School of Physics:

Academic Researcher:	Professor Marcela Bilek
Project Title:	**Modelling plasma surface functionalisation of additively manufactured, porous, prosthetic implants**
Project Summary:	This project will develop multiphysics models of plasma surface treatment to enable the creation of prosthetic implants with controllable surface properties and long-term biostability. The Applied Physics and Plasma Surface Engineering group is seeking applications from highly motivated PhD candidates with strong communication skills, a demonstrated ability to work independently, and a desire to make meaningful contribution to state-of-the-art biomedical and plasma technologies. Potential candidates with backgrounds in plasma physics, computational fluid dynamics/finite element modelling, chemical engineering, mechanical engineering, chemistry, or surface engineering are encouraged to apply.
Project Synopsis:	Conventional prosthetic implants suffer from poor long-term stability in the body, along with suboptimal material properties such as stiffness. Additive manufacturing has enabled the production of porous implants with mechanical properties that can be tuned to match the host environment. Low temperature plasmas can be used to functionalise the surfaces of these materials for the immobilisation of cell adhesion and signalling proteins and/or antimicrobials, thereby enabling cell attachment and tissue integration for robust biocompatibility. Careful control of the plasma treatment process, which is dependent on local fluid pressure and electric field strength throughout the porous matrix, is critical to ensure consistent surface functionalisation. This multidisciplinary project will offer candidates the opportunity to develop and optimise finite element models of the complex physical phenomena occurring within a range of plasma reactors. Fluid flow and electric field modelling will be used to survey candidate materials and structures, whilst plasma dynamics will be investigated using drift-diffusion and heavy species transport models to understand the strong spatial and temporal gradients typical of low temperature plasmas. Candidates will work closely with experimentalists to apply the knowledge gained from the modelling to guide surface treatment experiments.

Academic Researcher:	Professor Marcela Bilek
Project Title:	**Modelling plasma synthesis of nanoparticles for non-invasive diagnosis and targeted treatment of disease**
Project Summary:	This project will develop multiphysics models of a low temperature capacitively coupled plasma reactor to engineer functionalised nanoparticles for biomedical applications.This project will develop multiphysics models of plasma surface treatment to enable the creation of prosthetic implants with controllable surface properties and long-term biostability. The Applied Physics and Plasma Surface Engineering group is seeking applications from highly motivated PhD candidates with strong communication skills, a demonstrated ability to work independently, and a desire to make meaningful contribution to state-of-the-art biomedical and plasma technologies. Potential candidates with backgrounds in plasma physics, computational fluid dynamics/finite element modelling, nanotechnology, chemical engineering, mechanical engineering, chemistry, or surface engineering are encouraged to apply.

Project Synopsis:	Nanomedicine promises a range of therapeutic functions including targeted drug delivery and new diagnostic techniques, due to the ability of nanoparticles to carry molecules into cells. We are developing the technology to engineer nanoparticles capable of delivering drugs to specific targets, such as tumours, whilst being monitored non-invasively. These nanoparticles are synthesised in our lab from organic materials using radio frequency capacitively coupled plasma. Strict control of the plasma properties is necessary to produce nanoparticles with the desired properties, whilst an effective method to collect the nanoparticles from the reactor gases is also critical. This multidisciplinary project will offer candidates the opportunity to develop and optimise finite element models of the complex physical phenomena occurring within an experimental capacitively coupled plasma reactor. Plasma dynamics will be investigated using drift-diffusion and heavy species transport models to understand the strong spatial and temporal gradients formed during operation, whilst fluid-particle models will be used to monitor the behaviour of fluid-entrained nanoparticles subjected to a range of forces within the plasma. Candidates will work closely with experimentalists to apply the knowledge gained from the modelling to guide nanoparticle synthesis and collection experiments.

