Diode Laser Beam Conditioning for pumping Ti:sapphire lasers

Project ID: TBC **Division:** IoP

Primary Supervisor: Alan Kemp **Email:** alan.kemp@strath.ac.uk

Secondary Supervisor(s): Niall Simpson / Martin Lee

Project Background: High performance Ti:sapphire lasers are a workhorse laboratory tool across the photonic sciences, including important multi-disciplinary areas such as microscopy, spectroscopy, and quantum technology. This is a result of their excellent and adaptable performance characteristics. They are, however, bulky and expensive lasers, in large part because of the requirement to pump them with another relatively large and complex laser. This project will look at some of the practicalities and challenges of replacing the current pump lasers with inexpensive, but lower optical quality, diode lasers..

Aim: To assess how best to utilise inexpensive 450nm diode lasers for pumpng high performance Ti:sapphire lasers

Tasks: The project will attempt to reassess the pumping arrangements for Ti:sapphire lasers in the context of the availability of inexpensive diode lasers at 450nm. Depending on progress of associated work in the team (https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/T014288/1), the project will involve some combination of characterisation of diode lasers, design of lens systems for these lasers, testing of methods for combining these lasers, design of laser cavities suitable for diode laser pumping, and calculations (and possibly experiments) on the thermal management implications of diode laser pumping. The project would suit a student with an interest in photonics and, in particular, laser engineering, and will contribute to the work of a wider research group in this area. It would also be well suited to a student taking PH455 – the project will build significantly on the ideas introduced in this module.

Key references:
[1] P. W. Roth, A. J. Maclean, D. Burns, and A. J. Kemp, "Directly diode-laser-pumped Ti:sapphire laser," Optics Letters, vol. 34, pp. 3334-3336, 2009.
[2] J. C. E. Coyle, A. J. Kemp, J.-M. Hopkins, and A. A. Lagatsky, "Ultrafast diode-pumped Ti:sapphire laser with broad tunability," Optics Express, vol. 26, pp. 6826-6832, 2018
[3] H. Liu, S. Sun, L. Zheng, G. Wang, W. Tian, D. Zhang, H. Han, J. Zhu, and Z. Wei, "Review of laser-diode pumped Ti:sapphire laser," Microwave and Optical Technology Letters, vol. 63, pp. 2135-2144, 2021.

Theory: 0% **Comp:** 0% **Exp:** 100%

Recommended Background or Pre-Requisites: No pre-requisites but student should normally be taking PH455 (Topics in Photonics).

Safety Training (if applicable): Laser safety training must be be undertaken prior to any lab work.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Suitiable for up to 2 students. With 2 students, the experimental computation balance is likely to be closer to 50/50 across the two students depending on student interests and availablitliy of lab space.

Photonic neurons with lasers for ultrafast brain-inspired computing

Project ID: TBC

Division: IoP

Primary Supervisor: Antonio Hurtado

Email: antonio.hurtado@strath.ac.uk

Secondary Supervisor(s): Julian Bueno

Project Background: Neuromorphic photonics aims at emulating the brain's powerful computational capabilities for novel paradigms in ultrafast, energy efficient information processing. Biological neurons respond by firing spikes when stimulated. Semiconductor lasers, such as Vertical Cavity Surface Emitting Lasers (VCSELs) can also produce spiking responses similar to those observed in biological neurons but several orders of magnitude faster. This feature makes them ideal candidates for the use in novel brain-inspired systems for all-optical information processing.

Aim: This project will analyse in theory neuronal-like spiking regimes in Vertical-Cavity Surface Emitting Lasers (VCSELs). This project will thus explore numerically the spiking responses obtained in VCSELs and the potential of these devices for neuromorphic processing tasks (e.g. image feature detection, pattern recognition) for use in future light-enabled Artificial Intelligence (AI) systems.

Tasks: Background of the project, literature review on photonic spiking neuronal models with lasers including VCSELs. The student will be provided with simulation tools in Matlab modeling the fast spiking responses in VCSELs. The student will familiarise themselves with the simulations and will reproduce recent experimental/numerical result obtained by our group. Expand the simulation work to model the operation of VCSEL-based photonic neurons in tasks using spikes to process information. These will include image processing and pattern recognition among others.

Key references:

[1] J. Robertson et al, "Toward neuromorphic photonic networks of ultrafast spiking laser neurons", IEEE JSTQE, 26, 770715 (2020)
[2] J. Robertson et al, "Ultrafast optical integration and pattern classification for neuromorphic photonics based on spiking VCSELs", Scientific Reports, 10, 6098 (2020)
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Basic knowledge in photonics is desirable. Knowledge of Matlab. Attendance to PH455 is also recommended.

Safety Training (if applicable): No special training required

Suitable for: MPhys

Misc:

Spiking neurons with resonant tunneling diodes for high speed and energy efficient neuromorphic nanophotonic computing

Project ID: TBC

Division: IoP

Primary Supervisor: Antonio Hurtado

Email: antonio.hurtado@strath.ac.uk

Secondary Supervisor(s): Juan Alanis

Project Background: Neuromorphic photonics aims at emulating the brain's powerful computational capabilities for novel paradigms in ultrafast, energy efficient information processing. Biological neurons respond by firing spikes when stimulated. Resonant Tunneling Diode devices can also produce spiking responses similar to those observed in biological neurons but several orders of magnitude faster and with very low energy requirements. This feature makes them ideal candidates for the use as nanoscale spiking neuronal models for novel brain-inspired computing systems for future optoelectronic neural network implementations for future low energy and high speed light-enabled Artificial Intelligence systems.

Aim: This project will analyse in theory neuronal-like spiking regimes in Resonant Tunneling Diode (RTD) devices for high-speed and energy efficient neuromorphic nanophotonic computing systems for Artificial Intelligence (AI).

Tasks: Background of the project, literature review on optoelectronic spiking neuronal models with RTD devices. The student will be provided with simulation tools modedling the fast and low energy responses in RTD devices. The student will familiarise themselves with the simulations and will reproduce recent experimental and numerical results produced by our group and our European colleagues as part of the EU FET Open project 'ChipAI' (www.chipai.eu). Expand the simulation work to simulate the operation of RTD-based artificial spiking neurons to investigate the potentials for very high operation speeds (GHz rates) and low energy requirements (<pJ/spike). Explore the use of RTD spiking neurons for neuromorphic processing tasks at high data rates.

Key references:

[1] B. Romeira et al, "NanoLEDs for energy-efficient and gigahertz-speed spike-based sub-λ neuromorphic nanophotonic computing", Nanophotonics, Ahead of Print (2020). DOI: https://doi.org/10.1515/nanoph-2020-0177
[2] B. Romeira et al, "Regenerative memory in time-delayed neuromorphic photonic resonators", Scientific Reports, 6, 19510 (2016)
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Basic knowledge in optoelectronics is desirable. Knowledge of Matlab. Attendance to PH455 is also recommended.

Safety Training (if applicable): No special training required

Suitable for: MPhys

Misc:

Dual-frequency operation of visible semiconductor disk lasers (SDLs)

Project ID: TBC

Division: IoP

Primary Supervisor: Dr Jennifer E. Hastie

Email: jennifer.hastie@strath.ac.uk

Secondary Supervisor(s): Dr Paulo Hisao Moriya

Project Background: Ultra-coherent light sources are key for the development of cold atoms-based quantum technologies (QT). Each QT system requires few lasers to exploit the quantum nature of matter with various levels of output power with high beam quality and stability, and low noise at different wavelengths from the UV to IR required for each atomic species. Semiconductor disk lasers (SDLs), also known as vertical-external-cavity surface-emitting lasers (VECSELs), combine all the required features with an external cavity geometry, allowing for intracavity techniques, such as filtering and doubling, to be performed efficiently inside the laser cavity. Frequency splitting leading to dual frequency, or dual colour, operation can also be achieved to target two transitions with a small frequency separation, potentially reducing not only the bulkiness and complexity of the laser systems used but even their total number.

Aim: Theoretical modelling and experimental implementation of dual-frequency operation in red-emitting SDLs for quantum technologies.

Tasks: In this project, the student will perform a literature review on SDLs and dual frequency operation; calculate the expected frequency separation and its tunability; design and construct a dual frequency SDL (DF-SDL) cavity; characterise the free-running DF-SDL performance; impleement frequency stabilisation, characterise its performance when locked and estimate the DF-SDL linewidth; compare the results with a single frequency SDL.

Key references:

[1] P.H. Moriya et al., "Sub-kHz-linewidth VECSELs for cold atom experiments," Opt. Express 28, 15943-15953 (2020).
[2] H. Liu et al., "Ultra-low noise dual-frequency VECSEL at telecom wavelength using fully correlated pumping," Opt. Lett. 43, 1794-1797 (2018)
[3] M. Guina, A. Rantamäki and A. Härkönen, “Optically pumped VECSELs: review of technology and progress”, Journal of Physics D 50, 383001 (2017).

Theory: 20% **Comp:** 20% **Exp:** 60% (subject to restrictions)

Recommended Background or Pre-Requisites: Student should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations; Origin for plot and data analysis . Recommended modules PH462 Topics in Quantum Optics, PH455 Topics in Photonics,

Safety Training (if applicable): Laser safety training is required.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: This project is open to one student.

Nanosecond pulsed light-emitting diodes

Project ID: TBC

Division: IoP

Primary Supervisor: Johannes Herrnsdorf

Email: johannes.herrnsdorf@strath.ac.uk

Secondary Supervisor(s): Jonathan McKendry

Project Background: Owing to recent and ongoing advances in silicon based single photon detector technology, the field of nanosecond timescale imaging is rapidly evolving and has important applications. These include fluorescence lifetime imaging which is an important tool for life sciences, and light detection and ranging (LIDAR) which is being used, for example, in remote gas sensing or in self driving cars. This project will contribute to utilising light-emitting diodes (LEDs) as the illumination source for these types of imaging applications. LEDs have revolutionised the lighting and display sectors through their energy efficiency, colour rendering and colour gamut capabilities, and display contrast. Recent research has shown that Gallium Nitride based LEDs with emission wavelengths in the ultraviolet to visible wavelength region (280 nm - 520 nm) have switching characteristics that approach a regime normally associated with lasers. There have been some early stage demonstrations of using nanosecond pulsed LEDs for fluorescence lifetime measurements and 3D range imaging.

Aim: To investigate different methods of generating few nanosecond long optical pulses with light-emitting diodes for use in conjunction with single-photon detectors for remote sensing applications.

Tasks: familiarisation with important characteristics of LEDs; familiarisation with different methods of operating LEDs in nanosecond pulsed mode; characterisation of optical output pulses (pulse duration, rise/fall times, pulse energy, repetition rate); assessment of the measured characteristics with respect to the requirements of remote sensing applications

Key references:

[1] Rae et al., A CMOS Time-Resolved Fluorescence Lifetime Analysis Micro-System Sensors 9, 9255-9274; doi:10.3390/s91109255 (2009)
[2] Griffiths et al., Multispectral time-of-flight imaging using light-emitting diodes, Opt. Express 27, 35485, https://doi.org/10.1364/OE.27.035485 (2019)
[3]

Theory: 20% **Comp:** 10% **Exp:** 70%

Recommended Background or Pre-Requisites: Optics and Photonics

Safety Training (if applicable): Laser safety training required, building access to TIC 507 required

Suitable for: MPhys, BSc

Misc:

Photon propagation through scattering and absorbing media

Project ID: TBC **Division:** IoP

Primary Supervisor: Jonathan McKendry **Email:** jonathan.mckendry@strath.ac.uk

Secondary Supervisor(s): Johannes Herrnsdorf

Project Background: The absorption and scattering of light in media such as air or water has significant implications for applications such as optical wireless communications or remote sensing, as these processes can attenuate the transmitted signals as well as affect their spatial and temporal characteristics. It is particularly important to understand how transmitted signals are affected by these processes and understand what are the resulting implications for system performance, such as achievable data rates and range.

Aim: To undertake a study of the absorption and scattering of optical signals in media such as air and water, with particular emphasis on the implications for optical wireless communication and sensing using visible or UV light.

Tasks: Review the known physics of scattering of UV-visible light in water and air. Familiarisation with the basic principles of optical communication and remote sensing in order to provide a basic analysis as to how these signals would be affected by the processes of light absorption and scattering.

Key references:

[1] The second semester will combine some simple channel modelling (using e.g. Monte Carlo code written in MATLAB/Python, or commercial ray-tracing software such as Zemax OpticStudio). This will be compared with results obtained from laboratory-based experiments on scattering water samples and the accuracy of predictions made by the computer modelling analysed.
[2] Optical communications through water: G. N. Arvanitakis et al., "Gb/s underwater wireless optical communications using series-connected GaN micro-LED arrays," IEEE Photonics Journal, vol. 12, no. 2, pp. 7901210-7901210, 2020, doi: 10.1109/jphot.2019.2959656.
[3] Optical communications using ultraviolet light: D. M. Maclure et al., "10 Gbps wavelength division multiplexing using UV-A, UV-B, and UV-C micro-LEDs," Photonics Research, vol. 10, no. 2, pp. 516-523, 2022/02/01 2022, doi: 10.1364/PRJ.445984

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background or Pre-Requisites: Knowledge of either Matlab or Python. Experience with operating light-emitting diodes and/or laser diodes would be beneficial.

Safety Training (if applicable): Laser safety training

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: If lab-access is not possible, then stronger emphasis on computer-based modelling is possible.

Detection of photonic correlations with a single-photon detector

Project ID: TBC

Division: IoP

Primary Supervisor: Lucia Caspani

Email: lucia.caspani@strath.ac.uk

Secondary Supervisor(s): Michael Strain

Project Background: The possibility to generate and characterise quantum states of light is at the core of many quantum technologies. Among the different characterisation techniques, coincidence detection (the measurement of the simultaneous arrival of two photons) is probably the most widespread in quantum photonics.

This is typically achieved by correlating the output of two single-photon detectors. It is possible to properly modulate the signal to be measured in time so that only one detector can be used, thus reducing resource overload.

Aim: The student will develop the time-multiplexer and measurement system to perform photon coincidences with only one single-photon detector.

Tasks: A literature review of coincidence measurements and their applications. The student will then develop the experimental setup to perform time multiplexing and the required software for the coincidence detection.

The student will then use the system developed to perform coincidence detection in the lab.

Key references:

[1] L. Caspani et al., "Integrated sources of photon quantum states based on nonlinear optics," Light Sci. Appl. 6, e17100 (2017).
[2] D. Stucki et al., “Photon counting for quantum key distribution with Peltier cooled InGaAs/InP APDs”, Journal of Modern Optics 48, 1967 (2001).
[3]

Theory: 0% **Comp:** 30% **Exp:** 70%

Recommended Background or Pre-Requisites: Recommended module PH455 (Topics in Photonics). Previous experience with Matlab (or Python) will be useful, but not essential. An understanding of optics and electromagnetic fields will be a useful background.

Safety Training (if applicable): Laser safety training.

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Unclonable physical encryption using photonic chips

Project ID: TBC

Division: IoP

Primary Supervisor: Michael Strain

Email: michael.strain@strath.ac.uk

Secondary Supervisor(s): Jack Smith

Project Background: Data transmission security and unique device identification are crucial elements in electronic security systems. A particularly promising form of physical encryption relies on the concept of Physically Unclonable Functions. By creating a device that cannot be reverse engineered from its response to some stimulus, a physically secure challenge-response authentication scheme can be implemented. For example, the reflection spectrum response from an optical device to a laser input would allow remote connection and verification of an unclonable system via optical fibre connection. To implement such a scheme, Photonic Integrated Circuit (PIC) components can be used. PICs are compact systems-on-a-chip that allow the integration of micron scale optical devices in complex circuits. The fabrication of these devices is subject to nanoscale physical variations, which under the right conditions can be used to create physically unclonable systems. Furthermore, by adding active electronic control to the PIC a vast parameter space can be accessed producing complex device responses that can be varied in micro-second timescales, enhancing the security of the system. Thus far only simple, passive or single electronic control systems have been demonstrated. This project will aim to show multi-control, high speed generation of randomised optical functions robust to even machine learning based attacks.

Aim: Experimental measurement of reconfigurable photonic chips to demonstrate unclonable functions.

Tasks: Training on optical device testing setup (laser injection, optical chip handling, electronic probes and measurement equipment). Electronic control of automated measurement systems to enable large data set collection from existing optical chip devices with electonic controls. Data analysis and verification of physically unclonable function generation. Comparison of nominally identical devices to demonstrate random function generation and unclonability.

Key references:

[1] F. Bin Tarik, D. Joyce, Y. Lao, and J. D. Ryckman, "Electrically Reconfigurable Photonic PUF Based on a Moiré Quasicrystal Interferometer," Conf. Lasers Electro-Optics JW3A.30 (2022).
[2] T. H. Talukdar, A. L. Hardison, and J. D. Ryckman, "Moiré Effects in Silicon Photonic Nanowires," ACS Photonics 9(4), 1286–1294 (2022).
[3]

Theory: 10% **Comp:** 30% **Exp:** 60%

Recommended Background or Pre-Requisites: A background in photonics and familiarity with basic lab equipment (oscilloscopes, labview programming, optical fibres etc.) would be beneficial but not expected.

