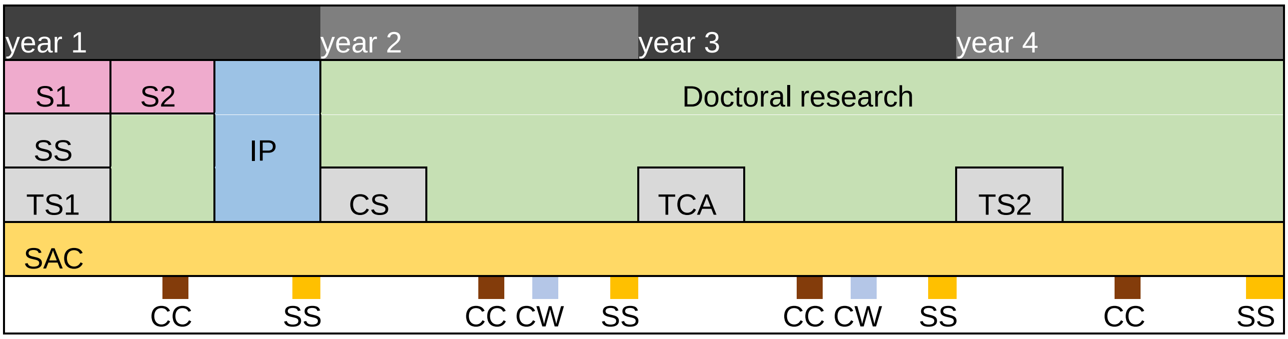
EPSRC Centre for Doctoral Training in Quantum Technology Engineering – 2025

Information for Students

The EPSRC Centre for Doctoral Training in Quantum Technology Engineering (CDT-QTE) has been designed, with industry advice, to match the needs of the expanding quantum technology industry and set you up for a successful and rewarding career in or beyond the quantum technology sector, from academic research to business development. The PhD will take 4 years and combine an exciting research programme with a training programme to equip you with a range of scientific, technical and commercial know-how to support your future career, backed by communications coaching, a 12-week industry placement, and shared challenges to build your peer network and foster cross-fertilization of research ideas.

The PhD has the following structure:



Science 1 & 2 (S1,S2): two Masters-level modules to bolster understanding of the specific area of doctoral research. These modules are assessed.

Scientific Skills (SS): workshops, exercises and a practical challenge addressing experiment and trial design; control, measurement & simulation; and systematic problem solving.

Technical Skills 1 (TS1): training/practical exercises in common design & fabrication techniques.

Technical Skills 2 (TS2): workshops and exercises covering systems engineering (SE).

Commercial Skills (CS): taught module with exercises, workshops and guest lectures.

Technical & Commercial Awareness (TCA): talks, examples, exercises and discussions covering a range of concepts and considerations likely to be encountered in future careers.

Scientific Awareness & Communication (SAC): a programme-long series of scientific and technical seminars, critical analysis, and training in communication and presentation.

Communications Coaching (CC), Summer School (SS), Challenge Week (CW).

Industry Placement (IP): a 12-week placement with an industrial partner.

Further Details:

About the CDT:	https://qte.ac.uk/
Application procedure:	https://qte.ac.uk/phd-opportunities/
General inquiries:	qte@soton.ac.uk

We look forward to hearing from you.

Tim Freegarde, Marina Carravetta, Peter Horak

PhD projects in Quantum Technology Engineering – 2025

1 - Quantum-Enhanced Mid-IR Spectroscopy for High-Precision Sensing

Prof Senthil Murugan Ganapathy, Dr Katrina Morgan-Innes, Prof Liudi Jiang

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This project aims to revolutionise diagnostics with a quantum-enhanced mid-IR sensing platform for quick, easy and non-invasive detection of pollutants and disease markers. By integrating advanced materials, it will enable ultra-sensitive, real-time environmental and health monitoring, offering a powerful tool for early disease detection and improved pollutant tracking.

Imagine a world where detecting pollutants or diagnosing diseases is as simple as a quick, non-invasive test. This project aims to make that vision a reality by developing a quantum-enhanced mid-IR sensing platform with the power to transform environmental monitoring and biomedical diagnostics. The technology will allow for the real-time detection of low-concentration pollutants, such as volatile organic compounds (VOCs), and enable rapid, precise screening for disease biomarkers, like cancer, at ultra-low levels.

To achieve this, we will integrate Photonic Integrated Circuits (PICs) with Transition Metal Dichalcogenides (TMDCs) and advanced metasurfaces. Known for their tunable optical properties, TMDCs will boost light-matter interactions, while metasurfaces amplify specific resonances to increase mid-IR detection sensitivity. These quantum sensors, leveraging phenomena like coherence and superposition, will detect subtle thermal changes from mid-IR absorption. This innovative approach promises ultra-sensitive, compact, and scalable molecular fingerprinting solutions, setting new standards for environmental and health diagnostics.

Additionally, this project will be highly multidisciplinary, and the student will be strongly supported by a supervisory team with expertise across three Schools: Optoelectronics Research Centre, Electronics and Computer Science, and Engineering.

2 - Physics inspired quantum machine learning methods for inverse problems

Prof Thomas Blumensath

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In this PhD project, you will develop and evaluate novel quantum machine learning approaches to solve large scale inverse problems using near term quantum computing systems. By formulating inverse problems in a physics informed learning framework, efficient encoding of the data will be achieved, whilst at the same time allowing efficient hybrid model training. This framework also naturally allows for the inclusion of regularisation constraints.

Quantum physical principles provide an exciting new basis for the design of the next generation of computers. Based on the 4 basic postulates of quantum physics, these quantum computers utilise simple mathematical principles that allow us to define quantum states, their evolution, measurement, and integration to develop novel computational rules that allow the development of a wide range of novel algorithms. Due to the inherent nature of quantum parallelism, many of these approaches have been shown to efficiently solve several challenging computational problems.

Quantum computation has thus found a wide range of applications in machine learning. These advances have led to a re-evaluation of many traditional algorithms that run on classical computational hardware, with many novel Quantum Inspired algorithms leading to significant computational advantages even in classical settings.

In this PhD project, you will develop and evaluate novel quantum machine learning approaches to solve large scale inverse problems using near term quantum computing systems. By formulating inverse problems in a physics informed learning framework, efficient encoding of the data will be achieved, whilst at the same time allowing efficient hybrid model training. This framework also naturally allows for the inclusion of regularisation constraints.

This is a field where there is significant scope that allows you to follow your interests to pursuit different directions, whether these are theoretical, by looking at theoretical algorithm performance and convergence properties, or whether these are more practical, by applying these ideas to realistic tomographic data-sets from the fields of acoustic or X-ray tomographic imaging.

3 - Qubit transmission: Connecting single photon sources with emerging hollow core optical fibres

Prof Radan Slavik, Prof Francesco Poletti, Dr Yongmin Jung

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In this project we will develop novel ways to interconnect a new class of optical fibres with single photon sources and detectors used in quantum memories, computers and networks. The Optoelectronics Research Centre is world-leader (activity led by Prof. F. Poletti, a co-supervisor of this project) in design and manufacturing of these novel fibres that guide light through a hole (hence the name, hollow core fibres) rather than through glass.

Optical fibres can transport light over long distances with very low loss. However, transporting quantum bits (qubits) using photons suffers from the interaction of the qubits with the glass through which the light propagates in traditional optical fibres. Qubits are also often generated at wavelengths where optical fibres do not have low attenuation, severely reducing the distance over which they can be transported.

Hollow core fibres are an emerging class of optical fibres in which light is guided by a hole surrounded by a special glass structure. This allows light guidance through a core that has lower refractive index than the surrounding material, enabling the core to be formed by empty space. This is not possible in traditional fibres that guide light based on total internal reflection. Recently, design and manufacturing of hollow core fibres reached such a level that they can transport light with lower attenuation than standard optical fibres and can have this low attenuation at wavelengths unachievable by traditional fibres.

In this project we will develop novel ways to physically interconnect hollow core fibres with single photon sources and detectors used in quantum memories, computers and networks.

The project is supported by a collaboration with Microsoft Azure.

4 - Quantum imaging of bioelectric signalling in colorectal cancer organoids

Dr Rosalia Moreddu, Prof Hywel Morgan, Dr Paola Sanjuan Alberte

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This project will investigates the bioelectric heterogeneity of colorectal cancer (CRC) and its correlation with bowel diseases and drug response, using quantum diamond sensing. Nitrogen-vacancy centers in diamond will image the spatial distribution of bioelectric fields within CRC organoids with high accuracy. Responses will be analysed using machine learning algorithms.

