Tyndall National Institute
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SUMMER FELLOWSHIP PROGRAMME 2026
PROJECT DESCRIPTIONS

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BRINGING PHOTONICS TO LIFE

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Electronic devices fabricated from 2D materials

Theme: CMOS & Emerging Platforms
Supervisor: Aashi Gupta
Co-Supervisor: Ray Duffy

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Background:

The aim of this project is to gain a better knowledge of 2D materials for applications in novel electronics, in terms of physical and electrical properties, as well understanding 2D materials device fabrication. Transition Metal Dichalcogenides (TMD) 2D materials and devices have made strides in recent years, however problems still remain that could limit their uptake as a technology. Problems include crystal quality (too small grain size), defectivity which can degrade carrier mobility, lack of controlled active doping to high enough levels, and non-optimised contact formation which affects conductivity and parasitic resistance. TMD devices are typically fabricated from thin semiconductors. The material consists of the general formula of MX_2 (M is a transition-metal atom such as Mo, W, Hf etc. and X is a chalcogen atom such as S, Se, or Te). Ultrathin characteristics of TMDs (such as a monolayer of MoS_2 with the thickness of 0.65 nm) make it a promising material for novel electronics, in terms of physical and electrical properties. Looking to the future, advanced semiconductor processing has proven beneficial and has unlocked potential when applied to these problems in other semiconductor materials (e.g. silicon), and therefore the benefits to TMD materials (e.g. MoS_2) require exploration.

Methods:

The overall objective of the work is to characterise 2D materials and devices, fabricated at Tyndall. It is targeted to extract parameters associated with the electrical properties of the MoS_2 layers. Characterisation will include electrical test of Field Effect Transistor (FET) devices for resistivity, carrier mobility, and contact resistance extraction. The project will enable the student to gain experience in the fields electronic devices, advanced novel materials, and evaluation of semiconductor processes and characterisation up close. Furthermore, electrical testing of the fabricated devices will facilitate experience in the field of material science and functional device performance.

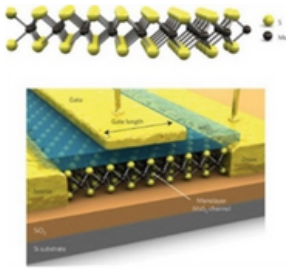

Fig.1: Schematic representation of an MoS2 TMD layer, and device implementation.

Predicted results and impact:

- To measure the electronic behaviour of 2D materials based electronic nanodevices.
- To extract meaningful figures of merit of the devices, related to material sheet resistance, resistivity, transistor gate-modulated current switching behaviour, and carrier mobility.
- To contrast different device fabrication approaches by means of the electrical data, to predict which semiconductor processing methodology is suitable for future nanoelectronic technologies.

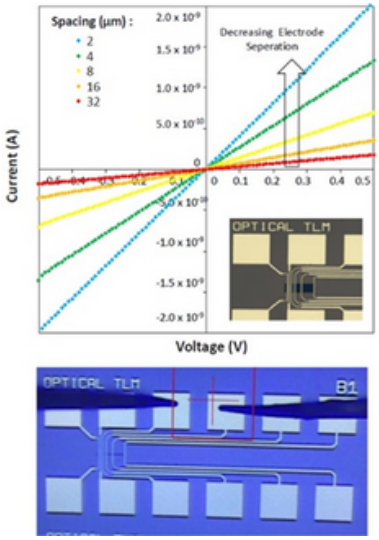

Fig.2: Representative electrical behaviour and optical microscope images of MoS2 devices in the lab.

Fig. 3: Open Access Characterisation Facility lab in Tyndall that would be used in this project.

References:

1. https://pubs.acs.org/doi/10.1021/acs.chemmater.2c01154
2. https://pubs.aip.org/aip/jap/article-abstract/120/12/125102/345824/Air-sensitivity-of-MoS2-MoSe2-MoTe2-HfS2-and-HfSe2?redirectedFrom=fulltext
3. https://iopscience.iop.org/article/10.1088/1361-6641/ab121b

Location: Tyndall **Type**: In-person

Key words: 2D materials, field-effect-transistors, MOS devices, resistance, carrier mobility.

Degree(s) that will suit this project: Engineering, Materials Science, Physics

Fabrication and stabilisation of p-type of semiconducting metal oxides via atomic layer processing

Theme: CMOS & Emerging Platforms
Supervisor: Ian Povey
Co-Supervisor: Akendra Chabungbam

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Background:
As the drive for three-dimensional device integration has evolved the use of semiconducting metal oxides offers significant advantages over traditional materials due to their thermal and processing robustness. For n-type oxides high quality performance has already been realised, for example, amorphous InGaZnO, for p-type materials this is more challenging. For example, p type character can be compensated by native defects that are inherent in metal oxides and thermodynamic stability of p materials is often poor. In addition, the mechanisms of conduction (of holes) in p-type materials requires the alignment of p-orbitals and hence crystallinity, conversely for n- type materials electrons can migrate through the overlap of o-orbitals, the change from axial to spherical symmetry removes the requirement for crystallinity in electron conduction. This requirement for crystallinity adds significant complexity to fabrication of p-type materials as the right phase must be generated, defects minimised and stability ensured.
In this project atomic layer processing methodologies will be tuned to facilitate the growth and stabilisation of a semiconducting metal oxide and the stabilisation of p-type properties.

Methods:
Metal oxide films will be fabricated, and modified, using atomic layer deposition, in conjunction with plasma annealing and doping strategies, to generate films on the nanometre scale. Materials will be assessed in terms of, morphology and crystallinity (conformality, crystal phase grain size), electrical behaviour (mobility, carrier concentration, resistivity), spectral response (Raman) and composition (XPS). The stability of these properties will also be assessed.

Predicted results and impact:
Generation and characterisation of p type semiconducting oxide and evaluation of its stability.

Location: Tyndall **Type**: In-person

Key words: ALD, semiconducting metal oxides, heterogeneous integration, channel material, logic devices

Degree(s) that will suit this project: Physics, Chemistry, Electrical and Electronic Engineering, Materials Science

Electronic and optical properties of G-center defects in Si1-xGex materials

Theme: CMOS & Emerging Platforms
Supervisor: Kaynat Alvi
Co-Supervisor: Felipe Murphy Armando

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Background:

The G-center is a carbon-related color center in silicon that emits in the telecomO-band and has emerged as a leading CMOS-compatible single-photon source with fast radiative lifetimes. It can be created deterministically via ion implantation, laser writing, spectrally trimmed, and coupled to integrated photonics and optical cavities [1–3]. Literature evidence converges to a Cs–Sii–Cs motif, equivalently, a Ci-Cs complex interacting with a Si interstitial is the structure responsible for G-center emission [4-6].

SiGe is a mature CMOS material, whose Ge content tunes strain, band edges, and phonons, providing practical levers to modulate G-center properties while preserving foundry compatible. In relaxed SiGe, Ci and CiCs complexes form, and alloying modifies their stability and electronic levels. Transitions associated with CiCs (the G-center precursor) is reportedto be only weakly affectedwithin the exploredcomposition range [7,8]. After nanofabrication of SiGe/Si quantum-well wires, a new sharp photoluminescence peak near 0.97 eV appears in the spectral region of the Si G-line. A concise, first-principles study mapping how the host band structure, band gap, band dispersion, and photoluminescence evolve with Ge fraction (x), with a G-center model, will provide clear targets for later experiments.

We will compute band structures and band dispersions for Si(1-x) Gex at a few compositions and compare them to the electronic band structure after introducing a G-center motif, evaluating its effect as the alloy composition varies. We will calculate the telecom-range emission energy, oscillator strength and determine the frequency-dependent dielectric function $\varepsilon(\omega)$and its modification by the G-center.

Methods:

The study will employ special quasirandom structures (SQS) supercells (129 atoms) with multiple seeds per composition (x) to capture realisticlocal Si/Ge statistics. The G-center will be introduced as a minimal Cs–Si– Cs motif in the supercell, and the resulting defect bands/states will be identified relative to the host bands. Electronic structures will be obtained with VASP: LDA for structural relaxations followedby TB-mBJ for band-edge accuracy. Optical properties will be computed via the standard linear-response workflow; excitonic effects will be included using the Bethe Salpeter Equation (BSE) to obtain ε(ω) with electron–hole interactions. Where relevant, spin-orbit coupling will be included to capture Ge-induced valence-band splitting.

Predicted results and impact:
PL spectra should reproduce O-band emission and quantify oscillator strengths relevant to cavitycoupling and waveguide integration on SiGe.The resulting composition dependent trends will guide experimental efforts on emitter activation and optical characterization.

References:
[1] Hollenbach et al.,Nat. Commun. 13,7457 (2022).
[2] Beaufils et al.,Phys. Rev. B 97,035303 (2018).
[3] Durand et al., Phys. Rev. B 110,L020102 (2024).
[4] Durand et al., Phys. Rev. X 14,041071 (2024).
[5] Saggio et al.,Nat. Commun. 15,3528 (2024).
[6] Baron et al.,arXiv:2204.13521 (2022).
[7] Hollenbach et al., J. Appl. Phys. 132,033101 (2022).
[8] Mesli & Larsen, J. Phys.: Condens.Matter 17, 3451 (2005).

Location: Tyndall **Type**: Hybrid 3 days/week

Key words: SiGe heterostructure, G-centers, special quasirandom structures, Density Functional Theory, Photoluminescence.

Degree(s) that will suit this project: Physics, Materials Science, Electrical/Computer Engineering, or Applied Mathematics

Machine-learning accelerated modelling of group 13 nitride deposition chemistry

Theme: CMOS & Emerging Platforms
Supervisor: Karl Rönnby
Co-Supervisor: Cara-Lena Nies

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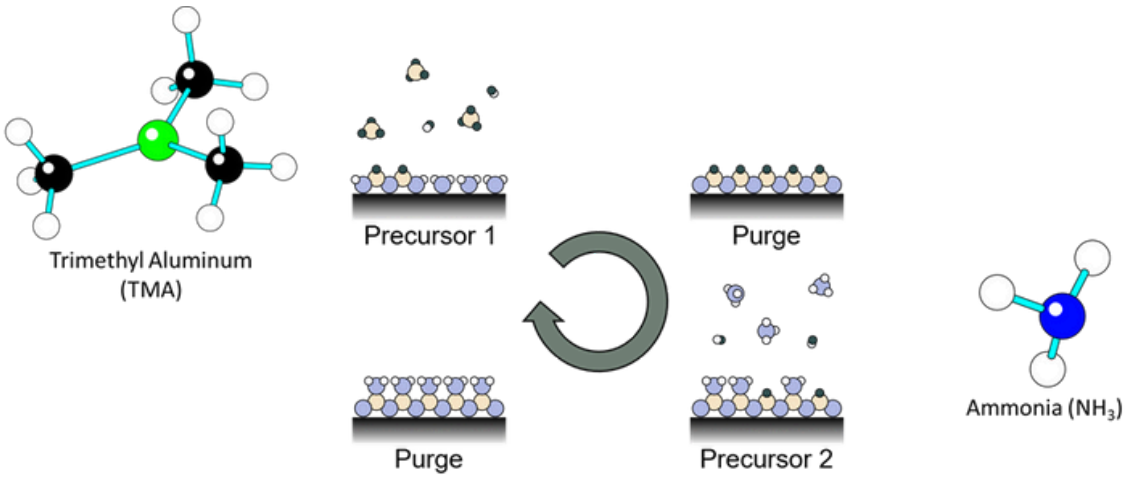
Background:

Light emitting diodes (LEDs) have become the staple in lighting applications, due to them being more energy efficient and lasting longer than traditional incandescent lights. The colours of LEDs are determined by the electronic properties of the semiconductor material in the LED. Aluminium nitride (AlN), gallium nitride (GaN) and indium nitride (InN) and their alloys have been widely used in LEDs as they allow emitted light from infrared (IR) e.g., InN to ultraviolet (UV), e.g., (Al,Ga)N alloy, covering the whole light spectrum. These materials are often called the group 13 nitrides (13Ns).

