter-site interaction in the system. We also study the resonant tunneling transport in the array at low temperature as a mean of probing the features of the Hubbard physics, such as the Hubbard bands and the Mott gap. Two mechanisms of localization which suppresses transport in the array are investigated: The first arises from the electron-ion core attraction and is significant at low filling; the second is due to the sharp oscillation in the tunnel coupling caused by the inter-valley interference of the donor electron's wavefunction. This disorder in the tunnel coupling leads to a steep exponential decay of conductance with channel length in one-dimensional arrays, but its effect is less prominent in two-dimensional ones. Hence, it is possible to observe resonant tunneling transport in a relatively large array in two dimensions. Finally, we discuss a proposal of using transport measurement to probe topological edge states in a one dimensional superlattice of Si:P.

Session 4: Qubit implementation and control

(Invited) Electrically driven electron spin resonance mediated by spin-orbit coupling in a silicon quantum dot

Y M Niquet[2,3], A Corna[1,2], L Bourdet[2,3], R Maurand[1,2], A Crippa[1,2], D Koketar-Patil[1,2], H Bohuslavskyi[1,2,4], R Laviéville[2,4], L Hutin[2,4], S Barraud[2,4], X Jehl[1,2], M Vinet[2,4], S De Franceschi[1,2] and M Sanquer[1,2]

[1]CEA, INAC-PHELIQS, France, [2]University Grenoble Alpes, France, [3]CEA, INAC-MEM, France, [4]CEA, LETI-MINATEC, France

Electron spins in silicon quantum dots represent a leading approach for the development of solid-state quantum computing. However, spin manipulation by magnetic spin resonance is a serious bottleneck in view of a large scale integration. On the other hand, the electrical manipulation of the spin of electrons is notoriously difficult in silicon due to the weak spin-orbit coupling in the conduction band. Here we demonstrate electric dipole spin resonance (EDSR) in the conduction band of a silicon-on-insulator (SOI) nanowire quantum dots device. We show that the experimental EDSR spectrum is consistent with an electrically driven spin resonance resulting from the interplay between valley and spin-orbit coupling. We support our theory with tight-binding simulations. In particular we reveal that spin-orbit coupling in the conduction band is enhanced in the “corner” dots typical of SOI nanowire devices. Our findings open new perspectives for the development of compact and scalable electron spin qubits in silicon.

A silicon-based single-electron interferometer coupled to a fermionic sea

A Chatterjee, S Shevchenko, S Barraud, R Otxoa, F Nori, J Morton and F Gonzalez-Zalba

University College London, UK

We study Landau-Zener-Stückelberg-Majorana (LZSM) interferometry [1,2] under the influence of projective readout, using a charge qubit tunnel-coupled to a fermionic sea. This allows us to characterise the coherent charge qubit dynamics in the strong-driving regime.

The device is realised within a silicon complementary metal-oxide-semiconductor (CMOS) transistor. We first read out the charge state of the system in a continuous non-demolition manner by measuring the dispersive response of a high-frequency electrical resonator coupled to the quantum system via the gate [3]. By performing multiple fast passages around the qubit avoided crossing, we observe a multi-passage LZSM interferometry pattern.

At larger driving amplitudes, a projective measurement to an even-parity charge state is realised, showing a strong enhancement of the dispersive readout signal. At even larger driving amplitudes, two projective measurements are realised within the coherent evolution resulting in the disappearance of the interference pattern. Our results demonstrate a way to increase the state readout signal of coherent quantum systems and replicate single-electron analogues of optical interferometry within a CMOS transistor.

[1] Oliver W. D. et al., Science, 310 1653 (2005)
[2] Shevchenko S.N., Phys. Rep. 492, 1-30 (2010)
[3] Gonzalez-Zalba M.F. et al., Nature Commun., 6, 6084 (2015)

Long decoherence time in Silicon Isolated Double Quantum Dot charge qubits at 4.2 K