This project aims to investigate the bioelectric heterogeneity of colorectal cancer (CRC) and its correlation with bowel diseases and drug response, using quantum diamond microscopy (QDM). We will utilize nitrogen-vacancy (NV) centers in diamond to image the spatial distribution of bioelectric fields within CRC organoids derived from established cell lines (e.g., HCT116, HT-29) and patient-derived samples. By correlating bioelectric signatures with drug sensitivity profiles, we aim to identify novel biomarkers for predicting treatment response and pave the way for personalized CRC therapy. QDM imaging will be performed using a custom-built wide-field microscope with a spatial resolution of < 1 µm. Organoid drug response will be assessed using cell viability assays and correlated with spatially resolved bioelectric data using machine learning algorithms. This project will provide fundamental insights into the role of bioelectricity in CRC, and establish QDM as a powerful tool for drug screening and personalized medicine. Our group has previously pioneered the field of in vitro cancer bioelectricity by discovering that highly metastatic cancer cells fire voltage spikes at frequencies > 100 Hz, paving the way toward the study of cancer signalling using bioelectricity, as well as developing bioelectricity-based cancer diagnostics methods.

5 - Continuous-Variable Quantum Key Distribution with 5G Technology Integration

Dr Chao Xu, Prof Lajos Hanzo, Dr Yasir Noori

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The objective of this project is to integrate quantum communication into emerging wireless networks, paving the way for a global quantum network in time for 6G.

Continuous-variable quantum key distribution (CV-QKD) modulates its information onto the phase or amplitude of the electromagnetic wave. This enables quantum-secured applications such as banking and healthcare to be delivered using off-the-shelf wireless transceivers.

Nonetheless, the current wireless CV-QKD systems face two significant limitations. Firstly, transmission distance is constrained by both atmospheric turbulence and the multipath effect in electromagnetic wave propagation. Secondly, the generation rate of secret key is orders of magnitude lower than the classical communication data rate. To mitigate these challenges, on one hand, 5G-compliant error correction codes will be designed for enhancing CV-QKD's robustness against channel impairments. On the other hand, leveraging the principal waveform of orthogonal frequency division multiplexing (OFDM) in 5G, the secret key rate is expected to increase with the number of OFDM subcarriers, thereby optimizing wireless spectrum access.

This project will be supervised by Dr Chao Xu, who's the first researcher from the University of Southampton to achieve the highest score 100/100 in the EU's Marie Sklodowska-Curie Actions (MSCA) fellowship proposal evaluation. This project will also co-supervised by Prof Lajos Hanzo (Fellow of the Royal Academy of Engineering and Life Fellow of the IEEE) as well as by Dr Yasir Noori (Senior Lecturer, Chartered Physicist and Engineer).

This project will provide a unique cross-disciplinary training to an aspiring PhD student. The PhD student and the supervisors will intensively collaborate with their industrial collaborators. Moreover, the knowledge gleaned by this project will be transferred to students through teaching by the supervisors, which will inspire more Southampton students to get into quantum research.

6 - Quantum topology optimisation for aerospace design

Prof Ali Elham

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This project investigates the development of quantum algorithms to enable large-scale topology optimisation in aerospace. The goal is to overcome computational barriers in designing energy-efficient, sustainable aircraft configurations by leveraging quantum methods, advancing beyond the limits of conventional optimisation for practical aerospace applications.

Topology optimisation is a transformative engineering tool capable of designing optimal geometries/structures from the ground up. Its applications span diverse fields, but its potential in aerospace, particularly in aircraft configuration design, is yet to be fully realised. Despite a century of aviation advancements, we still lack an optimal configuration for energy-efficient flying vehicles.

Our lab has pioneered a topology optimisation approach tailored for the aerodynamic design of low-speed micro-air vehicles. However, scaling this method to practical, full-scale aerospace applications presents a massive computational challenge. Realistic designs require billions of design variables and the integration of multi-physics solvers, including fluid-structure interaction—a level of complexity beyond current computational capabilities.

Emerging quantum optimisation algorithms offer a promising path forward, showing the potential to accelerate high-dimensional, complex optimisation tasks. This PhD project will focus on developing quantum optimisation algorithms specifically for large-scale topology optimisation in aerospace design. The successful candidate will contribute to creating a new paradigm in sustainable aerospace configurations, addressing real-world design constraints such as energy efficiency and emission reduction.

We invite motivated applicants with a background in computational science, optimisation, aerospace engineering, or related fields to join us in this cutting-edge research journey.

7 - Molecular design of rare-earth-ion complexes for quantum light-matter interactions on nanophotonic platforms

Dr Patrick Ledingham, Dr Alberto Politi

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The future Quantum Internet requires efficient devices that store and recall arbitrary quantum states of light. These devices, known as quantum memories, can synchronise entanglement operations between distant locations. This project focuses on the development of rare-earth molecular complexes integrated with silicon nitride integrated photonic circuits.

Light is the underpinning platform for realising future quantum-enhanced technologies such as quantum computers and the quantum internet. Quantum information can be encoded into particles of light, photons, that can travel long distances in low-loss telecommunication fibers under ambient conditions, without noise, at high bandwidth, and at light speed. Optimising the efficiency of the memory is crucial for successfully operating the quantum network, and miniaturising form factors enable the industrial-scale rollout of devices. In this project, you will develop and build the next-generation solid-state quantum memory integrated with microfabricated photonic circuits.

As a PhD candidate, you will gain hands-on experience synthesising rare-earth molecular complexes, characterising their optical and coherence properties. You will also engage with the state-of-the-art cleanroom facilities, gaining experience in the microfabrication of photonic waveguides and resonators, and testing their performance. You will bring these parts together with the deposition of rare-earth molecular complexes onto the photonic circuits. You will test quantum memory protocols on this compact nanophotonic platform, benefiting from the enhanced light-matter interaction, paving the way for building global quantum networks.

Within this project, you will have the flexibility to follow your particular interests and determine your own direction of travel. A strong background in quantum physics, familiarity with solid-state physics, molecular chemistry, and photonics, as well as a keen interest in experimental development, would be beneficial. There will be plenty of opportunities to engage with industrial partners and collaborators in the UK and abroad.

8 - Optimal control methods for strongly coupled spin systems in solid materials

Prof Marina Carravetta, Prof Ilya Kuprov, Prof Peter P. Wells

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NMR uses magnetic moments from nuclear spin in a magnetic field. Complex, correlated spin states involving multiple spins and higher order quantum coherences can be created, with a severe efficiency cost. This project will use quantum optimal control to design and experimentally demonstrate new NMR quantum optimal control methods.

Nuclear magnetic resonance (NMR), is wide-spread as one of the most common analytical tools for characterization of materials in a range of physical states and temperature regimes. However, as most quantum mechanical methods at the moment, it is very far from the sensitivity and accuracy that it could potentially have. Manipulation of correlated spin states provide a powerful source of information on the local atomic environment, symmetry and proximities. Experimental efficiency drops steeply in large spin systems to create high-level correlated spin states, i.e., for homonuclear or heteronuclear correlations and higher order multiple quantum excitation: our current ability to control nuclear spin dynamics is limited and many existing methods are highly inefficient.

This project will explore the use of quantum optimal control theory to design magnetic resonance methods with radically better performance for correlated spin states involving multiple spins and higher order quantum coherences, in the context of magic-angle spinning solid state NMR, and demonstrate experimentally the new approaches. Applications will include gaining a better understanding of catalytic processes; for example using these advancements to follow hydrogen spillover processes on supported metal nanoparticles. This project will develop skills and expertise in quantum theory, quantum control, supercomputing, microelectronics and magnetic fields, and nuclear magnetic resonance. A good background in some of these topics to start with would be beneficial.

9 - Theoretical study of quantum techniques for reducing communication complexity in distributed systems

Dr Man Shun (Andersen) Ang

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This project explores how quantum techniques can reduce communication complexity in distributed systems. It involves studying classical and random communication complexity theories, and applying quantum methods like entanglement and superposition. The goal is to understand and lower the number of interactions needed, enhancing efficiency and reducing costs.

Communication complexity in theoretical computer science examines the amount of communication required to solve a problem when the input is distributed among two parties. This project aims to explore how quantum techniques can reduce communication complexity, thereby lowering costs in distributed systems.

