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Welcome to the MCN
Dr Sean Langelier

The Melbourne Centre for Nanofabrication (MCN) makes a range of micro and nanofabrication equipment and expertise available to academic or industry users. The ISO 9001-certified centre is home to the Southern Hemisphere’s largest open-access cleanroom, housing a series of Class 10,000-100 cleanroom spaces, Biochemical, Advanced Microscopy, PC2, PDMS laboratories and essential tools. The Centre is the flagship facility of the Australian National Fabrication Facility’s Victorian Node (ANFF-VIC) and headquarters for ANFF’s national network.

The MCN is a joint venture between:
Synthesis of Advanced PANI Based Conductive Composites Using Methacrylate Groups Based Materials for Aerospace Applications

Santwana Pati

University of Tokyo

The aerospace industry is transforming significantly by adopting composites for the structure of the aeroplanes. Polyaniline (PANI) being a conducting composite already used in electrochemistry, sensors, conducting films can be used to make doped PANI based carbon fiber-reinforced plastics (CFRP) composites that can provide lightning strike protection, EMI shielding, corrosion resistance hence enhance the lifetime of the aircraft as well as improve fuel efficiency.

Our team has been working on the fabrication of conducting composite using PANI with dodecylbenzene sulfonic acid (DBSA) and divinylbenzene (DVB). This research is based on the synthesis of a novel PANI based conducting composite material introducing a new material: 2-Methacryloyloxyethyl acid phosphate (P-2M).

Material Development:

P-2M has basically two types of chemical groups: the acidic group that aids in the doping procedure giving conductivity and the Polymethyl methacrylate (PMMA) like methacrylate group that facilitates in curing through radical polymerization that provides strength.

The highest conductivity of 30.4 S/m was obtained and the curing of the matrix to form a high strength conducting composite was accelerated by adding another new material named Trimethylolpropane trimethacrylate (TMP). The detailed morphology, thermal properties and electrical properties were characterised using UV-Vis Spectroscopy, Thermal Microscope, Scanning electron microscope, Differential scanning microscope, Fourier transform infra-red spectroscopy, and electrical conductivity measurement.
Semiconductor materials are playing a dominant role in modern technology, and its nanostructured counterparts represent an interesting field of research for a plethora of applications. Amongst the group IV semiconductors Germanium (Ge) has a high dielectric constant of 16.2, in comparison with 11.7 for Si, and high refractive index ($n = 4.2$) silicon ($n = 2.6$), these properties in combination with its high electron hole mobility at 300 K ($3900 \text{ cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1}$) in comparison with Si ($1600 \text{ cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1}$) makes Ge a promising candidate for photovoltaics, microelectronic systems, photonics, optoelectronics, infrared detectors and field effect transistors. Furthermore, nanostructured Ge has unique physiochemical, electronic, and optical properties and is biocompatible. Here, we investigated electrochemical and dry etching fabrication techniques to develop a library of homogenous and reproducible Ge nanostructures including meso-porous Ge (meso-pGe), macro-porous Ge (macro-pGe), and Ge nanowires (GeNWs) that offer tuneable morphologies and surface chemistry. In this talk we will present our novel fabricated Ge nanostructures, and its application as an analytical platform for illicit drugs detection and as a versatile platform for pH biosensing.
Hydrogenated amorphous carbon (a-C:H) films have been gathering attention recently for their high hardness, chemical inertness, low friction coefficient and high wear resistance, which enable a-C:H films to be a good coating materials in tribology fields. On the other hand, these properties are greatly influenced by microstructure of a-C:H films, and the microstructure is changed according to coating methods and parameters. In our previous study, Raman spectroscopy was used to clarify the microstructure of a-C:H films, and the mechanical properties (hardness, Young’s modulus, internal stress) of the films were successfully correlated with the Raman parameters. In this study, the correlation between the microstructure of a-C:H films and their tribological properties was investigated.

From the evaluation of the microstructure of a-C:H films using Raman spectroscopy, it was found that the structure of a-C:H films can be classified into three main categories, i.e., polymer-like carbon (PLC), diamond-like carbon (DLC) and graphite-like carbon (GLC) structures. Since it is well known that a-C:H films have strong dependency of relative humidity, we have conducted the friction tests at 10% RH and 75% RH in air.