A Andreev, T Yang, T Ferrus, K Hammura, K Watanabe and D A Williams

Hitachi Cambridge Laboratory, UK

Long decoherence times (T2) up to tens of microseconds were observed in a silicon-based charge quantum bit (qubit) device at 4.2 K. The coherence times demonstrated in this work are two orders of magnitude longer, and the operating temperature is two orders of magnitude higher than the reported semiconductor charge qubit systems. In contrast to other approaches, in this work the qubits are formed by trench isolated double quantum dots instead of surface gate-defined quantum dots. The devices were fabricated on industry-standard SOI wafers. The silicon layers were doped with phosphorus. The device patterns were defined by means of both photo- and electron-beam lithographies. Reactive-ion etching was then applied to form the trenches. The thermal oxidation was then performed to form thin SiO2 cap layers. The one or two qubit devices consist of single electron transistor (for qubit state readout), isolated double quantum dot as charge qubit and electrostatic gates for qubit state manipulation. The obtained results have been analysed using the developed comprehensive model that takes the 3D details of the device as an input and then uses self-consistent solution of the Poisson and Shrodinger equations with many-body effects for qubit quantum states and master equations for qubit detection and time-dependent qubit state evolution taking account of possible decoherence and quantum leakage mechanisms. We demonstrate that the qubit quality factor can be significantly increased by choosing the optimum working points and pulse amplitudes and also by changing the design of the device.

Posters

P01 Continuous-time quantum computing

V Kendon, J Morley, A Callison, P Scruby, C Arthurs and N Chancellor

University of Durham, UK

Solid state systems have natural Hamiltonians that are used to engineer quantum gates, but can also be used more directly for computation, as is done for special purpose quantum simulators. Continuous time quantum walks (QW), closed system adiabatic quantum computing (AQC), and open system dominated quantum annealing (QA), are usually thought of as three distinct models of quantum computation. However, all three can be implemented with the same driving and problem Hamiltonians. Rather than thinking of these as three distinct models of quantum computation, one should consider these as three distinct mechanisms which can potentially solve problems cooperatively. As proof-of-principle examples, we show that an optimal quantum speed up can be obtained for unstructured search using protocols which superimpose arbitrary amounts of the mechanisms behind AQC and QW, by modulating the shape of the annealing schedule. These protocols can even obtain the same speed up if run `backwards', starting from the problem Hamiltonian and turning on the driving Hamiltonian (in analogy with STIRAP quantum optical control). We also show how the mechanism behind QW can be used to find low energy states of spin glasses, a problem which has previously been examined in the context of AQC, and discuss how these make use of a mechanism based on energy conservation. This mechanism may play a significant role in real protocols, where the optimal annealing schedule is not known, and the protocols may be run far too fast to be adiabatic.

P02 Many-body effects in 1D degenerately-doped silicon nanowire device

M M Mirza, F J Schupp, J A Mol, D A MacLaren, A D Briggs and D J Paul

University of Glasgow, UK

Nanowire transistors are being investigated to solve short-channel effects in future CMOS technology nodes [1, 2] but such devices are also a potential scalable platform for quantum information processing devices. Here we demonstrate degenerately-doped silicon nanowires with 8.0 ± 0.5 nm diameter using a wrap-around gate junction-less transistor based on silicon-on-insulator (SOI) structure [1], fabricated using top-down approach involves electron-beam lithography [2], low damage dry etch [3] and thermal oxidation. As the nanowire diameter is scaled below the Fermi wavelength, the channel switches from metallic to insulating behaviour demonstrating 1D electron transport characteristics with excellent electrostatic control of the channel. In this regime, near ideal sub-threshold (SS) slopes of 66 mV/dec at room temperature, I_{on}/I_{off} ratios above 10^8 and I_{on} up to 35 μA/nanowire (4.4 mA/μm gate width) at V_D=V_g=1.5 V are observed. Universal conductance scaling as a function of voltage and temperature comparable to previous reports of Luttinger liquid transport and Coulomb gap behaviour at low temperatures indicate that many body effects including electron-electron interactions are significant in describing the electron transport. Our results indicates many body effects such as electron-electron interactions are essential in determining the electron transport in such ultra-scaled nanowires. Routes to multiple gate devices for coupled quantum dots will be described.

[1] M.M. Mirza, et al., *Scientific Reports*, 7, 3004 (2017).
[2] C. Busche, et. al., *Nature* 515, 545 (2014).
[3] M.M. Mirza, et al., *JVST-B*, 30, 06FF02 (2012).