Manufacturing of 13Ns with the required purity and over complex substrates require advanced deposition methods such as atomic layer deposition (ALD). In ALD a thin film is made by reaction of precursor molecule vapour with a substrate, leading to deposition of the required material. Between each precursor or co-reactant, the reaction is purged by an inert gas to remove any residue or by-products. This ensures that surface reaction between precursor and film are the only available reaction and gives a fine control over film thickness. ALD has been used to deposit 13Ns using precursors such as trimethyl metals and ammonia. However the deposition chemistry is poorly optimised leading to much of the precursor being left unreacted and discarded, wasting both time and resources.[1] Previous modelling studies of the ALD chemistry have revealed complicated reaction pathways with a multitude of surface structures during the deposition process.[2,3]



Methods:
In this project we will use a combination of the first principles atomic scale modelling tool density functional theory (DFT) and state-of-the-art machine learning interatomic potentials (MLP). DFT is widely used to study materials and their properties at the atomic level. We will use it to investigate how common precursor molecules (e.g. trimethyl metals and ammonia) interact with a 13Ns surface, and how they can decompose to deposit atoms forming the desired film. We have previously demonstrated that MLPs greatly reduce the computational cost, in some cases from months to minutes per calculation.[4] Adding MLP to our materials modelling workflow will therefore allow for investigation of many more possible reactions. MLPs will be trained on the calculated DFT data as well previous DFT data available through literature.

Predicted results and impact:
The aim of this project is to explore the ALD chemistry of the 13Ns to understand how precursors react and thereby how to improve the deposition of these materials. The project will also demonstrate the possibilities of using MLP to accelerate materials modelling workflows. This project will give the student (i) experience using DFT and MLP tools used in state-of-the-art materials research and (ii) learn how materials modelling can be used to study material properties and chemical reactions with real applications.

References:

1. Rönnby, K.; Pedersen, H.; Ojamäe, L. Kinetic Modeling of Ammonia Decomposition at Chemical Vapor Deposition Conditions. J. Vac. Sci. Technol. A 2020, 38 (5), 050402. https://doi.org/10.1116/6.0000369.
2. Rönnby, K.; Pedersen, H.; Ojamäe, L. Surface Structures from NH_3 Chemisorption in CVD and ALD of AlN, GaN, and InN Films. J. Phys. Chem. C2022, 126 (13), 5885–5895. https://doi.org/10.1021/acs.jpcc.2c00510.
3. Rönnby, K.; Pedersen, H.; Ojamäe, L. Surface Chemical Mechanisms of Trimethyl Aluminum in Atomic Layer Deposition of AlN. J. Mater. Chem. C 2023, 11 (40), 13935–13945. https://doi.org/10.1039/d3tc02328a.
4. Rönnby, K.; Nolan, M. Predicting the Morphology of Cobalt, Copper, and Ruthenium on TaN for Interconnect Metal Deposition. J. Chem. Phys. 2025, 162 (24), 244704. https://doi.org/10.1063/5.0256958.

Location: Tyndall **Type**: Hybrid 2 days/week

Key words: Materials modelling, atomic layer deposition, group 13 nitrides, density functional theory, machine learning

Degree(s) that will suit this project:

Simulating metal contacts on 2D materials for next generation semiconductor devices.

Theme: CMOS & Emerging Platforms
Supervisor: Michael Nolan
Co-Supervisor: Michael Sweetman

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Background:

2D materials such as MoS_2 and WS_2 are being explored as active layers in next generation semiconductor devices aiming to the sub-2nm size regime. Initial results on these materials show promise as the channel region in a transistor and very recent work also suggests their use to prevent conducting metal interconnects migrating into active regions. This then delivers the ultimate in miniaturisation by using materials that are, in principle, only one layer thick. A key aspect that needs to be better understood is how conducting metals that act as contacts or interconnects nucleate and grow on these 2D materials.

To this end, the aim of this Fellowship project, within the wider NanoIC Pilot Line, is to apply sophisticated kinetic Monte Carlo and machine learning atomistic simulations to explore how a range of metals, initially tungsten, nickel and titanium nucleate on target 2D materials MoS_2 and WS_2 by

1. (Simulating the deposition of the target metals on the 2D materials substrates with our newly developed atomistic kinetic Monte Carlo Simulation approach [1]
2. Explore the role of the state of the substrate, including presence of defects, number of 2D layers
3. Predict the formation of flat or island morphologies of deposited metals to allow rational choice of suitable 2D-metal combinations

The work will involve building and running the kMC simulations using first principles simulation data generated within the group for metal deposition on 2D materials, followed by the analysis of the resulting structures. We plan to explore the use of machine learning (ML) to accelerate key parts of the first principles simulations, targeting atom migration barriers that are used in the kMC.

Methods:

First principles simulations using the density functional theory (DFT) approach are widely used to simulate the structure of metal species deposited on substrates [2,3]. We can also extract the activation barriers for the migration of metal species that contribute to the formation of different metal structures when deposited on substrates. When a metal is deposited we can picture this as individual metal atoms arriving at the surface with some energy (based on deposition temperature). The metals can move over the surface and with enough metal atoms, the chemistry drives the formation of flat or island metal structures. By computing the barriers for metal atom migrations, we can obtain rate constants for steps, such as an atom moving from the substrate upwards to build up a new layer of metal atoms [1,2].

Using this information, the starting substrate and the structure of the deposited metal together with a set of deposition parameters (temperature, time, flux) the kMC simulations yield deposited structures which are analysed for their quality. For 2D materials this allows us to obtain combinations of 2D substrates and metals that promote formation of conducting metal layers for contacts or interconnectes.

Predicted results and impact:
kMC simulations for deposition of tungsten, nickel and titanium on 2D materials giving predictions of the final structure of the deposited metals. Exploring machine learning potentials to predict the activation barriers at low cost to accelerate the simulations. New metal-2D materials combinations. Training of the Fellow in advanced atomistic simulations and wider, transferable skills development of the Fellow.

References:
[1]: S Aldana, CL Nies, M Nolan, 2024 arXiv preprint arXiv:2410.06133
[2] CL Nies, SK Natarajan, M Nolan, Chemical Science 2024, vol. 13 (3), 713-725,
[3] CL Nies, M Nolan, Journal of Physics: Materials 2014, vol. 6 (3), article 035008

Location: Tyndall **Type**: Hybrid 3 days/week

Key words: kinetic Monte Carlo, 2D materials, metal deposition, atom migration, machine learning, Python, CMOS, semiconductor, materials

Degree(s) that will suit this project: Materials Science, Chemistry, Physics, Theoretical Physics, Chemical Physics.

Multi-scale simulation of thermal atomic layer etching chemistry

Theme: CMOS & Emerging Platforms
Supervisor: Michael Nolan
Co-Supervisor: Rita Mullins

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Background:

Thermal atomic layer etching (tALE) is an atomic level processing approach that enables the processing of a broad range of materials layers in electronic devices at the few-to-sub-nm regime and in three-dimensional, high aspect ratio structures. It allows fine control of etching of high and low-k dielectrics, oxides, metals and nitrides exploiting the self-limiting and layer-by-layer manner inherent in atomic level processing approaches such as atomic layer deposition (ALD). Challenges in tALE that we address with this multi-scale simulation project include:

Atomistic level understanding of tALE processes, in particular bringing the details of how reactants modify the starting surface in the first ALE half-cycle.

tALE uses fluorinated reactants, which are difficult to handle and increasingly incompatible with sustainable materials processing; eliminating or using less impactful reactants in ALE processes will drive sustainability targets and simulation supports this ambition.

Simulation approaches use first principles density functional theory (DFT), which is resource intensive, with limitations on the complexity of the system that we can model. Our extensive DFT data (since 2019) will be used to train neural network Machine Learning Potentials to accelerate discovery of ALE chemistries and simulate complex chemistries.

Methods:

The project uses first principles density functional theory (DFT) simulations of the surface chemistry in tALE with the VASP code using a well-established surface simulation approach: periodic models of the surface, using low energy and less stable surfaces (representing complexity in nanostructures and polycrystalline films). The surfaces can be terminated in different ways, e.g. defects, hydroxyls. Thermodynamic calculations model the finite temperature reaction energy (Gibbs free energy) for conversion of a starting surface into a modified surface. The preference for a self-limiting, non-continuous etching process is predicted at different temperatures.

Modelling of explicit surface reactions explores how the reactant modifies the starting surface, accounts for the coverage of the reactant predicts the by-products (e.g. for HF on HfO2, H2O is produced and F inserts into the surface), barriers for atom diffusion over the surface, and the maximum coverage of reactant, from which theoretical etch rates are computed.

For ML, DFT data is used for training and testing and the potential is implemented into the LAMMPS and ASE codes to predict activation barriers and run very long timescale simulations of ALE dynamics for the first time.

Predicted results and impact:
Predictions of ALE chemistries on target substrates, impact of different reactants (fluorinated molecules, BCl_3, SF_4), new ML potentials for ALE, long timescale dynamics of ALE chemistry.

References:
J. Vac. Sci. Technol. A 40, 022604 (2022), https://doi.org/10.1116/6.0001614, Chemistry of Materials 2020, https://doi.org/10.1021/acs.chemmater.9b05021

Location: Tyndall **Type**: Hybrid 3 days/week

Key words: DFT, machine learning, atomic layer etching, surface chemistry

Degree(s) that will suit this project: Chemical Physics, Materials Science, Theoretical Physics

Development and application of Machine Learning Potentials for Novel Functional Materials.

Theme: CMOS & Emerging Platforms
Supervisor: Michael Nolan
Co-Supervisor: Karl Rönnby, James Brown

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Background:

Atomistic simulations using density functional theory and molecular dynamics are routinely used in discovering and understanding materials, chemistries and processes to produce functional thin films. The Materials Modelling for Devices Group at Tyndall is at the forefront of this work with applications in semiconductor devices, catalysts for removal of pollutants, materials processing and discovering sustainable materials, e.g. replacement of fluorine-containing chemicals.

The cost of simulations is significant requiring days to months to complete a calculation, even on high performance computing systems. Machine learning trained on available simulation data is now established as an approach to rapidly screen materials and chemistries to explore a wider chemical space and arrive at useful candidate materials – essentially it can provide a filtering approach where rapid ML simulations can filter out undesired options, leaving a small number for deeper investigation.

The aim of this Fellowship is to work with members of the group to take their atomistic simulation data and outputs and train a machine learning potential that can deliver accurate simulation data on a wider range of materials and chemistries thus allowing candidate materials to be chosen. The targeted applications include:

- Prediction of metal deposition on metal nitrides and 2D materials for semiconductor devices
- Prediction of novel ferro- and piezoelectric materials and the role of defects
- Prediction of porous materials for sensing and capture of PFAS chemicals in semiconductor processing.

Methods:

First principles simulations using state of the art first principles density functional theory (DFT) are being used within the host group for novel materials discovery on high performance computing infrastructure. This yields the structure, stability and relevant chemical properties of target materials to predict their performance. Unfortunately, this powerful and crucial approach to materials development is limited by the time and computing resources needed for full DFT calculations. The neural network potential method implemented in the DeepMD code that will be deployed in this Fellowship will use these DFT data as training data to produce new neural network potentials that can be used to rapidly compute relevant properties of candidate materials - ca. 2 minutes compared to days for DFT so that thousands of structures can be rapidly assessed. Coding is required as part of the training, validation and deployment of the potentials.

Predicted results and impact:
Using existing (and new data as needed) DFT results for materials are used to train new neural network potentials to enable simulation of structures with thousands of atoms, including (i) simulation of defects, (ii) simulation of complex surface chemistries and reactivity and (iii) longer timescale simulations. This will also deliver new ML models for wider use within the group. A key impact is the training of the Fellow on advanced simulation tools and applications in real materials as well as wider transferable skills development.

References:
https://docs.deepmodeling.com/projects/deepmd/en/r2/index.html,
https://www.sciencedirect.com/science/article/pii/S0010465518300882,
https://link.aps.org/doi/10.1103/PhysRevLett.120.143001,
https://pubs.aip.org/books/monograph/137/book-pdf/12805891/9780735425279.pdf#page=116,
https://journals.aps.org/prb/abstract/10.1103/PhysRevB.107.224301
MMD Paper using ML: https://pubs.aip.org/aip/jcp/article/162/24/244704/3350717

Location: Tyndall **Type**: Hybrid 3 days/week

Key words: Machine learning, Python, Catalysts, Metal Oxides, Deposition, Materials

Degree(s) that will suit this project: Materials Science, Chemistry, Physics, Theoretical Physics, Chemical Physics.