Safety Training (if applicable): Laser safety training.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: 1 student only

Thermal measurement and modelling of neural microLED probes

Project ID: TBC

Division: IoP

Primary Supervisor: Niall McAlinden

Email: niall.mcalinden@strath.ac.uk

Secondary Supervisor(s): Keith Mathieson

Project Background: As neural devices become more sophisticated more electrically active elements are being implanted in the brain. These active elements produce heat which alters the properties of the neural circuits you are attempting to study. Therefor, accurate measurement of the thermal properties of devices is critical before devices can be implanted. Thermal modelling can also be used to give new insights into temperature flow in devices and to suggest design optimisations.

Aim: To measure the thermal properties of microLED probes for neural applications. The temperature of active elements of the device will be measured in air using a thermal camera and in water using a fluorescent based technique. Furthermore a thermal model of the device will also be developed which may point to design improvements.

Tasks: 1) Review current technologies for illuminating brain tissue, including implantable waveguides and LEDs. 2) Survey literature on the temperature dependence of fluorophores. 3) Develop a COMSOL model to study the thermal properties of a neural probe. 1) Measure the thermal properties of a neural probe in air using a thermal camera 2) Measure the thermal properties of a neural probe in water based solution. This will be more representative of how the device will behave in tissue.

Key references:

[1] Depth-specific optogenetic control in vivo with a scalable, high-density µLED neural probe https://doi.org/10.1038/srep28381

[2] Multisite microLED optrode array for neural interfacing https://doi.org/10.1117/1.NPh.6.3.035010

[3] Injectable, Cellular-Scale Optoelectronics with Applications for Wireless Optogenetics https://doi.org/10.1126/science.1232437

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background or Pre-Requisites: Students should have a strong background in photonics. Students should have access to a good internet connection, they will be required to remote login to a computer to run COMSOL simulations. Previous experience of using COMSOL is helpful but not essential.

Safety Training (if applicable): Laser safety training will be required before lab work begins

Suitable for: Suitable for MPhys, BSc Hons, BSc Maths and Physics, Physics with Teaching

Misc:

Reflectometry-based readout of semiconductor quantum devices

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Alessandro Rossi

Email: alessandro.rossi@strath.ac.uk

Secondary Supervisor(s): Robert Martin

Project Background: Gate-based reflectometry readout promises to solve a number of issues for probing quantum bits in semiconductors, which the research community is currently facing in scaling up small rudimentary quantum machines towards large-scale commercially viable computers. I have collected reflectometry data on silicon quantum devices throughout the years. There is a need for these to be modelled and, in-so-doing, explain the signature left by quantum mechanical processes on the experimental signals obtained via reflectometry readout. The student will be provided with a set of experimental data to be analysed with scientific software such as Matlab, Python or Origin. The aim will be to develop a self-contained physical model that fits the experimental results. This analysis will provide crucial information for understanding the reflectometry readout capabilities (e.g. extraction of quantum capacitance, coupling factor, noise figure). The main features that the physical model developed by the student will include are:

- Description of a double quantum dot system in terms of its Hamiltonian and energy spectrum
- Calculation of the reflectometry signal based on the energy levels and charge state of the system
- Account for non-ideal experimental conditions such as electrical crosstalk and temperature instability

Aim: Modeling experimental data with a computational approach

Tasks: Familiarising with relevant literature and experimental data. Model a standard double quantum dot system through computational approach based on a software of choice. Theoretical description and formulation of the experiment. Fit the experimental data.

Extract unknown experimental parameters and check their consistency with established literature. Report.

Key references:

[1] Ahmed et al., Phys. Rev. Applied 10 (1), 014018 (2018)
[2] West et al., Nature Nanotechnology 14 (5), 437 (2019)
[3] Schaal et al.,Nature Electronics 2 (6), 236 (2019)

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background or Pre-Requisites: Matlab

Safety Training (if applicable): none

Suitable for: all

Misc: 1 student only

Twisted nano structures

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Ben Hourahine

Email: benjamin.hourahine@strath.ac.uk

Secondary Supervisor(s): Oliver Henrich

Project Background: In addition to the familiar repeating arrays of atoms in crystals, there are several other types of large ordered arrangements of atoms which occur in nature which are not periodic. Traditionally these are investigated by either using large clusters of atoms to describe segments of the structure, or as a crystal with a large number of atoms in its unit cell which approximates the real geometry. Both of these approaches require the simulation of very large numbers of atoms (in principle up to an infinite number in some cases), even though the fundamental repeating unit is often much smaller. Systems to be studied in this project are helical tubes and ribbons of modern 2D materials.

Aim: This project applies concepts from the study of the properties of mater to understand the results of simulating complex nanostructures.

Tasks: 1) Review literature discussing helical nano-structures and concepts related to the electronic structure and mechanics of bending, torsion and stretching of nanostructures. 2) Learn, by working through tutorial materials, how to use the DFTB+ code for large scale quantum mechanical modeling. 3) Simulate electronic and mechanical properties of helical nanostructures.

Key references:

[1] Formation of helices in graphene nanoribbons under torsion. Nikiforov et al. Journal of Physical Chemistry Letters 5, 4083 (2014).

[2] Collapsed carbon nanotubes: From nano to mesoscale via density functional theory-based tight-binding objective molecular modeling. Xu et al. Carbon, 143, 786 (2019).

[3] DFTB+, a software package for efficient approximate density functional theory based atomistic simulations, Hourahine et al. J. Chem. Phys. 152, 124101 (2020)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Interest in Solid State Physics and nanoscience (previous attendance of PH386 Condensed Matter Physics or equivalent) and registration to attend PH454 Topics In Nanoscience

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Low cost, multi-modal microscopy

Project ID: TBC **Division:** Nanoscience

Primary Supervisor: Brian Patton **Email:** brian.patton@strath.ac.uk

Secondary Supervisor(s): David McKee

Project Background: Traditional wide-field microscopes use simple illumination configurations with their design being fixed by the imaging mode (brightfield, darkfield, phase contrast) to be performed. Switching imaging modes is typically not a trivial task and may even be impossible in some designs. Adaptive optics enhancement of the widefield microscope using dynamically reconfigurable devices such as deformable mirrors or spatial light modulators has typically only addressed the detection path of the microscope and has left the illumination path untouched. A recent paper has shown how the incorporation of a low-resolution liquid crystal display (LCD) into the illumination path greatly expands the usefulness of a given wide-field microscope.

This project aims to develop a testbed for these dynamically reconfigurable illumination systems. It will initially involve some simple optical design and construction to build the testbed microscope. The majority of the project will involve programming the LCD to generate the test patterns used in the different imaging modes and analysing the data generated by the imaging system.

Aim: By incorporating consumer LCD displays into the illumination path of a microscope, this project will allow multiple imaging techniques be implemented on a single device.

Tasks: Designing and building a simple wide-field microscope. Incorporating an LCD display into the illumination arm. Programming the display to precisely control the illumination. Testing the different imaging techniques that this will allow.

Key references:
[1] “Microscopy illumination engineering using a low-cost liquid crystal display”, Kaikai Guo et al., DOI: 10.1364/BOE.6.000574
[2] "Programmable aperture microscopy: A computational method for multi-modal phase contrast and light field imaging", Chao Zuo et al., DOI: 10.1016/j.optlaseng.2015.12.012
[3]

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background or Pre-Requisites: Interest in optics. Good ability with Python programming is absolutely essential.

Safety Training (if applicable): Laser safety training will be needed. Depending on the test system, we may identify a need for biological safety training in the second semester.

Suitable for: All

Misc:

LED arrays for differential phase contrast microscopy

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Brian Patton

Email: brian.patton@strath.ac.uk

Secondary Supervisor(s): Gail McConnell

Project Background: By changing the illumination source on a microscope from a simple, uniform illumination, to one that can generate specific illumination patterns at the sample, it becomes possible to determine the impact of a sample of the phase of the light propagating through it. This is useful when looking at almost transparent samples, such as cells or some small aquatic organisms. This project will implement a version of active illumination using LED arrays to perform differential phase contrast imaging. The image reconstruction techniques will be based on the work of Prof Laura Waller's group in Berkeley.

Aim: Direct control over illumination patterns allows information on the refractive index of a complex sample be determined. This project will implement a scheme using low cost LED arrays to do differential phase contrast microscopy.

Tasks: Designing and building a simple wide-field microscope. Incorporating an LED display into the illumination arm. Controlling the illumination to obtain images suitable for DIC imaging. If time allows, testing some of the more computationally complex approaches from the Waller lab.

Key references:

[1] "3D differential phase-contrast microscopy with computational illumination using an LED array", Lei Tian et al., DOI: 10.1364/OL.39.001326

[2] "Quantitative differential phase contrast imaging in an LED array microscope", Lei Tian et al., DOI: 10.1364/OE.23.011394

[3] http://www.laurawaller.com/opensource/

Theory: 30% **Comp:** 30% **Exp:** 40%

Recommended Background or Pre-Requisites: Interest in Optics. Good ability with Python is essential.

Safety Training (if applicable): Due to the other work within the reserch group, laser training will be essential.

Suitable for: All

Misc:

Modelling scattering from natural particle populations in the marine environment.

Project ID: TBC

Division: Nanoscience

Primary Supervisor: David McKee

Email: david.mckee@strath.ac.uk

Secondary Supervisor(s): Brian Patton

Project Background: Scattering of light by particles plays an imprtant role in determining the reflectance signal measured by ocean colour satellites. The volume scattering function (VSF) describes the angular distribution of light scattering. Simplistic modelling of the particle size distribution (PSD) suggests that the VSF is wavelength independent. However, fiedl observations suggest the VSF is wavelength dependent. This project will use Mie theory to model particulate light scattering and assess the sensitivity of the VSF to deviations from assumed power law PSDs.

Aim: Test the sensitivity of particle scattering properties to changes in particle size distribution.

Tasks: 1. Literature review. 2. Familiarisation with Mie Theory. 3. Development of integrated optical mode (PSD - VSF). 1. Validate optical model against literature. 2. Systematically test deviations from power law PSD on VSF. 3. Assess impact of optically complex particles.

Key references:

[1] https://doi.org/10.1364/AO.53.001067
[2] https://doi.org/10.1364/AO.57.001777
[3] https://doi.org/10.1016/j.jqsrt.2019.106730

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background or Pre-Requisites: Competent programming ability in either Matlab or Python.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Could run with more than one student, but would be running in parallel towards same goal.

How to measure the bandgap energy of wide bandgap semiconductors?

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Fabien Massabuau

Email: f.massabuau@strath.ac.uk

Secondary Supervisor(s): Rob Martin

Project Background: The bandgap energy of a semiconductor is commonly defined as the difference in energy between the bottom of the conduction band and the top of the valence band. Experimental manifestations of the bandgap can be seen across a range of techniques, including in UV-vis spectrophotometry where the absorption spectrum displays a clear edge at the bandgap energy. However, putting an actual number on the bandgap energy can be a challenging task, in part due to different ways to interpret the above definition of the bandgap.

In the context of UV-vis spectrophotometry, several data analysis methods have been suggested to extract the bandgap energy from the absorption spectrum, with perhaps the most widespread of them tracing back to Tauc's work in the 1960s [Ref. 1]. Since then, the "Tauc method" has been generalised and employed across a range of semiconductors, but its validity and applicability remains controversial. More generally, the question of determining the bandgap energy of semiconductors is still an open debate.

In this project, we aim to investigate the definition of bandgap and how it applies to UV-vis spectrophotometry of wide bandgap semiconductors.

Aim: Investigate experimental methods to determine the bandgap of semiconductors

Tasks: The student will (i) review and critically assess the methods to determine the bandgap, (ii) acquire UV-vis spectrophotometry dataset for a range of wide bandgap semiconductors (e.g. Ga_2O_3, BN, AlGaN), and (iii) analyse the dataset in light of the literature search.

Key references:

[1] Tauc et al., Phys. Stat. Solidi B 15, 627 (1966) https://doi.org/10.1002/pssb.19660150224
[2] Zanatta, Sci. Rep. 9, 11225 (2019) https://doi.org/10.1038/s41598-019-47670-y
[3]

Theory: 30% **Comp:** 40% **Exp:** 30%

Recommended Background or Pre-Requisites: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386).

Attendance to "Topics on Solid State Physics" module (PH453) is strongly recommended.

Safety Training (if applicable): Technology and Innovation Centre building induction training

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Photoconduction in wide bandgap semiconductors

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Fabien Massabuau

Email: f.massabuau@strath.ac.uk

Secondary Supervisor(s): Paul Edwards

Project Background: Photoconduction is one of the fundamental properties of semiconductors where incident photons at the appropriate energy generate free carriers in the material, thus increasing its conductivity (This is the mechanism underpinning solar cell operations). In the case of wide bandgap semiconductors (bandgap typically >3.5 eV), photoconduction happens in the ultraviolet region of the light spectrum.

Studying photoconduction – for example, how much current is generated upon illumination, at which wavelength current is generated, or how fast the current responds to light stimuli – can reveal a great deal of information about the electronic structure of the material. However when it comes to wide bandgap materials, knowledge in that field is lacking.

Our group has recently built a setup specifically designed to conduct photoconduction measurements of wide bandgap semiconductors (such as Ga2O3, AlGaN, etc).

Aim: Analyse the photoconduction properties of wide bandgap semicondutors

Tasks: The student will (i) assess the literature on photoconduction on other materials to identify gaps of knowledge in wide bandgap semiconductor characterisation, and (ii) use these methods to guide the data acquisition on our setup and perform the resulting data analysis.

Key references:

[1] Reynolds et al (2017). Photoconductivity in Materials Research. In: Kasap, S., Capper, P. (eds) Springer Handbook of Electronic and Photonic Materials. Springer Handbooks. https://doi.org/10.1007/978-3-319-48933-9_7
[2] Bube, Photoelectronic properties of semiconductors, Cambridge University Press 1992
https://suprimo.lib.strath.ac.uk/permalink/f/2esacs/SUALMA2142838120002996
[3] Belgacem et al., Phil. Mag. 99, 131 (2019) https://doi.org/10.1080/14786435.2018.1532120

Theory: 20% **Comp:** 40% **Exp:** 40%

Recommended Background or Pre-Requisites: The student should be comfortable with the content of the “Condensed Matter Physics” module (PH386).

Attendance to “Topics on Solid State Physics” module (PH453) is strongly recommended.

Safety Training (if applicable): Technology and Innovation Centre building induction training

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Fabrication of low-cost and tuneable UV detectors

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Fabien Massabuau

Email: f.massabuau@strath.ac.uk

Secondary Supervisor(s): Paul Edwards

Project Background: Gallium oxide (Ga2O3) is an emerging wide bandgap semiconductor (bandgap ~5eV) that finds applications in high power transistors, and ultraviolet detectors. Owing to its role in UV detection, Ga2O3 holds the key for a more sustainable future – in particular for ensuring access to clean water.

However, the production of current Ga2O3 materials relies on expensive processed and multi £M equipment. In order to ensure prompt development of the technology and ensure access to clear water for all, it is imperative to design low-cost routes to design the materials.

Being a metal oxide, Ga2O3 can in principle be produced using chemical solution deposition, which presents the benefit of being much more versatile and cost-effective than conventional fabrication routes. However, that approach has been overlooked by the community, and the conditions leading to high-performing devices using that route are at the moment unexplored. The project aims to fill in that gap of knowledge.

Aim: Synthesise and characterise Ga2O3 materials produced through chemical soution deposition

Tasks: The student will (i) review the literature on chemical solution deposition of gallium oxide and related materials, (ii) produce Ga2O3 films exploring a range of parameters, and (iii) characterise the films using scanning electron microscopy and UV-vis spectrophotometry. If time allows, (iv) we will process the films into UV detectors and test their characteristics.

Key references:

[1] Kokubun et al, Appl. Phys. Lett. 90, 031912 (2007) https://doi.org/10.1063/1.2432946
[2] Kokubun et al, Phys. Status Solidi A 207, 1741 (2010) https://doi.org/10.1002/pssa.200983712
[3] Tak et al., J. Phys. D: Appl. Phys. 54, 453002 (2021) https://doi.org/10.1088/1361-6463/ac1af2

Theory: 10% **Comp:** 30% **Exp:** 60%

Recommended Background or Pre-Requisites: The student should be comfortable with the content of the "Condensed Matter Physics" module (PH386).

Attendance to "Topics on Solid State Physics" module (PH453) is strongly recommended.