Objective: The objective is to understand the theoretical complexity bounds on the number of interactions needed to solve distributed problems. By leveraging quantum techniques, we aim to demonstrate reductions in communication requirements compared to classical methods.

Content: The project is about a theoretical study of classical communication complexity theory, random communication complexity theory, and the role of quantum techniques in reducing complexity. Key areas of focus include:

- Classical Communication Complexity: Understanding the foundational principles and limitations.
- Random Communication Complexity: Exploring probabilistic methods and their impact on communication efficiency.
- Quantum Communication Complexity: Investigating how quantum entanglement and superposition can reduce communication needs.

Technicality: The project will delve into

- Rank of Boolean Matrices: Analyzing the rank and its implications for communication complexity.
- Graph Theory: Utilizing graph-based models to represent communication protocols and their efficiencies.
- Theoretical Complexity: Studying the theoretical bounds and computational limits of various communication protocols.

Skills: The project requires a strong background in mathematics and a math-oriented mindset. Proficiency in linear algebra, probability theory, discrete mathematics will be essential.

Impact: The project is aimed to provide a deeper understanding of the complexity bounds and to demonstrate how quantum techniques can offer substantial improvements in efficiency and cost reduction in distributed systems.

10 - Entanglement of Frequency-Distinct Superconducting Qubits Through Spatiotemporal Josephson Metasurfaces

Dr Sajjad Taravati

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This project studies nonreciprocal entanglement between frequency-distinct superconducting qubits, enabled by spatiotemporal modulation. The system features a reflective quantum state-converting metasurface designed for millikelvin-temperature quantum technologies, utilizing cascaded spacetime-modulated Josephson field-effect transistors. This study demonstrates that time-varying metasurfaces enable highly efficient quantum state conversion with a high frequency distinction ratio.

Entanglement is the linchpin of quantum mechanics and a pivotal enabler of quantum technologies, wherein the states of particles are intrinsically correlated, such that the state of one instantaneously influences the other, regardless of the distance between them. Reciprocal entanglement and coupling between qubits often lead to unwanted bidirectional interactions and reflections, which degrade quantum states and reduce quantum coherence. This project studies nonreciprocal entanglement between frequency-distinct superconducting qubits, enabled by spatiotemporal superconducting metasurfaces. The system features a reflective quantum state-converting metasurface designed for millikelvin-temperature quantum technologies, utilizing cascaded spacetime-modulated Josephson field-effect transistors (JoFETs). This spatiotemporal metasurface transcends the limitations of traditional linear space-time metasurfaces by incorporating Josephson junctions, offering highly efficient state-frequency conversion at millikelvin temperatures with conversion gain, along with a novel platform for quantum wave engineering. This work demonstrates that spatiotemporal superconducting metasurfaces enable highly efficient quantum state conversion even for superconducting qubits with a high frequency distinction ratio. The candidate joins the Smart Electronic Materials and Systems research group at the University of Southampton and become part of a PhD project that emphasizes strong industrial collaborations and commercialization potential. The project is supervised by Dr. Taravati, who has extensive experience in electromagnetics, active and space-time-modulated metasurfaces and their applications to wireless communications, biomedicine, and quantum computing at the University of Oxford, University of Toronto, University of Montreal, Concordia University, and University of Southampton. Additionally, he has successfully established a spinout company in Canada specializing in active metasurfaces for advanced wave processing in telecommunication systems.

13 - Next-generation ultrahigh density spin electronic devices

Dr Iris Nandhakumar

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In this project we will utilise state-of-the-art 3D lithography in combination with state of the art electrodeposition to realise magnetic nanowires with controllable “flying” domain wall qubits, paving the way towards a quantum computer based upon spin textures in 3D magnetic nanowires.

A paradigm shift is occurring in nanomagnetism whereby nanostructuring materials into 3D geometries provides a foundation for next-generation ultrahigh density spin electronic devices, for which qubits can be encoded within spin textures or within magnetic domain wall racetracks [1]. Two-photon lithography in combination with deposition methods can enable the fabrication and exploration of the physics of 3D magnetic nanostructured materials [2]. Recently 3D magnetic nanowires with feature sizes of 70 nm and direct measurement of domain wall injection and pinning have paved the way to low energy, ultrahigh density magnetic data storage devices [3].

In this project we will utilise state-of-the-art 3D lithography at Cardiff University in combination with state of the art electrodeposition at Southampton to realise magnetic nanowires with controllable “flying” domain wall qubits [4], paving the way towards a quantum computer based upon spin textures in 3D magnetic nanowires. In particular this will involve the preparation of templates with tunable geometries and sizes by two-photon beam lithography that will be utilised for electrochemical deposition of magnetic materials to study static domain wall textures and dynamics.

[1] S. Li et al. Materials Today Quantum 2, 2950 (2024)

[2] G. Williams et al. Nano Research 11, 845 (2018)

[3] J. Askey et al. Nanoscale 16, 17793 (2024)

[4] Phys. Rev. Research 5, 033166 (2023)

15 - Algorithm development for molecular simulations on quantum computers

Dr Karl Michael Ziems

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Dive into the fascinating world of quantum computing by developing new algorithms for molecular simulations and running your algorithms on actual quantum hardware. Your interest and background shapes the project with a focus on quantum chemistry inspired method development, algorithms enabling ultrafast dynamics, or error mitigation schemes.

Quantum computing is poised to be the next big emerging technology with the potential to fundamentally change our capabilities to model materials and thus impact discoveries in chemistry, physics, and biology. The necessity to completely re-think our algorithm design and adapt to new architecture operating around superposition and entanglement makes it a high-impact, interdisciplinary, and exciting field of study. Material simulation on quantum computers is not just a hot academic topic but is also addressed by start-ups, traditional industry, and policymakers, with a growing demand for talent from academia.

This project aims to develop quantum algorithms enabling molecular simulations on quantum computers. You will derive new methods, develop classic and quantum computing code together with senior researchers and your PI, simulate experiments and finally run your newly developed algorithms on actual quantum hardware. Depending on your background and interests, various project pathways can be explored, including electronic structure theory [1,2,3], quantum or semi-classical dynamics [4,5,6], (early) fault-tolerant algorithms based on time evolution, or chemistry-focused error mitigation schemes [1].

Candidates with a wide range of scientific backgrounds will be considered. Most important qualifications are coding experience (preferably python), solid mathematics for science background, and previous exposure to any kind of algorithm development/implementation. Optional experiences includes: method/algorithm development in 2nd quantization, quantum chemistry, quantum dynamics, or quantum information/computing.

An optional stay in Denmark is possible via collaboration with the Danish quantum project HQC2 (https://hqc2.github.io/)

Selected publications from the group:

[1] doi.org/10.48550/arXiv.2408.09308

[2] doi.org/10.1021/acs.jctc.3c01402

[3] doi.org/10.1021/acs.jctc.4c00574

[4] doi.org/10.1038/s41566-024-01436-9

[5] doi.org/10.3389/fchem.2022.942633

[6] doi.org/10.1088/1361-6455/acc4fa

17 - Manufacture of atom and ion traps via ultra-precision diamond machining

Prof James Gates, Dr Paul Gow

gates@soton.ac.uk, School: Optoelectronics Research Centre

This project will develop the core components of superconducting and atom/ion trap quantum systems using ultra-precision diamond machining. The project will work with leaders in the field (academia and industry) to create vacuum systems with integrated photonics and electrical functionality.

Quantum Technologies present new challenges for manufacturing engineering. Southampton has been developing ultra-precision machining systems for the scalable manufacture of superconducting and atom/ion trap quantum systems. These components are the kernel of quantum sensing and quantum computing systems. You will work with leaders in the field (academia and industry) to create vacuum systems with integrated photonics.

In this project, you will design, fabricate, and test atom and ion trap systems while working with experimentalists to demonstrate quantum sensing and computing. If you are interested in a PhD looking to do computer modelling and have the required skills, the project can also be adjusted for this. Areas include:

- Development of atom and ion trap cells using diamond milling systems. You will create miniature vacuum cells from silicon, silica (glass) and sapphire. These will contain optical windows, integrated mirrors and electrical and vacuum feedthroughs.
- Fabrication of integrated optical waveguides and large area tilted Bragg gratings to couple light out of integrated waveguides to form free-space beams for micro-atom traps.

- Development of freeform micro-optics (lenses, mirrors, resonators, etc) enabling the creation of more compact (SWaP-C) and more efficient quantum photonic systems.