Atomic layer processing of two-dimensional transition metal dichalcogenides for heterogeneous integration

Theme: CMOS & Emerging Platforms
Supervisor: Sabir Hussian
Co-Supervisor: Ian Povey

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Background:

Transition metal dichalcogenides (TMDs) have emerged from graphene initiatives as alternative 2D-materials due to their diverse functionality. More specially, they can be engineered to exhibit properties from semi-metals through to wide band semiconductors opening application spaces in logic, memory, sensors and catalytic materials [1-3]. Until recently the study of TMDs has focussed on mechanically exfoliated flakes from bulk materials and the transfer of layers from high temperature chemical vapour deposition (CVD) processes. However, such processes are not compatible with the stringent requirements for heterogeneous integration, for example conformality over complex 3D structures and the thermal budget restrictions for back-end of line (BEOL) processes [4]. This has necessitated a drive to low temperature processes, where nucleation control is of paramount importance for film quality, both in terms of defect control and conformality. For example, in Figure 1 the CVD of MoS_2 can be seen to be influenced by substrate material and architecture; where a process optimised for planar SiO_2 on silicon does not perform well on crystalline Al_2O_3 or at high aspect ratios.

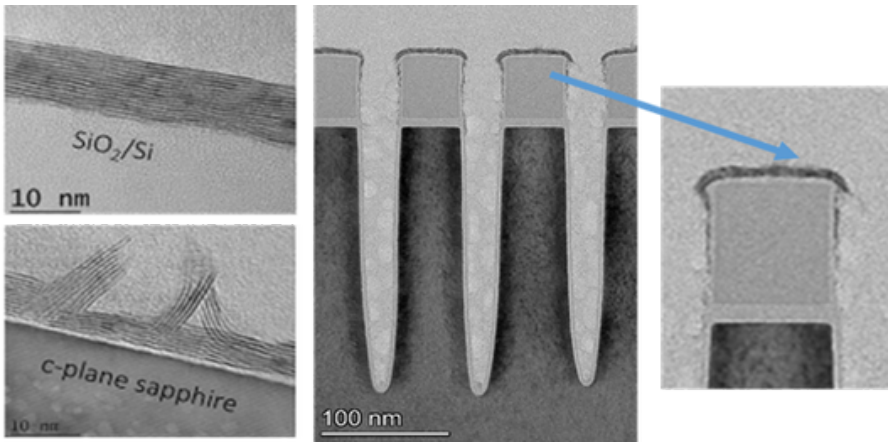

Figure 1. Illustration of the influence of substrate on growth mode of MoS2 under the same CVD process conditions (a) in plane growth on SiO2, out of plane growth on sapphire, c), non-conformal growth on SiO2 coated trenches.

In this project atomic layer processing methodologies will be tuned to facilitate the growth and modification of the 2D transition metal dichalcogenides (TMDs) MoS2 with emphasis on the influence of the morphology and composition of the underlying substrate on the resultant material's properties.

Methods:
TMD films will be fabricated, and modified, using atomic layer deposition, and atomic layer etching, in conjunction with plasma annealing and doping strategies to generate both n and p type films of a few atoms thickness. Materials will be assessed in terms of, morphology (conformality, grain size), electrical behaviour (mobility, carrier concentration, resistivity) and spectral response (Raman, photoluminescence).

Predicted results and impact:
TMD process formulation to generate pathways for 3D integration of TMD's into heterostructures.

References:
1. Manzeli et al., Nat Rev Mater 2, 17033 (2017). DOI:10.1038/natrevmats.2017.33
2. Chhowalla et al., Two-Dimensional Semiconductors for Transistors. Nat. Rev. Mater. 2016, 1, 16052, DOI: 10.1038/natrevmats.2016.52
3. Mondal and Vomiero, Adv. Funct. Mater. 2022, 32,2208994. DOI:10.1002/adfm.202208994
4. Lin et al., 2D Mater. 8 (2021) 025008. DOI: 10.1088/2053-1583/abc460

Location: Tyndall **Type**: In-person

Key words: ALD, ALE, TMDs, heterogeneous integration, 2D, 3D

Degree(s) that will suit this project: Physics, Chemistry, Electrical and Electronic Engineering, Materials Science

Modelling and Simulation of Magnetoelectric Elliptical Split Ring Resonators (ESRRs)

Theme: CMOS & Emerging Platforms
Supervisor: Saibal Roy
Co-Supervisor: Tilottoma Saha

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Background:
Next-generation wireless communication systems, including 6G devices, demand ultra-compact and highly efficient antennas. Lately, magnetoelectric (ME) devices are thought to be the key to this miniaturization, as they allow for strong coupling between magnetic and electric fields in a tiny footprint. The proposed device would be designed as an Elliptical Split Ring Resonator (ESRR) based on ME thin films, designed for frequency agility and superior performance. Before committing to expensive and time-consuming micro fabrication, robust numerical modelling is essential to optimize the resonator's geometry, select appropriate materials, and validate the dynamic response. This modelling and simulation work will significantly accelerate the path to realising a highly miniaturized functional prototype.

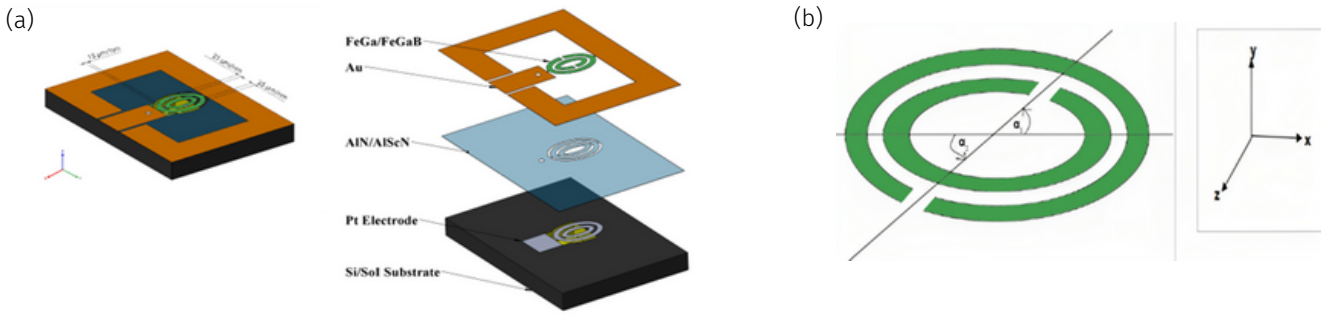

Figure 1: (a) Proposed typical design of ESRR; (b) Skew angle of ESRR

Methods:
The intern will primarily use Finite Element Method (FEM) software, such as COMSOL Multiphysics to perform Multiphysics simulations. The work will proceed in following steps:

- Building 2D/3D FEM geometries of ESRRs incorporating magnetostrictive (e.g., FeGa/FeGaB) and piezoelectric (e.g., AlN/AlScN) multi-layers.
- Simulating DC and AC responses, including magnetostriction, mechanical resonance, piezoelectric voltage generation, and ME transduction.
- Analysing frequency-domain behaviour in the kHz–GHz range and identifying resonance conditions.
- Investigating the effects of geometric parameters—ellipticity, skew angle, layer thickness, airgap, and material grading—on device response.
- Assessing power transfer efficiency, impedance behaviour, quality factor (Q-factor), S-parameters and bandwidth that are potential for wireless energy harvesting, sensing or signal transmission.
- Using MATLAB/Python for post-processing, parametric sweeps, and optimisation.

Predicted results and impact:
The core result will be a validated, high-fidelity numerical model of the magnetoelectric ESRR. This will yield a set of optimized geometric parameters and a comprehensive understanding of the device's predicted performance, including its maximum efficiency and achievable frequency tunability range. This simulation data is a critical prerequisite for the subsequent fabrication and experimental testing phases of the main project, effectively serving as a high-impact, low-cost proof-of-concept. The findings are expected to be compiled into a detailed final report and potentially will contribute to a peer-reviewed high impact publication.

References:

1. Zaeimbashi, M., et al. (2021). Ultra-compact dual-band smart NEMS magnetoelectric antennas for simultaneous wireless energy harvesting and magnetic field sensing. Nature Communications, 12(1), 23256.
2. Gentile, S., et al. (2015). Effect of controlled translational motion on resonance frequency and coupling in elliptical split-ring resonators. ACS Photonics, 2(10), 1485-1491.
3. Paul, K., et al. (2021). Tapered nonlinear vibration energy harvester for powering Internet of Things. Applied Energy, 283, 116267.

Location: Tyndall **Type**: Hybrid 2 days/week

Key words: Magnetoelectric, Split Ring Resonators (SRR), Finite Element Method (FEM), Computational Electromagnetics, Multiphysics Simulation, Frequency Agility.

Degree(s) that will suit this project: Engineering, Physics

Defects in semiconducting oxides thin film transistors

Theme: CMOS & Emerging Platforms
Supervisor: Sooraj Sanjay
Co-Supervisor: Khushabu Patil, Karim Cherkaoui

NanoIC

Background:

Field effect transistors (FETs) based on oxide semiconductors (OSCs) are currently explored for embedded DRAM applications [1, 2]. OSCs based circuits can be integrated above logic circuits, which enables significant energy savings and latency reductions when compared to systems requiring off-chip memory access [3]. Significant energy savings can also be achieved due to the long charge retention and low refresh rates afforded by the low off state current in OSC FETs.

Amorphous OSCs such as Indium Oxide or Zinc Oxide have attracted a great deal of attention recently as they possess several technological advantages and excellent charge transport properties, including low-temperature large-area deposition and high carrier mobility. These properties make them suitable channel materials in FETs integrated at the back end of line (BEOL). Tungsten(W)-doped In_2O_3 (IWO) based FETs demonstrated recently outstanding properties such as Ion/Ioff ratios of $4x10^9$ [4].

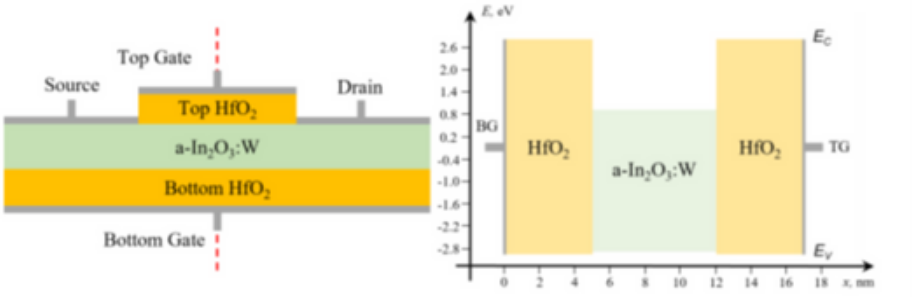

Figure 1: Example of simulated double gated OSC FET and associated energy band diagrams [5]

The objective of this internship is to explore thin film transistor properties with amorphous semiconducting oxide channel materials for applications requiring extremely scaled BEOL compatible FETs. The project will focus on electrically active defects in the FETs' gate oxide and at the interface with, or inside the oxide channel material. Experimentally, the main challenge is to devise methodologies which can discriminate between the defects in the gate oxide and those in the channel oxide and ultimately identify their origin and understand how they affect transistor operation. The effort in this internship will be dedicated to identifying the electrical signature of defects of different nature, location and energy distribution and to identify the most appropriate experimental measurements conditions to detect them.

Methods:
The Ginestra® modelling platform [6] will be used to simulate the device electrical characteristics. At its core, Ginestra enhances more traditional simulation workflows based on a drift-diffusion description by including a defect-centric [7] picture of trap-assisted phenomena numerically treated thanks to its internal kinetic Monte Carlo engine.

Predicted results and impact:
Understanding the role of electrically active defects and their impact on device behaviour and reliability. The project will enable the student to gain experience in device physics and develop expertise in advanced physics-based simulation tools.

