Report on the UCL/France Science & Technology Workshop: "Hybrid Spin-Superconducting Quantum Devices"

Summary:

A workshop on the topic of "hybrid quantum systems" - focusing on the coupling of spins in silicon with superconducting quantum electronic devices - was held at UCL on the 7th and 8th of April 2014. The workshop was used to discuss a number of technical sub-topics with the aim of conveying the state-of-the-art in:

- Superconducting qubit technologies,
- Techniques for achieving long spin coherence times in donor-doped silicon,
- Theoretical approaches/protocols for implementing high fidelity hybrid superconducting quantum memories, and
- Methods of coupling single donors in silicon with superconducting circuits.

The overall objective of the workshop was to strengthen ties between UCL and CEA Saclay – formalising collaborations that will see the mutual exchange of knowledge and techniques for creating hybrid superconducting-donor devices.

The workshop was attended by seven researchers from UCL and five from CEA Saclay, Prof Daniel Esteve and Dr Denis Vion from CEA were unfortunately not able to attend. This meeting was considered a great success in achieving the above objectives. It has led to joint projects and extended personnel visits between the institutions. A follow-up meeting is expected to take place in the first half of 2015.

Attendees:

Below is listed some basic background information on the attendees of the workshop.

UCL

Prof Sougato Bose
Position: Professor of Physics
Departmental Affiliation: Department of Physics and Astronomy, Faculty of Maths and Physical Sciences

Core Research Interests: Entanglement in spin chains, Quantum communication, Quantum Optics, Foundations of Quantum Mechanics.

Dr Dan Browne
Position: Lecturer
Departmental Affiliation: Department of Physics and Astronomy
Core Research Interests: Dr Dan Browne's research interests are in theoretical architectures for quantum computation and quantum technologies, and include linear optics and cavity QED methods, the measurement-based quantum computational model and implementations of fault-tolerant quantum computing.

Dr Cheuk Chi Lo
Position: Postdoctoral Fellow (1851 Fellow)
Departmental Affiliation: London Centre for Nanotechnology
Core Research Interests: Spin-dependent transport phenomena in semiconductor devices, nano-scale semiconductor device fabrication and device physics, spin-based quantum information processing, applications of electron paramagnetic resonance and electrically detected magnetic resonance to semiconductor devices.

Prof John Morton
Position: Royal Society University Research Fellow & Professor in Nanoelectronics / Nanophotonics
Departmental Affiliation: London Centre for Nanotechnology, Department of Electronic and Electrical Engineering
Core Research Interests: Coherent control of electron and nuclear spins in solid state materials and devices, with a focus on quantum technologies.

Dr Jarryd Pla
Position: Postdoctoral Fellow (Marie Curie Fellow)
Departmental Affiliation: London Centre for Nanotechnology
Core Research Interests: Spin-based quantum information processing, transport in nano-electronic devices, quantum computing with individual donor atoms in silicon, hybrid quantum systems.

Dr Edward Romans
Position: Lecturer
Departmental Affiliation: London Centre for Nanotechnology, Department of Electronic and Electrical Engineering
Core Research Interests: Pulsed laser deposition of high temperature superconductor thin films and new oxide materials for nanoscale devices, superconducting electronics, quantum interference and frustration in multi-junction arrays, nano-scale SQUIDs for single photon and spin detection.

Mr Gary Wolfowicz
Position: PhD Student

Departmental Affiliation: London Centre for Nanotechnology, Department of Electronic and Electrical Engineering
Core Research Interests: Quantum information processing with spins in silicon.

CEA Saclay

Dr Patrice Bertet
Position: Permanent Researcher, CEA
Departmental Affiliation: CEA Saclay /Service de physique de l'Etat Condensé /Quantronics
Core Research Interests: Hybrid quantum circuits and superconducting quantum memories.

Ms Audrey Bienfait
Position: PhD Student
Departmental Affiliation: CEA Saclay /Service de physique de l'Etat Condensé /Quantronics
Core Research Interests: Hybrid quantum circuits.

Ms Cecile Grezes
Position: PhD Student
Departmental Affiliation: CEA Saclay /Service de physique de l'Etat Condensé /Quantronics
Core Research Interests: Hybrid quantum circuits and superconducting quantum memories.