Academic Researcher:	**Professor Marcela Bilek**
Project Title:	**Modelling atmospheric plasma processes for biofunctionalization in additive manufacturing**
Project Summary:	This project will develop multiphysics models of atmospheric pressure plasma systems to engineer interfaces and biofunctionalised scaffolds in 3D bioprinting. The Applied Physics and Plasma Surface Engineering group is seeking applications from highly motivated PhD candidates with strong communication skills, a demonstrated ability to work independently, and a desire to make meaningful contribution to state-of-the-art biomedical and plasma technologies. Potential candidates with backgrounds in plasma physics, computational fluid dynamics/finite element modelling, nanotechnology, chemical engineering, mechanical engineering, chemistry, or surface engineering are encouraged to apply.
Project Synopsis:	3D bioprinting, also known as biofabrication, promises highly patient-specific disease models and biomedical implants. However, an ability to tailor surface biocompatibility and interfacial bonding between printed components, such as polymers and hydrogels, is currently lacking. We are developing atmospheric pressure plasma processes that can locally activate polymeric surfaces for the reagent-free covalent attachment of proteins and hydrogel in a single-step process at desired locations throughout the printed structures. To develop the process further we need a deep understanding of the mechanisms that underpin the surface activation we observed. This multidisciplinary project will offer candidates the opportunity to develop and optimise finite element models of the complex physical phenomena occurring within an experimental atmospheric pressure plasma jet. Plasma dynamics will be investigated using drift-diffusion and heavy species transport models to understand the strong spatial and temporal gradients formed during operation, whilst fluid-particle models will be used to monitor atmospheric entrainment in plasma jets. Candidates will work closely with experimentalists to apply the knowledge gained from the modelling to guide atmospheric plasma process design and 3D printing biofunctionalisation experiments.

Academic Researcher:	[Professor Marcela Bilek]
Project Title:	**Plasma surface modification for applications in microfluidic diagnostic systems and implantable cardiovascular devices**
Project Summary:	You will develop novel hemocompatible, bioactive surfaces in microfluidic models for cardiovascular applications. The project is part of an existing collaboration between medical scientists from the Central Medical School and Heart Research Institute with plasma physicists and materials scientist from the Schools of Physics and Biomedical Engineering. In this context, students working on it will develop the skills required to communicate and work successfully as part of a multidisciplinary team. Mentoring from across all of these fields will be provided. There are a number of PhD projects, both experimental and theoretical, available. The projects present opportunities to learn and utilize a wide range of physical and biochemical surface characterization techniques, including attenuated total internal reflection Fourier transform infrared spectroscopy (ATR-FTIR); X-ray photoelectron spectroscopy (XPS); scanning electron microscopy (SEM); electron paramagnetic resonance (EPR) spectroscopy; tensiometry for surface energy analysis; visible/ UV and IR ellipsometry; atomic force microscopy (AFM) and surface profilometry. Biochemical and biomedical techniques include enzyme linked immunosorbent assay (ELISA), fluorescence and confocal microscopy, flow cytometry and cell culture. Through collaboration with plasma physicists, the project will also provide exposure to a variety of plasma processes for materials modification and advanced plasma diagnostic equipment, including fast CCD camera, high resolution gated optical emission spectroscopy (OES), ion energy analysers and Langmuir probes. Theoretical studies for microfluidic systems design will utilize finite element codes such as COMSOL or ANSYS.
Project Synopsis:	**Challenge**: To create materials and medical devices that are compatible with the body and prevent adverse biological reactions to medical devices. **Mission**: Develop materials and surface coatings that do not cause blood clots (thrombosis) whilst providing optimal interactions with biological systems. **Overview**: Medical device use is increasing with the increasing disease burden of aging populations. However, despite technological improvements, medical devices are lagging behind due to a lack of compatibility of medical device materials with the body. There is an urgent clinical need to understand how the interactions of blood and materials cause blood clots (thrombosis) and to develop materials that reduce thrombosis. Materials that can prevent thrombosis will represent a major advance for implantable biomedical devices as well as for ex-vivo diagnostic or disease/physiology modelling platforms. **Group/Team:** Join a multi-disciplinary lab with expertise in biology, bioengineering, applied physics and materials science, and have access to the world class research facilities in the Charles Perkins Centre, the Sydney Nano Institute and the Australian Centre for Microscopy and Microanalysis. Opportunities to travel to international collaborating laboratories including to the Wyss Institute for Biologically Inspired Engineering at Harvard University, will be part of the project. Project: This project will develop methods to understand the interactions of blood components (blood proteins, platelets and leukocytes) with medical device materials that have been modified by plasma-based techniques. In particular, plasma activated coatings (PAC) and plasma immersion ion implantation (PIII) have been used to modify surface properties of multiple medical grade materials to manipulate biological response. PAC