If you are interested in quantum technologies, photonics and micro-fabrication, you would be highly suitable for this project. You will benefit from our world-leading expertise in these fields and enjoy working in a highly supportive environment in our Southampton group and collaborating with partner groups within the UK National Quantum Technology Programme.

Our research group:

https://www.southampton.ac.uk/research/institutes-centres/optical-engineering-quantum-photonics-group

https://www.planarphotonics.com/

18 - Up-conversion Photonics for Quantum Technologies

Prof Corin Gawith, Dr Goronwy Tawy

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Nonlinear parametric photonics is used to control quantum systems and as a source for photonic qubits. We have led the development of quasi-phase-matched non-linear systems. This project combines novel fabrication approaches with established commercial materials to expand the operation range into the ultra-violet and mid-infrared wavelength regions for quantum photonics.

In this project, you will design, fabricate and test parametric devices for quantum technologies, working with our interdisciplinary team of students, postdocs, and senior researchers to apply these devices to quantum systems. If you are looking to do computer modelling and have the required skills, the project can also be adjusted for this. Areas of research include:

- Development of blue/UV-generating parametric waveguides for the control of atom and ion trap systems. These will generate blue and UV light from infrared light sources.
- Investigating type II non-linear waveguides for single photon generation. Including the use of coupled cavities to enhance the efficiency. Applying this to develop prototype systems that can be used in photonic quantum computing.
- Developing up-conversation devices (combining two low-energy photons) for single photon imaging in the mid-infrared for environmental monitoring and life-science imaging.

Both these areas involve fabrication of devices, optical testing and metrology, and working with our partners to apply the devices to quantum systems. This project will closely work with the UK Quantum Technology Hub in Sensing, Imaging and Timing (QuSIT) and will have opportunities to engage with the other partners on the project.

If you are interested in quantum technologies, photonics and micro-fabrication, you would be highly suitable for this project. You will benefit from our world-leading expertise in these fields and enjoy working in a highly supportive environment in our Southampton group and collaborating with partner groups within the UK National Quantum Technology Programme.

Our research group:

https://www.southampton.ac.uk/research/institutes-centres/optical-engineering-quantum-photonics-group

https://www.planarphotonics.com/

19 - Low-loss photonics for quantum networks

Prof James Gates, Dr Rex Bannerman

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Unlike optical telecoms, where amplifiers compensate losses, in the world of Quantum Technology, every photon is precious. This project will create new ultra-low-loss optical components, reducing losses and allowing us to create large, entangled quantum states.

We are looking for a PhD student to join our interdisciplinary team of students, postdocs, and senior researchers developing systems for quantum technologies.

We will develop core components for interfacing quantum computers and networks using Southampton's state-of-the-art fabrication facilities. This project will focus on new ultra-low-loss optical components allowing us to create large, entangled quantum states. In particular, the project will develop quantum memories and switchable delays.

The project will look at various approaches, including an all-optical fibre-based system and integrated atomic vapour devices. You will design, fabricate, and test these photonic systems in this project. You will also work with experimentalists to validate the system. If you are interested in a PhD looking to do computer modelling and have the required skills, the project can also be adjusted for this.

If you are interested in quantum technologies, photonics and micro-fabrication, you would be highly suitable for this project. You will benefit from our world-leading expertise in these fields and enjoy working in a highly supportive environment in our group in Southampton while collaborating with partner groups around the country within the UK National Quantum Technology Programme.

Find out more about:

Our department and research group:

https://www.southampton.ac.uk/research/institutes-centres/optical-engineering-quantum-photonics-group

https://www.planarphotonics.com/

20 - Integrated Ultra-High-Q Ring Resonators

Prof James Gates, Dr Chris Holmes, Dr Bruno Moog

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Integrated ring resonators are a key component in photonics and will be an enabling technology in several areas, including the stabilisation of atom trap clocks, rotation sensors and narrow-linewidth lasers. With our partner (California Institute of Technology, Caltech), you will develop ultra-high-Q ring resonators, for rotation sensing and timing.

We are looking for a PhD student to join our interdisciplinary team of students, postdocs, and senior researchers developing systems for quantum technologies.

In conjunction with our partner (California Institute of Technology, Caltech), you will develop ultra-high-Q, ring resonators, for rotation sensing and timing. These integrated resonators are a key component in photonics and will be a key enabling technology in several areas, including the stabilisation of atom trap clocks, rotation sensors and narrow-linewidth lasers. We will also work with other UK and international collaborators and PhD students to develop and demonstrate these applications.

In this project you will design, fabricate, and test these ring resonator systems. A key aspect of the project will be glass deposition, using the state-of-the-art facilities in the university's cleanroom facilities. You will also work with researchers at Caltech (with the opportunity for visits, if desired) to develop and test the fabricated devices. If you are interested in a PhD looking to do computer modelling and have the required skills, the project can also be adjusted for this.

If you have an interest in photonics, microfabrication, and quantum technologies, you would be highly suitable for this project. You will benefit from our world-leading expertise in these fields and enjoy working in a highly supportive environment in our group in Southampton while collaborating with partner groups around the country within the UK National Quantum Technology Programme.

Find out more about:

Our department and research group:

https://www.southampton.ac.uk/research/institutes-centres/optical-engineering-quantum-photonics-group

https://www.planarphotonics.com/

21 - Advanced Lasers for Quantum Enhanced Microscopy

Dr Lin Xu, Prof Sumeet Mahajan

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Quantum enhanced microscopy imaging offers advancements of greater resolution, higher sensitivity and faster speed than classical optical imaging method, and therefore is a promising next-generation imaging technique for biomedical research. This project will explore and develop advanced photon entangled source to realize quantum enhanced microscopy imaging application.

Optical microscopy remains one of the most rapidly developing technologies in scientific research as it allows visualizing biology in its physiological context. However, current optical microscopy technologies are generally based on near-infrared or visible light, which remain largely inadequate in coping with label-free or deep-penetration imaging requirements. On the other hand, the mid-infrared spectral region covers distinctive rotational and vibrational resonant frequencies of specific molecules; this spectral fingerprint can be used as a contrast mechanism for mid-infrared imaging, circumventing the need for labelling. Such non-invasive and label-free imaging techniques are especially important for bioimaging procedures, as they permit the observation of largely unaltered living tissues. One of the main problems in mid-infrared microscopy is the detection of signals for imaging due to the lack of readily available high-performance detectors in the mid-infrared.

The unique properties of quantum physics could help solve such problems in a meaningful way named quantum enhanced microscopy. This breakthrough technology utilizes entangled photons rather than classical light sources and allows one photon to pass through the imaged object while image information is revealed exclusively with the photon that does not interact with the object. A pair of entangled photons (at different wavelengths) is used with one photon in the mid-infrared acting as a probe and the other in the near-infrared acting as a sensor. The mid-infrared photon facilitates deep penetration and distinctive characterization while the near-infrared photon allows to use readily available high-performance detectors. This project will develop advanced laser techniques to generate highly efficient entangled photons for quantum enhanced microscopy.

22 - Atom matterwave interferometry for inertial sensing

Prof Tim Freegarde, Dr Peter Horak

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Atom interferometry uses laser light to split, steer and recombine atomic wavefunctions, and promises inertial and magnetic field sensors of exquisite sensitivity. Practical realization requires a combination of photonic and atomic physics with optimal control techniques borrowed from magnetic resonance. This project involves experimental construction, computational optimization, and field testing.

Quantum inertial sensors, based upon atom interferometry, use pulses of laser light to split, steer and recombine atomic wavefunctions with precision and fidelity, promising major improvements in sensitivity, bias and scale factor stability for applications from navigation to geological survey. However, intensity variations across a laser beam and the motion of atoms even at microkelvin temperatures can limit sensor performance. To solve similar problems, magnetic resonance uses computationally-designed phase and amplitude shaping within each pulse. We have already applied these optimal control techniques to design individual ‘mirror’ and ‘beamsplitter’ pulses for atom interferometry, yielding impressive improvements in control fidelity. So far, however, we have only addressed individual interferometer pulses; optimization of a full interferometer sequence would be both more effective and more closely aligned to optimization of the inertial measurement overall.