References:
[1] S. Liu et al., IEEE TED, vol. 71, no. 5, pp. 3329-3335, 2024
[2] F. F. Athena et al., IEEE International Electron Devices Meeting (IEDM), 2024, pp. 1-4
[3] S. Datta et al., IEEE Micro, vol. 39, no. 6, pp. 8-15, 2019
[4] W. Chakraborty et al., IEEE Symposium on VLSI Technology, pp. 1-2, 2020
[5] A. Palmieri et al., IEEE Electron Devices Technology & Manufacturing Conference (EDTM), 2023, pp. 1-3
[6] Applied Materials Ginestra® https://www.appliedmaterials.com/eu/en/semiconductor/solutions-and-software/software-solutions/ginestra-simulation-platform.html
[7] L. Vandelli et al., IEEE Transactions on Electron Devices, vol. 58, no. 9, pp. 2878-2887, Sept. 2011

Location: Tyndall **Type**: In-person

Key words: Amorphous oxides, Semiconductor, Device simulation, TCAD, CMOS, Defects

Degree(s) that will suit this project: Materials Science, Physics, Chemical Physics, Electrical and Electronic Engineering

Design of CMOS RF Front-end for FR3 Band Using Integrated Circuit Design Software Platforms

Theme:	CMOS & Emerging Platforms
Supervisor:	Vishal Jagtap
Co-Supervisor:	Yuhao Yang

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Background:

RF front-end circuits are fundamental to wireless communication systems, as they directly affect transmitted and received signal quality, coverage, and overall system efficiency. Key components of a front-end transceiver include the voltage-controlled oscillator (VCO), power amplifier (PA), low-noise amplifier (LNA), and mixer, which together enable signal generation, amplification, and frequency conversion for both transmission (TX) and reception (RX). High-performance integration of these blocks is critical for supporting advanced communication.

Methods:

The internship provides an opportunity to gain practical understanding of the implementation of state-of-the-art high-speed transistor technology in a system and hands-on experience on the latest CAD simulation tools and process development kit of the state-of-the-art silicon foundry processing technology. Following are the aims and objectives of the fellowship:

- Conduct a literature review on CMOS RF front-end design, including VCO, PA, LNA, and mixer architectures, with emphasis on wideband operation, high output power, and linearity in the FR3 band.
- Design and simulate one of RF blocks (VCO, PA, LNA, mixer) using the selected process, evaluating key performance metrics such as output power, power-added efficiency (PAE), gain, noise figure, linearity (1 dB compression point, IMD3), and phase noise.
- Develop documentations and examples to replicate the designs and extend the project.

Predicted results and impact:

The fellow will have an opportunity to contribute to the ongoing innovative research project on RF systems for high-speed large bandwidth wireless communications. The fellow will present the results within the institute's internal forums and will have the opportunity to be on the contributing authors' list for scientific publications.

References:

- W. Lee, C. Ozdag, J. -O. Plouchart, A. Valdes-Garcia and B. Sadhu, “A 24 to 30-GHz Phased Array Transceiver Front End With 2.8 to 3.1-dB RX NF and 22 to 24% TX Peak Efficiency,” IEEE Journal of Solid-State Circuits, vol. 59, no. 9, pp. 2788-2804, Sep. 2024.
- Y. Xu, X. Sun, X. Zhu, P. -L. Chi and T. Yang, "A 2–18-GHz Frequency-Reconfigurable GaN Power Amplifier With More Than 33% Average Power Added Efficiency," in IEEE Transactions on Microwave Theory and Techniques, vol. 73, no. 4, pp. 2320-2333, Apr. 2025.

Location: Tyndall **Type**: In-person

Key words: Silicon, Integrated circuits, Radio-frequency front-end, wireless communications

Degree(s) that will suit this project: Electronics, Electrical, Photonics, Physics, Material Science

Simulation and Testing of Silicon THz Detector Components: Antennas and Transistor Topologies for Sensitivity Enhancement.

Theme: CMOS & Emerging Platforms
Supervisor: Vishal Jagtap
Co-Supervisor: Luis G. Magallon

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Background:

THz silicon detector which is mainly composed of silicon transistor topology and THz broadband on-chip antenna are used for non-contact signal detection, enabling high-speed, high-resolution measurements with excellent sensitivity and broadband response, making them ideal for next-generation imaging applications. The implementation of THz detector is based on silicon technology, which offers multiple advantages over other materials, including low cost, high compatibility with CMOS fabrication processes, and scalability. These features make it an excellent platform to further develop and optimize, as well as to improve current designs.

Methods:

The internship provides an opportunity to gain hands-on experience in the simulation and testing of silicon THz detector and antenna, focusing on antennas and transistor topologies for sensitivity enhancement.

- Design and simulate detector topologies using CAD tools such as Cadence to analyze circuit response and noise characteristics.
- Perform electromagnetic simulations to evaluate the radiation properties of on-chip antenna and extract its impedance characteristics.
- Implement co-simulation and co-optimization between the detector circuit and on-chip antenna to refine and improve the overall topology.
- Conduct laboratory measurements of the detector module, analyze experimental data, and prepare detailed test reports.

References:

- L. G. Magallon, Y. Yang, A. Cayeux, G. C. M. Raju, and V. Jagtap, "Integrated silicon broadband detectors toward miniaturized terahertz hyperspectral imaging platforms," in SPIE Sensors + Imaging 2025, International Society for Optics and Photonics, SPIE, 2025 (submitted, request for PDF copy).
- V. S. Jagtap, et al, "Monolithically Integrated Silicon Photodiodes For Terahertz Electronic-Photonic Integrated Systems," 2022 47th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), Delft, Netherlands, 2022, pp. 1-4, doi: 10.1109/IRMMW-THz50927.2022.9895657.

Location: Tyndall **Type**: In-person

Key words: Antennas, THz waves, Circuit analysis, Integrated circuits, System-on-chip, Transistor topology.

Degree(s) that will suit this project: science and engineering

A theoretical study of dissipative Kerr soliton formation in highly nonlinear micro resonators

Theme: Communications
Supervisor: Eoin Russell
Co-Supervisor: Fatima Gunning

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Background:

Dissipative Kerr solitons (DKSs) are a special waveform that can propagate in optical resonators, resulting in a stable pulse whose shape does not change as it propagates through the cavity. In recent years the phenomenon of soliton formation has been observed in a variety of microring cavities and has seen application in many groundbreaking fields, including optical communication, metrology and spectroscopy [1].

In the time domain, DKSs are described as optical pulses with an unchanging envelope, but their frequency domain behaviour is of particular interest in many applications. In the frequency domain, DKSs produce a spectrum known as an optical frequency comb (OFC) [2]. OFCs are a light spectrum consisting of many discrete wavelengths separated by a near identical frequency spacing. These optical spectra resemble the teeth of a comb, hence the name. OFCs have proven to be incredibly useful in many applications, and their importance was recognized in 2005 with the Nobel prize in physics being awarded to John L. Hall and Theodor W. Hänsch for their contributions to OFC development.

Traditionally, the formation of DKSs in micro resonators has been explored in centrosymmetric materials such as silicon and silicon nitride. These materials have third order nonlinearity which is required for soliton formation but lack a second order nonlinearity due the crystal symmetry. In this project the student will explore the formation dynamics of solitons in materials that are non-centrosymmetric and have a strong second order nonlinearity. Through the theoretical studies carried out in this project we hope to gain insight into the benefits of using dually nonlinear materials for chip-scale soliton formation.

Methods:

The first stage of this project will consist of an extensive literature review of both the fundamental modelling techniques used to simulate DKSs as will as a review of material candidates for simulation in the project.

The second stage of the project will involve using a modified version of a preexisting python model to simulate the soliton dynamics formed in micro resonator structures based on different materials [3]. The code will need further modification by the student to account for the new material properties.

Predicted results and impact:
The results of this project should give insight to the fundamental formation dynamics of solitons in micro resonator. If successful we will have new material candidates and potentially new physical phenomena to explore for future chip scale nonlinear photonic devices.

References:
[1] Tobias J. Kippenberg et al. “Dissipative Kerr solitons in optical microresonators”, Science361, eaan8083(2018). DOI:10.1126/science.aan8083.
[2] R. Paschotta, article on "Frequency Combs" in the RP Photonics Encyclopedia, retrieved 2024-11-11. https://doi.org/10.61835/h9j
[3] Moille, G. , Li, Q. , Lu, X. and Srinivasan, K. (2019), “pyLLE: a Fast and User Friendly Lugiato-Lefever Equation Solver”, Journal of Research (NIST JRES), National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/jres.124.012

Location: Tyndall **Type**: In-person

Key words: Solitons, Micro resonators, Nonlinear Photonics, Optical Frequency Combs

Degree(s) that will suit this project: Physics, Theoretical Physics, Maths & Physics, Electronic Engineering

Power from light

Theme: Compound Semiconductors
Supervisor: Brian Corbett
Co-Supervisor:

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Background:
There are now fields containing arrays photovoltaic panels located across the south of Ireland harvesting the power from the sun at an economic cost. Who would have believed that! This is a result of major improvements in the performance of silicon and the reduction in cost through volume manufacturing. Further improvement in performance can be obtained through other materials and through new light management concepts. In addition, there are opportunities to convert other wavelengths to power such as for indoor light or for hot bodies like incinerators which emit infrared light. Lasers are also carry power and can deliver it remotely through free space or through optical fibres. This makes power conversion of light a strong current topic of research.

Methods:
One key step to optimising the performance of a power converter is by minimising its volume while efficiently coupling the light into the semiconductor material, which has a high refractive index. Simulations and experiments will be done to understand this. Another strategy is to down-convert light to a different wavelength using luminescent materials and direct that concentrated light to the photovoltaic cell. Simulations will be used to design how that can be best done. Devices will be characterised for their photoresponse as a function of input power and wavelength. Power conversion will be investigated experimentally using a solar simulator and measuring the resultant current-voltage characteristics. The data will be analysed to lead to improved performance through better light distribution and better device selection.

Predicted results and impact:
Better understanding of the factors involved in advancing photovoltaic performance. This will help in defining a roadmap to increasing power conversion. The results will help the uptake of light based power conversion in new applications such as powering devices during surgery and in powering devices for information of things, for example.

References:

- Eduardo Camarillo Abad, Light management in ultra-thin solar cells: a guided optimisation approach, Opt. Express 28, 39093-39111 (2020) https://opg.optica.org/oe/fulltext.cfm?uri=oe-28-26-39093
- Eli Yablonovitch, Thermodynamics of the fluorescent planar concentrator J. Opt. Soc. Am. 70, 1362-1363 (1980) https://opg.optica.org/josa/fulltext.cfm?uri=josa-70-11-1362
- C. Algora, et al, Beaming power: Photovoltaic laser power converters for power-by-light. Joule 6, 340 (2022). https://doi.org/10.1016/j.joule.2021.11.014.
- B Roycroft, et al., Laser to laser power conversion with remote signalling, Optics Express 29, 16611 (2021). https://opg.optica.org/oe/fulltext.cfm?uri=oe-29-11-16611

Location: Tyndall

Type: In-person

Key words: Power, Photovoltaics, Lasers, Optical Fibres

Degree(s) that will suit this project: Physics, Engineering

Effect of Sb on the dopant incorporation in III-V-based material grown by MOVPE

Theme: Compound Semiconductors
Supervisor: Camille Barbier
Co-Supervisor: Emanuele Pelucchi

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Background:

III-V semiconductors are key materials for a wide range of devices in various applications- typically opto-electronics and related fields- due to their emitting light properties and broad wavelength tunability. The performance of photonic devices depends strongly on the crystal quality, the control on the doping levels and a low impurity incorporation, especially when high conductivity material is needed. Metal Organic Vapour Phase Epitaxy (MOVPE) is a well-established crystal growth technique for device fabrication due to the high control of material deposition, sharp interface and broad doping possibilities [1]. Despite the strong developments of this technique as an industry scale, many physical phenomena are still poorly understood and limited the potential development of III-V applications.

Our group recently demonstrated for the first time that Sb, used as a surfactant during growth, improves the control of Zn (p-dopant) incorporation on InP and GaAs-based materials [2]. Following findings showed that (with Sb) a higher Zn doping level and lower oxygen impurity concentration can be obtained while keeping a good crystal quality for various materials. Interestingly, the same improvement was not observed for Si (n-dopant) incorporation, while surface modifications were detected. In addition, discrepancies in the doping level were measured for high Al concentration AlGaAs:Si using different doping characterization techniques. Similar observations were reported in the literature, but no consensus exist on the physical phenomena [3-5]. In this context, it seems important to revive the investigation of the incorporation of dopants and impurities incorporation for different materials in the III-V family (e.g. GaAs, InP) and the effect of Sb and its surfactant properties.

