Centre for Micro-Photonics 2020 Physics Honours Projects

1. Silicon nanoparticle fabrication using femtosecond pulsed laser ablation for deep tissue biolabelling

Supervisors: Associate Professor James W. M. Chon, Professor Saulius Juodkazis

Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Silicon nanoparticles have the ability to pick up magnetic field of visible and near-infrared light. This provides wealth of choice for oscillation modes in the visible and NIR range, which makes silicon nanoparticle attractive for biomedical imaging contrast. It is proposed that these nanoparticles can penetrate deep into tissue for brain and neural network imaging. Recently fabrication methods of silicon nanoparticles have greatly improved with femtosecond pulsed laser irradiation. In this project, we use amplified femtosecond pulsed laser to synthesise silicon magnetic nanoantennas and characterise them using multiphoton microscopy and spectroscopic technique. We plan to fabricate monodisperse silicon nanoparticles with controlled sizes from 50 -250 nm in diameters, with high throughput. Students are expected learn nonlinear optics, plasmonics, numerical simulation methods and spectroscopic techniques.

2. Graphene Hybridisation with Plasmonic Nanostructures

Supervisors: Associate Professor James W. M. Chon

Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Graphene is a two-dimensional carbon based material that has extraordinary electrical and optical properties. This material has potential to revolutionize consumer chip based electronics and display devices. We are interested in applying them in single molecular biosensing and in this project, we study single layer graphene hybridised with plasmonic nanosheets using Raman spectroscopy, nonlinear spectroscopy and dark- field scattering microscopy to understand the interaction between the two materials. This new hybrid platform will be applicable to single molecule sensing, sub-nanometre distance and charge sensing. The electron beam lithography platform (Raith II) within the university will be utilised to fabricate the nanoplasmonic hybrid materials. Finite difference time domain simulation package of plasmonic wave propagation (Lumerical package) will also be utilised.

3. T-rays: wavelength selection for mm-wavelengths

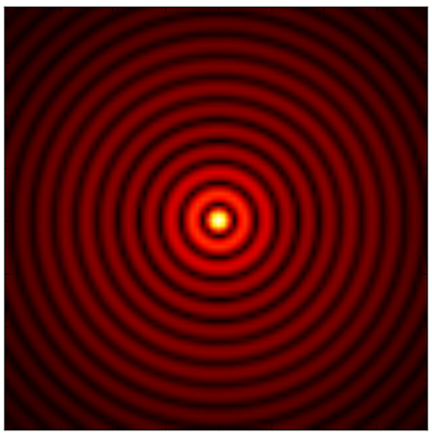
Supervisor: Prof Saulius Juodkazis

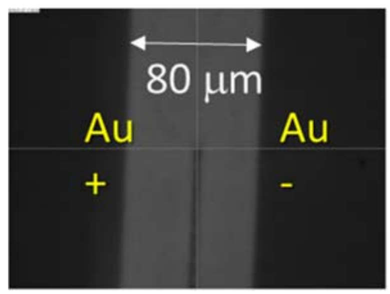
Contact: sjuodkazis@swin.edu.au

Project Description: Future telecommunications are exploring the mm-wavelength range and a wide use of THz technology (T-rays) is used for revealing secondary structures of bio- materials at those frequencies. The Australian synchrotron (Melbourne) has unique capability to produce coherent radiation at 0.3-1 mm wavelengths with highest powers at this non-ionising spectral window. However, there is lack of available spectral filters and optical elements to handle radiation at those wavelengths. We have recently demonstrated that 3D printing can be potentially used to print optical elements at those wavelengths. In this project, thin sheets of photo-sensitive materials will be used to make transmission filters tailored for a specific spectral range at THz wavelengths from 1 mm to 0.1 mm. Simple mask projection lithography will be implemented to expose photo-polymer and after development and metal coating with plasma sputtering the final binary-transmission filter will be made. Different thickness polymer sheets will be used and after metal coating from two sides will create a field enhancement inside the holes. This can be used for sensors based on enhanced absorption. Filters will be tested at the Australian synchrotron using beam time application or technical test by beamline scientists. Project can lead to Hons project of further development of polarisation optics using less lossy dielectric and semiconductor materials and micro-optical elements. Such tool set is strongly required for future T-ray technologies.