Safety Training (if applicable): Chemical safety training (COSHH)

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Optical characterisation of 3D printed lenses

Project ID: TBC
Division: Nanoscience

Primary Supervisor: Gail McConnell
Email: g.mcconnell@strath.ac.uk

Secondary Supervisor(s): Liam Rooney

Project Background: In 2014, the first 3D printing of glass was achieved and now there are many techniques available for precision printing of multi-element glasses with complex shapes, including fused deposition modelling and laser-assisted filament melting. These methods have produced individual optical-quality 3D printed glass elements with nanometre-scale surface roughness. These include the production of optical-quality prisms with high optical transmission using a standard consumer-grade 3D printer, and using a spin coating post-processing step, a surface roughness of <100 nm was achieved. There are also several examples of 3D printing of individual optically transparent lens elements with good focusing power, ranging from simple camera lenses to graded-index lenses. Our aim is to produce multi-element 3D printed lenses that can be used for advanced imaging applications. To achieve this, we must define a repeatable and accurate test protocol to assess lens performance. This project will involve the application of existing lens characterisation methods such as beam profiling and optical transparency methods to help define this quality test and assurance pipeline.

Aim: The aim of the project is to use existing optical characterisation methods to measure the properties of 3D printed glass lenses.

Tasks: 1 - 3D printing of plano-convex lenses (CAD, 3D printing). 2 - Characterisation of optical performance and damage thresholds. 3 - Analysis of data.

Key references:

[1] N. Vaidya & O. Solgaard. Nat. Micro & Nano. 4:18 (2018).
[2] S. Bakas et al. biorxiv (2021). https://doi.org/10.1101/2021.02.13.431066
[3] R. Dylla-Spears et al. Sci. Adv. 6:eabc7429 (2020).

Theory: 0% **Comp:** 25% **Exp:** 75%

Recommended Background or Pre-Requisites:

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Disruption of mature colony biofilms using magnetic fields

Project ID: TBC **Division:** Nanoscience

Primary Supervisor: Gail McConnell **Email:** g.mcconnell@strath.ac.uk

Secondary Supervisor(s): Liam Rooney

Project Background: Biofilms are densely packed communities of microbes which are inherently tolerant to chemical/drug treatment due to their physical makeup which restricts penetration. Therefore, they are a major issue for industry and public health, where 80% of chronic infections are biofilm-associated. A recently discovered network of nutrient transport channels has shown promise for introducing exogenous materials into the biofilm (such as nanoparticles). Exploiting the uptake role of biofilm channels to transport magnetic beads into the core of the biofilm could provide a new approach to erradication of difficult-to-treat infections. Application of a magnetic field to permeated biofilms could increase the porosity, and so the penetration of downstream antimicrobial therapies. This project will involve the manufacturing, introduction, and manipulation of magnetic particles to determine if biofilm integrity can be compromised by increasing the porosity of the superstructure.

Aim: The aim of the project is to develop a method of biofilm disruption using magnetic nanoparticles to imrpove downstream antimicrobial therapies.

Tasks: 1 - Manufacture of magnetic nanoparticles. 2 - Growth of E. coli biofilms and introduction of magnetic nanoparticles. 3 - design and use of an experimental setup to apply magneitc fields to biofilms. 4 - Mesoscopic imaging of biofilms with and without nanoparticle manipulation. 5 - data analysis

Key references:

[1] Shi et al. Rationally designed magnetic poly(catechol-hexanediamine) particles for bacteria removal and on-demand biofilm eradication. Colloids Surf. B, 2019, 186(2020):110728

[2] Li et al. A new tool to attack biofilms: driving magnetic iron-oxide nanoparticles to disrupt the matrix. Nanoscale. 2029, 11:6905

[3] Rooney et al. Intra-colony channels in E. coli function as a nutrient uptake system. ISME J. 2020, 14(10):2461-2473

Theory: 0% **Comp:** 25% **Exp:** 75%

Recommended Background or Pre-Requisites:

Safety Training (if applicable): Biological safety training

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Building crystal models for backscatter electron diffraction studies

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Jochen Bruckbauer

Email: jochen.bruckbauer@strath.ac.uk

Secondary Supervisor(s): Carol Trager-Cowan

Project Background: Knowing the crystal structure of materials is crucial for analysing electron backscatter diffraction (EBSD) patterns. The scanning electron microscope technique of EBSD can be used to analyse and map the crystallographic properties of materials, such as crystal structure and crystal orientation. This project aims to build crystal models of alloyed semiconductors, for example, InGaN which is an alloy of GaN and InN. On changing the alloy composition, crystal properties, such as lattice constants and density will change. The influence of alloy composition on crystal structure, and hence its associated EBSD pattern, will be studied by simulating EBSD patterns for different model structures.

Aim: Building crystal structures for analysing backscatter electron diffraction patterns from alloyed semiconductors.

Tasks: Build crystal models for different alloys using VESTA. Simulate electron diffraction patters using these crystal models.

Key references:

[1] K. Momma and F. Izumi, J. Appl. Cryst. 41, 653 (2008)
[2] K. Momma and F. Izumi, J. Appl. Cryst. 44, 1272 (2011)
[3] A. J. Schwartz et al., Electron Backscatter Diffraction in Materials Science (Springer, 2009)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: An aptitude and enthusiasm for programming and for crystallography is essential. The project involves using a 3D visualisation program (VESTA) for crystal structures.

Safety Training (if applicable): None.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Numerical modelling of FRET in beta-amyloid

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Olaf Rolinski

Email: o.j.rolinski@strath.ac.uk

Secondary Supervisor(s): Yu Chen, Karina Kubiak-Ossowska

Project Background: Proteins/peptides are the compositions 20 different aminoacids, three of which (phenylalanine, tyrosine and tryptophan) are fluorescent. This allows using Phe-Tyr or Tyr-Trp pairs as donor-acceptor pairs in FRET-based fluorescence sensing. Because FRET efficiency depends on the donor-acceptor distances, changes in protein conformations due to their physiological or pathological activities can be monitored non-invasively (only by optical exciting fluorescent aminoacids and detectiong their fluorescence) by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of beta-amyloid peptides immersed in physiological water, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for beta-amyloid studies.

Aim: Generate the numerical model of intrinsic fluorescence intensity decays of Phenylalanine in the presence of Phenylalanine to Tyrosine FRET in beta-amyloid peptides.

Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays. Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:

[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Numerical modelling of FRET in nanostructures

Project ID: TBC **Division:** Nanoscience

Primary Supervisor: Olaf Rolinski **Email:** o.j.rolinski@strath.ac.uk

Secondary Supervisor(s): Sebastian Van de Linde, Karina Kubiak-Ossowska

Project Background: The selection of different fluorescent donor-acceptor pairs will be studied in FRET-based fluorescence arrangements. Because FRET efficiency depends on the donor-acceptor distances, changes in conformations of several labelled nanostructures will be monitored indirectly and non-invasively by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of the labelled nanostructures immersed in physiological liquid, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for structural studies of nanostructures.

Aim: Generate the numerical model of fluorescence intensity decays of the Donor in the presence of the Donor-Acceptor FRET in selected nanostructures.

Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays. Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:

[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Numerical modelling of FRET in Human Serum Albumin

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Olaf Rolinski

Email: o.j.rolinski@strath.ac.uk

Secondary Supervisor(s): Yu Chen, Karina Kubiak-Ossowska

Project Background: Proteins/peptides are the compositions 20 different aminoacids, three of which (phenylalanine, tyrosine and tryptophan) are fluorescent. This allows using Phe-Tyr or Tyr-Trp pairs as donor-acceptor pairs in FRET-based fluorescence sensing. Because FRET efficiency depends on the donor-acceptor distances, changes in protein conformations due to their physiological or pathological activities can be monitored non-invasively (only by optical exciting fluorescent aminoacids and detectiong their fluorescence) by measuring changes in FRET effects. In this project, student will perform Molecular Dynamics (MD) calculations of the HSA immersed in physiological water, estimate resulting FRET effects and predict expected changes in fluorescence intensity decays. Research will demonstrate feasibility of the proposed approach for albumin studies.

Aim: Generate the numerical model of fluorescence intensity decays of Tyrosine in the presence of Tyrosine to Tryptophan FRET in human serum albumin.

Tasks: 1. Attending the MD course; 2.Gaining the experience in calculating trajectory using a simple 1 molecule in water system; 3. calculating donor-acceptor distances and mutual orientations between donors and acceptors; 4. Calculating the rate of FRET and predicted fluorescence intensity decays. Expanding the methods developed in the 1st semester to the real molecular systems. Simulating experimental data obtained in fluorescence time-resolved experiment.

Key references:

[1]
[2]
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should be fluent in using computer, but the training in using MD software will be provided.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Web-based electron diffraction tool

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Paul Edwards

Email: paul.edwards@strath.ac.uk

Secondary Supervisor(s): Carol Trager-Cowan

Project Background: The diffraction of electrons provides a valuable method of characterising crystalline materials in an electron microscope. The observed "Kikuchi" diffraction pattern changes with the orientation of the crystal, and this project aims to produce web-based code for visualising this dependence. Open-source JavaScript crystal modelling software (JSmol) will be combined with a pre-calculated Kikuchi sphere to produce an interactive educational and research tool.

Aim: Implement JavaScript code for interactive visualisation of electron diffraction in a crystal

Tasks: Review basics of crystallography (including Miller index notation). Literature survey on electron backscatter diffraction (EBSD) and the simulation of Kikuchi patterns. Learn the basics of JavaScript/Jsmol/WebGL using online resources. Adapt existing JavaScript code to implement models of crystals (Jsmol) and display Kikuchi sphere (WebGL). Research and implement necessary code for integrating these aspects.

Key references:

[1] Electron Backscatter Diffraction in Materials Science
https://suprimo.lib.strath.ac.uk/permalink/f/1jihtat/TN_cdi_springer_primary_978-0-387-88136-2_95665
[2] Many-beam dynamical simulation of electron backscatter diffraction patterns
https://doi.org/10.1016/j.ultramic.2006.10.006
[3] Jsmol interctive scripting documentation https://chemapps.stolaf.edu/jmol/docs/

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: While prior knowledge of JavaScript is not required, an aptitude and enthusiasm for coding is essential.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Electron microscope analysis of semiconductor alloys

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Paul Edwards

Email: paul.edwards@strath.ac.uk

Secondary Supervisor(s): Robert Martin

Project Background: AlN, GaN and InN are semiconducting materials with bandgaps spanning the near-IR to the deep-UV. Mixtures of these materials have properties which are strongly dependent on the alloy composition, which can be accurately measured using wavelength-dispersive X-ray analysis. Advances in detector design and simulation software have opened up the possibility of acquiring similar information using the quicker and less expensive technique of energy-dispersive X-ray spectroscopy. This project will test how this method can be applied to nitride materials, combining simulations using the NIST DTSA-II Monte Carlo code and measurement data from our scanning electron microscope.

Aim: Simulate the generation of X-rays from semiconductor alloys in an electron microscope

Tasks: Review basics of electron microscopy and characteristic X-ray generation. Literature survey on the use of energy-dispersive X-ray (EDX) microanalysis in the quantitative determination of elemental compositions. Develop familiarity with the use of DTSA-II Monte Carlo simulations to generate and analyse EDX spectra. Undertake systematic range of simulations to investigate the limitations of the technique imposed by resolution and noise. Develop a model to predict the precision in elemental composition achievable for given experimental parameters.

Key references:

[1] Microcomposition and luminescence of InGaN emitters
http://dx.doi.org/10.1002/1521-396X(200207)192:1%3C117::AID-PSSA117%3E3.0.CO;2-W
[2] EDS measurements of X-Ray intensity at WDS precision and accuracy using a silicon drift detector
https://doi.org/10.1017/S1431927612001109
[3] DTSA-II documentation https://www.nist.gov/services-resources/software/nist-dtsa-ii

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Enrollment on PH453 Topics in Solid Sate Physics would be an advantage

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Electrical control of spin qubits in Silicon Carbide (SiC)

Project ID: TBC **Division:** Nanoscience

Primary Supervisor: Prince Khatri **Email:** prince.khatri@strath.ac.uk

Secondary Supervisor(s): Dr. Alessandro Rossi

Project Background: Point defects in Silicon carbide (SiC) can host quantum bits or qubits, the quantum counterpart of the the classical binary bits in modern computers. These defects can be created on demand with techniques like electron irradiation, ion beam implantation or thermal annealing, providing localised solid-state array of qubits that could enable large scale quantum computers to be realised. SiC is a material that has been used to make the first LED in 1907 and is widely employed for high power electronics. For these reasons its manufacturing is mature and comes at a fraction of the cost of competing quantum technologies like diamond or superconductors. The initialization and readout of SiC qubits can be easily done with optical techniques like optically detected magnetic resonance (ODMR) and photoluminescence measurements (PL) which generate flying qubits for entanglement. A major hurdle for the commercialisation of SiC quantum devices is that optical techniques are neither scalable nor economical for industry applications.

Aim: In this project, the student will aim to prepare a blueprint technique to electronically read, manipulate and initialize qubits in Silicon Carbide (SiC).

Tasks: Student will explore gate based dispersive readout techniques for this purpose which senses change of capacitance in the electron box coupled to the defect making it ultra-sensitive for defects lying very close to the sensor. To achieve this target, one needs to consider: (i) choice of atomic dopant species best suited for electrical readout. (ii) Effects of defect location from the sensor box as well as implantation depth in the sample. (iii) Design of the gate structure to achieve desired potential profile in the device. (iv) Quantitative prediction of the resonator phase response via simulation, taking into consideration the parameters such as potential profile, coupling, defect sensor proximity and nearby disorders.

Key references:

[1] Stefania Castelletto and Alberto Boretti 2020, Silicon carbide color centers for quantum applications, J. Phys. Photonics 2 022001

[2] Christle, D., Falk, A., Andrich, P. et al. Isolated electron spins in silicon carbide with millisecond coherence times. Nature Mater 14, 160–163 (2015).

[3] Son, N. T., Anderson, C. P., Bourassa, A., Miao, K. C., Babin, C., Widmann, M., Niethammer, M., Ul Hassan, J., Morioka, N., Ivanov, I. G., Kaiser, F., Wrachtrup, J., & Awschalom, D. D. (2020). Developing silicon carbide for quantum spintronics. In Applied

Theory: 100% **Comp:** 0% **Exp:** 0%

Recommended Background or Pre-Requisites: The student must have a background in semiconductor physics and photonics (e.g. PH963, PH962 and PH957) and basic research paper reading skills. This project is primarily computational and theory based providing flexible/remote working. There will be opportunity to visit to our under construction dilution cryostat lab and electroluminescence measurement setup. We don't expect up-to-date knowledge of quantum electronics but a willingness to learn and logical thinking is crucial.

Safety Training (if applicable): No specail trainings, only lab inductions if required.

Suitable for: MPhys, BSc Physics

Misc: 1 student

Simulation and measurement of X-ray microanalysis of semiconductors

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Robert Martin

Email: r.w.martin@strath.ac.uk

Secondary Supervisor(s): Paul Edwards

Project Background: A key to enhancing the range and performance of semiconductor devices, such as laser diodes or transistors, is the production of new alloys with different band-gaps, carrier mobilities, etc. One example of this is the development of laser diodes using devices based on AlGaAs for CDs, then GaInP for DVDs and onto GaInN for BluRay. An electron probe microanalyser (EPMA), such as the one in the TIC building (https://ssd.phys.strath.ac.uk/facilities/) analyses emitted X-rays to measure the elemental composition of these semiconductor alloys. The experimental results can be simulated using well-developed Monte-Carlo software programs, such as NIST DTSA-II or PENEPMA (see references for more information). Comparison of simulated data with that measured in the lab. from various semiconductor layers, such as novel BGaN samples, will be used to assess the accuracy of the simulations and the measurements.

Aim: To use and compare two software packages that simulate X-ray emission from semiconductor samples and then relate these to spectra measured in the lab.

Tasks: Task 1: Develop understanding of the basics of characteristic X-ray generation and of electron probe microanalysis. Task 2: Work with the DTSA-II and PENEPMA software tools to achieve simulations of X-ray spectra from specific semiconductor alloys and go on to establish how to generate elemental compositions by comparison with standard samples.

Key references:

[1] [1] Publication based on previous project : D.A. Hunter at al. "Assessing the Impact of Secondary Fluorescence on X-Ray Microanalysis Results from Semiconductor Thin Films" Microscopy & Microanalysis 2022 : doi:10.1017/S1431927622000770

[2] [2] PENEPMA : X Llovet and F Salvat 2016 IOP Conf. Ser.: Mater. Sci. Eng. 109 012009 : doi:10.1088/1757-899X/109/1/012009

[3] [3] DTSA-II documentation : https://www.cstl.nist.gov/div837/837.02/epq/dtsa2/index.html

Theory: 0% **Comp:** 70% **Exp:** 30%

Recommended Background or Pre-Requisites:

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Optical properties of metal-dielectric nanocomposites

Project ID: TBC **Division:** Nanoscience

Primary Supervisor: Yu Chen **Email:** y.chen@strath.ac.uk

Secondary Supervisor(s): Francesco Papoff

Project Background: There is a strong drive for further miniaturization of lasers, photonics devices and sensors. Confining light to small, in particular sub-wavelength, scales requires high refractive index contrasts for waveguides as well as periodic photonic structures. Plasmonic nanostructures can confine electromagnetic fields into spatial regions well below the diffraction limit, resulting in significant enhancement of the fields. Specially, noble metal nanoparticles have localized surface plasmon resonance dependent on their size, shape and dielectric constant of medium [1], exhibiting tuneable refractive index when they are embedded in a dielectric matrix and form metasurfaces [2]. A recent study on the plasmonic nanoparticle superlattices found that photonic crystals based on noble metal nanoparticles of controlled spacing have high refractive indices even far away from the plasmon frequency where losses are low, suggesting a potential high performance dielectric materials based on noble metal nanoparticles [3].