Methods:

This project will focus on the investigation of the Sb effect on different semiconductor compound doped by DEZn and Si_2H_6. Systematic characterizations will be performed to reach insights in the physical processes involved. Another goal is to determine the saturation doping level of the two dopants while using Sb.

Series of (Al)GaAs and InP-based materials will be grown by MOVPE with systematic variation of the dopant concentration with and without Sb to allow a comprehensive analysis. Several experimental techniques will be used routinely to establish crystal quality and other properties. High resolution X-Ray Diffraction (HRXRD) allows to precisely determine the composition of the grown layer. The surface morphology (and defects) will be observed and quantified by Nomarski optical microscope and atomic force microscopy (AFM) with sub nm resolution.

Scanning electronic microscopy (SEM) observations correlated with XRD will give us access to the layer thickness. Doping level will be measured using both Hall effect and electrochemical capacitance-voltage (ECV) techniques and compare to carrier concentration obtained by Secondary Ion Mass Spectrometry (SIMS). In a feedback-driven optimization loop, new samples will be grown to investigate the Sb effect, determine the saturation dopant level and improve the crystal quality.

Predicted results and impact:

We anticipate that the Sb will improve the surface morphology and limit the defect formation of the grown layer for both dopants. We expect to observe a higher Zn incorporation in the material with the use of Sb resulting in a better layer electrical property. The techniques comparison for the AlGaAs doped with Si will allow us to determine the best characterization procedure and improve our understanding.

The results will provide valuable insights of the dopant and impurities incorporation mechanism and the effect of Sb, contributing to the development of next generation devices for opto-electronics. The student will have the opportunity to observe the epitaxial growth and will gain hands-on experience in material/dopant characterization. Ultimately, this work will improve Tyndall's epitaxial capabilities through the implementation of Sb in material growth and is expected to lead at least a publication and further collaborative research within and outside Tyndall.

References:

[1] G.B. Stringfellow, Organometallic Vapor-Phase Epitaxy: Theory and Practice, Elsevier (1999)
[2] A. Ozcan-Atar et al., Applied Surface Science 688 (2025) 162360
[3] Watanabe M.O et al. Jpn. J. Appl. Phys., 23 (2A) (1984) L103
[4] Kuech T.F. et al., Journal of Crystal Growth 98 (1989) 174—187
[5] Pfeffer T.L. et al., Journal of Crystal Growth, 146 (1–4) (1995) 399–403

Location: Tyndall **Type**: In-person

Key words: Epitaxy, doping level, structural characterization, electrical characterization

Degree(s) that will suit this project: Physics, Engineering

Photonic Integrated Circuit Design for Microwave Receiver

Theme: Compound Semiconductors
Supervisor: Fatih Atar
Co-Supervisor: Abi Waqas

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Background:
Use of photonic systems to replace, complement or out-perform the functionalities of microwave electronic devices has been called “Microwave Photonics”. Such photonic systems used to be limited to expensive and bulky setups. Utilization of photonic integrated circuits (PICs - small chips on which light can travel, carrying “information”) has the promise to miniaturize these systems to the chip scale. Development of photonic devices (lasers, modulators, and photodetectors) for integration on such photonic chips is a very active field of study at Tyndall National Institute. The research activities on photonic devices and integrated photonics have constantly opened up new research challenges and enabled further innovation. The project aims to employ the learnings from the ongoing research in innovative PIC designs to realize the desired RF functions.

Methods:
Photonic integrated circuit (PIC) design, photonic device characterization, high frequency electronic device characterization

Predicted results and impact:
The goal of this project will be to design PICs that are capable of recovering the data from the carrier signal (RF downconversion) by investigating concepts such as locking to the operation wavelength of the input carrier laser and introducing phase control. The student will learn characterization of the PIC and various photonic devices, carry out simulation/modelling of PICs on Lumerical Interconnect software and design PICs that can achieve the downconversion operation. The student will use existing PICs for the initial characterization and learning process, and test the feasibility of her/his proposed approach with modelling/simulations supported by these preliminary measurements. The student will test the fabricated PICs of their own design for future utilization and publications.

References:

1. CHANG, Matthew P., et al. Integrated microwave photonic circuit for self-interference cancellation. IEEE Transactions on Microwave Theory and Techniques, 2017, 65.11: 4493-4501.
2. HUANG, Linbojie, et al. Microwave photonic RF front-end for co-frequency co-time full duplex 5G communication with integrated RF signal self-interference cancellation, optoelectronic oscillator and frequency down-conversion. Optics Express, 2019, 27.22: 32147-32157.
3. MARPAUNG, David, et al., Integrated microwave photonics, Nature photonics, 2019, 13.2: 80-90.
4. Atar, Fatih Bilge, et al. "On-Chip Microwave Photonic System Through Multi-Component Micro-Transfer Print Integration." 2024 International Topical Meeting on Microwave Photonics (MWP). IEEE, 2024.

Location: Tyndall **Type**: in-person

Key words: Integrated photonics, microwave photonics, heterogeneous integration

Degree(s) that will suit this project: Engineering (Electronics), Physics

Automation of photonic testing using Microcontrollers

Theme: Compound Semiconductors
Supervisor: Frank Peters
Co-Supervisor: Jordan Walsh

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Background:
In photonic research, the use of computers has led to increasingly more complex and sophisticated experiments. For the most part, the cost of these automated experiments increases with the level of sophistication. Recently however, the proliferation of very low-cost microcontrollers has enabled new hand-held devices and point of care equipment, and this is altering many commercial markets. The goal of this project is to use these same low-cost microcontrollers to improve photonic characterisation without adding a large cost to the systems.

Methods:
In this summer project, the intern will build circuitry and then design custom PC boards that will be populated with surface mount components. The intern will write code so that the equipment can be controlled by a computer using Python or LabVIEW. The following are some possible applications:

1. Building a computer controlled optical switch control system. Here relative low-cost optical fibre based optical switches will be purchased. The goal is to have these controlled by the computer to microcontroller interface.
2. Building a computer controlled multi-channel current source. Here the intern would need to build the current sources and confirm their operation using a microcontroller that is controlled by a PC using Python or LabVIEW.
3. Learning how to add custom hardware to the above, such as LCD or e-ink screens, wireless capabilities and other external circuitry.
4. Developing more sophisticated interface software between the PC and microcontroller. For example, using the on-chip memory to store calibration data that can be used by the unit.

The internship is flexible. The focus can range from primarily programming to primarily circuit development. Much of the work can be done at home if the student has access to a PC. Soldering will need to be done at UCC, and other lab work will be done at UCC and/or Tyndall. Computers would be made available at Tyndall and UCC with the required software, while the microcontrollers and all other electronics would be provided as part of the internship.

Predicted results and impact:
Following the completion of the breadboard designs, a small run of PCBs will be ordered to test the designs as pre-production prototypes. Then these prototypes will then be tested for operation in the photonics labs at Tyndall.

References:
https://www.analog.com/media/en/technical-documentation/application-notes/an90f.pdf
https://www.sciencedirect.com/science/article/pii/B9780123851857000172?via%3Dihub
https://www.numberanalytics.com/blog/optical-switches-101
https://www.adafruit.com/categories

Location: Tyndall **Type**: Hybrid 2 days/week

Key words: Electronics, photonics, Arduino, automation, characterisation, lab

Degree(s) that will suit this project: Physics, Electronic Engineering

Sustainable Electrolytes for Supercapacitors: Comparative Study of Chitosan Hydrogels, EMIMBF$_4$ Ionic Liquid, and food-derived electrolytes for green energy applications.

Theme: Environment & Energy
Supervisor: Alessandra Imbrogno
Co-Supervisor: Jahidul Islam

Background:

In recent years, the demand for wearable electronic devices and sensors (commonly powered through electrochemical processes via batteries, capacitors and fuel cells), many of which are single use or disposed of in general waste, has raised new concerns regarding the sustainability of constituent materials and fabrication processes [1-2]. The research community is investigating alternative "green" solutions featuring natural materials and low embodied energy fabrication. Challenges for supercapacitor sustainability include aqueous electrolytes such as H_2SO_4 and KOH, which are volatile and present a small electrochemical potential window limiting device performance [3]. Valid alternatives are ionic liquid-based electrolytes with excellent thermal stability, high ionic conductivity and wide electrochemical window [4]. Polymer electrolytes are also possible, with chitosan-based blends among the most promising candidates to transition from liquid-state to solid-state electrolytes [5]. Other studies explored food-based formulations for gel electrolytes to ensure sustainability and low toxicology. For example, novel electrolytes based on egg white [6] and soy protein [7] were synthesised and tested in supercapacitors, reaching specific capacitances of 420.8 F/g at 0.5 A/g and 141.74 F/g at 1.0 A/g respectively, demonstrating that completely "green" supercapacitors from food waste are biodegradable. This project focuses on replacing the standard PVA electrolyte with sustainable alternatives such as ionic liquids (EMIMBF4), chitosan blends or food-derived electrolytes (e.g., egg white). Electrolytes will be characterised with electrochemical impedance spectroscopy to assess ionic conductivity (< 1–8 mS/cm depending on electrolyte type), and with linear sweep voltammetry to confirm electrochemical stability.

Methods:

The sustainable electrolytes (ion liquid, chitosan blends and food-derived electrolytes) will be synthesised from either commercially available precursors or extracted directly from raw food.
In particular, the ionic liquid, chitosan blends and food-derived electrolytes' chemical composition will be confirmed via Fourier Transform Infra-Red spectroscopy (FTIR). A study of crystallinity will also be conducted using the X-Ray Diffraction spectroscopy (XRD) in order to identify the most amorphous electrolyte. The thermal stability of the electrolytes will be investigated via Thermogravimetric Analysis (TGA); an important parameter to evaluate the decomposition temperature, and thus the biodegradability of the electrolyte at its end of life. Finally, the ionic conductivity will be assessed via impedance spectroscopy, targeting values ranging between < 1 mS/cm and < 8 mS/cm depending on the type of electrolyte. The compatibility of the electrolytes with electrodes fabricated in the Nanotechnology group's lab will be tested via cyclic voltammetry.

Predicted results and impact:
At the end of the summer fellowship, the student will have acquired experience in running a research project, including hands-on experience in chemical synthesis and material characterisations, device fabrication and testing, but also data collection, analysis and report writing, all invaluable skills to pursue a research career in academia or in industry. The student will co-author one publication on development of green supercapacitors.

References:
[1] http://www.irishstatutebook.ie/eli/2014/si/149/made/en/print
[2] https://ec.europa.eu/environment/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_it
[3] T. S. Bhat et al., J. Energy Storage, 2022, 50, 104222 (DOI: 10.1016/j.est.2022.104222)
[4] M. F. El-Kady et al., Nat. Commun., 2013, 4(1), 1475 (DOI: 10.1038/ncomms2446)
[5] M. M. Amaral et al., J. Energy Chem., 2022 67, 697-717 (DOI: 10.1016/j.jechem.2021.11.010)
[6] R. Na et al., Electrochim. Acta, 2018, 274, 316-325 (DOI: 10.1016/j.electacta.2018.04.127)
[7] W. Gu et al., Adv. Sci., 2022, 9(11), 2103623 (DOI: 10.1002/advs.202103623)

Location: Tyndall **Type**: In-person

Key words: sustainable electrolytes, electrochemistry, supercapacitors

Degree(s) that will suit this project: physics, chemistry, nanotechnology, material science

Pocket Spectrometer for Water Quality Monitoring

Theme: Environment & Energy
Supervisor: Chinna Devarapu
Co-Supervisor: William Whelan-Curtin

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CAPPA
Innovation Through Light

Background:

Access to clean water remains a critical global challenge, with approximately 2 billion people lacking safely managed drinking water services (WHO, 2019). Traditional water quality testing methods require expensive laboratory equipment, trained personnel, and significant time delays between sample collection and analysis. Recent advances in miniaturized optical sensors present opportunities to develop portable, real-time water quality monitoring systems that can democratize access to water testing capabilities.