4. Bessel beam generator for Free-Electron-Laser

Supervisors: Professor Saulius Juodkazis
Contact: sjuodkazis@swin.edu.au





5. Force required to kill bacteria

Supervisor: Prof Saulius Juodkazis, Ms Denver Linklater

Contact: sjuodkazis@swin.edu.au

Project Description: Laser tweezers (Nobel prize 2018) will be used to measure force applied to laser trapped objects when they are pushed against antireflective nanotextured surfaces such as black-Si and nanotextured plastic. Calibration of the laser trap stiffness will be carried out with spherical polystyrene and glass beads. Bacteria solutions will be used for laser manipulation and measurement of the trapping forces. Pushing bacteria against nanopillars will reveal the force required to break bio-membrane of a cell. This is an important measure which is still poorly known in the field of nanotextured surfaces which act as mechanical antibiotics. In the project you will be trained to work in bio-lab and handle cell cultures. Laser trapping will be carried out with a dedicated setup based on an optical microscope without requirement of a laser beam steering and alignment. No prior training in biotechnology or lasers is required.

6. Nanotextured surfaces for astro-photonics

Supervisor: Prof Saulius Juodkazis, An Le

Contact: sjuodkazis@swin.edu.au

Project Description: Larger area antireflection surfaces with wide range of acceptance angles are required for modern astro-photonic applications including free space as well as fibre optics at wide range of wavelengths from visible to infra-red. For open air applications optical coatings cannot be used due to durability concerns and nano-textured surfaces have to be made on curved surfaces and covering large areas with cross sections up to tens-of- cm. In this project we search for an industrially scalable solution to nano-texture a glass lens surface using metal coating with a subsequent annealing and de-wetting into nano-islands followed by plasma etching. Metal nano-islands will serve as an etching mask. We plan to use a two step repetition of such procedure to create hierarchical surfaces on lenses. Optical characterisation by transmission, reflection, and scattering will be carried out using range of spectrometers. Such surfaces will have range of potential applications in bio- medical and solar cell applications due to their bactericidal, hydrophobic, and antireflective properties. Project includes collaboration with astrophysics team at Swinburne and will be co-supervised by Nanotechnology facility engineer. No prior experience in nanotechnology is required.

7. Free-space releasable micro-optical elements

Supervisor: Prof Saulius Juodkazis, Tomas Kaktus

Contact: sjuodkazis@swin.edu.au

Project Description: Opto-mechanical manipulation of materials has an increasing impact in wide range of applications and for fundamental science of light-matter interaction (Nobel Prize for laser tweezers in 2018). In particular, the linear and angular momentum transfer from light to nano-/micro-object is at the focus of this project. The largest challenge in this field is a simple fabrication and on-demand release of tiny complex structures with designed optical function. Structures for the most efficient momentum transfer have to be fabricated with a standard high sub-wavelength precision required for the polarisation optics and not compromised by procedures of their release for a free-space manipulation in air or liquid or at their interface. In this project we will develop a protocol for simple release of polarization active optical elements deposited by evaporation or/and plasma sputtering on a metal film. The metal film will be released by wet etching and free-floating micro-optical elements will be obtained. Definition of the shape of the optical element will be carried out by focussed ion etching. All fabrication will be carried out in Swinburne's Nanotechnology facility. Collaboration with Vilnius and Bordeaux Universities is ongoing for this research focus. Fabricated samples will be further tested and characterised using laser tweezers (available also at Swinburne). Project can be scaled up to Hons and PhD stages (a cotutelle PhD can be setup with collaborating labs).