In this project, you’ll join our small team to work on a combination of experimental development, optimal control theory, computational optimization and field trials for our prototype atom interferometric rotation sensor: the balance of experiment, theory and computation will be matched to your strengths and interests. There will be opportunities to work with international optimal control experts and partners from the Quantum Technology industry, to use the facilities of Southampton’s nanofabrication cleanrooms and Institute for Sound & Vibration Research, and to undertake practical trials at the National Oceanography Centre Southampton. The project will help you to develop skills and expertise in quantum technologies, atomic and laser physics, computational optimization, digital modelling, microfabrication, photonics, imaging, control and instrumentation.

23 - Quantum-corrected Floquet dynamics: a new approach to quantum control

Dr Elinor Twyeffort

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Increasingly sophisticated control of quantum systems using classical fields is a crucial tool in emerging scientific and technological applications. At heart, however, control fields are quantum. In this theoretical project, you will study how the quantum nature of the field changes the dynamics of the quantum system being controlled.

Controlling and manipulating quantum systems using electromagnetic fields underpins many cutting-edge quantum technologies. Typically, these fields are assumed to be classical. Recent work in the Quantum Optics Theory group at Southampton [Phys. Rev. Lett. 129, 183603 (2022)] has proposed a new mathematical description of the quantum-to-semiclassical transition in the interaction of light with matter, challenging the assumption that fields containing many photons can always be treated classically.

In this PhD project, you will build on this mathematical framework to develop practical mathematical and/or computational techniques for analysing the effects of field quantisation on quantum control in the cutting-edge ultrastrong coupling regime. This work will have applications in the emerging field of Floquet engineering, which uses periodic driving to steer and modify processes in a wide range of systems – materials, quantum gases, even chemical reactions.

Within this project, you will have flexibility to determine your own directions, following your particular interests. In addition to a solid background in quantum physics and an interest in mathematical and/or numerical techniques, familiarity with quantum optics or quantum information/technology would be beneficial. There will be opportunities to pursue collaborations with other research groups, both within the University of Southampton and around the world. The Quantum Optics Theory group and the School of Physics and Astronomy combine research excellence with a supportive environment where students can thrive.

25 - Hybrid semiconductor quantum dots for tunable single-photon emitters

Dr Silvia Motti, Dr Bruce (Jun-Yu) Ou

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Perovskite quantum dots show great potential for tunable light emitters. In particular, they can be employed as single-photon emitters, which are key building blocks for quantum communication networks. This project will study the fundamental photophysics behind photon emission of perovskite semiconductor nanoparticles and develop new platforms for quantum technologies.

Perovskite nanocrystals can be easily fabricated in colloidal suspensions and offer a wide range of colour tunability with high radiative efficiency, making them excellent candidates for light emission applications. Nanoparticles of size comparable with the exciton Bohr radius present quantum confinement and provide another degree of tunability. In addition to classical light emitters, these nanocrystals act as quantum dots and present promising potential for single-photon emitters, which are key building blocks for quantum communications. Perovskite quantum dots offer high radiative efficiency, defect tolerance, high purity at room temperature, and low-cost fabrication. Furthermore, mixed crystal compositions allow us to tune the emission wavelengths to match specific transitions of quantum memories and other components. Further development is required to improve stability, minimise blinking, and understand and optimise the factors that regulate single photon purity and indistinguishability. The chemical composition, shape anisotropy, and the choice of capping ligands must be optimised to improve efficiency, stability, radiative rates, and quantum coherence. This project aims to study the photophysics of perovskite nanoparticles and optimise their application as quantum dots for quantum light emission. The project will involve some material processing and fabrication, construction and alignment of optical setups, study of semiconductor photophysics by laser spectroscopy, and fabrication of photonic structures for the integration of quantum dots into functional devices.

26 - Perovskite nanocrystals for tunable quantum emitters: investigation by optical and NMR methods

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Metal halide perovskite nanocrystals are a promising platform for classical and quantum light emitters. They have great potential for single-photon emitters, which are key building blocks for quantum communication networks. This project combines synthesis, optical characterisation, and NMR studies of metal halide perovskite quantum dots and their optimisation for quantum emitters.

Metal halide perovskite quantum dots are a promising platform for classical and quantum emitters. They have great potential for single-photon emitters, which are key building blocks for quantum communication networks. Perovskite quantum dots can be fabricated as colloidal suspensions of nanocrystals that offer high radiative efficiency, defect tolerance, high purity at room temperature, and low-cost fabrication. Furthermore, mixed-halide compositions allow us to tune the emission wavelengths to match specific transitions of quantum memories and other components. Nuclear magnetic resonance (NMR) can probe the immediate chemical environment of nuclei to disentangle the bulk and surface composition, identify defects, and reveal short-range chemical heterogeneities in mixed-halide alloys that may not be detected by optical methods. Although such short-range heterogeneities have a minor impact on the bandgap and emission wavelength, they affect the material stability and exciton properties that dictate the mechanism of light emission. The project will include the synthesis of colloidal nanocrystals, optical characterisation, and NMR studies. It will also include the development of a custom setup for in-situ NMR under resonant illumination of the samples, to further reveal the impact of electron-phonon coupling. The setup will also allow for the study of illumination-induced structural transformations associated with ionic migration, providing key insights into the peculiar photophysics of these exciting materials. In addition to fundamental studies, the project aims to optimise the composition, processing methods, capping ligands, and solid-state matrix of the quantum dots, aiming to develop tunable single-photon emitters with improved efficiency and long-term stability.

28 - Gravimetry and magnetometry in space by levitated mechanics

Prof Hendrik Ulbricht

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We aim to provide quantum sensors to operate at real world setting to the acceleration noise level of 10-10 m/s2/√Hz based on levitated mechanics. Such sensors will allow to significantly improve our ability to track masses (gravimetry) to monitor their movement and change as well as to detect small magnetic fields (magnetometry).

Levitated mechanical sensors are based on optical or magnetic trapping of particles in vacuum. Particles are cooled to the quantum ground state or state engineered in a different quantum way by quantum-limited measurement-based protocols. We operate laboratory systems of both the magnetic and optical platforms and have started to develop compact versions of these sensors for extreme environments and in remote operation. Some sensors are optimised for use in space on small satellites for geodesy and consistent data production for processes relevant from climate change. We have completed our first space payload as a steppingstone for development of levitated optomechanical quantum technology, and with the aim to fly a large space mission by 2030. Other sensors may be for use under water and in underground settings. Integrated sensor networks will be used to enhance spatial and temporal resolution for specific sensing applications.

This PhD project will contribute to our quantum sensor developments by designing, implementing and testing new platforms to optimise and enhance operation. The ideal candidate will have an undergraduate degree in STEM topics, a good set of skills in practical physics, computation and data analysis, basic electronics. Experience in working with optical setups and vacuum systems will be of advantage. Most important is an open attitude to approaching and solving new and challenging tasks for realising the sensing platforms. We are looking for motivated candidates working with us on discovering new ways of doing things and building devices which did not exist anywhere before the start of the project.

29 - Quantum sensing based on exceptional points

Dr Dongyang Wang, Dr Bruce Ou, Dr Nikitas Papasimakis

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An exceptional point is a singularity point in the energy bands of non-Hermitian systems, which possesses exponential sensitivity to external perturbations. Such exceptional points appear in open quantum optical systems such as nanocavities, nanomechanical resonators, and quantum interferometers. This project aims to build exceptional points in quantum optical systems and use them for sensing applications.

This project will start with the design of nanocavities or metamaterials to achieve exceptional points in the non-Hermitian energy bands, which will be characterized with the sensitive response to external parameters, e.g., light stimulation, electric/magnetic field change, refractive index change, and thermal fluctuations. The student will gain knowledge in photonic crystals/metamaterials design, optical simulation techniques, and general non-Hermitian physics in the first year.

In the second year, this project will proceed to incorporate high-quality-factor cavities to increase the photon lifetime and explore the possibility of achieving sensitivity at quantum level. Such cavities will be achieved by building the bound state in the continuum (BIC) using photonic crystals design, and the signal to noise ratio around the lasing threshold will be studied. The student will gain knowledge in quantum noise theory and topological singularity physics in the second year.

In the third year, this project will be devoted to exploring the limit of sensitivity enabled by the exceptional points. Experiments will be designed to test the exact sensitivity of the nanocavity or metamaterial. The student will gain optical lab experience in the third year and finish the PhD thesis.

31 - Quantum Gas Sensing

Dr Ian Davidson, Prof Natalie Wheeler, Dr Thomas Kelly

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Gas sensing is a vital technique for many applications, including medicine and environmental monitoring. However, there can be difficulties with many commonly used techniques. The use of quantum technology (such as entangled photons and single photon counting techniques) may be able to alleviate these, and this project will explore this.