Current water quality parameters that can be measured through spectrophotometric analysis include turbidity, chlorine residuals, nitrate, phosphate, iron, copper, and pH (through indicator dyes). Previous implementations of miniaturized spectrophotometers for water testing have demonstrated feasibility but often lack multi-parameter capability or require complex calibration procedures. This project leverages the AS7341 sensor which employs 8 visible spectrum channels in one chip. The spectral range of the AS7341 overlaps with absorption peaks of common water quality indicators. Therefore, the development of a portable, multi-parameter water testing device addresses several critical needs: (1) rapid field screening of water sources, (2) continuous monitoring of water distribution systems, and (3) educational applications in environmental science.

Methods:

An initial pocket spectrometer has been developed and it includes functional firmware for controlling LED illumination, adjusting sensor sensitivity, and collecting spectral data across visible and near-infrared wavelengths. The device features a small sample chamber that holds a standard cuvette and displays results on a color screen. This project will focus on improving the current system for reliable field testing and developing educational demonstrations for student training.

The primary work will involve testing and refining colorimetric measurement protocols for common water quality parameters. Students will adapt established test procedures using color-forming reagents that can be measured by the device's spectral channels. Initial targets include free chlorine testing using DPD reagent tablets (which produce pink color), nitrate analysis using cadmium reduction methods (producing yellow-orange color), and phosphate detection using molybdate reagent (producing blue color). Each test will be calibrated using known standard solutions to establish accurate concentration measurements.

Additionally, students will investigate fluorescence-based measurements for detecting organic contaminants and natural organic matter in water. This involves exciting samples with specific wavelengths and measuring the emitted fluorescence at different wavelengths, leveraging the device's multi-channel detection capability. Students will compare measurements against standard laboratory instruments to assess accuracy and identify areas for improvement. The project will also develop simplified operating procedures and educational materials suitable for demonstrating water quality testing principles to other students, making spectroscopy concepts more accessible through hands-on experimentation.

Predicted results and impact:

The improved water testing device is expected to successfully measure multiple water quality parameters with accuracy suitable for field screening applications. Nitrate and phosphate measurements using colorimetric reagent kits are anticipated to detect concentrations from 0.1-10 mg/L and 0.1-5 mg/L respectively, enabling identification of nutrient pollution in lakes and rivers. Turbidity measurements using the 90-degree light scattering approach should cover 0.1-1000 NTU, allowing assessment of water clarity from clear drinking water to highly turbid surface waters.

The educational impact extends beyond the immediate research team. Simplified operating procedures and demonstration protocols will enable the device to be used in undergraduate laboratory courses, making spectroscopy more tangible and relevant through water quality applications. At under $50 per device, this project demonstrates how accessible technology can support both environmental monitoring and science education, potentially inspiring students toward careers in environmental science or analytical chemistry.

References:

ColorX: A Fitness Tracker-Based Device for Rapid, Optical Sensing of Water Quality Parameters, Sensors 2025, 25(16), 4935; https://doi.org/10.3390/s25164935.

Location: Tyndall, MTU

Type: Hybrid 3 days/week

Key words: Spectrophotometer, water quality, analytical devices, AS7341 sensor, colorimetric analysis, IoT, environmental sensors.

Degree(s) that will suit this project: Engineering or Science Degrees with Physics, Chemistry

Investigation of the electromagnetic fields of submarine power cables.

Theme: Environment & Energy
Supervisor: Herman Alexander Jaeger
Co-Supervisor: Damien Haberlin

Tyndall National Institute
Institiúid Náisiúnta

Background:
Offshore marine renewable energy sources use submarine power cables to transfer power from the generating source to the mainland electricity grid. These high-voltage alternating current (HVAC) cables lie either on or below the seabed. These cables produce electromagnetic fields (EMF) in the surrounding environment whose effects on aquatic life is an area of significant interest [1]. Certain classes of animal such as elasmobranchii are sensitive to electric fields. The ability of such animals to navigate and hunt prey with using electric fields may be impacted by the presence of EMF [2]. The increased uptake of offshore renewable energy sources will result in many more submarine cables being used off the coast of Ireland. In order to better understand the impact of these fields on such species of fish, a robust electromagnetic model of the EMFs from multiple submarine cables in seawater is required.

Methods:
- Student will review existing models for estimating the electromagnetic fields different submarine cables topologies – (3-phase twisted, 3-phase parallel).
- Electromagnetic finite element simulation software will be used to model the electromagnetic fields of these different cable topologies at different seawater and burial depths and seabed mineral compositions.
- Investigate the effects of imbalanced 3-phase loads on the resulting fields.

Predicted results and impact:
The cables EMFs will exhibit wave-like behaviour in seawater. The extent to which this happens will depend on the placement of the cable and the material composition of the seabed. This work will inform experimental work taking place at the Sustainability Institute in Ringaskiddy Co. Cork where the behaviour of the lesser spotted cat shark in the presence of EMF is being studied.

References:

[1] EMF and the Flounder (https://www.youtube.com/watch?v=gNkVGajNyNc)

[2] A. Hermans, H. V. Winter, A. B. Gill, and A. J. Murk, 'Do electromagnetic fields from subsea power cables effect benthic elasmobranch behaviour? A risk-based approach for the Dutch Continental Shelf', Environmental Pollution, vol. 346, p. 123570, Apr. 2024, doi: 10.1016/j.envpol.2024.123570.

Location: UCC, Tyndall **Type**: In-person

Key words: Electromagnetics, EMF, Simulation, Sustainability, Aquatic life, Renewable energy.

Degree(s) that will suit this project: Electrical & Electronic Engineering, Physics

Design Optimization of Piezoelectric resonator-based Power Inductor/Transformer

Theme: Environment & Energy
Supervisor: Sambuddha Khan
Co-Supervisor:

Tyndall National Institute
Institiúid Náisiúnta

Background:

Magnetic inductors and transformers get bulky and lossy as we move to higher (MHz) frequencies. A piezoelectric resonator can act like an inductor when operated between its series and parallel resonances, and paired resonators can show transformer-like voltage step-up or step-down - without magnetic cores. This project keeps the scope simple and material-agnostic: you will develop clear, easy-to-use models and design rules so we can later choose the best material and geometry for a compact, high-Q "piezo inductor/transformer."

Methods:

Weeks 1–2: Foundations

- Short primers: what piezoelectricity is; what "resonance/anti-resonance" mean; why a resonator can look inductive.
- Define a few practical figures of merit (FoMs): effective inductance L_{eff}, quality factor Q, and (for transformer mode) voltage gain.

Weeks 3–4: Simple Circuit Models

- Build the basic Butterworth–Van Dyke (BVD) model in a circuit simulator (LTspice/PSPICE/ADS).
- Learn how each parameter (capacitance, motional resistance, etc.) changes the observed inductive region and Q.
- Produce small "how-to" notes so others can reuse your setup in minutes.

Weeks 5–6: Material-Agnostic Parameters

- Make a table of typical ranges for density, stiffness, piezoelectric and dielectric constants (no single material is chosen).
- Sweep these ranges in your circuit model to see how they change L_{eff} and Q.
- Summarize "good" property windows (e.g., "if dielectric loss < X, inductive bandwidth improves by Y%").

Weeks 7–8: Geometry & Mode Basics

- Compare two simple device shapes (a thickness plate and a lateral bar).
- Vary only a few dimensions (thickness, width, electrode length) and record how resonance and inductive behaviour shift.
- Sketch an easy checklist: "If you want more inductance, try…; if you want higher Q, try…".

Weeks 9–10: Gentle Simulation Check (Optional FEM)

- If time and tools allow, run an introductory Eigen frequency simulation (2D/3D) on one geometry to confirm the main resonance.
- Cross-check the frequency and trend with your circuit model. Keep this light—aim for insight, not perfection.

Weeks 11–12: Wrap-Up & Handoff

- Create a one-page design guide, a parameterized circuit file, and a short slide deck.
- Recommend 2–3 material/geometry "starting points" for future lab prototypes and more advanced modelling.

Predicted results and impact:

By the end, you will deliver:

1. A beginner-friendly modeling kit that shows when a piezo resonator behaves like an inductor;
2. Clear plots and tables linking property ranges and simple geometry changes to L_{eff} and Q; and
3. A short, practical guide for initiating a longer-term research program on piezoelectric inductors/transformers (no power-converter design required). This lowers the barrier for future students and speeds our path to prototype devices.

References:

1. T. Ikeda, Fundamentals of Piezoelectricity (intro to piezo physics).
2. S. J. Rupitsch, Piezoelectric Sensors and Actuators (device modeling basics).
3. Selected publications and talks by Prof. Jessica D. Boles on piezoelectric passives for power electronics (for context and direction).

Location: Tyndall **Type**: Hybrid 2 days/week

Key words: Piezoelectric resonator; inductive behavior; anti-resonance; transformer action; BVD model; high-Q; material-agnostic design; MEMS; MHz passives

Degree(s) that will suit this project: Physics or Applied Physics, Electrical or Mechanical Engineering, Mechatronics

Electrochemical Sensor for Acetaminophen (Panadol) Detection

Theme: Environment & Energy
Supervisor: Shane O'Sullivan
Co-Supervisor: Alan O'Riordan

Tyndall National Institute
Institiúid Náisiúnta

Background:

Acetaminophen (ACT) is one of the most widely consumed non-prescription medications worldwide, with its global market predicted to increase even further to $16.6 billion by 2034. [1,2] This near all pervasive drug is not as benign as it is often publicly perceived, with the ability to cause potentially fatal liver damage, as well as several other side-effects, when recommended doses are exceeded. ACT toxicity is currently the most common cause of liver failure in the United States. [3,4] With societal consumption of ACT at an all-time high, ACT has begun to be detected in aquatic environments, stemming from hospital waste, consumer use, manufacturing facilities and incorrect disposal. [5]As such it is of ever-increasing importance to ensure accurate and rapid detection of ACT. While current lab-grade methods exist, these lack the potential for point of care (POC) analysis that electrochemical sensors can offer, having been shown for a variety of analytes. [6–9]

While work has been done over the years on electrochemical sensors for ACT detection, little work has been done on the incorporation of more advanced electrochemical techniques, such as Generator-Collector (GC) electrochemistry. GC employs a method whereby two sensors are used instead of the typical one, to enhance performance. Furthermore, the utilisation of GC mode sensing can not only enhance sensor performance, but also crucially, remove interferences. In this project, we aim to first compare the suitability of a variety of sensor materials via surface modification, such as gold and platinum, for the optimum sensor design, before continuing on to employ GC detection for ACT. The use of GC sensing will enable the detection of ACT in the presence of interferents, enabling detection in complex media such as river water or serum. This project will build on preliminary work carried out previously by the supervisor, with the aims of generating both a POC sensing device for ACT but also a potential publication for literature. This project will develop several useful skills for the student, and potentially, give the student a taste of what life in academic research is like, in a vibrant and welcoming group.

Methods:

Sensor Development, Cyclic Voltammetry, Square Wave Voltammetry, Electrodeposition, Chronoamperometry, Chronopotentiometry, Generator-Collector (GC) sensing, Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM)

Predicted results and impact:
Development of a point of care ACT sensor in complex media, with a subsequent publication based on this. Enabling portable accurate detection of acetaminophen in a variety of media, while in the presence of interferences.