Dr Yuimaru Kubo
Position: JSPS Postdoctoral Fellow
Departmental Affiliation: Quantronics group, SPEC, CEA Saclay
Core Research Interests: Hybrid quantum systems, solid-state quantum devices/systems (e.g. superconducting qubits and spins in solids).

Dr Michael Stern
Position: Postdoctoral Researcher, CEA
Departmental Affiliation: CEA Saclay /Service de physique de l'Etat Condensé /Quantronics
Core Research Interests: Hybrid quantum circuits.

Other

A small number of attendees outside of the UCL/Saclay network were invited in order to enhance discussions on topics where additional expertise was required. These attendees included:

Oxford University (UK): Prof Andrew Briggs, Dr Jan Mol, Dr Natalia Ares

Imperial College London (UK): Dr Florian Mintert

Aarhus University (Denmark): Prof Klaus Mølmer, Dr Pinja Haikka

Programme:

The workshop was held over one-and-a-half days. The first day served as a forum for presenting new results and ideas in the groups' respective areas of expertise. The second half-day focused on discussions of future research directions and the identification of the biggest problems facing the field, in addition to potential solutions.

Monday

9:30	*Morning Coffee*		
10:00	Cécile Grezes	Microwave photon quantum memories	Hybrid ensembles
10:45	Florian Mintert	Control of spin-ensembles through driven cavities	
11:30	Jarryd Pla	Bi based superconducting quantum memory	
12:15	Klaus Mølmer	It is difficult to make predictions, especially about the past	
13:00	*Lunch*		
13:45	Audrey Bienfait	Progress towards single-spin to resonator coupling	Single spin coupling
14:30	Michael Stern	Potential for single-spin to flux qubit strong	
15:15	Ed Romans	Nano SQUIDs	
15:45	*Afternoon tea*		
16:00	Sougato Bose	Quantum simulators in circuit-QED	Wider topics
16:45	Natalia Ares	A Rabi electron pump	
17:15	Jan Mol	Acceptor spins in silicon	
17:45	*Pub*		
19:00	*Dinner*		

Tuesday

9:00	*Morning Coffee*	
9:30		Discussion on future directions for hybrid ensembles
10:30		Discussion on future directions for single spin coupling
11:30		Lab Tours
12:30	*Lunch*	

Workshop venue: Marconi Room, room 1103 Roberts Building (11th floor).

Potential for future collaboration:

Projects

Projects/ideas discussed at the workshop to be explored further include:

- Detection and manipulation of a single donor spin in isotopically enriched silicon using high quality factor superconducting resonators. This would allow the non-demolition readout of the electron spin in addition to serving as a potential method of entangling donors separated by large distances.
- Quantum storage of a single microwave photon using a donor spin ensemble in isotopically enriched silicon. The goal of this project is to take advantage of the long spin coherence times in isotopically pure ^{28}Si in order to create a long-lived single microwave photon quantum memory.
- Quantum computing in spin ensembles – multiple qubit storage (and coherent manipulation) within a macroscopic ensemble of donors.

Future workshops

The planning for a follow-up workshop is already underway. It will be held at Oxford University in early 2015. The meeting will include most of the personnel present at the UCL/Saclay "hybrid quantum systems" 2014 workshop.

Academic visits

Dr Jarryd Pla will visit CEA Saclay for one month in September 2014. He will use this time to carry out device fabrication and experimental characterisation, in collaboration with CEA research staff, for the projects outlined above.

Funding:

The funding provided to host this workshop was utilized for travel and subsistence of the French attendees in addition to meals and refreshments for all UCL/French participants during the workshop. Representative costs are outlined in the table below.

French visitor costs	**Cost**
Travel per person	£180
Accommodation for two nights @ £81/night	£162
Number of French participants	5
Total visitor cost	**£1,710**
Workshop costs	**Cost**
Coffee and pastry cost for four breaks/person	£189
Workshop lunch day 1	£221
Workshop lunch day 2	140

Workshop dinner	£891
Total workshop cost	**£1,441**

Grand total	**£3,151**

Acknowledgements:

The organisers would like to sincerely thank the French Embassy for graciously providing the financial means to host this workshop. It has generated many new ideas that will foster strong UCL/French collaborations in the years to come.