SYDNEY QUANTUM ACADEMY

SQA Undergraduate Research Scholarships

Projects (Round 2)

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Project 1: Characterisation of oxide quality for silicon quantum dot devices (Professor Andrew Dzurak)

University: UNSW Sydney
School or Department: Electrical Engineering and Telecommunications
Faculty: Engineering
Secondary or co-supervisor: Dr Wee Han Lim
Student suitability: 3rd year engineering or physics student
Project delivery: Completely face-to-face

Due to their similarity to conventional CMOS devices and their ability to leverage existing industrial technology and know-how, quantum dot devices in silicon hold immense potential for the realisation of full scale quantum computers. In these MOS quantum devices, the quantum dots are formed by accumulating carriers against the Si/SiO2 interface, and therefore the properties of this interface can influence the behaviour of the quantum dots. This project aims to further our understanding of the properties of the oxide interface, which is critical to the development of these MOS devices. The student will measure Hall effect devices in cryogenic test setups to determine properties of the interface, such as the mobility and carrier density in order to extract oxide parameters relevant to quantum device operation.

Project 2: Modelling and simulation of silicon qubit devices (Dr Chris Escott)

University: UNSW Sydney
School or Department: Electrical engineering & Telecommunications
Faculty: Engineering
Secondary or co-supervisor: Dr Andre Saraiva
Student suitability: 3rd year engineering or physics student
Project delivery: Completely remote

Adapting industrial CMOS technology to silicon-CMOS quantum dot qubit device fabrication is a promising road towards full-scale quantum computers. Devices currently used for successful demonstration of 1- and 2-qubit gates possess strong similarities to conventional CMOS devices, by making use of biasing gates to accumulate electrons at the Si/SiO2 interface. Understanding the influence of the electrode/gate geometry and the biasing configuration in many-electrode devices is paramount to further improvements in device design and control. This project will require the student to simulate the electrostatics of silicon quantum dot devices to capture the influence of biasing, design, cryogenic operation and real-world imperfections. The simulations will be performed with a mix of industry standard and bespoke tools to accurately describe the behaviour of the quantum dot devices.

Project 3: Topological transport in 1D quantum point contacts (Professor Alexander Hamilton)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Secondary or co-supervisor: Dr Karina Hudson
Student suitability: 2nd and 3rd year Physics or Eng students who have covered quantum physics
Project delivery: Completely face-to-face

Topological quantum states hold promise for a new generation of electronics and class of quantum computing. Semiconductor quantum wires are particularly interesting as their size and shape can be exactly controlled to result in topological quantum states. This project will involve learning about quantum point contact architecture, and hands-on low-temperature, low-noise electrical transport measurements to understand how to optimize semiconductor quantum wires to host topological quantum states.

Project 4: Semiconductor hole spin qubits (Professor Alexander Hamilton)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Secondary or co-supervisor: Dr Scott Liles
Student suitability: 2nd and 3rd year Physics or Eng students who have covered quantum physics
Project delivery: Completely face-to-face

Our understanding of the quantum mechanical properties of positively charged holes in nanoscale electronic devices is far from complete, despite the fact that your mobile phone contains billions of transistors that use holes. This is because although undergraduates are often taught that valence band holes are essentially just heavy electrons, with a positive charge and a positive effective mass, holes are spin-3/2 particles whereas electrons are spin-1/2. The spin-3/2 nature of holes means they make excellent spin quantum bits, and this project will involve hands on laboratory research to study how to read and manipulate hole spin qubits.

See http://www.phys.unsw.edu.au/QED for more details.