The ability to detect and quantify gases at trace (potentially sub-ppm) levels is vital for many applications, including environmental monitoring, biomedicine, and combatting climate change. The ability to do this optically has many benefits, including the range and speed at which measurements can be made, but also some drawbacks, such as potentially lower sensitivity.

Recently hollow-core fibres (HCFs), a type of speciality optical fibre which guide light in a hollow, gas-filled core, have been used to enhance these optical sensing techniques by extending the light-matter interaction length. But this approach is not problem free, as they may still involve weak signals or difficult (mid-IR) wavelengths.

Quantum technology, such as the generation of entangled photons (at differing wavelengths) or single-photon counting, offers the potential to solve these problems, further enhance these approaches.

This project will, therefore, investigate some of the following concepts:

- The use of superconducting single-photon detectors to further improve the sensitivity of HCF-enhanced Raman gas sensing, and enable distributed measurements,
- The generation and use of quantum light, i.e. entangled, correlated and squeezed light sources, at selected wavelengths to allow HCF-enhanced mid-IR absorption spectroscopy to be further improved through the measurement of non-interacting near-IR photons,
- The use of gas-filled HCFs to generate entangled photons for use in mid-IR gas sensing measurements

To achieve this, you will work with our existing research team in our state-of-the-art facilities to explore these topics. These new colleagues, being experts in their fields, will help guide and support your work, ensuring your success.

33 - Hollow-Core Optical Fibre Quantum Light Sources

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Quantum technology often requires non-classical, quantum light. Hollow-core fibres, a highly interesting speciality optical fibre where light is guided in a gas filled core, offer a promising route to generate, transmit, and distribute this non-classical light, and this will be the focus of this project.

Quantum systems typically rely on the generation, transmission, and distribution of non-classical light, such as single or entangled photons. Numerous approaches to achieve this are available but these can be difficult to combine into larger system.

Optical fibres already form the backbone of much of our existing data communication infrastructure and as such are a highly mature technology where may solutions for integration already exist. Hence, the development of fibre-based single and entangled photon sources is a highly interesting area of research but one that has been held back by the properties of traditional all-glass, solid-core fibres.

Hollow-core fibres (HCFs), a relatively new form of speciality fibre where light is guided in a hollow gas filled core, offer a route to solving this issue and hence will be the focus of this project. The main goal will be to tailor the performance of HCFs for the generation of single and entangled photons through design, pressurisation, and post-fabrication processing. As such the project will consist of both experimental and theoretical (modelling/simulation) tasks. Further, HCFs also offer a route to transmit and distribute this light, which will potentially be another project focus.

This work will be undertaken as part of our existing HCF research team, who will help guide and support your work, and will make use of our existing, state-of-the-art facilities. The project will also build upon our recent ground-breaking hollow-core fibre research results and will see you working in a highly interesting, rapidly developing, and important area of research.

34 - Integrated photonics resonators for quantum technologies

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We are looking for a PhD student to join our interdisciplinary team of students, postdocs, and senior researchers developing chip-based, microscale optical resonators for quantum technologies. Optical resonators strongly enhance the interaction between matter and light and integrating them on a microchip will allow scalable quantum computing, communication, and sensing.

In this project you will contribute to the design and numerical simulation of advanced photonic microresonators tailored for quantum applications, working in close collaboration with fabricators and experimentalists. We can also offer a project that combines modelling with experiments if you have the required skills. Potential areas of research include:

- Integrated optical waveguides and Bragg gratings: Investigate the incorporation of grating couplers to generate beams of well-defined shape and polarisation for interaction with stationary trapped quantum particles (e.g. atoms or ions), combined with micromirrors for optical enhancement.
- Integrated microdisc resonators: Exploit the extremely high light confinement and low loss of microring resonators for quantum sensing and nonlinear frequency conversion.
- Microresonators with optimised geometries: Optimise the shape of micromirrors to create resonator fields with higher photon enhancement than regular spherical mirrors.
- Slow light: Exploit Bragg grating structures in waveguides to slow down light by orders of magnitude leading to strong enhancement of light-particle interaction.
- Optical parametric oscillators: Different quantum technologies (based on ions, atoms, superconducting circuits etc.) each come with their preferred photon frequency. On-chip photon frequency conversion will allow for hybrid quantum networks linking these together.

If you have an interest in photonics, quantum technology, and computer-based modelling, you would be highly suitable for this project. You will benefit from our world-leading expertise in these fields and enjoy working in a highly supportive environment in our group and collaboration with partner groups across the University of Southampton and around the country.

35 - Integrated detectors for photonic quantum technologies

Dr Alberto Politi, Dr Oliver Trojak

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Quantum photonics is key to develop the next generation of quantum technologies. This project will develop a silicon-nitride platform for visible-wavelength quantum photonics: you will learn all aspects of the project, including simulation of optical/electronic components, nanofabrication, optical characterization and quantum science.

Quantum photonics is one of the most promising approaches to develop the next generation of quantum technologies, including quantum computers, networks and sensors. Integrated photonics provides many advantages over the various free-space approaches for building quantum devices. Extensive work has been done on the established platform at telecommunication wavelengths, however there are various applications and advantages for quantum light sources and systems to operate within the visible spectrum. This project will expand on work developing a silicon-nitride based platform [1] for visible-wavelength integrated quantum photonics [2]: developing and refining the design of semiconductor detectors for monolithic integration with photonic circuits. You will learn how to simulate and optimize optical and electronic designs of the device, nano-fabricate devices using the extensive cleanroom facilities available at the University, perform lab-based characterization of the devices and integrate with photonic circuitry on-chip to perform non-classical operations on states of light.

[1] R Cernansky, A Politi. APL Photonics 5 (10) 101303 (2020)

[2] R Cernansky, F Martini, A Politi. Optics Letters 43 (4), 855-858 (2018)

36 - On-chip Quantum Cryptography Using Two-Dimensional Materials

Dr Yasir Noori, Chao Xu

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The objective of this PhD project is to develop an on-chip entangled photon source that can be integrated within a quantum cryptography system to enable ultimate security of digital communication based on the laws of quantum physics.

Existing techniques to encrypt data in our Internet networks are vulnerable to being easily breakable by emerging quantum computers. IBM has recently released a 1000 qubit quantum computer and the challenge of finding alternative techniques to encrypt our data is becoming ever more urgent. Fortunately, quantum cryptography is a suitable solution to overcome this challenge.

However, quantum cryptography requires unique lasers that emit entangled photons at one time. In this PhD project, you will use two-dimensional (2D) materials as light sources for entangled photons for quantum cryptography applications. You will have hands-on experience in fabricating on-chip photonic structures in a cleanroom environment to improve the emission of entangled photons and engineer integrated waveguides to manipulate the polarisation of these photons, store them in memory devices and sense them at the receiver end.

During your PhD, you will design, simulate, fabricate and test various on-chip photonic structures to develop single photon sources. You will work within the Sustainable Electronic Technologies Group, a vibrant group of Academics, Research Fellows and PhD students at the School of Electronics and Computer Science. Your research will involve accessing a large set of experimental facilities that are hosted by the group, equipping you with expertise and skills for performing research and development within academic and industrial settings.

Your background is expected to be in Physics, Electronic Engineering, Materials Science or a related discipline.

37 - Dynamic control of quantum systems by symmetry-induced selection rules

Prof Malcolm H. Levitt, Prof Marina Carravetta

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Quantum systems evolve in time. The pathway which a quantum system follows may be controlled by imposing selection rules on the dynamical evolution. The project involves a combination of theory, numerical simulation, and experiments involving local NMR equipment and through international collaborations.

The aim of this project is to control the pathway which a quantum system follows by imposing selection rules on the dynamical evolution. This may be done by imposing control fields which obey certain symmetry relationships in time and space. This principle was originally developed for solid-state nuclear magnetic resonance (NMR), where technologies based on this principle are widely used for molecular structure determination in, for example, structural biology. In this project we wish to generalise and extend the symmetry-based control principle to other dynamical quantum systems, including other forms of NMR, magnetic resonance imaging (MRI), electron paramagnetic resonance (EPR), and nanoscale magnetometry using nitrogen-vacancy centres in diamond.

This PhD project will expose the student to a wide variety of quantum systems of technological importance, including techniques on the forefront of quantum technology development, such as nanoscale quantum sensing. The project involves a combination of theory, numerical simulation, and experiments involving local NMR equipment and through international collaborations.