References:

1. E.P. Krenzelok, M.A. Royal, Confusion: Acetaminophen Dosing Changes Based on NO Evidence in Adults, Drugs R D 12 (2012) 45. https://doi.org/10.2165/11633010-000000000-00000.
2. Acetaminophen Market Size & Share Report, 2025 – 2034, (n.d.). https://www.gminsights.com/industry-analysis/acetaminophen-market (accessed August 26, 2025).
3. S. Agrawal, B.P. Murray, B. Khazaeni, Acetaminophen Toxicity, Toxicology Cases for the Clinical and Forensic Laboratory (2025) 75–77. https://doi.org/10.1016/B978-0-12-815846-3.00035-1.
4. R.A. Mitchell, S. Rathi, M. Dahiya, J. Zhu, T. Hussaini, E.M. Yoshida, Public awareness of acetaminophen and risks of drug induced liver injury: Results of a large outpatient clinic survey, PLoS One 15 (2020) e0229070. https://doi.org/10.1371/JOURNAL.PONE.0229070.
5. H. Montaseri, P.B.C. Forbes, Analytical techniques for the determination of acetaminophen: A review, TrAC - Trends in Analytical Chemistry 108 (2018) 122–134. https://doi.org/10.1016/j.trac.2018.08.023.
6. Y. Yang, A. O'Riordan, P. Lovera, Highly sensitive pesticide detection using electrochemically prepared Silver-Gum Arabic nanocluster SERS substrates, Sens Actuators B Chem 364 (2022) 131851. https://doi.org/10.1016/J.SNB.2022.131851.
7. L.A. Wasiewska, I. Seymour, B. Patella, R. Inguanta, C.M. Burgess, G. Duffy, A. O'Riordan, Reagent free electrochemical-based detection of silver ions at interdigitated microelectrodes using in-situ pH control, Sensors and Actuators B-Chemical 333 (2021) 129531. https://doi.org/ARTN 129531 10.1016/j.snb.2021.129531.
8. M.R. Adib, C. Barrett, S. O'Sullivan, A. Flynn, M. McFadden, E. Kennedy, A. O'Riordan, In situ pH-Controlled electrochemical sensors for glucose and pH detection in calf saliva, Biosens Bioelectron 275 (2025) 117234. https://doi.org/10.1016/J.BIOS.2025.117234.
9. S. O'Sullivan, F.G. Diaz, I. Seymour, A. O'Riordan, Electrochemical Approach for In Situ pH Control and Monitoring in Hydrodynamic Environments, ACS Electrochemistry (2025). https://doi.org/10.1021/ACSELECTROCHEM.5C00196.

Location: Tyndall **Type**: In-person

Key words: Electrochemistry, Sensors, Point of care, Acetaminophen

Degree(s) that will suit this project: Chemistry

High-Frequency Wireless Driving System to Magnetics Components for Next-Generation AI Power Systems

Theme: Environment & Energy
Supervisor: Yi Dou
Co-Supervisor: Ranajit Sai, Youssef Kandeel

Background:

As AI systems grow more powerful, their powering systems must advance too. Magnetic components — the core energy elements in AI engines' powering system— can achieve greater precision and performance validation when driven with high-frequency excitation signals (up to 50 MHz), even in non-contact setups. Traditional wired excitation limits flexibility and can introduce DC bias. This project applies wireless power transfer (WPT) principles to develop a compact, isolated, and efficient wireless excitation system for MHz-range operation — a key step toward next-generation AI power architectures.

Students working on this project will operate at the crossroads of **magnetics, wireless power, and advanced circuit design** — key technologies driving the magnetic components in the powering systems. You'll gain hands-on experience in:

- High-frequency (MHz) circuit and system design
- Wireless power transfer (WPT) principles and implementation
- Practice on industry standard magnetic simulation (FEM) and circuit design tools

Methods:

1. Literature Study – Study MHz-range magnetic excitation and WPT techniques.
2. Circuit Design and Simulation – Create a 50 MHz resonant TX/RX coil system with efficient driver and matching network.
3. Prototyping & Testing – Build and validate PCB-based circuits and evaluate magnetic performance.
4. Documentation – Summarize design process, results, and generate final report/publication.

Predicted results and impact:

The results are expected to be published in the leading power electronics conference. Besides, the circuit prototype will be fabricated and tested, demonstrating real-operating feasibility.

This work will advance next-generation, AI-driven power systems toward smarter and more efficient operation.

References:
[1] A. J. Hanson, J. A. Belk, S. Lim, C. R. Sullivan and D. J. Perreault, "Measurements and Performance Factor Comparisons of Magnetic Materials at High Frequency," in IEEE Transactions on Power Electronics, vol. 31, no. 11, pp. 7909-7925, Nov. 2016, doi: 10.1109/TPEL.2015.2514084.
[2] Y. Dou, L. Ye, T. Tsuchida, S. Kishimoto, T. Hiraoka, M. Nagano, R. Sai, and C. O'Mathuna, "In-resonance large-signal characterization of metal alloy-based chip inductors for MHz power converters," in IEEE the Ninth International Workshop on Power Supply on Chip (PwrSoC), Sep. 2025.

Location: Tyndall **Type**: In-person

Key words: AI engines, Wireless Power Transfer, Power Electronics, Magnetic Component Characterization, Circuit Design and Testing

Degree(s) that will suit this project: science

Improving performance of upconversion nanoparticles using pulsed excitation

Theme: Health & Wellbeing
Supervisor: Louise Frost
Co-Supervisor: Katarzyna Komolibus

IPIC
BRINGING PHOTONICS TO LIFE

Background:

Biophotonics is a subfield of photonics focused on using light to improve medical diagnostics and treatments. This approach is particularly exciting because light-based techniques can often be non-invasive, reducing or even eliminating many side effects associated with traditional procedures. However, one major challenge when using light in biological tissue is attenuation; high-energy (short-wavelength) photons are strongly absorbed and scattered, making deep-tissue imaging or therapy difficult or often impossible. A promising solution to this problem is the use of lanthanide-doped upconversion nanoparticles (UCNPs). These particles can convert near-infrared (NIR) light, which can penetrate deeper into tissue, into higher-energy visible light. The unique electronic structure of these ions, especially their 4f orbitals, allows for unusually long-lived excited states. Because of this, an excited electron can be excited again. This can happen multiple times, leading to the emission of a photon with higher energy than the excitation light. Other advantages of UCNPs include their lack of autofluorescence, high photostability, and low cytotoxicity. These properties make them promising candidates for deep-tissue photodynamic therapy aimed at destroying cancer cells.

While UCNPs show great potential, one major limitation is their low efficiency; only a small fraction of the absorbed photons is converted into higher-energy emission. This efficiency, known as the quantum yield (QY), is a critical parameter for real-world applications. Importantly, the QY of UCNPs depends nonlinearly on the excitation power density. The higher excitation power, the higher QY. This insight opens an interesting possibility: by using a pulsed light source instead of continuous-wave (CW) illumination, we can achieve higher peak powers while keeping the average power within safe limits for tissue.

Methods:

This project is a part of an ongoing study of the dynamics of UCNP, specifically at depth using materials mimicking tissue optical properties to push the limits of deep tissue diagnostics/therapeutics. The project will involve

(1) hands-on experience in the lab, using existing setups to characterize the QY of UCNP, and observe upconverted emission from the UCNP at depth (CW and pulsed mode)

(2) perform measurements using current tissue phantoms and, potentially fabricate new phantoms with tailored optical properties (such as scattering and absorption coefficients) to better simulate specific tissue types

(3) data analysis.

Predicted results and impact:
By the end of the project, the summer fellow will understand the physical principles behind upconversion in lanthanide-doped nanoparticles, apply this knowledge in laboratory experiments, and analyse data to evaluate UCNP performance under different excitation conditions and depths in tissue-mimicking phantoms. Through this process, they will develop skills in experimental optics, data interpretation, and critical evaluation of results, ultimately gaining the ability to propose potential improvements.

References:
[1] Liu, H., Xu, C.T., Lindgren, D., Xie, H., Thomas, D., Gundlach, C. and Andersson-Engels, S., 2013. Balancing power density based quantum yield characterization of upconverting nanoparticles for arbitrary excitation intensities. Nanoscale, 5(11), pp.4770-4775.
[2] Idris, N.M., Gnanasammandhan, M.K., Zhang, J., Ho, P.C., Mahendran, R. and Zhang, Y., 2012. In vivo photodynamic therapy using upconversion nanoparticles as remote-controlled nanotransducers. Nature medicine, 18(10), pp.1580-1585.

Location: Tyndall **Type**: In-person

Key words: Biophotonics, upconversion nanoparticles, quantum yield, optics, phantom measurements

Degree(s) that will suit this project: Physics, Engineering

MetabolismTracker - long-wavelength near infrared optical spectroscopy for continuous monitoring of metabolic activity over time.

IPIC
BRINGING PHOTONICS TO LIFE

Theme: Health & Wellbeing
Supervisor: Shree Krishnamoorthy
Co-Supervisor: Walter Messina

Background:
Metabolism refers to the biological process that converts food to energy. This could be respiration, fermentation etc. One of the key processes is to look at break down of simple sugars like glucose and lactate in low-oxygen condition (or hypoxic conditions). In this project, we will be building a metabolism tracking system based on spectroscopy in the 2000-2500 nm wavelength range to continuously monitor metabolic process in milk fermentation (kefir).

Methods:
We develop a multi-laser benchtop spectroscopy system that is capable of continuous monitoring of fermenting sample. For this, we will be setting up laser drivers for three different laser sources, modifying the benchtop optical system to monitor cuvette in a continuous manner, and programming the palm-sized spectrometer to measure periodically. Subsequently, the data analysis will be done offline and time-series data will be plotted. This project suits those interested in hands-on optical bench setups, learning about lasers and the practical implementation, an ability to write programs to a mid-skill level. Some basic biochemistry skill will be also learnt during the project.

Predicted results and impact:
Demonstration of continuous monitoring of the fermentation process with custom optical spectrometer system. This project will be then used in the clinical sector to assess hypoxia at physiological levels.

References:
[1] Cummins, Gerard, et al. "Sensors for fetal hypoxia and metabolic acidosis: a review." Sensors 18.8 (2018): 2648.
[2] S. Krishnamoorthy, et al. "Non-invasive continuous hypoxia assessment in intra-partum fetus through long wavelength near infrared spectroscopy." Photonic Instrumentation Engineering X. Vol. 12428. SPIE, 2023.

Location: Tyndall **Type**: In-person

Key words: laser spectroscopy, molecular spectroscopy, optical spectroscopy, near-infrared spectroscopy, BioPhotonics, vibrational spectroscopy

Degree(s) that will suit this project: Electrical engineering, Physics

Testing of a VCO ADC

Theme: Packaging & Integration
Supervisor: Daniel O'Hare
Co-Supervisor: Piotr Klys

MCCI
MICROELECTRONIC CIRCUITS CENTRE IRELAND

Background:
Advanced CMOS technologies such as the leading 2nm technologies from TSMC, Intel and Samsung are designed for digital processors like GPUs and high density plus high-speed memory. The best CMOS technology for analogue circuits like amplifiers and Digital to Analogue Converters is 180 nm. When both digital and analogue is required on the same advanced CMOS chip, the area cost of implementing amplifiers and capacitors is expensive. This creates a need for analogue circuit architectures using small digital sub-blocks or components. Ring Oscillator Voltage Controlled Oscillators (VCO) ADCs are such a topology using current starved inverters and Delay Flip-Flop (D-FF) to build a voltage to phase converter and a phase to digital converter. In MCCI we have designed a novel VCO ADC [2] and we would like to test this chip as a summer fellowship project.

Methods:
This project will involve testing a VCO ADC, it will involve the use of oscilloscopes, waveform generators and voltage supplies. It will also involve data capture using a Raspberry Pi interface and post processing of the measured results using Python.

Predicted results and impact:
The planned outcome is measured results to demonstrate the effectiveness and performance of the VCO ADC. This will lead to a scientific publication and inform future research in VCO ADCs.

References:
[1] G. G. E. Gielen, L. Hernandez and P. Rombouts, "Time-Encoding Analog-to-Digital Converters: Bridging the Analog Gap to Advanced Digital CMOS-Part 1: Basic Principles," in IEEE Solid-State Circuits Magazine, vol. 12, no. 2, pp. 47-55, Spring 2020, doi: 10.1109/MSSC.2020.2987536
[2] S. Chevella, I. O'Connell and D. O'Hare, "Extended bandwidth open-loop VCO based ADC using Interleaving with a single VCO channel," 2025 IEEE International Symposium on Circuits and Systems (ISCAS), London, United Kingdom, 2025, pp. 1-5, doi: 10.1109/ISCAS56072.2025.11043230.

Location: Tyndall **Type**: In-person

Key words: Analogue Integrated Circuits, Analogue to Digital Converter (ADC) , Voltage controlled Oscillator (VCO)

Degree(s) that will suit this project: Electronic Engineering

Theory of quantum tunnelling in direct-gap hexagonal germanium

Theme: Quantum
Supervisor: Christopher Broderick
Co-Supervisor:

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Background:
The properties of a semiconductor are dictated by the material's electronic band structure: the quantum mechanical energy eigenstates of the crystal lattice. An intrinsic semiconductor exhibits a fully occupied valence band (VB) and empty conduction band (CB). Contemporary microelectronic technologies are based on metal-oxide semiconductor field-effect transistor (MOSFET) architectures, in which current flow from source to drain is controlled by the energetic height of a potential barrier. Applying a gate voltage regulates current flow by moderating this barrier height, a process intrinsically limited by thermionic emission of electrons and holes over the barrier. This places a lower limit S = 60 mV/decade on the subtreshold swing, S, limiting MOSFET scaling and energy efficiency.