	modified materials have shown excellent blood compatibility, but the mechanism by which this occurs is currently unknown. This multidisciplinary project aims to study the effects of both low pressure and recently developed atmospheric pressure plasma processes for surface modification and functionalisation of materials used in implantable biomedical and microfluidic devices. State-of-the-art biomedical assays will be used to reveal the mechanisms underpinning the thrombogenicity of the surface modified materials both with and without immobilized biofunctional molecules present. Differences in blood responses to untreated, plasma treated, and biofunctionalized channels will provide insight into the effects of particular surface properties on thrombosis. The most promising surface modifications will be translated towards applications with industrial and clinical partners. The knowledge generated can ultimately be used to improve or generate new materials for use in medical devices to improve their function and patient outcomes.

Academic Researcher:	[Professor Marcela Bilek]
Project Title:	**Nanoparticle-based biomolecule detection systems**
Project Summary:	You will develop novel systems to detect biomolecular expression profiles for use in imaging and flow cytometry. This multidisciplinary project aims to improve our understanding of cellular differentiation, in particular the differentiation of blood cells, using flow cytometry and imaging with a novel nanoparticle-based detection system. This system could readily be adapted to improve current diagnostic systems. The knowledge generated can ultimately be used to improve diagnosis, assist in improving health outcomes and expanding our understanding of cellular signaling and differentiation. The project is part of an existing collaboration between medical scientists from the School of Medical Sciences, Faculty of Medicine and Health with plasma physicists and materials scientist from the Schools of Physics and Biomedical Engineering. In this context, students working on it will develop the skills required to communicate and work successfully as part of a multidisciplinary team. Mentoring from across all of these fields will be provided. The project presents opportunities to learn and utilize a wide range of techniques including plasma reactor generation of nanoparticles, attenuated total internal reflection Fourier transform infrared spectroscopy (ATR-FTIR); X-ray photoelectron spectroscopy (XPS); scanning electron microscopy (SEM); electron paramagnetic resonance (EPR) spectroscopy; tensiometry for surface energy analysis; dynamic light scattering (DLS) nanoparticle sizer; zeta potential measurement; microplate readers; fluorescence microscopy; ultracentrifuges; flow cytometry; live cell imaging; surface plasmon resonance (SPR). Biochemical and biomedical techniques include fluorescence and confocal microscopy, flow cytometry and cell culture. Through collaboration with plasma physicists, the project will also provide exposure to a variety of plasma processes for materials modification and advanced plasma diagnostic equipment, including fast CCD camera, high resolution gated optical emission spectroscopy (OES), ion energy analysers and Langmuir probes. Theoretical studies will utilize finite element codes such as COMSOL or ANSYS.
Project Synopsis:	**Challenge**: To create new methods for detecting expression of molecules by cells that do not rely on antibodies. **Mission**: Improve cellular molecular detection using nanoparticles with the

	ultimate goal of generating novel diagnostic and research technologies. **Overview**: Over 6,000 genes in the human genome encode surface proteins and yet we only have antibodies capable of detecting a small number of these surface proteins. This project will focus the development of a novel nanoparticle biomolecular detection system. **Group/Team**: Join a multi-disciplinary lab with expertise in biology, bioengineering, applied physics and materials science, and have access to the world class research facilities in the Charles Perkins Centre, the Sydney Nano Institute and the Australian Centre for Microscopy and Microanalysis. **Project**: The human genome contains over 6,000 genes encoding surface proteins including a broad range of receptors, transporters and channels that we currently cannot detect due to a lack of antibodies. This project will develop novel methods to detect protein expression by different cell types, with the goal of improving our understanding of cellular differentiation pathways. This is a multidisciplinary project bringing together nanoparticle technology with flow cytometry and cellular imaging.