Aim: The aim of the project is to understand the correlation between nanocomposite structure/composition and their refractive indices.

Tasks: literature search to review the optical properties of noble metal nanostructures of different structure and composition; design/select nanostructures for simulation; study FDTD simulation FDTD simulation of selected nanostructures; study the correlation between structure and refractive indices; writing report.

Key references:

[1] Eustis, S. and El-Sayed, MA. Why gold nanoparticles are more precious than pretty gold. Chem. Soc. Rev. 35, 209-217 (2006)
[2] Doyle, D. et al. Tunable subnanometer gap plasmonic metasurfaces, ACS Photonics, 5, 1012 (2018).
[3] Sun, L., et al. Design principles for photonic crystals based on plasmonic nanoparticle superlattices, PNAS, 115, 7242 (2018).

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: An interest in nanoscience and photonics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Plasmon enhanced fluorescence

Project ID: TBC

Division: Nanoscience

Primary Supervisor: Yu Chen

Email: y.chen@strath.ac.uk

Secondary Supervisor(s): Olaf Rolinski

Project Background: Fluorescence spectroscopy and microscopy are powerful tools for non-invasive and non-destructive detection and visualization, capable of sensing and imaging at single molecule level. Despite the advantages, fluorescence technique is limited by weak emission from intrinsic fluorescence. Noble metal nanoparticles have unique optical properties dominated by localized surface plasmon effect. These plasmonic nanostructures are sensitive to local environment and can influence the optical process of adjacent molecules. As a result, they have broad applications ranging from chemical and biological sensing to light-harvesting enhancement in solar cells. Plasmonic nanostructures can enhance fluorescence emission via enhances excitation rate of a fluorescence emitter and changes the radiative and nonradiative decay rates. So far, a variety of plasmonic nanostructures has been developed to achieve fluorescence enhancement effect including metallic thin films, nanoparticles, ordered structures, waveguides and nanoantennas, resulting in increased brightness of molecular emission and improved detection sensitivity.

Aim: The aim of this project is to understand the influence of geometrical structure on enhancement factor

Tasks: Study basic theory about fluorescence and fluorescence enhancement processes; literature search to review the development in metal enhanced fluorescence and its application; Study the influence of geometrical structure on the enhancement factor; analyze experimental data; writing report.

Key references:

[1] Li, J. et al. Plasmon-enhanced fluorescence spectroscopy, Chem. Soc. Rev. 46, 3962 (2017)
[2] Sun, S. et al. Critical role of shell in enhanced fluorescence of metal-dielectric core-shell nanoparticles, J. Phys. Chem. 124, 13365 (2020)
[3] Yu, H. et al. Plasmon-enhanced light-matter interactions and applications, NPJ Compu. Mat. 5, 45 (2019)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: An interest in nanoscience and photonics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum electron transport simulation for semiconductor single-electron devices

Project ID: TBC **Division:** NPL

Primary Supervisor: Masaya Kataoka, Daniel Oi **Email:** masaya.kataoka@npl.co.uk

Secondary Supervisor(s): John Jeffers

Project Background: Developing capabilities to control individual electrons in semiconductor quantum devices is important in the field of quantum electrical metrology towards the realisation of electrical units, and in the various aspect of quantum technology applications. One branch of such developments at NPL is electron quantum optics, in which electrons are channelled into electron waveguides, quasi-one-dimensional channels such as quantum Hall edge states, and various experiments analogous to those in quantum optics are performed. In this project, the student(s) will develop a framework for numerical simulations in order to support NPL's effort in improving the performance of single-electron devices.

Aim: To simulate the single-electron transport characteristics in semiconductor quantum devices

Tasks: Develop Python codes using KWANT (and possibly TKWANT) module(s) [https://kwant-project.org/] to simulate single-electron transport (time-dependent, if possible).

Set up device layout realistic to NPL's experimental devices, and investigate the electron transport characteristics.

Key references:

[1] S. P. Giblin et al., Nature Communications 3, 930 (2012)
[2] C. Bauerele et al., Rep. Prog. Phys. 81 056503 (2018)
[3] C. W. Groth et al., New J. Phys. 16, 063065 (2014).

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Programming skills in Python.

Basic knowledge and interest in solid-state physics.

Being able to visualise the results using Python/Origin/Matlab etc.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Up to two students can take this project.

Students should have their own computer (or have access to computers) to run Python with KWANT module.

Supervision will be mainly done remotely.

Control of spatially rotating structures in diffractive Kerr cavities

Project ID: TBC

Division: Optics

Primary Supervisor: Alison Yao

Email: alison.yao@strath.ac.uk

Secondary Supervisor(s): Duncan McArthur

Project Background: The interplay of diffraction and intensity-dependent nonlinearity is known to give rise to the formation of Turing patterns. Optical pumps carrying orbital angular momentum (OAM) have been shown to produce Turing patterns that rotate at particular speeds. Full control over the speed can be obtained by tuning the intensity and polarisation structure of the light and has potential applications in particle manipulation and stretching, atom trapping, and circular transport of cold atoms and BEC wavepackets.

Aim: The aim of this project is to investigate the formation of spatially rotation light patterns in nonlinear optical cavities.

Tasks: Reading and understanding the background literature; become familiar with using a linux system and learn how to run pre-written codes with different input parameters; learn how to display and analyse large sets of data; reproduce results in the literature. Use your understanding of results in current literature to investigate the speed of rotation. Extend the model to include saturating nonlinearities.

Key references:

[1] L. A. Lugiato and R. Lefever, Phys. Rev. Lett. 58, 2209 (1987).
[2] A. M. Yao, C. J. Gibson & G.-L. Oppo, Opt. Express 27, 31273 (2019).
[3] Q. Zhan, Adv. Opt. Photon. 1, 1 (2009).

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: No previous knowledge of programming is required, but an interest is highly recommended.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc Maths and Phys

Misc:

Structured light and BECs

Project ID: TBC

Division: Optics

Primary Supervisor: Alison Yao

Email: alison.yao@strath.ac.uk

Secondary Supervisor(s): Gian-Luca Oppo

Project Background: Light with helical phase fronts carries orbital angular momentum (OAM). When this light co-propagates with a Bose-Einstein Condensate, there is a coupling between the light and atoms. For far-red-detuned light both light and BEC can fragment into a controllable number of coupled solitons that carry angular momentum. The aim of this project is to investigate how different parameter regimes (e.g. detuning, scattering) can be used to control the propagation.

Aim: Understanding the interaction of structured light and BECs

Tasks: 1. Understand the complex mathematical model describing the propagation of the light and atoms and how these relate to the physical processes taking place. 2. Use pre-existing numerical codes to simulate different parameter regimes and provide prrof-of-principle operating regimes.

Key references:

[1] Mark Saffman and Dmitry V. Skryabin, Coupled Propagation of Light and Matter Waves: Solitons and Transverse Instabilities," in Spatial Solitons, edited by Stefano Trillo and William Torruellas (Springer Berlin Heidelberg, Berlin, Heidelberg, 2001) pp. 433{447).
[2] G Henderson, GRM Robb, GL Oppo, AM Yao, "Control of light-atom solitons and atomic transport by optical vortex beams propagating through a Bose-Einstein Condensate", to be published in Phys. Rev. Lett. arXiv:2203.11640 (2022).
[3] AM Yao, MJ Padgett, "Orbital angular momentum: origins, behavior and applications", Adv. Opt Photon 3, 161 (2011)

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Strong background in electromagnetism and an interest in numerical modelling

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: 1

Computational Modelling of X-ray Free Electron Lasers

Project ID: TBC **Division:** Optics

Primary Supervisor: Brian McNeil **Email:** b.w.j.mcneil@strath.ac.uk

Secondary Supervisor(s): Gordon Robb

Project Background: X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2]. The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level. The supervisor of this project Dr Brian McNeil works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Aim: Predict new effects that can enhance or extend current XFEL performance.

Tasks: Starting from the basic working equations that describe the FEL process, the student will gain an understanding of how an XFEL works. You will then use numerical methods to solve the simplest case. This will involve solving equations describing the electron trajectories through the combined undulator and light fields, while simultaneously solving the equation that describes how the light field is driven by the electrons. Initially a code like MATLAB can be used. The student may wish to then use a lower-level language like Fortran, C or Java (your choice), to solve the same or extended equations describing further effects (e.g. harmonic light generation) and then present the solutions in a meaningful way using available plotting packages. The skills that you will learn are generic to a working theoretical/computational physicist and will prepare you well for a future career in this field. A good student should be able to take the analysis further and begin looking at more advanced topics. This will be like performing 'numerical experiments'.

Key references:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, 4, 814, 2010
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Theory: 25% **Comp:** 75% **Exp:** 0%

Recommended Background or Pre-Requisites:

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc (Maths Physics)

Misc:

The theory of X-ray Free electron Lasers

Project ID: TBC **Division:** Optics

Primary Supervisor: Brian McNeil **Email:** b.w.j.mcneil@strath.ac.uk

Secondary Supervisor(s): Gordon Robb

Project Background: X-ray Free-Electron Lasers (XFELs), such as the LCLS at SLAC in California [1] and SACLA at Spring-8 in Japan, use high energy electron bunches, produced by particle accelerators, to generate intense pulses of X-rays within a long magnet called an undulator [2]. The spatial and temporal resolution available from the high brightness ultra-violet to x-ray pulses generated by these XFELs, is making feasible the observation and ultimately the potential to control ultra-fast, optionally non-linear processes in all forms of matter. With the ability to probe correlated electronic processes within atoms at short timescales, to measure how electrons and nuclei re-organise themselves, either individually within atoms due to external stimulus, during molecular bond making and breaking, or while undergoing subtle catalytic or biological processes, we can begin to unravel how all matter functions at this fundamental level. The supervisor of this project Dr Brian McNeil works closely with the UK's Accelerator Science and Technology Centre, along with international collaborators in this field. In the UK he is closely involved with the proposed CLARA facility based at Daresbury near Warrington [3]. Previously, good project students have obtained a summer studentship working there.

Aim: Predict new effects that can enhance or extend current XFEL performance.

Tasks: This project will involve the derivation of the working equations that describe the FEL process from the coupled Maxwell and Lorentz force equations. This will involve deriving equations that describe the trajectories of the relativistic electrons as they propagate through the undulating magnetic fields, how they consequently radiate light, how they then couple to this light, and how this coupling feeds back onto the electrons. Once derived, these non-linear equations can be analysed and simplified to obtain a set of coupled linear differential equations that can be solved analytically to obtain a solution. The skills that you will learn are generic to a working theoretical physicist and will prepare you well for a future career in any theoretical field. A good student may be able to take this theoretical analysis further and begin looking at more advanced topics involving a degree of research into areas that have previously not been well explored, and perhaps even predicting new and useful practical ideas.

Key references:

[1] https://portal.slac.stanford.edu/sites/lcls_public/Pages/Default.aspx
[2] B.W.J. McNeil & N.R.Thompson, 'X-ray free-electron lasers', Nature Photonics, 4, 814, 2010
[3] http://www.stfc.ac.uk/ASTeC/Programmes/38749.aspx

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites:

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc (Maths Physics)

Misc:

Harnessing non-adiabatic quantum dynamics

Project ID: TBC

Division: Optics

Primary Supervisor: Callum Duncan

Email: callum.duncan@strath.ac.uk

Secondary Supervisor(s): Andrew Daley

Project Background: For the most part we assume that a quantum state evolves under the adiabatic theorem, with the state following those of the time-indepdendent Schrödinger equation. This is true even of state-of-the-art quantum experiments. However, adiabatic evolution is not generally fulfilled and this results in undesired transitions between quantum states. Normally this is considered to be a bad thing, with the quantum system not performing how we want it to. This project will turn this thought on it's head by demystifying non-adiabatic quantum dynamics. By understanding quantum dynamics through the new Adiabatic Gauge Potential, we can instead harness the unwanted non-adiabatic dynamics to be something that is useful.

Aim: To understand non-adiabatic quantum dynamics through analytical methods and harness the results to investigate new physics.

Tasks: Derive the adiabatic gauge potential for specific models, e.g. the quantum harmonic oscillator or tight-binding model. Find the dominant terms that explain the non-adiabatic quantum dynamics. Compare the derived analytical reuslts against numerical simulations.

Key references:

[1] Paper introducing the adiabatic gauge potential, https://doi.org/10.48550/arXiv.1607.05687
[2] lecture and notes on the adiabatic approximation, https://youtu.be/pgEFvhkEp-c; https://ocw.mit.edu/courses/8-06-quantum-physics-iii-spring-2018/resources/mit8_06s18ch6/
[3] Review on quantum simulators, https://doi.org/10.1140/epjqt10

Theory: 100% **Comp:** 0% **Exp:** 0%

Recommended Background or Pre-Requisites: Strong background in quantum courses. Knowledge of a programming language would be beneficial. Comfortable with performing analytical calculations.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Space Levitated Optomechanics

Project ID: TBC

Division: Optics

Primary Supervisor: Daniel Oi

Email: daniel.oi@strath.ac.uk

Secondary Supervisor(s): TBA

Project Background: Levitated optomechanical systems are promising candidates for fundamental tests of quantum physics. They may also be useful for enviromental sensing of the residual atmosphere in low Earth orbit and the flow field around a satellite. This project would investigate the properties of the atmoshere and its interaction with a nanosphere trapped by optical dipole forces. This work may support future space missions using CubeSats.

Aim: Determine low Earth Orbit atmospheric effects on a levitated optomechanical system

Tasks: Determine an atmospheric model for 100-1000km altitude. Develop model of trapped nanosphere interacting with hypersonic gas flows. Establish parameters for nanosphere size, optical trap, and orbital altitude for inertial and pressure sensing.

Key references:

[1] MAQRO -- BPS 2023 Research Campaign Whitepaper, https://doi.org/10.48550/arXiv.2202.01535

[2] Vovrosh J, Rashid M, Hempston D, Bateman J, Paternostro M, Ulbricht H. Parametric feedback cooling of levitated optomechanics in a parabolic mirror trap. JOSA B. 2017 Jul 1;34(7):1421-8.

[3] Ferreras J, Spencer J, Salter M, Valenzuela T, Riou I, Kiss-Toth M, Renshaw R, Trigatzis M, Moore L, Maddox S, Holynski M. Cold Atom Space Payload Atmospheric Drag Mission (CASPA-ADM). SSC22-P2-18 https://digitalcommons.usu.edu/smallsat/2022/all2022/258/

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should have numerical modelling skills including proficiency in Matlab, Python, or similar.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths with Physics

Misc: Student should have access to their own computer to run code

A Paul trap for macroscopic charged particles

Project ID: TBC **Division:** Optics

Primary Supervisor: Erling Riis **Email:** e.riis@strath.ac.uk

Secondary Supervisor(s): Paul Griffin

Project Background: Ion traps are a very interesting physical system as they allow for trapping and control of individual ions. Single trapped ions are already being used for quantum computing and for some of the most precise atomic clocks. Quantum technologies such as these are not only driving new advances in science but also have great potential to excite new generations of young scientists to the possibilities of what physics, optics, and quantum can offer society.

Within this project we will build an ion trap that can hold macroscopic particles that can be seen with the naked eye. The device will be a scale model of a trap that is being used at the UK's National Physical Laboratory for research into quantum information processing. The project will be used for future public demonstrations of science

Aim: This project is to build a working scale model of a single-ion trap, of the type used for quantum compouting, for use as a public demonstration of science.

Tasks: This project will allow the successful candidate to develop new skills in computer aided design, 3D printing, electronics, and optics. The project will require some computer simulations in Python. The successful candidate will be closely supported by the supervisors.

Key references:

[1] CD Bruzewicz et al, "Trapped-ion quantum computing: Progress and challenges" Applied Physics Reviews 6, 021314 (2019); https://doi.org/10.1063/1.5088164

[2] H Winter, 'Simple demonstration of storing macroscopic particles in a Paul trap' Am. J., Phys. 59, 807 (1991); https://doi.org/10.1119/1.16830

[3] K.G. Libbrecht et al., "Improved microparticle electrodynamic ion traps for physics teaching" Am. J. Phys. 86, 539 (2018); : https://doi.org/10.1119/1.5034344

Theory: 15% **Comp:** 15% **Exp:** 70%

Recommended Background or Pre-Requisites: The main criteria are that you are keen to work on experiments and as part of a team.