8. Where laser ablated particles will fly?

Supervisor: Prof Saulius Juodkazis, Jovan Maksimovic
Contact: sjuodkazis@swin.edu.au

Project Description: Precise control of laser ablation is required when feature sizes of patterns reach wavelength dimensions. Using threshold effect of material modification, features of tens-of-nm can be ablated, melted, phase-changed. It is very important to avoid or minimise deposition of ablation debris. For a fast laser drilling, dicing, and cutting, debris cause an additional step of sample washing. However, the smallest nanoparticles placed on the surface of a workpiece cannot be removed without causing additional surface damage. In this project we will use electrical field applied at two sides along the laser cutting trajectory on the surface of sample to control deposition of ablated nanoparticles. Ultra- short laser pulses will be used to ablate metal coating into two half planes which will become electrodes for subsequent laser ablation experiment. Preliminary results already showed that this method can be used for a debris control in laser micro-structuring. Since the applied electrical field will have strong gradients we also explore an electrophoretic action of particle selection by mass, shape and dielectric function. Deeper studies of this phenomenon will lead to Hons and PhD projects. Collaboration with Vilnius University and École polytechnique fédérale de Lausanne - EPFL is planned for this project including possibility of joint PhD (cotutelle). No prior knowledge of laser fabrication is required. Project will be co-supervised with PhD student and Nanolab engineers.

9. Are we at a tipping point?

Supervisor: Prof. Damien Hicks

Contact: dghicks@swin.edu.au

Project Description: The natural world is dynamic, constantly changing and evolving in time. Molecules jostle and react, liquids flow and churn, cells divide and die. The sum of all this microscopic turmoil is often a steady state: gases equilibrate, flows balance themselves, and populations stabilise. In reality, these steady states never last. Eventually they transition, sometimes rapidly and unexpectedly, to new states. Thus, healthy tissue becomes cancerous, peaceful crowds turn violent, and the earth's climate, after thousands of stable years, suddenly becomes uninhabitable. Is it possible to detect precursors to these transitions to know when you are getting "near the edge"? In this project you will focus on what we can infer about dynamical behaviour from high-dimensional snapshots of system features. This is a mathematical and computational project. Prospective students should be proficient in Python programming and be interested in how physics can improve the human condition.

10. Acoustic frequency comb generation

Supervisor: Dr Ivan Maksymov
Contact: imaksymov@swin.edu.au

Project description: This project is an excellent opportunity for a student interested in theoretical and numerical modelling to work on the emergent and interdisciplinary topic of acoustic frequency combs. Similar to an optical frequency comb, an acoustic frequency comb is a spectrum consisting of a series of discrete, equally spaced elements that have a well-defined phase relationship between each other. Acoustic combs will benefit marine sciences, underwater positioning and navigation, also opening up novel opportunities for industries using unique properties of liquids, droplets and bubbles (e.g. biomedicine). In this project, we will investigate nonlinear physical phenomena in acoustic, microfluidic and optical systems by developing and using computational codes based on finite-difference methods (FDTD) and other numerical techniques. There would also be opportunities to be involved into experimental research.

Further reading:

PhysicsWorld magazine, https://physicsworld.com/a/acoustic-frequency-comb-measures-up/;

YouTube, "Why you need an optical frequency comb", https://www.youtube.com/watch?v=graq4kpd8-A

FDTD method, https://meep.readthedocs.io/en/latest/Introduction/

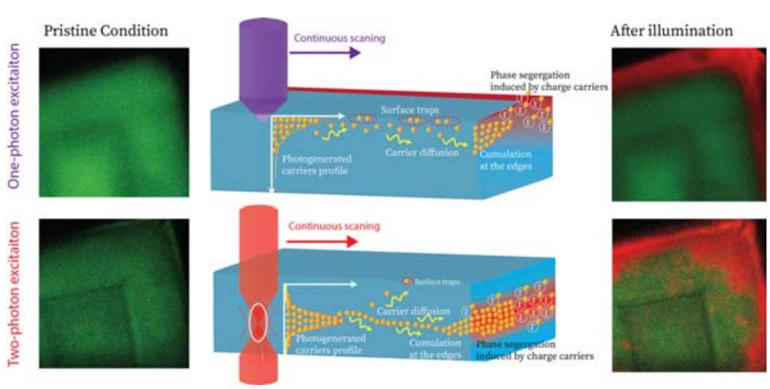
11. Laser illumination induced phase segregation and reversibility in mixed halide perovskite