One approach to overcome this limitation and achieve S < 60 mV/decade is the tunnelling field-effect transistor (TFET) [1]. A TFET exploits quantum mechanical band-to-band tunnelling (BTBT), in which electrons tunnel from VB to CB across the forbidden band gap, as a current-generating mechanism. While promising, TFETs face practical challenges including availability of materials that combine a narrow band gap and compatibility with industry-standard complementary metal-oxide semiconductor (CMOS) fabrication. While the CMOS-compatible group-IV semiconductor germanium (Ge) is indirect-gap and a poor TFET material in its cubic (diamond) phase, its metastable hexagonal (lonsdaleite) phase admits a narrow, direct band gap. Advances in nanowire growth allow to reliably fabricate hexagonal Ge, heralding a new candidate material for electronics, photonics and electronic-photonic integration [2].

Methods:
This theoretical/computational project seeks to establish quantitative analysis of the BTBT generation rate G vs. applied electric field F in hexagonal Ge. BTBT proceeds via the complex band structure: energy eigenstates corresponding to complex-valued Bloch wave vectors k (cf. Fig. 1) [3]. Computing G(F) requires a model Hamiltonian to compute the complex band structure, from which the BTBT transmission coefficient can be calculated. We will employ a model k.p Hamiltonian for hexagonal Ge, and apply the semi-classical Wentzel-Brillouin-Kramers (WKB) approximation to compute the BTBT transmission coefficient [4]. Time permitting, we can also consider more sophisticated approaches based on atomistic calculations.

Predicted results and impact:
BTBT is an important phenomenon, not only as an enabling mechanism for TFETs, but also as a performance-limiting mechanism in long-wavelength photonic devices including avalanche photodiodes. This project will produce the first quantitative analysis of BTBT in hexagonal Ge, providing information to motivate experimental research and inform device applications of this nascent material.

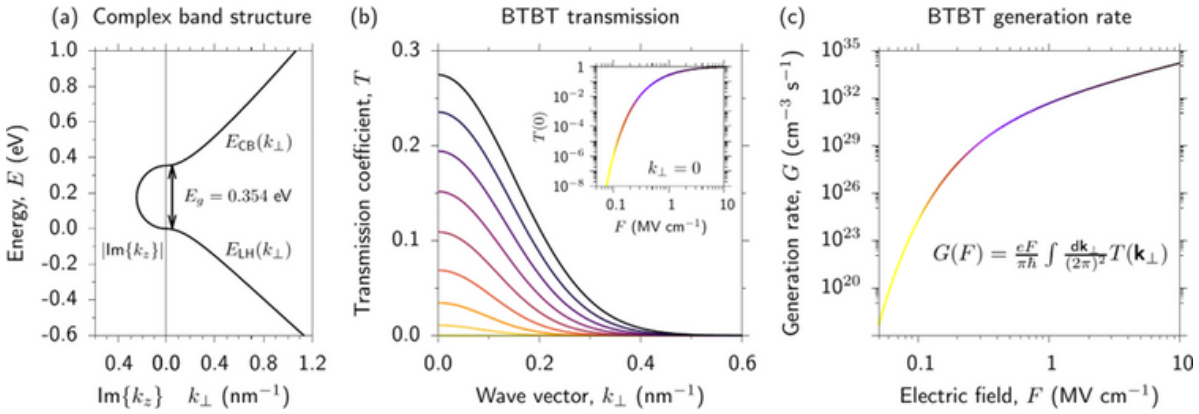

Fig. 1. BTBT in the III-V semiconductor InAs [4]. (a) Complex band structure. (b) BTBT transmission coefficient. (c) BTBT generation rate vs. applied electric field.

References:
[1] A. M. Ionescu and H. Riel, Nature 479, 329 (2011)
[2] E. M. T. Fadaly et al., Nature 580, 205 (2020)
[3] A. Pan and C. O. Chui, J. Appl. Phys. 116, 054508 (2014)
[4] S. Das, C. A. Broderick and E. P. O'Reilly, Phys. Rev. Applied 17, 014029 (2022)

Location: Tyndall **Type**: in-person

Key words: Semiconductors, electronic structure, band-to-band tunnelling

Degree(s) that will suit this project: Physics, Theoretical Physics

Quantum dot light emission profile characterization and optimization for integrated photonic quantum computation platforms

Theme: Quantum
Supervisor: Emanuele Pelucchi
Co-Supervisor: Gediminas Juska

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Background:

Integrated photonic circuits (IPCs) are essential for scalable quantum computing, where photons serve as qubits for quantum information processing. Quantum dots (QDs) are promising candidates for generating single photons on demand, but their light emission properties are often not ideal for efficient coupling into single-mode waveguides, a critical requirement for quantum computation. In their as-fabricated form, QD emissions typically display broad angular divergence, making the coupling into waveguides inefficient. To address this challenge, the emitted light from QDs must be engineered to exhibit a more directional, Gaussian-like intensity profile, allowing for efficient coupling to photonic waveguides.

Methods:

This project will focus on the characterization and optimization of quantum dot emission profiles to enable efficient integration with photonic circuits. The emission will be studied using spectrally-resolved Fourier microscopy, a powerful technique for analyzing the far-field angular emission profile of quantum dots.

The experimental setup will be built and calibrated in the initial phase of the project. We will study QDs embedded in microfabricated structures, specifically site-controlled pyramidal QDs[1,2] within pillar- and pyramid-shaped microstructures. These structures are designed to modify the emission profile and enhance coupling efficiency by altering the QD's surrounding geometry.

We will systematically vary the geometric properties of the microstructures (e.g., height, base dimensions, and aspect ratio) and characterize the resulting emission profiles. The results will be compared with theoretical predictions from simulations to identify key design parameters that influence the divergence and spatial distribution of the emitted light.

In a feedback-driven optimization loop, the team will fabricate new samples with modified geometries based on the initial experimental findings. The optimization process will be performed in collaboration with group members to iteratively refine the emission profile. This will allow for rapid adjustments and improvements to the design, ultimately leading to structures that exhibit better emission coupling characteristics.

Predicted results and impact:
We anticipate that the geometric modifications of the microfabricated structures will significantly reduce the angular divergence of the QD emissions and bring the intensity profile closer to a Gaussian distribution. This should improve the coupling efficiency into single-mode waveguides, which is critical for successful integration into photonic quantum computation platforms. The results will provide valuable insights into the relationship between QD emission characteristics and structural geometry, contributing to the development of high-efficiency photonic devices for quantum computing. Ultimately, this work will serve as the basis for a publication and further collaborative research within the group towards the integration of QDs into larger-scale quantum photonic circuits and the implementation of quantum computing protocols.

References:
[1] G Juska et al, Nature Photonics 7 (7), 527, 2013;
[2]TH Chung, G Juska et al, Nature Photonics 10 (12), 782, 2016.

Location: Tyndall

Type: in-person

Key words: quantum dot, quantum computing, spectroscopy

Degree(s) that will suit this project: Physics, Engineering

Coherent quantum dot excitation schemes for quantum information processing applications

Theme: Quantum
Supervisor: Gediminas Juska
Co-Supervisor: Emanuele Pelucchi

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Background:

Quantum dots (QDs) are a promising source of single photons for quantum information processing applications. For practical applications, photons must be indistinguishable – meaning they must have the same energy, narrow linewidths, and minimal temporal jitter. These properties are crucial for high-fidelity quantum operations such as photon entanglement, which enable quantum computing. The quality of emitted photons depends significantly on the excitation methods used to excite the quantum dots. Among various excitation schemes, coherent methods that minimally interact with the QD environment are most effective in producing indistinguishable photons. However, a significant challenge arises due to the close energetic overlap between the laser light used for excitation and the QD emission, which can lead to unwanted background interference from the laser. This project aims to explore and optimize two advanced coherent excitation schemes to improve photon indistinguishability and laser background rejection, making QDs more suitable for quantum communication.

Methods:

This project will focus on the application and testing of two coherent excitation schemes for QDs, with the goal of generating high-quality single photons that are indistinguishable and free from laser background interference:

1. Swing-Up of Quantum Emitter Population (SUPER) Scheme[1]: The SUPER scheme uses two laser pulses, each of which is energetically lower than the QD's exciton energy. These pulses act sequentially to "swing up" the QD from its lower-energy state to the excited state, in a coherent manner. By carefully varying the temporal and spectral properties of both laser pulses (such as intensity, pulse duration, and detuning), we aim to optimize the efficiency of photon emission while minimizing the effects of laser-QD interaction that can degrade photon quality.
2. Resonant Excitation with Dark-Field Microscopy[2]: In this method, the QD will be excited using a laser that is resonant with the QD transition energy. To address the challenge of laser-QD energy overlap, a dark-field microscope will be employed to suppress the scattered laser light, allowing for background-free detection of the QD emission.

The experiments will use site-controlled pyramidal QDs fabricated by the group [3], which are attractive candidates for these studies due to their well-defined emission properties and precise control over their position.

Predicted results and impact:
We expect that the two excitation schemes will significantly improve the quality of the single-photon emission from the quantum dots. Ultimately, the findings from this project will form the basis for a publication, providing valuable insights into the excitation and optimization of quantum dots for high-performance quantum communication and quantum information processing.

References:
[1] Nano Lett. 22, 16, 6567, 2022;
[2] Rev. Sci. Instrum. 84, 073905, 2013 ;
[3] G Juska et al, Nature Photonics 7 (7), 527, 2013.

Location: Tyndall

Type: In-person

Key words: quantum dot, quantum computing, spectroscopy

Degree(s) that will suit this project: Physics, Engineering

Optimization and Characterization of Vertically Coupled High Speed Modulators for Telecom Wavelengths

Theme: Wafer Scale & Chip Technologies
Supervisor: Ayse Ozcan Atar
Co-Supervisor: Frank Peters

IPIC
BRINGING PHOTONICS TO LIFE

Background:
Future communication technologies necessitate groundbreaking advancements in photonic integrated circuits (PICs) to meet high capacity demands and solutions for large-scale cost-effective production. PICs contain unique components like, lasers, modulators and detectors, that generate, manipulate and transmit light on a single component. This project focuses on integrating two key photonic components, specifically a laser and a Mach-Zehnder Modulator (MZM) modulator in a single combined vertical stack.
In the proposed design, both laser and the MZM will have their own waveguides sharing the high mobility n-contact. This configuration requires the laser to adopt an n–i–p structure (with n-type doping on top), which has historically been challenging due to Zn diffusion issues. This long-standing challenge has been successfully addressed at Tyndall, where an effective solution to suppress Zn diffusion was developed. The current project will investigate the applicability of this solution in the targeted PIC structure.

Methods:
Photonic integrated circuit design, photonic device characterization

Predicted results and impact:
The goal of this project will be to design integrated photonic components, namely modulators and lasers in a vertically stacked configuration (modulator on laser) for telecom wavelengths. The student will learn to simulate (model) and characterize fabricated PICs and various photonic devices. The student will also have the opportunity to see the epitaxy and fabrication processes. The designed PICs may later be incorporated into our future PIC designs, serving as a test platform for further development and publication.

References:

1. Agrell, Erik, et al. "Roadmap of optical communications." Journal of Optics 18.6 (2016): 063002.
2. Arafin, Shamsul, and Larry A. Coldren. "Advanced InP photonic integrated circuits for communication and sensing." IEEE Journal of Selected Topics in Quantum Electronics 24.1 (2017): 1-12.
3. Duggan, Shane P., et al. "P-substrate InP-based 1.5 μm lasers using an internal carbon-doped layer to block p-dopant diffusion." Microwave and Optical Technology Letters 60.10 (2018): 2363-2367.
4. Ozcan-Atar, Ayse, et al. “Why “Zn Diffusion” Is Not Always Diffusion: Surface Physics and a 40-Year-Old Epitaxy Problem.” Applied Surface Science 688 (2025): 162360.

Location: Tyndall

Type: In-person

Key words: Integrated photonics, vertical integration

Degree(s) that will suit this project: Physics, Electronics Engineering