Academic Researcher:	**Dr Cornelius Hempel**
Project Title:	**Quantum control engineering with trapped ytterbium ions**
Project Summary:	The development of well-controlled quantum systems for computational purposes is one of the most promising avenues to unlock solutions to hard and often intractable problems in areas ranging from chemistry and materials science to physics. While much progress has been made over the last decades, further improvements to the performance of quantum operations are required to turn small proof-of-principle demonstrators into reliable quantum computers and simulators that produce results even in the presence of unavoidable noise perturbing the quantum system. In this project, we use the most advanced trapped-ion quantum computing platform in Australia to experimentally realize novel quantum control schemes that are specifically tailored to suppress noise in quantum operations, aiming to bridge the gap to near-term usefulness by combining quantum physics with control engineering approaches.
Project Synopsis:	Classical electrical engineering uses a variety of techniques to characterize the time-domain evolution of control pulses and their corresponding representation in frequency space. This approach, known as the filter-function formalism, allows one to predict the performance and noise-susceptibility of control processes. In the quantum domain, a similar framework can be established and has been underpinning the research at the Quantum Control Laboratory for a number of years, yielding many contributions in both theory and experiment. Our experimental work is carried out using trapped ytterbium ions that encode quantum information in their internal hyperfine energy levels, which we manipulate using microwave and laser radiation. With phase coherence times beyond one second, ytterbium ions are among the best performing quantum bits available, offering a chance to work at the cutting-edge of what is technologically possible. This project will develop and use techniques to characterize both environmental noise and disturbances that are intrinsic to our control pulses. You will then craft special modulation sequences that change their frequency, amplitude and

	phase to suppress the detrimental effects of the noise and allow for an improved performance of the desired operation. Expected outcomes are both a full characterization of the error robustness of the augmented quantum operations as well as their use in a demonstration of superior performance in an application targeting a specific problem of interest, e.g. the experimental quantum simulation of chemical reaction.
Additional Information:	This project requires experimental work in a laboratory, operating and controlling lasers as well as microwave systems and a broad range of electronics. Previous experience in any of those fields is welcome; interest in hands-on laboratory work is a requirement.

Academic Researcher:	**Professor Anita Ho-Baillie**
Project Title:	**Accelerating perovskite solar cells for the real world**
Project Summary:	Hydrogen is an extremely important industrial chemical but is also a clean fuel or as an energy carrier whether in the form of liquid hydrogen or liquid ammonia replacing carbon-containing fuels thereby reducing CO2 emission. The concept of using H2 as an energy carrier has generated immense research and development activities as well as investment opportunities to promote the use of and the import of zero-emission hydrogen causing a resurgence of hydrogen economy. Cleary, carbon-free production of H2 (without the use of carbon-containing feedstock or the release of carbon-containing gas) is most desirable.
Project Synopsis:	The direct solar-to-hydrogen conversion via solar power electrolysis or photoelectrochemical (PEC) water splitting is a clean route for synthesizing high purity H2. The "storing" of solar energy in H2 also solves the problem of solar intermittency problem. In addition, stored solar energy is made "mobile" where liquid H2 or NH3 can be shipped from one geographical location to another. For practical application, high solar-to-hydrogen (STH) conversion efficiency is required motivating research into i) low cost and high performance photovoltaic tandem devices and ii) the use of tunnelling for the solid-liquid junction for efficient electron to ion transfer.

Academic Researcher:	**Professor Anita Ho-Baillie**
Project Title:	**The power of perovskites**
Project Summary:	Metal halide perovskites have attracted global research attention in the last decade. While their application for solar is promising being the fastest advancing PV technology with many start-ups commercialising the technology now, have we fully capitalised on the enabling properties of metal halide perovskites for other high-performance optoelectronics devices that have different cost structure and stability requirements? Join Anita Ho-Baillie's group and explore the use of this material for IR LED's, UV LED's, nanowire lasers, memristors useful for telecommunications, sterilization, on-chip devices and neural networks. The new science and new applications that will be explored and demonstrated will provide students with exciting opportunities to tackle challenging problems creating new inventions.
Project Synopsis:	Multiple projects will allow students to develop new sub-classes of metal halide perovskites such as layered perovskites, double perovskites and lead-free counterparts for engineering key properties such as binding energy, photo-responsibility, and for functionalizing material system. The goal is to improve performance and stability of perovskite optoelectronic devices exceed those of

	the state of the art. The relationship between dimensionality, properties and performance will also be explored.