38 - Luminescent Lanthanide Complexes for Future Photonic Quantum Computers

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The ability to design new more efficient downconversion systems will be of paramount importance for the quantum computing revolution. Molecular lanthanide cluster complexes comprising multiple Ln ions offer unrivalled control in the internuclear distances and donor-acceptor compositions, thereby allowing more sophisticated and efficient downconconverting devices to be prepared.

Downconverting (DC) systems are of paramount importance for the advancement of new quantum themes such as sensors for medicine and quantum computing. Research into the mechanistic intricacies is relatively limited due to the media in which it operates – primarily solid-state or nanoparticle materials. The main innovation here is a molecular chemistry approach which allows strategic design of the donor-acceptor pairs which give rise to the UC signal – which includes tailoring materials and thoroughly investigate and tune the ion-ion distances. This project involves a novel class of heteropolymetallic lanthanide complexes for downconversion, permitting a deeper understanding of the mechanism of photon DC. This is an area of high priority and novelty, only five groups globally are working on molecular lanthanide photon conversion. Molecular DC has not currently been realised but represents a significant goal in future quantum technologies.

The successful candidate will acquire proficiency in synthetic organic, coordination chemistry, photoluminescence spectroscopy, and X-ray crystallography. The researcher will have full access to a suite of techniques via state-of-the-art facilities including NMR spectroscopy, IR, HPLC and Mass-Spectrometry, in addition to world-leading X-ray diffraction facilities.

The candidate will also participate in group-meetings, school seminars and represent the group at national/international conferences. This will give them the opportunity to disseminate their research results with world-leaders in the area.

39 - Developing magnetic lenses and inductively coupled coils to sense individual quantum spins

Dr Giuseppe Pileio, Dr Yasir Noori

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Our objective is to develop Nuclear Magnetic Resonance spectroscopy to make it capable of detecting individual quantum spins. This goal will be achieved by developing magnetic lenses to amplify the signal from and out of the spin-hosting materials.

Magnetic Resonance is a non-destructive and harmless technique that provides static and dynamic information on various types of samples and can be used on both in-vivo and ex-vivo tissues. However, the technique suffers from low sensitivity that make it not particularly competitive to other imaging techniques when it comes to sensing individual quantum spins. Applications are invited for a PhD Studentship in nuclear magnetic resonance (NMR) to work on a project aimed at fabricating integrated radiofrequency coils and Lenz lenses to enhance the signal-to-noise in Nuclear Magnetic Resonance (NMR) Spectroscopy to achieve ultra-high sensitivity to detect individual quantum spins. During this PhD, you will be responsible for designing, simulating, fabricating and testing these lenses and coils to achieve the required sensitivity and signal enhancement, whilst matching the design of these devices to an integrated bioreactor where tissue cells are allowed to proliferate inside the NMR/MRI instrument itself.

The successful candidate will be part of a team that includes Dr Giuseppe Pileio (School of Chemistry, Director of the Magnetic Resonance Centre) and Dr Yasir Noori (School of Electronics and Computer Sciences) plus other staff in their research sections. The project is highly interdisciplinary. The student will have an active role in performing the simulation and fabrication of these coils in a state-of-the-art nanofabrication cleanroom, whilst testing the performance of these systems in nuclear magnetic resonance equipment working within a team of Electronic Engineers, Chemists and Life Scientists.

40 - Quantum computing for large-scale stochastic optimisation in energy system planning

Dr Hongyu Zhang, Dr Stefano Cipolla, Dr David Bernal Neira

School: Mathematics

This project explores quantum computing to enhance large-scale stochastic optimisation for energy system planning, addressing uncertainty in renewables. By integrating quantum and classical methods, it aims to solve large-scale models, advancing methodologies and supporting the energy transition.

Energy system planning is vital for achieving a net-zero European energy system by 2050. In this transition, renewable energy carriers such as wind and solar are pivotal. Managing the uncertainty associated with these sources is critical for a system with high penetration of renewables. Stochastic optimisation has been an important method for energy system planning under uncertainty. However, stochastic energy system planning models often become large and computationally intractable. Therefore, many optimisation decomposition algorithms have been developed to improve computational efficiency.

The rapid development of quantum machines presents an opportunity to develop quantum-based solution algorithms to tackle the complexity of real-world energy transition. However, significant gaps remain in developing and applying such algorithms.

This project aims to: (1) harness the inherent uncertainty of quantum computing, arising from quantum superposition, entanglement, and probabilistic measurement outcomes, for stochastic optimisation, (2) integrate quantum computing with classical decomposition algorithms for more efficient solution methods, and (3) apply these advanced techniques to solve large-scale energy system planning models, providing global insights into the energy transition.

Overall, the project seeks to leverage the rapid progress in quantum machines and classical optimisation algorithms to bridge the research gap, contributing to the methodology development of quantum-classical algorithms and supporting the energy transition.

The successful candidate will collaborate with experts in quantum computing, stochastic optimisation, computational optimisation, and energy systems. They will have the opportunity for a research stay at the SECQUOIA Research Group at Purdue University.

41 - nanoAGILE (Axially Graded Index LEns) for quantum technologies

Dr Nina Vaidya, Dr Alberto Politi

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Current photonic quantum systems suffer from the poor brightness of the single photon sources used as a source for the qubits. The PhD position will explore ways of enhancing light extraction from photon sources and ways to detect meaningful qubit information. This project is a combination of physics, engineering, materials, and advanced device fabrication that will be essential in the feasibility and scale up of quantum technologies.

Can novel device designs, materials, and fabrication techniques accelerate the development of quantum computing in the near future?

A challenge faced by photonic quantum systems is the poor brightness of the single photon sources used as a source for the qubits. A similar problem has already been solved in the macroscopic regime: the AGILE (Axially Graded Index Lens) light concentrating device. This project would be a collaboration between the group of Dr Nina Vaidya in the School of Aeronautics and Astronautics which has developed the AGILE device, and that of Dr Alberto Politi which has extensive experience in nanophotonic device fabrication. This PhD project will cover design, fabrication, and testing of quantum devices □ created with novel materials and fabrication processes. The student will have a chance to learn and contribute to the quantum era and explore light-matter interaction at the quantum level. These topics align well with future careers in academia, research, as well as the national and international engineering companies and start-ups.

https://news.stanford.edu/stories/2022/06/new-optical-device-help-solar-arrays-focus-light-even-clouds

42 - Silicon Nano-opto-electro-mechanical (NOEM) qubits

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A novel nano-opto-electro-mechanical (NOEM) qubit is proposed to bridge the gap between quantum computing and communication hardware. Mechanically-isolated NOEM qubits can transfer quantum information from charge to light within longer decoherence time. Design optimisation, device fabrication and low temperature measurements are planned to prove the benefit of the NOEM qubits.

This project will investigate a novel nano-opto-electro-mechanical (NOEM) qubit that has been realised on a nanoscale suspended beam, controlled electrically and read out via optical interaction. Thanks to mechanical isolation of NOEM qubits from the materials surrounded, longer decoherence time is expected. Via optical detection of the quantum state of NOEM qubits, quantum information on the mechanical suspended beam can be transferred efficiently into photon that is used for secure information transfer via quantum communication. Starting from the design of a single NOEM qubit, proof of principle of quantum information transfer between charge to photon on a NOEM qubit, and a demonstration of CNOT operation on double NOEM qubits on silicon nanobeams will be targeted within the PhD period. The research is aiming to fill the gap between two main quantum technology themes, quantum computation and quantum communication. Quantum computing is mainly performed via qubits on solid state media, while photon is a principal carrier of information in quantum communication. Successful development of NOEM qubits in this project will be able to demonstrate an on-chip solution of quantum information transfer between different media, leading to establish a solid basis of highly-integrated quantum computing and communication systems in future.

43 - Optomechanical metasurfaces for quantum magnetometry

Dr Bruce(Jun-Yu) Ou, Dr Yoshishige Tsuchiya

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Magnetometers are crucial in aerospace, geological mapping, and drone technology. Our innovative project leverages distributed quantum sensing, implemented on an array of optomechanical metasurfaces, to create room-temperature, chip-scale remote magnetometers with high signal-to-noise sensing capabilities in complex environments.

Magnetometers are pivotal in aerospace, geological mapping, and drone technologies, supporting functions like altitude measurement and magnetic geological surveys. They are equally essential in space exploration, helping to study Earth's magnetic properties, other planetary bodies, and the interplanetary magnetic field. A major challenge across these applications is achieving compact, lightweight, and energy-efficient sensor designs while optimizing signal-to-noise ratios and refresh rates.