Safety Training (if applicable): Standard safety training as part of EQOP group, including lasers and electronics

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum Dots Nanolasers

Project ID: TBC

Division: Optics

Primary Supervisor: Francesco Papoff

Email: f.papoff@strath.ac.uk

Secondary Supervisor(s): G.-L. Oppo

Project Background: Quantum Dots Nanolasers are one of the most promising ways to achieve the ultimate miniaturizzation of laser sources. They contain few tenths of quantum emitters and, as a result, behave as linear quantum systems. Macroscopic lasers instead contains millions of quantum emitters and can be modelled extremely well as non linear semi-classical systems. In this project we will investigate the transition from linear quantum systems to nonlinear semi-classical systems in lasers.

Aim: Determine the transition beween quantum linear systems and semi-classical non linear systems in lasers.

Tasks: 1) Review the litterature and familiarize with existing theoretical model. 2) Perform numerical simulations for different numbers of emitters. 3) Investigate analytically the limit of large numbers of emitters in models of nanolasers and verify that this explains the numerical simulations

Key references:

[1] W.W Chow, F. Jahnke and C. Gies. Emission properties of nanolasers during the transition to lasing. Light: Science & Applications 3, e201 (2014).

[2] 1) M. Florian, C. Gies, F. Jahnke, H.A.M. Leymann and J. Wiersig. Equation-of-motion technique for finite-size quantum-dot systems: Cluster expansion method . Phys. Rev. B 87, 165306 (2013). 2) M.A. Carroll, G D'Alessandro, G.L. Lippi, G.-L. Oppo, and F. Papoff, "Thermal, Quantum Antibunching and Lasing Thresholds from Single Emitters to Macroscopic De- vices", Phys. Rev. Lett. 126, 063902 (2021)

[3] S. Kreinberg, W.W. Chow, J. Wolters, C. Schneider, C. Gies, F. Jahnke, S. Höfling, M. Kamp and S. Reitzenstein. Emission from quantum-dot high-β microcavities: transition from spontaneous emission to lasing and the effects of superradiant emitter coupling

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Working knowledge of Mathlab or Python, good marks in Electromagnetism and Quantum Mechanics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Up to two students can work on variations of this project

Modelling Nanolasers

Project ID: TBC

Division: Optics

Primary Supervisor: Francesco Papoff

Email: f.papoff@strath.ac.uk

Secondary Supervisor(s):

Project Background: Nanolasers are extremely interesting from a technological point of view because have minimal footprint and thermal dissipation. They are also very useful to explore novel emission regimes in which different quantum emitters behave as a single super emitter. When this happens, the emission of photon is less noisy than in standard lasers, which is useful for quantum information. In this project, you will contribute to model this effect.

Aim: Model correlations between different emitters in nanolasers

Tasks: 1) Review the literature and familiarize with the existing theoretical model. 2) Include correlations between different emitters and investigate their effect on photon statistics. 3) Perform simulations to evaluate the reliability of the model

Key references:

[1] H.A.M. Leymann, A. Foerster and J. Wiersig. Expectation value based equation-of-motion approach for open quantum systems: A general formalism. Phys. Rev. B 89, 085308 (2014)

[2] 1) M. Florian, C. Gies, F. Jahnke, H.A.M. Leymann and J. Wiersig. Equation-of-motion technique for finite-size quantum-dot systems: Cluster expansion method . Phys. Rev. B 87, 165306 (2013). 2) M.A. Carroll, G D'Alessandro, G.L. Lippi, G.-L. Oppo, and F. Papoff, "Photon-number squeezing in nano- and microlasers", Appl. Phys. Lett. 119, 101102 (2021).

[3]

Theory: 70% **Comp:** 30% **Exp:** 0%

Recommended Background or Pre-Requisites: Working knowledge of Mathlab or Python, good marks in Electromagnetism and Quantum Mechanics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Up to two students can work on variations of this project

Weird interactions of Cavity Solitons

Project ID: TBC

Division: Optics

Primary Supervisor: Gian-Luca Oppo

Email: g.l.oppo@strath.ac.uk

Secondary Supervisor(s): Francesco Papoff

Project Background: Spatial optical solitons are beams of light in which nonlinearity counter-balances diffraction, leading to robust single-hump structures that propagate without change of form. In the case of light propagating through a medium, the simplest spatial soliton is due to self-focusing and Kerr nonlinearity, that is, a refractive index which changes in proportion to the intensity of the light. More general schemes where dissipation and driving are included can also support stable soliton-like solutions with lots of intriguing and new properties. Among these, localized bright and dark spots in driven-optical cavities (cavity solitons) have received a great deal of attention because of their applications in information processing [2].

Aim: This project aims at investigating a new kind of interaction between optical cavity solitons. Normal cavity solitons in random positions are susceptible to background noise fluctuations and can be described as a soliton gas. Above certain thresholds, however, cavity solitons in media pumped by two laser beams [1] can freeze at certain distances and form conglomerates similar to those observed in amorphous media such as glass. Characterization of the soliton glass phase, its origin and possible melting are among the objectives of the project. Please note that numerical codes are already in operation.

Tasks: Reading and undersanding the background literature; becoming familiar with the given Matlab codes; produce and understand plots that reproduce results in the literature Update codes to describe the specific device of interest; explore new regions of parameters using the new codes; produce plots of interest for the final report; understand the physics of the model equations and the obtained results

Key references:

[1] M. Esalmi et al., “Complex structures in media displaying electromagnetically induced transparency: Pattern multistability and competition”, Phys. Rev. A 90, 023840 (2014)
[2] T. Ackemann, W. J. Firth and G-L Oppo, “Fundamentals and Applications of Spatial Dissipative Solitons”, Adv. At. Mol. Opt. Phys. 57, 323 (2009)
[3]

Theory: 40% **Comp:** 60% **Exp:** understanding

Recommended Background or Pre-Requisites: Matlab

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc Maths and Phys

Misc:

Cold Atom-Light Interactions

Project ID: TBC

Division: Optics

Primary Supervisor: Gordon Robb

Email: g.r.m.robb@strath.ac.uk

Secondary Supervisor(s): Gian-Luca Oppo

Project Background: It is now possible to cool atoms down to temperatures close to absolute zero. At these temperatures, the interaction between light and atoms can change dramatically; with the optical forces acting on the atoms can play a significant effect.

Aim: Simulation of interactions involving light and cold atomic gases.

Tasks: 1. Review relevant theory on light-atom interactions. 2. Familiarise with code to simulate an interaction between light and a cold atomic gas. 3. Test code and benchmark code against published results. 1. Modify code and use to study variation of a parameter on the interaction e.g pump intensity. 2. Repeat 1 for other system parameters relevant to experiments e.g. pump frequency, pump profile, atom temperature

Key references:

[1] E. Tesio et al., Phys. Rev. A 86, 031801(R) (2012)

[2] G. Baio et al., Phys. Rev. Research 2, 023126 (2020).

[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Some experience of using at least one of e.g. Python, MATLAB, Fortran, C, Julia would be desirable.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

BEC simulations

Project ID: TBC

Division: Optics

Primary Supervisor: Gordon Robb

Email: g.r.m.robb@strath.ac.uk

Secondary Supervisor(s): Gian-Luca Oppo

Project Background: When a gas of atoms is cooled to a temperature < ~1mK , it can stop behaving as a cloud of classical particles and instead behave as a "matter wave" or Bose-Einstein Condensate (BEC), whose behaviour is governed by the laws of quantum mechanics [1]. The project will involve simulating the behaviour of a BEC under different physical conditions e.g. in a trap, interacting with light,...

Aim: Simulation of Bose-Einstein condensates under various physical conditions

Tasks: 1. Review relevant theory on BEC. 2. Familiarise with code to simulate a BEC under certain conditions (TBC). 3. Test code and benchmark code against published results. 1. Modify code and use to study variation of a parameter on the interaction e.g BEC density profile. 2. Repeat 1 for other system parameters relevant to experiments e.g. trap geometry…

Key references:

[1] Allan Griffin, D. W Snoke, S Stringari , Bose-Einstein condensation Cambridge, New York : Cambridge University Press (1995).
[2] G. R. M. Robb et al., Phys. Rev. Lett. 114, 173903 (2015).
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Some experience of using at least one of e.g. Python, MATLAB, Fortran, C, Julia would be desirable.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

Interactive Physics simulations

Project ID: TBC

Division: Optics

Primary Supervisor: Gordon Robb

Email: g.r.m.robb@strath.ac.uk

Secondary Supervisor(s): TBA

Project Background: Many interactive Physics simulations have been developed over the years in a variety of different languages e.g. JAVA, Adobe Flash, Shockwave etc. However, for several reasons many existing simulations have now become obsolete, e.g. Most modern browsers do not run JAVA easily, as it is perceived as a security risk; Many existing simulations cannot run on tablets or mobile phones.

The project will involve developing one or more interactive Physics simulations using HTML5 & Javascript, which allows them to be run on modern browsers and on mobile devices. Recent examples of such simulations and teaching activities which use them can be found in [1].

Aim: Develop one or more interactive simulations on a physics topic to be decided.

Tasks: 1. Decide on physics topic, design simulation and review relevant theory. 2. Familiarise with EJS/EJSS package [2]. 3. Develop preliminary simulation . 1.Extend previous simulation or design and write new simulation which builds on first. 2. Conduct numerical "experiment" using extended simulation.

Key references:

[1] https://phet.colorado.edu
[2] https://www.um.es/fem/EjsWiki/
[3]

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: The physics topic and the exact method of developing the simulation can be adjusted to suit the student’s degree programme and level of previous programming experience.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: This project is open to more than one student.

Chip-scale atomic metrology

Project ID: TBC
Division: Optics

Primary Supervisor: James McGilligan
Email: james.mcgilligan@strath.ac.uk

Secondary Supervisor(s): Paul Griffin

Project Background: The separation of atomic energy levels provides a previously unobtainable accuracy and precision in metrology, with an SI traceable reference to frequency and wavelength. Instrumentation that utilise atomic spectroscopy for metrology remain at the state-of-the-art for atomic clocks, magnetometers and wavelength references. Recent advancements in micro-electro-mechanical-system (MEMS) vapour cells have supported the miniaturisation and commercialisation of atomic metrological instruments in millilitre packages. Here in the Experimental Quantum Optics and Photonics team we are developing new techniques for system miniaturisation that offer the potential to revolutionise the next generation of atomic based quantum technologies.

Aim: This project aims to construct a chip-scale wavelength reference using coherent population trapping in a micro-fabricated platform.

Tasks: This project will focus on the development of a chip-scale wavelength reference, utilising a micro-fabricated package for rubidium vapour spectroscopy. The project will involve hands on experimental measurements for next generation atomic sensors, covering topics in micro-fabrication, atomic metrology and quantum sensors. Specifically, the project aims to realise a narrow atomic transition for laser locking in a millilitre package using coherent population trapping and measurement of different vapour cell dimensions. The completion of this study will establish a well understood narrow wavelength reference for chip-scale metrological applications.

Key references:

[1] John Kitching , "Chip-scale atomic devices", Applied Physics Reviews 5, 031302 (2018) https://doi.org/10.1063/1.5026238
[2] J. P. McGilligan et. al. "Invited Review: Micro-fabricated components for cold atom sensors "https://arxiv.org/abs/2208.00680
[3] S. Dyer, et. al. "Micro-machined deep silicon atomic vapor cells " https://arxiv.org/abs/2207.12904

Theory: 15% **Comp:** 15% **Exp:** 70%

Recommended Background or Pre-Requisites: The main criteria are that you are keen to work on experiments and as part of a team.

Safety Training (if applicable): Standard safety training as part of EQOP group, including lasers and electronics

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum Lidar

Project ID: TBC **Division:** Optics

Primary Supervisor: John Jeffers **Email:** john.jeffers@strath.ac.uk

Secondary Supervisor(s): Nigam Samantaray/Jon Pritchard

Project Background: Quantum Lidar is supposedly better than classical lidar at recognising the presence of objects. This project will investigate whether it is so.

Aim: Calculate detection statistics for a quantum lidar

Tasks: Study the quantum electromagnetic field, beam splitters, thermal states, photodetectors,etc. Calculate and simulate the detection statistics produced by a thermal state. Study the detection statistics produced by a thermal signal reflected off a target, then a quantum lidar signal.

Key references:

[1] https://doi.org/10.1117/12.2555390
[2]
[3]

Theory: 75% **Comp:** 25% **Exp:** 0%

Recommended Background or Pre-Requisites: A high mark in Quantum Physics and Electromagnetism. Good Integral and differenetial calculus. combinatorics. Probability theory.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum Volume for Rydberg Atoms

Project ID: TBC

Division: Optics

Primary Supervisor: Jonathan Pritchard

Email: jonathan.pritchard@strath.ac.uk

Secondary Supervisor(s): Natalie Pearson, Andrew Daley

Project Background: Quantum computers promise to outperform their classical counterparts to achieve unprecedented computational challenges by leveraging the properties of quantum mechanics. How good is your quantum computer really though? The quantum volume provides a metric that describes the maximum size of the circuit that can be run on a digital quantum computer to answer this question for any hardware. Rydberg atoms are one of such hardwares which promising a competitive scalable quantum computer. A motivated student will simulate a Rydberg atom experiment to determine the quantum volume of such a system.

Aim: Investigate the quantum volume of a Rydberg atom quantum computer

Tasks: Perform a literature review on quatum volume, become familiar with QUEST quamtum simulator, understand the basic mechanisms of Rydberg atoms Implement simulation of algorithm to determine quantum volume for Rydberg system

Key references:

[1] https://journals.aps.org/pra/abstract/10.1103/PhysRevA.100.032328
[2] https://questlink.qtechtheory.org/
[3] https://arxiv.org/pdf/2011.03031.pdf

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: quatum mechanics, mathematica or python

Safety Training (if applicable): No special training required

Suitable for: MPhs

Misc:

A Rydberg Atom Radio

Project ID: TBC

Division: Optics

Primary Supervisor: Jonathan Pritchard

Email: jonathan.pritchard@strath.ac.uk

Secondary Supervisor(s): TBA

Project Background: Many applications in communication, medicine or navigation require precise characterisation of electric fields in the microwave and terahertz domains making the need for a powerful sensor essential. Rydberg atoms are highly excited atoms which offer great potentiality for the development of such a sensor due to their large sensitivity to electric fields in these domains. The aim of the project is to setup a Rydberg atom RF sensor and characterise sensitivity and bandwidth for active demodulation of signals across the microwave spectrum.

Aim: Characterise a Rydberg atom RF receiver based on a optical probing Rydberg atoms in a room temperature vapour

Tasks: (1) Perform microwave spectroscopy using aRydberg atom sensor (2) Explore sensitivity to decoding using AM, FM and PM encoding schemes (3) Explore new detection paradigms based on frequency hopping

Key references:

[1] Rydberg atom quantuim technologies https://doi.org/10.1088/1361-6455/ab52ef
[2] Detecting and Receiving Phase Modulated Signals with a Rydberg Atom-Based Mixer https://doi.org/10.1109/LAWP.2019.2931450
[3] A Multiple-Band Rydberg-Atom Based Receiver/Antenna: AM/FM Stereo Reception https://doi.org/10.1109/MAP.2020.2976914

Theory: 10% **Comp:** 0% **Exp:** 90%

Recommended Background or Pre-Requisites: Students should be comfortable with using Matlab, Python, or similar scientific programming language for developing simulations. Recommended modules PH462 Topics in Quantum Optics, PH459 Topics in Atomic Physics

Safety Training (if applicable): Laser safety training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Generating defect free arrays for neutral atom quantum computing

Project ID: TBC

Division: Optics

Primary Supervisor: Jonathan Pritchard

Email: jonathan.pritchard@strath.ac.uk

Secondary Supervisor(s): TBA

Project Background: Quantum computing offers exciting new solutions to problems that are intractable on classical digital hardware. Neutral atom quantum computers are emerging as one of the most scalable platforms for computing, providing over 1000 identical qubits and high fidelity operations for both digital and analogue quantum computing. Essential to scaling this platform is the ability to perform efficient rearranging of stochastically loaded atoms, and this project aims to explore different approaches to minimise number of moves. Whilst a computational project, there is the opportunity to test the algorithms out on a real experiment using the SQuAre neutral atom qubit computer here at Strathclyde with over 100 individually trapped atoms.