Project 5: How does stacking order affect electronic properties of trilayer graphene? (Professor Alexander Hamilton)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Secondary or co-supervisor: Dr Feixiang Xiang
Student suitability: 2nd and 3rd year Physics or Eng students who have covered quantum physics
Project delivery: Completely face-to-face

Experimental Atomically Thin Quantum Materials: Graphene, a single layer of carbon atoms with honeycomb lattice structure, shows many exotic physics and promising properties for device applications. Stacking different layers together provides a degree of freedom to change electronic properties of graphene, such as electronic band structures. In this summer project, the successful applicant will work with a team from the Centre of Excellence in Low Energy Electronics Technologies in the UNSW School of Phyiscs to explore the fabrication of different layer stacks and how this affects their electronic properties. The successful applicant will participate in fabrication of van der Waals heterostructure and measuring their electronic properties in an environment of ultracold temperatures and high magnetic fields.

Project 6: Hole spins in strained Germanium (Professor Alexander Hamilton)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Secondary or co-supervisor: Dr Matt Rendell
Student suitability: 2nd and 3rd year Physics or Eng students who have covered quantum physics
Project delivery: Completely face-to-face

Experimental Quantum Devices 1: Despite being used in the first transistor, Germanium was replaced by Silicon in most semiconductor devices. Recently, strained Germanium has had a resurgence in nanoscale electronics due to its interesting quantum properties including spin-orbit interactions and coupling to superconductors. These properties make strained Germanium useful for quantum computing using spin qubits, low energy topological electronics, and exotic superconducting states. In this project you will have hands-on lab experience, measuring the quantum properties of holes in strained Germanium electronic devices using cryogenic systems and low noise measurement techniques.

Project 7: Compact holographic optical trap design for short range force sensing with optically levitated nanoparticles (Dr. Eric Howard)

University: Macquarie University
School or Department: Department of Physics and Astronomy
Faculty: Faculty of Science and Engineering
Secondary or co-supervisor: Dr. Cyril Laplane
Student suitability: Suitable for undergraduate Physics or Engineering students, 2nd-3rd year preferable. A basic knowledge of optical systems, coding, diffraction theory or engineering skills is advantageous.
Project delivery: Completely face-to-face

The student will design and build a compact volumetric optical trap using a liquid crystal Spatial Light Modulator (SLM) for trapping and control of levitated nanospheres. Such a holographic optical tweezer will enable us to control the structure of the light field and the shape of the optical potential from a doughnut-shaped confinement to an optical lattice. Ultimately, the system will contribute towards a larger project on developing an ultraprecise force sensor for fundamental tests of the gravitational inverse square law at micron scales, gravimetry as well as gravitational waves and dark matter detection within the QMAPP group (www.qmappmq.org), as part of the new state-of-the-art generation of quantum sensors.

Project 8: Simulating chemical dynamics on trapped ions (A/Prof. Ivan Kassal)

University: The University of Sydney
School or Department: Chemistry
Faculty: Science
Student suitability: A student who has completed second-year quantum mechanics.
Project delivery: Completely remote

You will join a collaborative project involving chemists and physicists at the University of Sydney attempting to carry out the first simulation of a chemical reaction on a quantum computer. This project will focus on the theoretical aspects of using tailored quantum simulators for simulating challenging problems in chemistry and materials science. The objective is to develop protocols for efficient and accurate quantum simulation that uses existing, noisy quantum hardware.

Project 9: The computational power of Marvel Cinematic Universe (Dr Maria Kieferova)

University: University of Technology Sydney
School or Department: Computer Science

Faculty: FEIT
Secondary or co-supervisor: Prof. Michael Bremner
Student suitability: The applicant should have a background in computer science and a understanding of complexity and computability.
Project delivery: A mix of face-to-face and remote

The goal of this project is to evaluate the computer-theoretic implications of physical laws and powers from Marvel Cinematic Universe (MCU). The technological advances presented in MCU will be analyzed and compared to computational models such as Turing machines and quantum computers.