P:03 Electron transport in top-down fabricated silicon nanowires using relaxed and scalable nanofabrication

N Radhakrishnan

University of Glasgow, UK

Silicon nanowire have shown promising potential in wide range of next generation CMOS electronics [1], opto-electronics, sensing applications [1] and quantum information processing. The strong confinement required to make quantum processes robust to temperature fluctuations and other scattering processes across large numbers of devices as required for many quantum computing proposals in silicon normally requires the aggressive scaling of devices to sub-10 nm dimensions which requires high quality lithography and well controlled etch processes [2-4]. Here we demonstrate a new approach to achieving high performance silicon nanowires using more relaxed lithography of 20 to 50 nm combined with multiple oxidation and etches to reduce the diameter of the silicon nanowires to less than half the written lithography linewidths. Temperature dependent electron transport measurements are used to determine the electronic scattering processes which limit the transport and a comparison is made to more conventional 8.0 ± 0.5 nm nanowires fabricated without the multiple oxidations and etches. Limitations of the technique along with the potential for scaling the technique for the mass fabrication of millions of devices will be discussed.

[1] C. Busche, et. al., *Nature* 515, 545 (2014).
[2] M.M. Mirza, et al., *Nano Letters* 14, 6056 (2014).
[3] M.M. Mirza, et al., *Scientific Reports*, 7, 3004 (2017).
[4] M.M. Mirza, et al., *JVST-B*, 30, 06FF02 (2012).

P:04 Quantum interference effects in degenerately doped silicon nanowire junction-less transistors

F J Schupp

University of Oxford, UK

We demonstrate quasi-ballistic transport in degenerately-doped silicon nanowire junction-less transistors with 8 ± 0.5 nm channel diameters. Previously we established that a combination of low damage dry etch processes [1] and a high quality surface passivation [2][3] are key to produce high performance devices, where neutral impurity scattering is the dominant scattering mechanism [2]. 1D electron behaviour can be observed even at room temperature [4]. Here we present dc measurements at 13 mK from nanowire transistors doped at 2×10^{20} cm^{-3} which demonstrate Coulomb blockade with over 500 Coulomb peaks in a single island along the entire nanowire. For Si nanowires doped at a lower 4×10^{19} cm^{-3}, quantum interference effects including universal conduction fluctuations dominate the transport up to 30 K and allow a phase coherence length of 63 ± 7 nm to be extracted. Further analysis of the fluctuations at mK temperatures allows a mean free path of 10 ± 2 nm to be extracted, significantly higher than the dopant spacing of 2.9 nm. The scattering lengths indicate 1D quasi-ballistic transport in the nanowires with either Coulombic or neutral impurity scattering rather than surface roughness scattering limiting the mobility. Coulomb gap behaviour also indicates strong many body interactions in the nanowires.

[1] M.M. Mirza, et al., *JVST-B*, 30, 06FF02 (2012).
[2] M.M. Mirza, et al., *Nano Letters* 14, 6056 (2014).
[3] C. Busche, et. al., *Nature* 515, 545 (2014).
[4] M.M. Mirza, et al., *Scientific Reports*, 7, 3004 (2017).

P:05 Modelling of the electronic states of silicon quantum dots through DFT & TD-DFT methods

N Iacobellis

Université Libre de Bruxelles, Belguim

The potential applications of quantum dots are numerous. One of them is of particular interest to the future of computer technology: the use of electronic states for quantum computing. In this case, the intervention of an external electromagnetic field is required. Our final goal is then to understand and manipulate the electronic dynamics of silicon QDs through the use of quantum control, i.e. the use of complex electromagnetic pulses to control phenomena at the pico- or even femtosecond time scale. This will for example allow us to populate a dark electronic state like we did for dark vibrational levels in acetylene in one of our previous works.

The first step involves getting knowledge of the structural variables of interest for our system: electronic levels, transition dipole moments, coupling matrix elements, etc. In order to do so, we use DFT and TD-DFT methods. This way, we were able to compute the electronic gap of different sizes and shapes of silicon quantum dots.