Aim: Develop and characterise sorting algorithms for generating defect free neutral atom arrays

Tasks: (1) Literature review to survey variety of algorithms explored to date (2) Develop python code to benchmark and charqacterise different sorting strategies (3) Identify benefits of translating algorithm to fast GPU hardware (4) Test and verify performance using real experimental hardware

Key references:

[1] An atom-by-atom assembler of defect-free arbitrary two-dimensional atomic arrays https://dx.doi.org/10.1126/science.aah3778

[2] Enhanced atom-by-atom assembly of arbitrary tweezers arrays https://doi.org/10.1103/PhysRevA.102.063107

[3] Efficient preparation of two-dimensional defect-free atom arrays with near-fewest sorting-atom moves https://doi.org/10.1103/PhysRevResearch.3.023008

Theory: 25% **Comp:** 70% **Exp:** 5%

Recommended Background or Pre-Requisites: Students should be confident using Python, keen to explore creative approaches to implementing sorting algorithms

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Arduino-based laser stabilisation

Project ID: TBC

Division: Optics

Primary Supervisor: Kali Wilson

Email: kali.wilson@strath.ac.uk

Secondary Supervisor(s): TBD

Project Background: Cold atom laboratories rely heavily on laser beams to cool, confine and probe ultracold atoms. The stability of the laser's power and pointing direction becomes important as small deviations add unwanted noise and reduce the efficiency of the laser cooling and trapping processes. The student will develop viable laser stabilization based on feedback provided to either polarization optics (laser power stabilisation) or a servo-motor-controlled mirror mount (pointing stabilisation).

Aim: Develop an Arduino-based controller for laser power and/or pointing stabilisation

Tasks: Semester 1: Review of relevant literature. Familiarisation with project optics & electronics. Servo design including integration of digital (Arduino) and analog components (simulation via LTSpice). Semester 2: Servo fabrication. Implementation and testing. Benchmarking.

Key references:

[1] How to Automate a Kinematic Mount Using a 3D Printed Arduino-Based System, Luis José Salazar-Serrano et al., Inventions 2018, 3, 39; https://doi.org/10.3390/inventions3020039

[2] Laser Intensity Stabilisation – Thesis – C. Giehr https://tiqi.ethz.ch/content/dam/ethz/special-interest/phys/quantum-electronics/tiqi-dam/documents/semester_theses/semesterthesis-caspar_giehr.pdf

[3] Step-by-step guide to 3D print motorized rotation mounts for optical applications, Daniel P.G. Nilsson, et al., Applied Optics Vol. 60, No. 13 / 1 May 2021 https://doi.org/10.1364/AO.422695

Theory: 50% **Comp:** 0% **Exp:** 50%

Recommended Background or Pre-Requisites: Knowledge of Arduino programming language "wire", analog circuit simulator 'LTSpice' and/or Python, familiarity with basic experimental optics.

Safety Training (if applicable): Laser safety training required.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Up to 2 students can work on variations of this project.

Laser technologies for cold atom physics.

Project ID: TBC **Division:** Optics

Primary Supervisor: Paul Griffin **Email:** paul.griffin@strath.ac.uk

Secondary Supervisor(s): Dr Oliver Burrow

Project Background: Using laser fields it is possibel to cool clouds of atoms to microkelvin temperatures. Clouds of laser-cooled atoms are the ideal medium for many modern quantum physics applications – atomic clocks, atom interferometeres, and quantum memories, to list just a few. Within EQOP group we have developed new techniques to greatly reduce the size and complexity of the system required to create an ultra-cold source of millions of atoms. New laser technology offers the potential for further improvements in performance while also reducing the size, weight, and power consumption.

This project involves the characterisation of new lasers and optical components for cool of atoms, with scope for extending the project. The experiment involves a variety of lasers, optics, vacuum equipment, computer control, and electronics. The ideal candidate will be interested in gaining more experience of experimental work. In return, the supervisory team will work with you to support developing your skills in lasers and optics, analysis of data, and presentation of results.

Aim: The validation of new laser and optical components for laser cooling of atoms

Tasks: The first semester will concentrate on developing practical experience of lasers and optical components. This will be supported by a literature review.

As the project progresses the work will focus on measuring and understanding the performance of new lasers and optical elements, such as lenses and shuters. Once fully characterised, the components will be added to the existing laser cooling experiment.

Key references:

[1] W. D. Phillips, "Laser cooling and trapping of neutral atoms", Rev. Mod. Phys. 70, 721 (1998).
[2] C. C. Nshii, et al "A surface-patterned chip as a strong source of ultracold atoms for quantum technologies", Nature Nanotechnology 8, 321 (2013).
[3]

Theory: 15% **Comp:** 15% **Exp:** 70%

Recommended Background or Pre-Requisites: The main criteria are that you are keen to work on experiments and as part of a team.

Safety Training (if applicable): Standard safety training as part of EQOP group, including lasers and electronics

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

A quantum magnetometer to measure human bio-signals

Project ID: TBC

Division: Optics

Primary Supervisor: Paul Griffin

Email: paul.griffin@strath.ac.uk

Secondary Supervisor(s): Dr Carolyn O'Dwyer

Project Background: The human body is a complicated subject for physicists to study; for most people in the John Anderson Building we are all just mobile bags of liquids and tissues of varying densities and conductivities, ultimately driven by electrical signals in muscles, nerves, and brains. One thing we are good at, however, is measuring very weak electrical signals. Knowledge of how these biological signals vary in space and time is crucial information in understanding human health and is why there is a huge drive to use sensitive quantum technologies to better understand the human brain.

The standard method for measuring electronic activity is through measuring the associated electric potential at the skin, which may be familiar from a technique known as electro-cardiography (ECG). However, human tissue is weakly conductive, which causes the loss of quantitative information due to patient-to-patient physiological effects, such as sweat and tissue type (fat, muscle, skin). A different sensing method uses the fact that the electrical signals are driven by current, which then give rise to magnetic fields that can be detected outside the body in a non-contact way using sensitive magnetometers. The advantage is that these magnetic signals can give new physiological information and better quantitative data, since human tissue is essentially transparent, or non-conductive, to magnetic fields.

The successful candidate will join a small group of researchers developing compact and portable quantum magnetometers for measuring bio-magnetic signals using quantum sensors.

Aim: Experimental work towards the development of a portable quantum magnetic sensor that can measure biological signals from humans.

Tasks: The project will provide an opportunity to develop experience in lasers, electronics, and data analysis. The ideal candidate will be interested in gaining more experience of experimental work and in data analysis. In return, the supervisory team will work with you to support developing your skills in lasers and optics, analysis of data, and presentation of results.

Key references:

[1] E Boto et al., Moving magnetoencephalography towards real-world applications with a wearable system Nature 555, 657 (2018) https://doi.org/10.1038/nature26147

[2] https://physicsworld.com/a/quantum-physics-gives-brain-sensing-meg-scanners-a-boost/

[3] T. M. Tierney et al. Optically pumped magnetometers: From quantum origins to multi-channel magnetoencephalography, NeuroImage 199, 598 (2019) https://doi.org/10.1016/j.neuroimage.2019.05.063.

Theory: 15% **Comp:** 15% **Exp:** 70%

Recommended Background or Pre-Requisites: The main criteria are that you are keen to work on experiments and as part of a team.

Safety Training (if applicable): Standard safety training as part of EQOP group, including lasers and electronics

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Quantum chaos with light-matter interactions

Project ID: TBC

Division: Optics

Primary Supervisor: Peter Kirton

Email: peter.kirton@strath.ac.uk

Secondary Supervisor(s):

Project Background: The Dicke model provides a simple way to analyse the quantum dynamics of cold atoms trapped in a single mode optical cavity [1]. It is known that both the classical and quantum versions of this model show chaotic dynamics [2]. In this project we will analyse this chaotic behaviour by examining both the level statistics of the Hamiltonian and out-of-time-ordered correlation functions [3]. We will go on to look at how these are affected by the presence of dissipation in the model.

Aim: To understand and quantify the signatures of chaotic behaviour in cavity QED systems.

Tasks:

Key references:

[1] Kirton et al. Adv. Quant. Tech. 2 1800043 (2019)
[2] Emary and Brandes Phys. Rev. E 67, 066203 (2003)
[3] Chávez-Carlos et al Phys. Rev. Lett. 024101, 122 (2019)

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background or Pre-Requisites: Programming in python or julia will be required. Background from PH389 and PH388

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: 1 student

Building a laser-pumped atomic magnetometer

Project ID: TBC

Division: Optics

Primary Supervisor: Stuart Ingleby

Email: stuart.ingleby@strath.ac.uk

Secondary Supervisor(s): Paul Griffin

Project Background: Optically-pumped magnetometers (OPMs) are an unusual type of quantum technology in so far as they can already be scaled down to handheld devices. We have an active research group in this area, combining chip-scale lasers, microfabricated atomic cells and compact processors to produce devices that exceed the performance of classical sensors.

Aim: The aim is to build the optics, electronics or software for an optically-pumped magnetometer, and take data to demonstrate its operation.

Tasks: This project will entail the development of one sub-system of the OPM- it may be 3D printed optical hardware, design and implementation of electronics, or coding and testing of software. The specific sub-system choice will be driven by both the requirements of the research team and the interests of the student, so it is important to discuss with the project supervisor when applying.

Key references:

[1] https://journals.aps.org/prapplied/abstract/10.1103/PhysRevApplied.10.034035
[2] https://journals.aps.org/pra/abstract/10.1103/PhysRevA.96.013429
[3]

Theory: 10% **Comp:** 10% **Exp:** 80%

Recommended Background or Pre-Requisites: The student can expect to use a range of techniques, including Labview coding, CAD design, electronics assembly and SPICE simulation. However, these can be learned as required. The main prerequisite is an ability to solve problems and learn new skills.

Safety Training (if applicable): Laser safety

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Up to two students can take this project.

A laser system for Rb spectroscopy

Project ID: TBC

Division: Optics

Primary Supervisor: Thorsten Ackemann

Email: thorsten.ackemann@strath.ac.uk

Secondary Supervisor(s): Paul Griffin

Project Background: External cavity diode lasers (ECL) are a versatile and relatively inexpensive lasers source for addressing narrow atomic lines in the near infrared spectrum and are hence the established workhorse for quantum technologies based on alkaline atoms like Rb or Cs. These ECL are built from off-the-shelf laser diodes with optical feedback from a grating [1]. They are stabilized against frequency drifts via saturable absorption spectroscopy [2,3]. The project will set up two ECL for cooling and trapping of Rb atoms, set up the frequency stabilization and characterize their stability. Depending on progress, extensions in the direction of amplifying the ECL or other nonlinear optical investigations are possible.

Aim: Set up a tunable laser and frequency stabilization to enable spectroscopy and nonlinear optical measurements in Rb vapour

Tasks: setting up and aligning optical setup, small electronic soldering taks, understanding PDI controllers, data analysis

Key references:

[1] Arnold et al., Rev Sci Instr 69, 1236 (1998); ibd. 72, 4477 (2001)
[2] Preston, Am J Phys 64, 1432 (1996)
[3] Kraft et al., Laser Phys Lett 1, 1(2004)

Theory: 5% **Comp:** 5% **Exp:** 90%

Recommended Background or Pre-Requisites: student should take PH445 Photonics and possibly PH453 solid state physics in sem 1, PH459 Atomic Physics in sem 2. Student need to be willing to undertake potentially tedious optical alignment tasks.

Safety Training (if applicable): Laser safety

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Spintronics in vertical-cavity gain structures

Project ID: TBC

Division: Optics

Primary Supervisor: Thorsten Ackemann

Email: thorsten.ackemann@strath.ac.uk

Secondary Supervisor(s): Konstantinos Lagoudakis

Project Background: The research field of spintronics aims at utilizing the carrier spin for applications in addition to the number of carriers as usual in electronics and semiconductor photonics [1,2]. However, electrical injection of spin polarized carriers is still limited to cryogenic temperatures or low temperatures in combination with a large magnetic field. At room temperature, optical pumping provides a convenient alternative to electrical injection since carrier spin and photon spin are coupled by angular momentum selection rules. III-V semiconductor gain media in vertical-cavity structures possess the necessary isotropy in the plane of the gain medium to investigate spin dependent effects. This project will look at surface emitting gain structures containing quantum well or quantum dots for the use in VECSELs, vertical-external cavity surface-emitting lasers. The measurements will start with analyzing the polarization properties of the photoluminescence in dependence on the polarization ellipticity of the optical pump field extending [3]. The final aim of the project is to achieve lasing.

Aim: to demonstrate spin memory in photoluminescence and potentially lasing in optically pumped quantum dot and quantum well vertical-cavity semiconductor gain structures

Tasks: setting up and aligning optical setup, understanding polarization and Stokes parameters, data analysis

Key references:

[1] Bhattacharya et al., Quantum dot polarized light sources, Semicond. Sci. Technol. 26 (2011) 014002
[2] Gerhardt & Hofmann, Adv Opt Tech 2012, 268949 (2012)
[3] Doogan et al., Evidence for spin memory

in photoluminescence of room temperature vertical-cavity quantum dot gain structure. Conference on Lasers and Electroptics - CLEO-Europe 2021. PD 1.1, 2021

Theory: 5% **Comp:** 15% **Exp:** 80%

Recommended Background or Pre-Requisites: student should take PH445 Photonics and ideally PH453 solid state physics in sem 1. Student need to be willing to undertake potentially tedious optical alignment tasks.

Safety Training (if applicable): Laser safety

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Thermalization of photons and Bose-Einstein condensation of photons in VCSELs

Project ID: TBC

Division: Optics

Primary Supervisor: Thorsten Ackemann

Email: thorsten.ackemann@strath.ac.uk

Secondary Supervisor(s): Konstantinos Lagoudakis

Project Background: The Bose-Einstein condensation of atoms constitutes a striking consequence of quantum statistics leading to the occupation of a macroscopic quantum state. Work focused on massive particles like cold atoms but quasi-particles can also condense. Photons are also bosons and acquire an effective mass in a microcavity. In [1] it was demonstrated that the interaction of photons in a dye-filled microcavity can lead to the thermalization of photons between transverse modes and a macroscopic occupation of the lowest order mode beyond a threshold interpreted as Bose-Einstein condensation of photons. Although there is still a discussion on the difference between BEC of photons and conventional lasing (e.g. [2]), the concept of photon BEC seems to be mainly accepted in the community by now. Very recently, thermalization of photons and potentially condensation [3] was reported in a semiconductor laser, a broad-area vertical-cavity surface-emitting lasers (VCSEL) [4]. The project will look experimentally into the transverse mode spectrum of VCSELs and collect evidence of thermalization and potentially condensation phenomena and its relation to lasing. Control parameters are device temperature and injection current. [1] Jan Klaers, Julian Schmitt, Frank Vewinger & Martin Weitz, Bose–Einstein condensation of photons in an optical microcavity, Nature 468, 545 (2010)

[2] Julian Schmitt, Tobias Damm, David Dung, Frank Vewinger, Jan Klaers, and Martin Weitz, Thermalization kinetics of light: From laser dynamics to equilibrium condensation of photons. Phys. Rev. A 92, 011602 (2015)

[3]S. Barland et al., Photon thermalization and a condensation phase transition in an electrically pumped semiconductor microresonator,Opt. Exp. 29, 8368 (2021).

[4] M. Miller et al., Improved Output Performance of high power VCSELs, IEEE J. Sel. Top. Quantum Electron. 7, 210 (2001)

Aim: Analyse the possibility of photon condensation in simple semiconductor lasers

Tasks: literature survey, characterisation of lasers, filter calibration, coding of data analysis data taking, analysis of data, further development of codes according to developping needs

Key references:

[1] Jan Klaers, Julian Schmitt, Frank Vewinger & Martin Weitz, Bose–Einstein condensation of photons in an optical microcavity, Nature 468, 545 (2010)

[2] Julian Schmitt, Tobias Damm, David Dung, Frank Vewinger, Jan Klaers, and Martin Weitz, Thermalization kinetics of light: From laser dynamics to equilibrium condensation of photons. Phys. Rev. A 92, 011602 (2015)

[3] S. Barland et al., Photon thermalization and a condensation phase transition in an electrically pumped semiconductor microresonator,Opt. Exp. 29, 8368 (2021)

Theory: 15% **Comp:** 45% **Exp:** 40%

Recommended Background or Pre-Requisites: Basic knowledge in Python or Matlab as taught in the BSc/MPhys programme and dedication to coding

Safety Training (if applicable): Laser safety

Suitable for: MPhys, BSc

Misc:

Quantum Computing with Quantum Versions of Random Walks

Project ID: TBC

Division: Optics

Primary Supervisor: Viv Kendon

Email: viv.kendon@strath.ac.uk

Secondary Supervisor(s): Rhonda Au Yeung

Project Background: Quantum versions of random walks have many diverse applications, for a review see [1], for applications to computation, see [2,3]. In this project, you will explore the behaviour of quantum walks in discrete or continuous-time evolution, and choose your applications from a wide range of options, depending on your interests and the current research projects we are engaged in. We are particularly interested in quantum computing applications [2,3], and applications to quantum transport. Quantum walks are easy to simulate numerically, and some cases are amenable to analytical solution. Quantum versions of random walks come in both discrete-time and continuous-time versions. We know that both can be used to do quantum computation. The simulations of quantum walks are straightforward with your current knowledge of Python (other programming languages are fine if you prefer). There is scope to develop your computational skills, it is also fine to take a more analytical approach and keep the numerical component simple (you'll at least want to produce some nice graphs, though). Continuous-time quantum walks can be solved analytically using Green's functions, and discrete-time walks using Fourier-space methods, provided there is enough symmetry in the particular problem being tackled.