To tackle these limitations, we propose an advanced solution leveraging optomechanical interactions with entangled photons on a single chip. This approach employs distributed quantum sensing on an array of optomechanical metasurfaces, enabling room-temperature, chip-scale magnetometer arrays with exceptional signal-to-noise performance in complex environments. It supports both two-dimensional (2D) and three-dimensional (3D) magnetic field mapping.

This project is a collaboration between the University of Southampton and the University of Alberta in Canada which hosts external placement.

What You Will Do:

- Design, develop, and prototype nanomechanical sensors that interact with entangled photons.
- Detect force and displacement using ultrasensitive nanomechanical sensors and quantum sensor network.
- Present your findings in leading journals and at international conferences.

Who We Are Looking For:

- Candidates with a strong background in photonics, physics, and/or engineering.
- Individuals who are innovative and have a passion for research.
- Excellent problem-solving skills and the ability to work independently.

44 - Nano-opto-electro-mechanical (NOEM) tunable SiC entangled photon source

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A novel nano-opto-electro-mechanical (NOEM) tunable SiC entangled photon source will be developed for future on-chip quantum photonic circuits technology. Design optimisation, device fabrication and single photon measurements are planned to prove the working principle and tunability of the device.

The aim of this project is to establish a solid technological platform to generate an entangled pair of photons in a controlled manner for future advanced quantum information and communication technology. Opto-Electro-Mechanical interactions are employed to control the timing of single photon emissions and to regulate the level of the entanglement of photons coherently generated from two adjacent photon sources. Silicon carbide is chosen as a platform material for future integrated on-chip reconfigurable quantum information and communication circuits. At the end of the project, a novel tunable entangled photon generator will be demonstrated on a silicon-based substrate. The outcome will make significant contribution not only to inspiring discrete photon generation device research field but also to opening up a path to on-chip photon-source-integrated quantum circuit technologies. This is a collaborative project between the University of Southampton and the Institute of Science Tokyo.

45 - Quantum Reservoir Computing via Nano-Opto-Electro-Mechanical (NOEM) coupled quantum oscillators

Dr Yoshishige Tsuchiya, Dr Srinandan Dasmahapatra

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A novel Quantum Reservoir Computing hardware using Nano-Opto-Electro-Mechanical (NOEM) coupled quantum oscillators is proposed to demonstrate quantum neural networks where quantum information is used as data in machine learning algorithms. Modelling approach or device fabrication route can be selected.

The aim of the project is to develop a novel platform technology for quantum reservoir computing, a promising approach for quantum neural networks where quantum information can be used as data in machine learning algorithms. We propose Nano-opto-electro-mechanical (NOEM) coupled oscillators are a potential candidate for quantum coupled oscillators and create models for the systems. Subject to the expertise and interest of a candidate, two approaches are possible. One is to develop mathematical or numerical models of NOEM-based quantum reservoir computing, which is more suitable for Computer Science students. Another approach is to develop NOEM-coupled oscillators that can get into the quantum regime and to demonstrate quantum coupled oscillators experimentally, which is more suitable for Physics or Electronic Engineering students.

48 - Detectors for Topological Quantum Light

Dr Nikitas Papasimakis, Dr Dong-Yang Wang, Prof Nikolay Zheludev

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This project will develop detectors for topologically structured light at the few- and single-photon level, enabling applications in imaging, metrology, and telecommunications.

Recent advances in structuring light in the spatial and temporal domain provide unprecedent control over the topology of light leading to the discovery of exotic forms of light. In particular, topological structuring of quantum light states, e.g. single photon and entangled states, are promising novel applications in telecommunications, imaging, and metrology, to name a few. The aim of the project is the realization of efficient nanophotonic detectors, sensitive to the topological and quantum properties of the incident radiation. This project will develop skills and expertise in experimental optics, nanofabrication, and computational electromagnetics.

50 - Quantum Materials as Sensors

Dr Makars Šiškins

School: Physics and Astronomy

Quantum materials exhibit extraordinary sensitivity to external stimuli near critical phase transitions, enabling novel sensing mechanisms. This project investigates novel materials such as twisted 2D materials and complex oxides to develop advanced sensors capable of detecting dynamic processes with ultra-high sensitivity for applications in nanometrology and nanoelectromechanical systems (NEMS).

The unique volatility of phase transitions in novel quantum materials like twisted 2D materials provides exceptional opportunities for sensing applications. These materials exhibit dramatic changes in free energy near critical points, making them highly sensitive to external triggers, such as strain, magnetic fields, and photons. By leveraging this sensitivity, this project aims to develop innovative sensors for detecting transient phenomena and dynamic processes with unparalleled precision.

The researcher will explore phase dynamics within these systems and identify sensing mechanisms based on transition fluctuations, relaxation dynamics, and frustration effects. Key materials include moiré 2D magnets and complex oxide membranes suspended over a cavity, which offer rich phase diagrams and diverse potential applications. The project will target sensing technologies for nanometrology, noise sensing via transition fluctuations, and dynamic sensing through relaxation and frustration for real-time monitoring of transient phenomena or dynamic processes.

The PhD candidate will engage in advanced nanofabrication, optomechanical experiments (incl. cryogenic), and thermodynamic phase diagram mapping, supported by collaborations with internationally recognised experts in 2D materials and nanomechanics. By the end of the project, the candidate will gain deep expertise in the fundamental physics of quantum matter and their transformative potential for sensing technologies.

Qualifications:

- Master's degree in physics/nanoscience or any other relevant field.
- Excellent understanding of the basics of condensed matter physics.
- Excellent written and verbal communication skills.
- Good knowledge of the field of 2D materials and/or complex oxides is an advantage.
- Experience with either optical equipment, nanofabrication, cryogenics or electron transport measurements is an advantage.

52 - Optimal control design of matterwave interferometer laser pulses for inertial and magnetic sensing

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Inhomogeneities degrade the performance of atom interferometers used for inertial and magnetic sensing. Optimal Control allows the design of laser pulse shapes that restore interferometer fidelity. This project will extend optimal control design beyond individual pulses to entire interferometer sequences and systems, and explore curious artefacts apparent from earlier work.

Quantum inertial sensors, based upon atom interferometry, use pulses of laser light to split, steer and recombine atomic wavefunctions with precision and fidelity, promising major performance improvements for applications from navigation to geological survey. However, intensity variations across a laser beam and the motion of atoms even at microkelvin temperatures can limit sensor performance. To solve similar problems, magnetic resonance imaging uses computationally-designed phase and amplitude shaping within each pulse. We have successfully adapted these optimal control techniques to design individual ‘mirror’ and ‘beamsplitter’ pulses for atom interferometry, and have already shown major improvements, but so far we have only optimized each pulse individually. Optimization of a full interferometer sequence would be more effective and could extend to optimization of the sensor system overall.

In this project, you’ll join our computational theorists to develop optimal control for entire interferometer sequences, addressing a variety of Raman and Bragg configurations and enhancements such as large momentum transfer. You’ll then work with our experimentalists to validate them on one of our cold-atom interferometers and apply them in field trials of a prototype sensor. Finally, you’ll explore curious features seen in the optimized waveforms that suggest intuitive interpretations for computational results; and adapt your solutions for alternative applications to atom-based quantum computing. The project will help you to develop skills and expertise in quantum technologies, digital modelling, computational optimization, photonics, atomic physics, control and instrumentation.

54 - Single-photon emitters integration in silicon nitride

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The project focuses on advancing quantum photonics through the development of scalable, on-chip single-photon sources using nitrogen-rich silicon nitride (N rich SiN). SiN is an advantageous material due to its high refractive index, low optical losses, and compatibility with semiconductor fabrication techniques. A key breakthrough underpinning this research is the discovery of room-temperature single-photon emitters (SPEs) in SiN films, which are essential for quantum technologies like communication, sensing, and computing.

The research aims to achieve three primary goals: understanding the photophysical properties of N-rich SiN SPEs, investigating UV-induced refractive index changes in SiN for precise optical tuning as well as develop an understanding on the UV exposure effect on the SPEs, and finally integrate these emitters with SiN waveguides for efficient light management. By leveraging these properties, the project seeks to create highly efficient, integrated quantum photonic circuits, contributing to advancements in quantum technology applications and positioning SiN as a critical material for future innovations.