P:06. A quantum interference capacitor

A Chatterjee

Hitachi Cambridge Laboratory, UK

We study Landau-Zener-Stückelberg-Majorana (LZSM) interferometry [1,2] under the influence of projective readout, using a charge qubit tunnel-coupled to a fermionic sea. This allows us to characterise the coherent charge qubit dynamics in the strong-driving regime.

The device is realised within a silicon complementary metal-oxide-semiconductor (CMOS) transistor. We first read out the charge state of the system in a continuous non-demolition manner by measuring the dispersive response of a high-frequency electrical resonator coupled to the quantum system via the gate [3]. By performing multiple fast passages around the qubit avoided crossing, we observe a multi-passage LZSM interferometry pattern.

At larger driving amplitudes, a projective measurement to an even-parity charge state is realised, showing a strong enhancement of the dispersive readout signal. At even larger driving amplitudes, two projective measurements are realised within the coherent evolution resulting in the disappearance of the interference pattern.

Our results demonstrate a way to increase the state readout signal of coherent quantum systems and replicate single-electron analogues of optical interferometry within a CMOS transistor.

[1] Oliver W. D. et al., Science, 310 1653 (2005).
[2] Shevchenko S.N., Phys. Rep. 492, 1-30 (2010).
[3] Gonzalez-Zalba M.F. et al., Nature Commun., 6, 6084 (2015).

P07 High-Q lumped-element resonators for gate-based dispersive readout

I Ahmed

Hitachi Cambridge Laboratory, UK

Semiconductor-based quantum computing architectures require sensitive electrometers to readout the state of the qubits. Typically, this is achieved with high-precision using external electrometers. With the purpose of reducing the number of circuit elements and facilitate scalability, a compact alternative for quantum state readout has been proposed: In-situ gate-based dispersive readout. Gate-based sensing couples the qubit to a resonant circuit via a gate and probes the qubit's state via its radiofrequency polarizability. So far this technique has been successfully used to determine averaged spin dynamics in GaAs [1] and thermally averaged spin distributions in Si [2, 3]. However, single-shot dispersive readout of an electron spin state, which is a crucial requirement for error correction protocols, has not been performed yet.

To facilitate time-resolved gate-based reflectometry, large coupling of a high-Q resonator to the quantum system is desired. Here, we present results on gate-based sensing of silicon corner state quantum dots with large gate-couplings. For the purpose of enhancing the Q factor of the resonator, we study the origin of the losses in the circuit and propose an optimised resonator configuration. Additionally, we fabricate and characterise NbN lumped-element inductors. We show that resonators with these NbN inductors have high uncoupled Q-factors at liquid helium temperatures. Overall our results pave the way to high-Q lumped-element resonators for high-sensitivity gate-based readout.

[1] Petersson, K. D. et al. Charge and spin state readout of a double quantum dot coupled to a resonator. Nano Lett. 2010, 10, 2789–2793.
[2] Betz, A. C. Dispersively detected pauli spin-blockade in a silicon nanowire field-effect transistor. Nano Lett. 2015, 15, 4622−4627.
[3] Urdampilleta, M. et al. Charge dynamics and spin blockade in a hybrid double quantum dot in Silicon. Phys. Rev. X. 2015, 5, 031024.

P08 Double-dot exchange-only qubit dynamics in presence of environmental noise

E Ferraro

CNR-IMM-Agrate Unit, Italy

The effects of magnetic and charge noises on the dynamical evolution of the silicon double-dot exchange-only qubit [1] is theoretically investigated. This qubit system consisting of three electrons arranged in a silicon double quantum dot deserves special interest in quantum computation applications due to its advantages in terms of fabrication, control and manipulation in view of implementation of fast single and two qubit operations through only electrical tuning. The presence of the environmental noise due to nuclear spins and charge traps is taken into account including random magnetic field and random coupling terms in the Hamiltonian [2,3]. The behavior of the return probability as a function of time for initial condition of interest is presented. Moreover, through an envelope-fitting procedure on the return probabilities coherence times are extracted when model parameters take values achievable experimentally.

[1] Z. Shi et al., Phys. Rev. Lett. 108, 140503 (2012).
[2] S. Das Sarma, R.E. Throckmorton and Y L Wu, Physical Review B 94, 045435 (2016).
[3] R.E. Throckmorton, E. Barnes and S. Das Sarma, Physical Review B 95, 085405 (2017).

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