Aim: Learn how quantum computing works using quantum versions of random walks, then develop applications. There is scope for testing using the free time available online on commercial quantum computers (this is the experimental component).

Tasks: Reproduce simple discrete time and continuous time quantum walks in one and two dimensions; apply the quantum walks to the quantum walk search algorithm in two and more dimensions; choose an application and develop a quantum walk algorithm to solve it; (optional) implement your quantum algorithm on one of the commercially available quantum computers. Other topics are possible within this framework, more options will be suggested during the first Semester.

Key references:

[1] Quantum walks: a comprehensive review, Salvador E. Venegas-Andraca, Quantum Information Processing vol. 11(5), pp. 1015-1106 (2012) https://arxiv.org/abs/1201.4780

[2] V Kendon, A random walk approach to quantum algorithms, Phil. Trans. R. Soc. A (2006) 364, 3407-3422 https://arxiv.org/abs/quant-ph/0609035

[3] Adam Callison, Nicholas Chancellor, Florian Mintert, Viv Kendon 2019 Finding spin-glass ground states using quantum walks, https://arxiv.org/abs/1903.05003

Theory: 20% - 70% **Comp:** 80% - 30% **Exp:** 0% - 20%

Recommended Background or Pre-Requisites: Any suitable programming language can be used (e.g., Python, Julia, Matlab, C/C++ …). There is a trade off between programming and theory, less of one means more of the other.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: More than one student can take this project; each will end up with a distinct project within the overall topic

Electron beam em-wave periodic surface lattice interactions

Project ID: TBC

Division: Plasma

Primary Supervisor: Amy J. MacLachlan

Email: amy.maclachlan@strath.ac.uk

Secondary Supervisor(s): Adrian W. Cross

Project Background: There is an immediate and rising demand for powerful coherent electromagnetic wave (EM) radiation sources at high frequencies (170GHz, 575GHz) for numerous and diverse high-impact applications including plasma heating and current drive, plasma diagnostics and advanced spectroscopic techniques.

Aim: The aim of this project is the exploitation of a cavity with a diameter many times greater than the radiation source wavelength that has a multi-dimensional surface corrugation on the inner wall of the interaction region. The interaction between multi-dimensional periodic surface lattice (PSL) structure and electromagnetic waves will be studied both theoretically and numerically.

Tasks: Undertake literature review of the relevant electron beam-wave interaction processes; understand numerical methods to be used; develop a computer model using the appropriate simulation tool and perform initial calculations. It may be possible to undertake some experiments however this is tentative at this time.

Key references:

[1] A.J. MacLachlan, C.W. Robertson, A.W. Cross, A.D.R. Phelps, "Volume and surface mode coupling experiments in periodic surface structures for use in mm-THz high power radiation sources", AIP ADVANCES, 8 , Nos 10, 105115, Oct 2018
DOI: 10.1063/1.5020542

[2] A.J. MacLachlan, C.W. Robertson, I.V. Konoplev, A.W. Cross, A.D.R. Phelps, K. Ronald, "Resonant Excitation of Volume and Surface Fields on Complex Electrodynamic Surfaces", Physical Review Applied, 11, 11, 034034, March 2019
DOI: 10.1103/PhysRevApplied.11.034034

[3] A.J. MacLachlan, C.W Robertson, K. Ronald, A.W. Cross and A.D.R. Phelps, "Mode coupling in periodic surface lattice and metamaterial structures for mm-wave and THz applications", SN Applied Sciences, 1, Nos 6, Article Number: 613, 2019

DOI: 10.1007/s424

Theory: 40% **Comp:** 40% **Exp:** 20%

Recommended Background or Pre-Requisites: Strong background in EM theory, vectors and vector calculus and mechanics/dynamics and lab skills important. Recommend students should be taking PH452 and (in due course) PH560. Programming skills beneficial, though no specific language pre-requisite. Students may find skills in matlab useful in understanding theory and interpreting results.

Safety Training (if applicable): Part 1 and Part 2 of Safety Induction Course. General lab safety inductions appropriate at outset in case lab experiments are undertaken. Specific Atome, beams and Plasmas (ABP) lab induction will be given if this is to take place on high power RF and microwave safety.

Suitable for: MPhys, BSc. Project particularly well suited to students with good mathematical ability and strong

Misc:

Stochastic particle heating of charged particles by plasma waves

Project ID: TBC

Division: Plasma

Primary Supervisor: Bengt Eliasson

Email: bengt.eliasson@strath.ac.uk

Secondary Supervisor(s): Kevin Ronald

Project Background: Plasmas are ubiquitous in space and laboratory. The Earth is surrounded by a plasma layer, the so-called ionosphere, which shields us from radiation and energetic particles from the sun, and in the laboratory, plasmas are artificially created and studied with application to magnetic confinement fusion and basic research. A plasma is an ionised gas in which there are free electrons and ions so that the gas is electrically conducting. The Earth's ionosphere is magnetized by the geomagnetic field, and in the laboratory, an external magnetic field is used to confine the plasma and prevent it from escaping to the walls. The acceleration of charged particles by plasma waves can lead to chaotic motion of the particles and a rapid heating of the magnetised plasma due to the complicated motion of the particles. This is important for heating of particles in the laboratory, in magnetic confinement fusion devices, in the solar corona, in the Earth's ionosphere, etc., where collisions between particles are relatively rare. Stochastic heating is therefore different from Ohmic heating which is due to collisions between particles.

Aim: To study rapid heating of an ionised gas (plasma) by the chaotic motion of particles in a plasma wave.

Tasks: Literature study of the topic. Initial simulations of stochastic heating using the code (in Matlab) provided by the supervisor Study stochastic heating and calculate statistical quantities such as temperature from a distribution of particles.

Key references:

[1] J. M. McChesney, R. A. Stern, and P. M. Bellan (1987) Observation of fast stochastic ion heating by drift waves, Phys. Rev. Lett. 59, 1436-1439.

[2] J. M. McChesney, R. A. Stern, and P. M. Bellan (1987) Observation of fast stochastic ion heating by drift waves, Phys. Rev. Lett. 59, 1436-1439.

[3] Najmi, A., B. Eliasson, X. Shao, G. M. Milikh, and K. Papadopoulos (2016), Simulations of ionospheric turbulence produced by HF heating near the upper hybrid layer, Radio Sci., 51, 704-717, doi:10.1002/2015RS005866.

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background or Pre-Requisites: Experience in simulations using Matlab (or any other programming language) and good theoretical skills are beneficial.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc:

Ion Channel Laser with Large Oscillation Amplitude

Project ID: TBC **Division:** Plasma

Primary Supervisor: Bernhard Ersfeld **Email:** bernhard.ersfeld@strath.ac.uk

Secondary Supervisor(s): Dino Jaroszynski

Project Background: The ion channel laser (ICL) is a proposed device for generating coherent radiation, similar to the free-electron laser (FEL), but much more compact. In the FEL, a relativistic electron beam radiates due to periodic deflection by the magnetic field of an undulator, whereas in the ICL electrons oscillate in the electrostatic field of a channel in plasma from which background electrons have been expelled (by an intense laser pulse or a relativistic particle beam). An important difference is that an efficient ICL requires oscillation amplitudes in excess of the electron beam width, which reduces the overlap with the emitted radiation and leads to non-linear effects, which are the subject of this investigation.

Aim: The project aims to investigate, analytically and numerically, effects of large oscillation amplitudes in ion channel lasers, e.g., harmonic generation and correlations between longitudinal and transverse electron motion.

Tasks: Familiarise with Key Ref. 1 (below); literature review; familiarise with existing C code for numerical work Extend theory to include non-linear terms/ harmonics; implement corresponding terms in C code; produce and analyse numerical results; prepare presentation; write ~30-page report.

Key references:

[1] : B. Ersfeld et al., “The ion channel free-electron laser with varying betatron amplitude”, New Journal of Physics 16 (9), 093025 (2014)
[2]
[3]

Theory: 50% **Comp:** 50% **Exp:** 0%

Recommended Background or Pre-Requisites: Knowledge in the following areas would be advantageous: wave propagation, Fourier theory; computer programming (C or similar).

Safety Training (if applicable): No safety training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Beam-driven Plasma Wakefield Acceleration of electrons to highest energies

Project ID: TBC

Division: Plasma

Primary Supervisor: Bernhard Hidding

Email: bernhard.hidding@strath.ac.uk

Secondary Supervisor(s): Andrew Sutherland/Fahim Habib

Project Background: Plasma wakefield acceleration (PWFA) is a revolutionary method of production and acceleration of electron beams with highest energy and intensity, in compact, university laboratory-scale setups. Such beams are required to power modern brilliant x-ray light sources and high energy physics colliders. The understanding and modelling of plasma wakefield acceleration is required in order to develop and apply this technology. This project will investigate the physics of PWFA and model it based on a semi-analytical framework and simulations.

Aim: Describe and model the physics of particle-beam driven plasma wakefield acceleration

Tasks: Review electron beam-driven plasma wakefield acceleration, strategies and state-of-the-art. Literature review. Explore methods and tools to describe and simulate the process with modelling and particle-in-cell simulations. Model PWFA based on scalings laws and semi-analytically. Simulate PWFA with particle-in-cell codes such as VSim or via the Sirepo framework. Compare simulation results with modelling, with a focus on the plasma photocathode injection approach.

Key references:

[1] Manahan, Habib .. Hidding, Single-stage plasma-based correlated energy spread compensation for ultrahigh 6D brightness electron beams, G.G. Manahan, F.A. Habib et al., Nature Communications 8, 15705 (2017)
[2] Deng .. Hidding, Generation and acceleration of electron bunches from a plasma photocathode, Nature Physics 15, pages 1156–1160(2019)
[3] http://nexource.phys.strath.ac.uk/

Theory: 40% **Comp:** 40%-60% **Exp:** 0%-20%

Recommended Background or Pre-Requisites: Student should ideally have had contact with Matlab, and/or Python, or similar scientific programming language for developing simulations. Previous knowledge in accelerator, laser or plasma physics useful, but not mandatory.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: This project is open to more than one student.

Space radiation reproduction with laser-plasma-accelerators and Monte Carlo codes

Project ID: TBC

Division: Plasma

Primary Supervisor: Bernhard Hidding

Email: bernhard.hidding@strath.ac.uk

Secondary Supervisor(s): Andrew Sutherland/Paul Scherkl

Project Background: Space radiation is a great danger to electronics and astronauts onboard space vessels. The spectral flux of space electrons, protons and ions for example in the van-Allen radiation belts is inherently broadband, which is a feature difficult to mimic with conventional radiation sources. Using laser-plasma-accelerators such as those developed at the Scottish Centre of the Application of Plasma-based Accelerators (SCAPA), however, has the potential to reproduce important kinds of space radiation exactly. Thus could have transformative impact for space exploration, because better testing may lead to better performance of space missions.

Aim: Investigate reproduction and modelling of space radiation in the laboratory

Tasks: Review radiation effects of charged particle radiation on matter in general, and on space electronics (such as spaceraft charging, single event effects etc.) and biomatter in particular. Explore methods of radiation hardness assurance testing and modelling. Investigate radiation effects on simple and more complex objects, modelled by RSim or other codes based on the Geant4 modelling framwework. Compare the flux and dosage levels with theoretical estimations based on stopping power.

Key references:

[1] RSim https://www.txcorp.com/products/rsim

[2] T. Königstein .. Hidding, Design considerations for the use of laser-plasma accelerators for advanced space radiation studies, Journal of Plasma Physics, Volume 78, Issue 4, pp. 383-391 (2012)

[3] B. Hidding et al., Laser-plasma-based Space Radiation Reproduction in the Laboratory, Scientific Reports 7, Article number: 42354 (2017)

Theory: 40% **Comp:** 40%-60% **Exp:** 0%-20%

Recommended Background or Pre-Requisites: Previous knowledge in accelerator, laser, space or plasma physics useful, but not mandatory.

Safety Training (if applicable):

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: This project is open to more than one student.

Investigation of a Microwave undulator for a Free-Electron Laser

Project ID: TBC

Division: Plasma

Primary Supervisor: Craig Donaldson

Email: craig.donaldson@strath.ac.uk

Secondary Supervisor(s): Liang Zhang, Adrian Cross

Project Background: Microwave undulators can serve as useful alternatives to traditional permanent magnet undulators when a shorter undulator period is desired for a free-electron laser. In this project, the student will learn how a free-electron laser works, and how to design a microwave undulator to generate the X-ray radiation.

Aim: Understanding the principle of a free-electron laser. Design a microwave undulator to generate X-ray radiation.

Tasks: Review the theory of free-electron laser, understand its physics. Study the waveguide and cavity theory to understand how to calculate the eigen frequency of the desired operating mode. Based on the theoretical study, carry out the design of a microwave undulator and evaluate and measure its performance using a Vector Network Analyser.

Key references:

[1] Systematic study of a corrugated waveguide as a microwave undulator, DOI:10.1107/S1600577518014297
[2] microwave undulator, DOI:10.1107/S1600577518014297
[3] Coupling Structure for a High-Q Corrugated Cavity as a Microwave Undulator, DOI:10.1109/TED.2019.2933557

Theory: 30% **Comp:** 50% **Exp:** 20%

Recommended Background or Pre-Requisites: Students should be comfortable with using Matlab, or Python for numerical calculations, also will need to learn the simulation tool CST Microwave / Particle Studio. Recommend students should be taking PH452 and (in due course) PH560.

Safety Training (if applicable): General lab safety inductions appropriate at outset in case lab experiments are undertaken. Specific Atoms, Beams and Plasmas (ABP) lab induction will be given if this is to take place on high power RF and microwave safety.

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

A coherent synchrotron source based on a laser-plasma wakefield accelerator

Project ID: TBC

Division: Plasma

Primary Supervisor: Dino Jaroszynski

Email: d.a.jaroszynski@strath.ac.uk

Secondary Supervisor(s): Antoine Maitrallain, Enrico Brunetti

Project Background: Laser wakefield acceleration in plasma (1) is a new scheme to accelerate particles, which enables bunch properties hitherto not achievable with conventional accelerators. Moreover, this type of accelerator can sustain accelerating fields 3-4 orders of magnitude higher than in a conventional RF accelerator, hence reducing the footprint of facilities substantially, which provides a unique source of electrons and electromagnetic radiation. Beams from laser wakefield accelerators have mono-energetic energy spectra at relatively high-energy and durations of approximately one femtosecond (10^-15s). Taking advantage of these extremely short bunches it is possible to directly produce coherent radiation using an undulator (2,3), which provides a unique compact femtosecond source of XUV coherent radiation.

Aim: The project will involve theoretical and numerical calculations (using software packages and purpose written routines) to study the evolution of the electron bunch properties during its propagation through the undulator and the characteristics of the radiation emitted.

Tasks: Literature review and in depth understanding of the field, familiarise with the codes used in the group, compare results with theory and potentially explain differences obtained Study bunch duration effects, space charge and energy effects on the radiation emitted after the undulator

Key references:

[1] Esarey E, Schroeder CB, Leemans WP. Physics of laser-driven plasma-based electron accelerators. Rev Mod Phys. 2009 Aug 27;81(3):1229–85.

[2] Schlenvoigt H-P, et al. A compact synchrotron radiation source driven by a laser-plasma wakefield accelerator. Nat Phys. 2008 Feb;4(2):130–3.

[3] D. A. Jaroszynski, et al., Coherent startup of an infrared free-electron laser, Phys. Rev. Lett. 71, 3798, 1993

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Knowledge of Fortran or C++, PYTHON, MATLAB etc., good marks in a theoretical course and/or numerical simulation.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: 1 Student for this project

Parametric Scattering and Coupling of Microwaves in Plasma

Project ID: TBC

Division: Plasma

Primary Supervisor: Kevin Ronald

Email: K.Ronald@strath.ac.uk

Secondary Supervisor(s): Bengt Eliasson, Colin Whyte

Project Background: Parametric scattering can arise when powerful EM waves proagate in a non-linear medium like plasma. These can arise in laser plasma interactions where they can be useful (Scattering of laser beams on Langmuir waves can give rise to useful energy transformation processes), or detrimental - Brillouin interactions are believed to cause undesired and damaging scattering of drive laser signals in inertial confinement fusion experiments. Similar dynamics arise when powerful radio waves are used to modulate the ionospheric plasma. In magnetically confined fusion plasmas the next generation of tokamak (ITER) will be difficult to drive with lower frequency signals (Ion Cyclotron Heating and Lower Hybrid Current Drive) as the antenna will need to be stood back from the hot, dense plasma to avoid damage. Coupling the energy across the evanesent 'vacuum gap' presents a difficult matching problem. In spherical aspect tokamaks like MAST, an attractive approach for future power generation, the grossly overdense plasma resulting from their exceptional confinement performance makes them inaccessable for electron cyclotron drive. Driving the plasma resonances by beating two powerful and higher frequency signals may be an attractive way to circumvent both issues. A 'linear' plasma experiment is being completed which will enable the fundamental underpinning physics to be studied in the microwave frequency range (directly relevant to magnetically confined fusion parameter space and of a normalised intensity as to be relevant to laser-plasma and ionospheric physics) in a cool tenuous plasma amenable to diagnostics. The project will aim to make numerical predictions of the dynamics whch may be expected in these experiments.