Project 10: Qubit mapping based on subgraph isomorphism (Professor Sanjiang Li)

University: University of Technology Sydney
School or Department: QSI
Faculty: FEIT
Student suitability: mathematics, computer science, programming skills (Python or C++)
Project delivery: A mix of face-to-face and remote

Quantum algorithms are often described as quantum circuits using single-qubit gates and special two-qubit gates (like CNOT or CZ). Before executing a quantum circuit C on a near-term quantum device D, one needs to transform the circuit by inserting SWAP or remote CNOT gates so that the connectivity constraints specified in the architecture structure of D are satisfied. This is known as the qubit mapping problem and this project aims to attack this problem by finding proper subgraph isomorphism. Existing related algorithms do not perform well on quantum devices with around 50 qubits (e.g., Google's Sycamore or IBM Q Rochester).

Project 11: Quantum Networks In Space (Professor Robert Malaney)

University: UNSW Sydney
School or Department: Electrical Engineering & Telecommunications
Faculty: Engineering
Student suitability: 3rd-4th Year Physics or Engineering Student
Project delivery: A mix of face-to-face and remote

With the emergence of next-generation quantum networks it is important to find optimal quantum routing schemes applicable to a wide range of circumstances. A particular focus of this project will be the routing of quantum signals through a large network of low-earth-orbit satellites. You will learn how to model and deploy quantum-routing techniques on a real quantum device, the IBM Q (the first cloud quantum computer platform available to the research community), and then use that experience to model the routing of quantum signals in space. You will work directly with an SQA PhD student already working in this area, in addition to a wider team of ten researchers led by Prof. R Malaney. This research is part of a wider project at UNSW sponsored by NASA and Northrop Grumman Corporation, and you should expect to obtain insights into how award-winning research at the forefront of space communications is carried out.

Project 12: Quantum-limited travelling wave parametric amplifier (Dr Jarryd Pla)

University: UNSW Sydney
School or Department: Electrical Engineering and Telecommunications
Faculty: Engineering
Student suitability: Second or third year Electrical Engineering or Physics students.
Project delivery: Completely remote OR A mix of face-to-face and remote

Quantum-limited parametric amplifiers are devices which can boost the strength of a signal whilst only adding the minimum amount of noise required by quantum mechanics. Typically, parametric amplifiers are made by placing a nonlinear element (which facilitate the parametric processes that lead to amplification) inside a cavity, or by creating long transmission lines with many instances of the nonlinearity (so called traveling wave amplifiers). Traveling wave geometries are attractive, since they offer amplification over wide frequency ranges, as opposed to cavity amplifiers which operate within a narrow resonant band. State-of-the-art traveling wave amplifiers in the microwave domain can use Josephson junctions as the nonlinear element, or the kinetic inductance intrinsic to thin superconducting films. Kinetic inductance traveling wave amplifiers have gained much attention recently, since they provide near-quantum-limited noise performance and exhibit dynamic ranges that are several orders of magnitude larger than their Josephson junction counterparts. This opens up many exciting possibilities, from multiplexed readout of large qubit arrays in quantum computers, to quantum-limited spin resonance spectroscopy. However, kinetic inductance amplifiers suffer from long physical lengths, ranging from tens of centimeters to several meters long, which poses significant fabrication and experimental challenges. This project aims to miniaturize kinetic inductance based traveling wave parametric amplifiers, reducing dimensions down to those only typically seen in Josephson junction devices. This will provide compact amplifiers and also allow them to operate at RF frequencies (i.e. < 1 GHz), which is of great interest to experiments in quantum computing and nuclear magnetic resonance.

The internship will mostly focus on designing and simulating the quantum-limited amplifier, with the possibility of some lab work. The student(s) will learn about the physics and engineering of traveling wave amplifiers and expose them to industry-leading microwave simulation software tools.