Supervisor: Dr Xiaoming Wen, Contact: xwen@swin.edu.au, 9214 8625

Organic-inorganic hybrid perovskites have attracted considerable research interest due to the enormous potential for highly efficient optoelectronic applications such as solar cells, light-emitting diodes (LEDs) and photodetectors. Mixed-halide perovskites are very promising materials for optoelectronics due to their tunable band gap in the entire visible region. A challenge remains, however, in the photoinduced phase segregation, narrowing the band gap of mixed-halide perovskites under illumination thus restricting applications. In this project, combining time-resolved photoluminescence (PL), fluorescence lifetime imaging microscopy (FLIM) and micro-PL spectroscopy and other optical techniques, you will investigate the light illumination induced phase segregation. This study will reveal the physical mechanism of phase segregation in mixed perovskites, providing the details of correlation between the conditions of illumination and sample fabrication with the phase segregation and recovery.

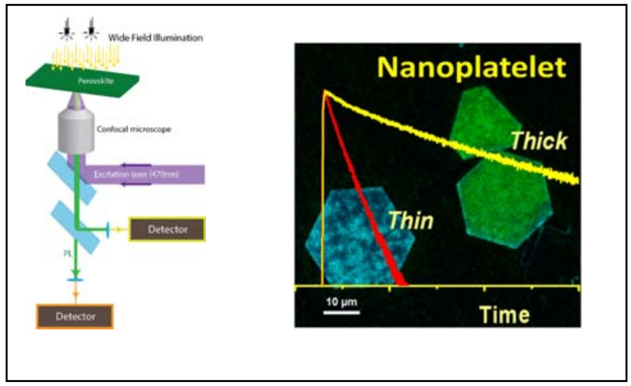
Further Reading:

1. Illumination-Induced Halide Segregation in Gradient Bandgap Mixed-Halide Perovskite Nanoplatelets, **Advanced Optical Materials**, 1801107 (2018) **(IF 7.43)**
2. Dynamic study of the light soaking effect on perovskite solar cells by in-situ photoluminescence microscopy, **Nano Energy** 46, 356-364 (2018) **(IF 15.548)**
3. Tracking Dynamic Phase Segregation in Mixed-Halide Perovskite Single Crystals under Two-Photon Scanning Laser Illumination, **Small Methods**, 2019, 1900273



12. Investigation of photogenerated carrier dynamics by time-domain and frequency-domain spectroscopic techniques.

Supervisor: Dr Xiaoming Wen, Dr. Weijian Chen, Contact: xwen@swin.edu.au, 9214 8625



Time-resolved photoluminescence (PL) has been widely applied for investigating the photogenerated carrier dynamics, providing invaluable information of charge carrier recombination, photon-phonon scattering, carrier transfer and extraction; and intimately correlated with their applications of photovoltaics, photocatalysis, PED and lasing etc. photonics, therefore critically important for renewable energy and LED/display industries. Basically, time-resolved PL can be performed in the time domain and in the frequency domain. In this project, the carrier dynamics of hybrid perovskite will be investigated using both time domain and in the frequency domain techniques. Each will provide useful information for the physical understanding of photogenerated charge carriers in perovskites.