Academic Researcher:	**Professor Anita Ho-Baillie**
Project Title:	**Accelerating Hydrogen Economy**
Project Summary:	While perovskite solar cells have been the fastest advancing PV technology, what else is needed to accelerate the deployment of this technology in the real world? Can more be "squeezed" out of the sun? Why do demonstrated modules have much lower efficiencies than world record cells on sub-millimetre size? Can perovskite solar cell last long? How long? What will be the most cost-effective method for manufacturing on large scale? Can we make solar cell cool when they are design integrated? Join Anita Ho-Baillie's group working with industry partners to accelerate the progress of perovskite solar cell technology providing students with exciting opportunities creating new inventions for clean energy technology.
Project Synopsis:	Multiple projects will be available for answering questions above. In particular, perovskite tandem solar cells with much higher efficiency potential are promising undergoing rapid performance improvement in only 5 years surpassing the efficiency record of single junction solar cells. The scope of research is immense. You will be given the challenges to overcome interesting problems such as electrical losses in the interlayers, process incompatibility, instability, and un-optimised optical coupling.

Academic Researcher:	**Dr Robert Wolf**
Project Title:	**Ground-state cooling and high-fidelity detection of large ion crystals in a penning trap for quantum simulations**
Project Summary:	The understanding of the dynamics of many-body quantum systems is one of the most challenging problems in physics today. Advancing our knowledge of these systems can lead to significant benefits in the understanding of condensed matter phenomena such as high-temperature superconductivity and spin liquids but also enable insights into dense astrophysical matter as found e.g. in neutron stars. To gain controlled access to these systems and engineer their interaction, we are using some of the most precise tools in atomic physics, the Penning ion trap and laser systems, to build and investigate multi-particle systems ion by ion.
Project Synopsis:	The controlled simulation of dynamics in quantum-many body systems is of central interest in the pursuit to further our understanding of condensed matter phenomena. Specially designed Penning ion traps enable experimental investigations into these topics using hundreds of ions trapped simultaneously. We have recently brought online the first and only such system in Australia at the Sydney Nanoscience Hub and now routinely trap large crystals of beryllium ions. The focus of the work is on finalizing the setup of the laser-based beryllium qubit manipulation and implementing software-based state analysis. Lasers near 313nm are used to address electric dipole transitions in beryllium ions. These transitions can be used to effectively Doppler laser cool an ensemble of ions to ~1mK temperature, such that it forms an ion crystal – a regular and stable lattice of charged particles, formed due to the equilibrium of Coulomb repulsion and electromagnetic confinement. However, for many envisaged experiments, the residual motional temperature has to be decreased even further, close to the ground state of motion. This can be achieved by implementing so-called ground state cooling techniques using lasers with different beam geometry and characteristics. The development and setup of this system, followed by the before mentioned state-of-the-art quantum

	simulation and metrology experiments is a possible project. To investigate correlations between individual ions, or qubits, in a quantum simulation, the spin state of the ion has to be read out. This is accomplished by detecting the ion's fluorescence photons. Ion crystals in a Penning trap rotate in the strong external magnetic field of a superconducting magnet due the Lorentz force. Therefore, a precise correlation between photon time an position is required. The setup of such detection systems and its integration into the existing experimental control software in combination with the development of algorithms employing machine learning is a possible project. These projects are expected to generate new knowledge in the area of quantum science and have a multitude of possible future applications in quantum technology, such as quantum scale materials, quantum sensing and quantum computation. In particular, understanding quantum magnetism is on the forefront of modern physics.