Project 13: Simulations of silicon qubits (A/Prof Rajib Rahman)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Student suitability: Second year physics/quantum mechanics/electrical engineering, python or Matlab experience
Project delivery: A mix of face-to-face and remote

We compute various aspects of silicon qubits hosted in donors or quantum dots. We have a suite of in-house tools and techniques to model qubits from a range of methods - atomistic first principles, effective mass, and effective spin based toy models. How qubits can be optimized in design to obtain large T1 and T2 times, as well as fast operation and high fidelity is the main goal of the simulations. We interact with experimental groups at UNSW closely to use these techniques to understand measurements.

More info: https://quantum.physics.unsw.edu.au/

Project 14: Simulation of hole qubits in Si and Ge (A/Prof Rajib Rahman)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Student suitability: Second year physics/quantum mechanics/electrical engineering, python or Matlab experience
Project delivery: A mix of face-to-face and remote

We want to perform simulations of hole based qubits in Si and Ge from our in-house tools and techniques, and understand the properties of these emerging qubits. We plan to calculate how hole qubits are affected by electric fields and magnetic fields, interactions with phonons, and other charge and magnetic noise in the environment. Finally, we also want investigate coupling two hole qubits.

Project 15: Simulations of III-V nanowires (A/Prof Rajib Rahman)

University: UNSW Sydney
School or Department: Physics
Faculty: Science
Student suitability: Second year physics/quantum mechanics/electrical engineering, python or Matlab

experience
Project delivery: A mix of face-to-face and remote

This project simulates the electronic structure of III-V nanowires from atomistic first principles methods in our in-house computational tools. We aim to understand spin-orbit interactions in these nanowires as a function of electric and magnetic fields. We also aim to calculate proximity effects of these semiconductors when a superconducting material is connected to these. Our goal is to obtain the decay of the superconducting gap in the semiconductor and how to distinguish topological states from other edge states arising from material disorder.

Project 16: Nonlinear Quantum Walks (A/Prof Alexander Solntsev)

University: University of Technology Sydney
School or Department: Mathematical and Physical Sciences
Faculty: Science
Student suitability: quantum mechanics, optics
Project delivery: Completely remote OR a mix of face-to-face and remote OR completely face-to-face

Quantum walks have emerged as a powerful paradigm with applications in quantum search. In 2021, the development of new experimental platforms in photonics enabled large scale quantum walks with simultaneous generation of walkers (entangled photons) through nonlinear optics. The general theoretical framework has been developed by our group. Now we need to find interesting regimes through analysis and numerical modelling, which will form the basis of the project.

Project 17: Trapped-Ion Quantum Computation (Dr Ting Rei Tan)

University: The University of Sydney
School or Department: Physics
Faculty: Science
Secondary or co-supervisor: Tomas Navickas
Student suitability: 3rd-year Physics Student
Project delivery: A mix of face-to-face and remote OR completely face-to-face

One of the most promising architectures for quantum computation and the simulation of other, less accessible quantum systems is based on trapped atomic ions confined by electric potentials in an ultrahigh vacuum environment. Record coherence times and the highest operational fidelities among all qubit implementations have enabled remarkable progress in recent years and, with the only two fullyoperational systems in Australia, the quantum control laboratory works at the forefront of research in this area. This project seeks to improve the quality of quantum state measurement in ytterbium ion qubit by employing experimental quantum control technique and explore novel machine-learning scheme based on knowledge on the atomic energy level properties. Project involves laboratory works including laser optics and microwave systems, as well as complementary software programming and numerical simulations.

Project 18: Partially distinguishable photons -- neither Bosons nor Boltzons. (Professor Peter Turner)

University: Macquarie University
School or Department: Physics and Astronomy
Faculty: Science
Secondary or co-supervisor: Alex Jones (University of Bristol)
Student suitability: Quantum information theory, mathematical physics, photonics. Strong theoretical interest/level.
Project delivery: Completely remote

Interference is a defining feature of quantum mechanics and an important resource in quantum information technologies. The well known Hong-Ou-Mandel effect is perhaps the best known example, where two indistinguishable photons (more generally, bosons) conspire to never leave the two exit ports of a balanced beam splitter simultaneously. This is in contrast to two distinguishable photons, which behave as independent classical particles ("Boltzons") and exit the ports randomly, with no such conspiracy.