Further Reading:

1. Zheng et al. Triggering the Passivation Effect of Potassium Doping in Mixed-Cation Mixed-Halide Perovskite by Light Illumination, **Advanced Energy Materials**, 1901016 (2019) **(IF 24.884)**
2. Hole Transport Layer Free Inorganic $CsPbIBr_2$ Perovskite Solar Cell by Dual Source Thermal Evaporation, **Advanced Energy Materials** 6 (7), 1502202 (2017) **(IF 24.884)**
3. Acoustic-optical phonon up-conversion and hot-phonon bottleneck in lead-halide perovskites, **Nature communications** 8, 14120 (2017) **(IF 11.88)**

13. Fabrication 3D high-resolution multi-color pattern in Mixed-Halide Perovskite single crystal using Direct Femtosecond Laser Writing

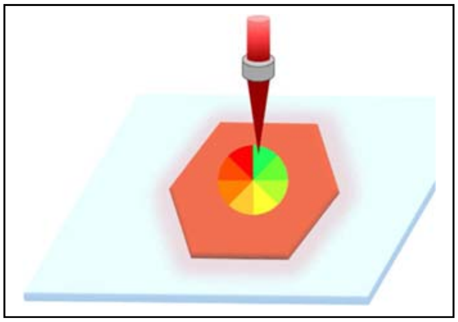
Supervisor: Dr Xiaoming Wen, Prof. Baohua Jia, Contact: xwen@swin.edu.au, 9214 8625

Lead halide perovskites are widely applied in not only photovoltaics but also on-chip light sources and photon detection. Femtosecond (fs) laser fabrication is used to be demonstrated significant advantages of high spatial resolution, low surround damage and high processing efficiency. In this project, fs laser is used for directly fabricate 3-dimension high resolution, multiple color pattern in mixed-halide perovskite single crystal. The mechanism of the fs laser writing and controlling will be investigated for various perovskite material and their nanostructures.

Further Reading:

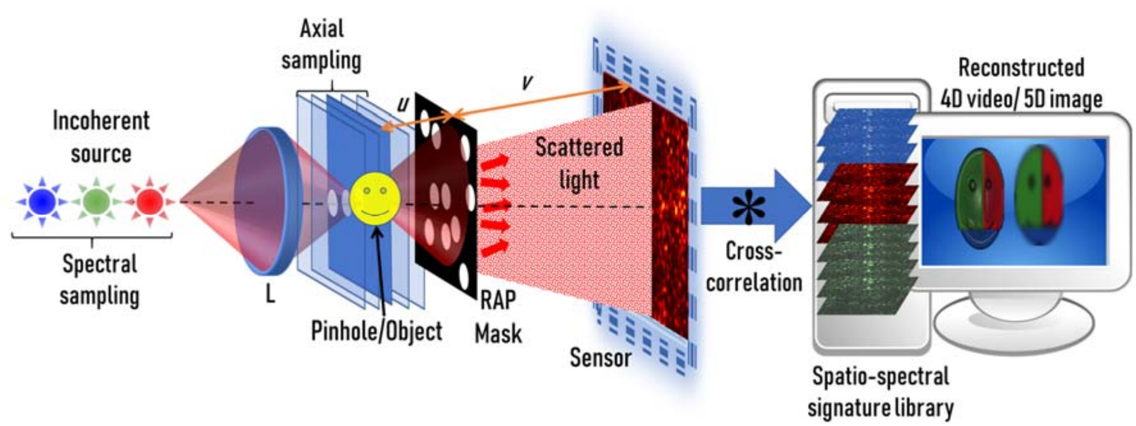
1. Spatially Modulating the Fluorescence Color of Mixed-Halide Perovskite Nanoplatelets through Direct Femtosecond Laser Writing, **ACS Appl. Mater. Interfaces (**2019) **(IF8.456)**

2. Chemical dopant engineering in hole transport layers for efficient perovskite solar cells: insight into the interfacial recombination, **ACS Nano** 12 (2018), 10452 (**IF13.903**)



14. Lensless, Interferenceless, Motionless, Non-Scanning, High Field of View, Multidimensional Imaging Technology

Supervisor: Dr Vijay Anand, Contact: vanand@swin.edu.au



Techniques/Skills acquired in this project

Optical Engineering, Computational Optical techniques, Automation and Data Acquisition, Lithography and Mask fabrication

Application

Fluorescence microscopy, Astronomical telescope, Imaging through scattering layers, Spectrophotometry

Possible upgradation

Deep learning modules, Mobile computation, Metalens fabrication