Aim: To numerically study microwave parametric interactions relevant to a new experimental facility

Tasks: Undertake literature review of the relevant parametric scattering processes and applications; understand numerical and experimental methods to be used; develop computer model in appropriate simulation tool; perform initial calculations in simple cases. Undetake more complete investiatons of simpler cases and compare/contrast with theoretical expectations. Seek to explore more complex ranges of density and magnetic field. It may be possible to undertake some experiments however this is tentative at this time.

Key references:

[1] R.M.G.M. Trines et al, 2011, Nature Physics 7, 87
[2] M.R. Amin and R.A. Cairns, 1990, Nucl. Fus. 30, 327-342
[3] Norin L. et al, 2009, Phys. Rev. Lett., 102, art. 065003

Theory: 15% **Comp:** 65% **Exp:** 20%

Recommended Background or Pre-Requisites: Strong background in EM theory, vectors and vector calculus and mechanics/dynamics and lab skills important. VERY Strongly recommend students should be taking PH452 and (in due course) PH560. Programming skills beneficial, though no specific language pre-requisite. Students may find skills in matlab/python/maple useful in understanding theory and interpreting results.

Safety Training (if applicable): General lab safety inductions appropriate at outset in case lab experiments are undertaken. Specific ABP lab induction will be given if this is to take place on high power RF and microwave safety.

Suitable for: MPhys, BSc. Project particularly well suited to students with good mathematical ability and strong experimental skills and for extension in the following year of MPhys

Misc: 2 projects possible with different mix of supervisors

RF-gated Thermionic Injector Gun for Free-Electron Laser

Project ID: TBC

Division: Plasma

Primary Supervisor: Liang Zhang

Email: liang.zhang@strath.ac.uk

Secondary Supervisor(s): Adrian Cross

Project Background: A thermionic injector gun has the advantages of a long lifetime and high average power. In this project, the student will learn to define the specifications of an RF-gated thermionic gun from the requirement of the accelerator. From the physics, concept to design and optimize the electron geometry. The student will learn how to bridge physics with a practical device.

Aim: Investigate the properties of an RF-gated thermionic injector gun in the application of Free Electron Laser

Tasks: Review the physics of thermionic emission and electron gun. Survey literature on the electron emission model and the Pierce type electron gun. Derive the equations that determine the gun structure. Carry out simulations on the RF gated electron gun and achieve the optimal result.

Key references:

[1] Electron injector based on thermionic RF modulated electron gun for particle accelerator applications, DOI: 10.1109/TED.2019.2954778

[2] A Gridded Thermionic Injector Gun for High-Average-Power Free-Electron Lasers, DOI: 10.1109/TPS.2012.2201962

[3] Review of x-ray free-electron laser theory, DOI: 10.1103/PhysRevSTAB.10.034801

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Students should be comfortable with using Matlab, or Python for numerical calculations, also will need to learn a new simulation tool CST Particle Studio.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc:

Focusing electron beams from a laser-plasma wakefield accelerator

Project ID: TBC

Division: Plasma

Primary Supervisor: Mark Wiggins

Email: mark.wiggins@strath.ac.uk

Secondary Supervisor(s): Dino Jaroszynski

Project Background: Laser-plasma wakefield accelerators (LWFAs) are very compact laser-driven accelerators that have the potential to replace conventional accelerators in a broad range of applications. Highly relativistic electron beams are generated in an LWFA when a high-intensity femtosecond duration laser pulse is focused into a gaseous or plasma target. Collimating and focusing the electron beams that emerge from a LWFA, by using quadrupole magnet arrays, can be crucial for many potential applications such as coherent radiation production, electron diffraction and radiotherapy. For example, very high energy electron radiotherapy is predicted to deliver a higher volumetric radiation dose when the electron beam converges onto the target tumour.

Aim: Study and optimise the evolution of electron beams as they are transported through magnetic arrays for a given application.

Tasks: Literature review of the background topic areas (laser-plasma accelerators, electron beam transport, applications). The student will become familiar with the MAD-X numerical simulation package and generate basic data. Concentrating on a particular application, the student will optimise the beam focusing system for a variety of accelerator scenarios to inform future experiments. Detailed literature review in that application area, comparing simulations results with published work.

Key references:

[1] T. Eichner, et al., "Miniature magnetic devices for laser-based, table-top free-electron lasers", Phys. Rev. ST Accel. Beams 10, 082401 (2007). https://doi.org/10.1103/PhysRevSTAB.10.082401
[2] S. M. Hooker, "Developments in laser-driven plasma accelerators", Nature Photon. 7, 775 (2013). https://doi.org/10.1038/nphoton.2013.234
[3] K. Kokurewicz, "Focused very high-energy electron beams as a novel radiotherapy modality for producing high-dose volumetric elements", Sci. Rep. 9, 10837 (2019). https://doi.org/10.1038/s41598-019-46630-w

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Knowledge of computational physics. Interest in high-power lasers, radiation and applications

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics, BSc Physics with Teaching

Misc: Suitable for 1 or 2 students

Spectral properties of reflected laser light from expanding plasma targets

Project ID: TBC

Division: Plasma

Primary Supervisor: Martin King

Email: m.king@strath.ac.uk

Secondary Supervisor(s): Ross Gray, Paul Mckenna

Project Background: The interaction of an intense laser pulse with a foil target results in ionisation of the target and the formation of a dense plasma. The laser light is then reflected from the critical surface where the plasma frequency is greater than the laser frequency. Due to the speed of the expansion/recession of this critical surface, the reflected light can experience a temporally varying Doppler shift. Understanding the resultant spectral properties of the reflected light can give insight into the underlying plasma dynamics that occur which is relevant for producing high energy ion beams and bright, X-ray sources that have applications in a range of fields such as medicine and science.

Aim: Determine the effect plasma expansion/hole-boring has on the spectrum of intense reflecting laser light

Tasks: Investigate the change in reflection spectra by varying plasma temperature, laser intensity and the impact of introducing a chirp to the input laser pulse.

Key references:

[1] S. C. Wilks, et al. Phys. Rev. Lett. 69, 1383 (1992)
[2] A. P. L. Robinson, et al. Plasma Phys. Control. Fusion, 51, 024004 (2009)
[3] A. Macchi, et al. Rev. Mod. Phys. 85, 751 (2013)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Python, good understanding of EM theory and an interest in plasma physics

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: No miscellaneous requirements. Only one student may take this project.

Atomic Processes for Astrophysical Plasmas I

Project ID: TBC

Division: Plasma

Primary Supervisor: Nigel Badnell

Email: n.r.badnell@strath.ac.uk

Secondary Supervisor(s): Martin O Mullane

Project Background: The upcoming JAXA/NASA XRISM mission with give rise to unprecedented resolution at X-ray wavelengths from numerous astrophysical sources. In particular, spectra arising from electron recombination with highly-charged He-like ions provides a critical temperature diagnostic. Recent developments to the general atomic code AUTOSTRUCTURE potentially provide a much improved description of such processes.

Aim: Explore the predicted spectral emission of X-ray sources expected to be seen by the upcoming XRISM mission.

Tasks: Review dielectronic recombination satellite spectra for He-like ions. Install Linux on your laptop (if windows based). Install Fortran compiler. Install AUTSOSTRUCTURE program to calculate atomic data from group webpages (amdpp.phys.strath.ac.uk/autos). Use the online guide to run simple examples of atomic structure and recombination processes. Set-up inputs to describe dielectronic recombination satellite spectra for He-like ions. Produce spectra expected to be seen by XRISM and contrast and compare with others based-on historic data.

Key references:

[1] https://heasarc.gsfc.nasa.gov/docs/xrism/
[2] Foster et al 2010, Space Sci. Rev. 157, 13 https://doi.org/10.1007/s11214-010-9732-1
[3] Badnell 2006, J.Phys.B 39, 4825

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Good theoretical skills. Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Mphys, BSc Maths and Physics

Misc:

Atomic Processes for Astrophysical Plasmas II

Project ID: TBC **Division:** Plasma

Primary Supervisor: Nigel Badnell **Email:** n.r.badnell@strath.ac.uk

Secondary Supervisor(s): Martin O Mullane

Project Background: Spectral absorption and emission by neutral and low-charged heavy elements (e.g. lanthanides) dominate the opacity of kilonovae and black-hole/neutron star mergers. The theoretical description of their atomic structure remains a challenge, especially so for the actinides. Recent developments to the general atomic code AUTOSTRUCTURE potentially provide a much improved description of such processes.

Aim: Explore the description of heavy elements seen in kilonovae and black-hole/neutron star mergers.

Tasks: Review the background of the description of heavy elements for opacity. Install Linux on your laptop (if windows based). Install Fortran compiler. Install AUTSOSTRUCTURE program to calculate atomic data from group webpages (amdpp.phys.strath.ac.uk/autos). Use the online guide to run simple examples of atomic structure. Set-up inputs to describe heavy elements. Compare various strategies to describe their energy levels and contrast and compare with observed.

Key references:

[1] Kasen et al Ap.J. 774, 25 (2013)
[2] Tanaka et al MNRAS 496, 1369 (2020)
[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: Good theoretical skills. Students should be familiar with scientific computing, preferably in a Unix environment.

Safety Training (if applicable): No special training required

Suitable for: Mphys, Bsc Maths and Physics

Misc:

Field Probe Diagnostics for High-Power Microwave Applications

Project ID: TBC

Division: Plasma

Primary Supervisor: Philip MacInnes

Email: philip.macinnes@strath.ac.uk

Secondary Supervisor(s): Kevin ronald

Project Background: When working with high-power microwave sources determination of the operating mode (i.e. the dominant EM field pattern) is of utmost importance. This may be achieved through the use of field-sensing probes, located at specific locations longitudinally and azimuthally around the interaction space, whereby the modal content can ascertained through comparison of the relative magnitudes and phases of the different signals.

Aim: experimental and theoretical characterisation of a novel E-field diagnostic

Tasks: This project aims to characterise the performance of a recently constructed field-probe diagnostic. There is a strong experimental component, coupled with numerical simulation for prediction / interrogation of results.

Key references:

[1] Huiskamp T. et al. "B-dot and D-dot Sensors for (sub)Nanosecond High-Voltage and High-Current Pulse Measurements", DOI: 10.1109/JSEN.2016.2530841

[2] Metwally I.A. "Coaxial D-dot probe: design and testing", DOI: 10.1109/CEIDP.1995.483722

[3]

Theory: 20% **Comp:** 20% **Exp:** 60%

Recommended Background or Pre-Requisites: Experience with MATLAB / Python is preferable but not a necessity, help will be available as required. A good understanding of the physics for PH352 would again be preffered with PH452 being a recommended class

Safety Training (if applicable): The project is based in the TIC building, all users must complre relevant induction material prior to working in TIC. Students must also review and adhere to the guidelines for use of workstations / VDUs. This project will include an experimental component, which will be supervised at all times; the student will be provided with an induction to good practice in high-power microwave experiments.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: only one student

Plasma Flare Electron Beam Dynamics in Relativistic Accelerating Diodes

Project ID: TBC

Division: Plasma

Primary Supervisor: Philip MacInnes

Email: philip.macinnes@strath.ac.uk

Secondary Supervisor(s): Colin Whyte

Project Background: A plasma-flare electron accelerator produces a relativistic electron beam by increasing the electrical stress on the emitter to the point it produces a plasma near its surface, from which the electrons are extracted; called space-charge limited emission. Obtaining an accurate prediction of performance for such an accelerator is a complicated task, as the dynamics of the effective emitter evolve with time. The ability to quantify what changes are required in the model, to better approximate real-world operation, allows for better predictive modelling of the microwave sources and amplifiers these accelerators are designed to drive.

Aim: Development of predictive numerical models for the operation of relativistic plasma-flare electron accelerating diodes

Tasks: The project aims to develop numerical models of a plasma-flare accelerating diodes, using CST: Particle Studio and its different solver techniques. These models will then be integrated into larger simulations to examine their impact on predicted performance from different microwave sources.

Key references:

[1] Humphries, Charged Paricle Beams (freely available): https://www.fieldp.com/cpb.html

[2] Verboncoeur J. P. et al., "Space-charge-limited emission models for particle simulation, DOI: 10.1109/PLASMA.2004.1340044

[3]

Theory: 30% **Comp:** 70% **Exp:** 0%

Recommended Background or Pre-Requisites: PH352 a pre-requisit with PH452 recommended. Experience / proficiency with programming languages will be benificial (python, MATLAB, C++, Visual Basic, etc.) though a willingness to learn their function is more key than specific existing expertise.

Safety Training (if applicable): The project is based in the TIC building, all users must complre relevant induction material prior to working in TIC. Students must also review and adhere to the guidelines for use of workstations / VDUs. This project will include an experimental component, which will be supervised at all times; the student will be provided with an induction to good practice in high-power microwave experiments.

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: only one student

Design and modelling of an electron spectrometer for the SCAPA facility

Project ID: TBC
Division: Plasma

Primary Supervisor: Robbie Wilson
Email: robbie.wilson@strath.ac.uk

Secondary Supervisor(s): Ross Gray, Paul McKenna

Project Background: Intense laser pulse interactions with a dense plasma will result in transfer of the laser energy to the electrons within the plasma. For sufficiently high laser intensities, such as those achieved by the 350 TW SCAPA laser, the electrons are accelerated to near the speed of light within a distance of a few laser wavelengths. Such high energy beams of electrons have applications in the new high energy radiation sources, non-destructive testing and fusion energy. In order to improve the energy and quality of the electron beams produced we must identify and design methodologies to measure them in the laboratory such as a high energy electron spectrometer. This project will focus on the design and modelling of a potential electron spectrometer that could be used in SCAPA and will include analysis of previous electron spectrum measurements to identify potential routes to an improved design.

Aim: To undertake a design study to support the development of an electron spectrometer for laser-solid experiments on SCAPA

Tasks: A thorough literature review will be conducted of relevant background areas (relativistic laser-plasma interactions, laser-electron energy coupling). Development of code using python for the processing and analysis of experimentally measured spectra.

Key references:

[1] S. C. Wilks, et al. Phys. Rev. Lett. 69, 1383 (1992)
[2] K. Tanaka, Review of Scientific Instruments 76, 013507 (2005)
[3]

Theory: 40% **Comp:** 60% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should be familiar with python. A good understanding of EM theory and relativity is required along with an interest in ultra-intense laser plasma interactions, high power laser physics and plasma physics.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: No miscellaneous requirements. Only one student may take this project.

Spectral analysis of experimentally measured back-reflected laser light from solid-density plasma targets

Project ID: TBC

Division: Plasma

Primary Supervisor: Timothy Frazer

Email: timothy.frazer@strath.ac.uk

Secondary Supervisor(s): Ross Gray, Paul McKenna

Project Background: The interaction of ultra-intense laser pulses with solid density foil targets results in rapid ionisation of the target and the formation of a high density plasma. The density is sufficiently high that a fraction of the incident laser pulse will be reflected from the temporally evolving critical density surface of the plasma. Due to the balance of laser-driven radiation pressure and the thermal and electrostatic expansion of the target, the velocity of the critical surface relative to the incident laser pulse will evolve over the duration of the interaction, resulting in a relativistic Doppler shift of the reflected light. By understanding how this will impact the measured spectra, the underpinning plasma dynamics may be elucidated. This can provide crucial information contributing to to the understanding of often complex ion acceleration and x-ray generation processes taking place during the interaction.

Aim: To develop computational techniques for the analysis of experimental backreflection spectra and to use this to explore related plasma dynamics.

Tasks: A thorough literature review will be conducted of relevant background areas (relativistic laser-plasma interactions, laser hole-boring, laser-driven ion acceleration, applications etc.). Development of code using python for the processing and analysis of experimentally measured backreflection spectra. Using this code to make measurments of relativistic Doppler shifts and hole-boring velocities of the plasma critical surface.

Key references:

[1] A. P. L. Robinson, et al. Plasma Phys. Control. Fusion, 51, 024004 (2009)
[2] A. Macchi, et al. Rev. Mod. Phys. 85, 751 (2013)
[3] A. Higginson, et al. Nature Communications, 9, 724 (2018)

Theory: 20% **Comp:** 80% **Exp:** 0%

Recommended Background or Pre-Requisites: Student should be familiar with python. A good understanding of EM theory and relativity is required along with an interest in ultra-intense laser plasma interactions, high power laser physics and plasma physics.

Safety Training (if applicable): No special training required

Suitable for: MPhys, BSc, BSc Maths and Physics

Misc: Only one student may take this project.