This project will look at the intermediate area between perfectly indistinguishable and completely distinguishable particles, which is important for real world applications of e.g. quantum photonics. We will explore three and four photon cases with mathematical techniques from quantum information theory and computer simulations, with the goal of characterising the role of distinguishability completely and identifying their experimental signature.

Project 19: Trapped Ion Crystals and Large-Scale Entanglement (Dr Robert Wolf)

University: The University of Sydney
School or Department: School of Physics
Faculty: Science
Student suitability: 2nd-year physics student
Project delivery: A mix of face-to-face and remote

The controlled simulation of dynamics in quantum-many body systems is of central interest in the pursuit to further our understanding of phenomena such as superconductivity and quantum magnetism. Specially designed Penning traps enable experimental investigations into these topics using hundreds of ions trapped simultaneously inside a large, superconducting magnet. We have recently brought online the first and only such system in Australia at the Sydney Nanoscience Hub and now routinely trap large crystals of beryllium ions. Possible summer student projects involve the characterization of coupling between the ions using a custom UV laser system, hardware-software interfacing, hardware development, and operation of the trap. These topics involve experimental work in the laboratory as well as complementary numerical simulations and will adapt based on starting date and current needs.

Project 20: Quantum adversarial strategies for Proof of Work Mining (Professor Gavin Brennen)

University: Macquarie University
School or Department: Physics and Astronomy
Faculty: Science and Engineering
Secondary or co-supervisor: Prof. Troy Lee (UTS)
Student suitability: 2nd or 3rd year student with some experience in coding (e.g. Python, Matlab, c++) and coursework in linear algebra and quantum computing.
Project delivery: A mix of face-to-face and remote

In this project you will investigate how future quantum computers will be used to perform proof of work (POW) mining for blockchain based cryptocurrencies like Bitcoin. POW involves solving for the preimage of a Hash function output that depends on transactions in the current block and also a Hash of the previous block. Because the Hash function has no known structure that can be exploited, it is assumed the best quantum method to solve the problem will be Grover's search algorithm [1].

For classical computers POW mining is progress free, meaning that because of the enormous search space an individual miner essentially makes no progress on the problem until a solution is announced on the network. In contrast, quantum computers can make partial progress due to the nature of the Grover search algorithm which, during each iteration, amplifies the probability of measuring the correct answer. This has two immediate consequences. First, whereas classical miners are incentivised to refresh their blocks during mining since transactions with higher fees may arrive at any time [2], this will not be as profitable for quantum miners who have already invested useful computational power on a particular block. Second, given the probabilistic nature of quantum computing, when a network consists of many competing quantum miners, there is some advantage to be gained by measuring the register early, before the computation has completed but where appreciable probability of success has accrued [3].

This strategy will affect the time to mine distribution function which in term will impact network dynamics and the price of crypto assets. This project will setup a network with nodes performing classical simulations of quantum proof of work mining on small sized inverse Hashing problems. The student will be involved in code development with simulating the quantum circuits and also analysis of optimal game theoretic strategies including restarts in the adversarial setting.

[1] D. Aggarwal, G.K. Brennen, T. Lee, M. Santha, & M. Tomamichel, “Quantum Attacks on Bitcoin, and How to Protect Against Them,” Ledger, 3. https://doi.org/10.5195/ledger.2018.127 (2018).
[2] S. d. Santos, S. Kamali and R. K. Thulasiram, “Candidate Set Formation Policy for Mining Pools,” IEEE International Conference on Blockchain (Blockchain), 415, doi: 10.1109/Blockchain50366.2020.00060. (2020).
[3] T. Lee, M. Ray, M. Santha, “Strategies for quantum races,” arXiv:1809.03671.