In 10% RH, a-C:H films with DLC structure showed the highest friction coefficient among these three carbon structures. Also, the friction coefficient of DLC structured a-C:H film increases in proportion to their hardness. By investigating the friction surface, we found that chemical species generated during sliding are one of the main reasons which affect the friction coefficient.

In 75% RH, PLC-structure films show the highest friction coefficient among them. In high humidity condition, thick water layer forms on the friction surface, and no more correlation can be observed between the hardness of a-C:H film and its friction coefficient. QCM (Quartz Crystal Microbalance) measurement revealed that PLC-structure films form a thick water layer, which attribute to the high friction coefficient of PLC-structure films.
Engineering Vertically Aligned Silicon Nanowire (VASiNW) Arrays for Delivering Bioactive Molecules to Mammalian Cells

Crystal Chen & Stella Aslanoglou

Monash University

Over the last years, vertically aligned silicon nanowire (VA-SiNW) arrays have been explored as platforms for direct intracellular delivery of a variety of biomolecules into broad cell types. However, the transfection efficiency mostly rely on the geometrics and surface functionalization of VA-SiNW arrays. Therefore, it is essential to map out and understand how these key physical characteristics affect the SiNW-cell interface and intracellular delivery thereafter.

In this study, we report on the development of a novel delivery platform for cell transfection studies in vitro, utilising VA-SiNW arrays with a positively tapered profile. Fabrication starts with self-assembly of a hexagonal close-packed (hcp) 2D array of polystyrene (PS) microspheres over a large area of a Si wafer via convective assembly. The resulting hcp monolayer array is then converted into non-close-packed monolayer arrays using O2 plasma etching. The etched PS microspheres then serve as a mask for the Deep Reactive Ion Etching (DRIE) of silicon using both the “Bosch” and “Pseudo Bosch” process. Alternatively, VA-SiNWs are fabricated using a combination of e-beam lithography with DRIE. Two different geometries are being scanned here. SiNW arrays with the same height and spacing but different tip diameter.

After surface functionalization, the as-fabricated SiNW arrays together with flat Si wafers (control) are applied to in vitro cell cultures. Both adherent and suspension cells have been included in this study. To evaluate the SiNW-cell interface, basic cellular functions such as viability, attachment and migration are investigated using different imaging techniques including confocal microscopy, SEM and FIB-SEM. Cell proliferation, after re-harvesting from the SiNW culture, is also examined using flow cytometry. Furthermore, the expression of the reporter fluorophore attached onto the cargo molecule was measured by fluorescence microscopy, as an indicator for transfection efficiency.

All the techniques mentioned above provide us information and feedbacks to obtain the optimal SiNW-cell interface for efficient NW-mediated intracellular delivery, with minimal toxicity induced to the cells.

Notes
Polymer Semiconductors showing transport of Delocalized Carriers

Yu Yamashita
University of Tokyo

The low-cost solution process of electronic devices are gaining great attention, as it can contribute to the cheap energy harvesting devices or devices for Internet of Things (IoT) systems. Here conjugated polymers, represented by poly-thiophene, are candidate materials, showing high solution processability and mechanical flexibility.

For the electronic performance, high charge carrier mobility is expected through their conjugated backbones, which is important for various applications. Although, the actual performance has been reported to be low ($1 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$) because of the disordered structures.

Recently, microscopic structures have been improved by the chemical synthesis approach and we have combined them with a new method to align to polymer chains macroscopically on the surface of ionic liquid. With this strategy, transport of delocalized carriers, band-like transport, was confirmed for the first time by the temperature dependence of mobility and Hall measurements. We are also working on methods to achieve adequate crystallinity and high carrier concentration doping at the same time, to inject carriers into delocalized states by the trap filling. These polymers with delocalized carriers are showing high mobility ~$10 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$, which would open up possibilities for various applications.

Notes
Synthesis of Ultrathin Composition Graded Lateral WSe2/WS2 Heterostructures

Zhipeng Li
RMIT

Lateral transition metal dichalcogenides (TMDCs) material and their heterostructures have attracted substantial attention, because of their appealing electrical and optoelectronic properties. However, there lacks a simple approach to produce large-scaled optoelectronic devices with graded composition. In particular, the incorporation of substitution and doping into heterostructure formation is rarely reported. Here, we demonstrate growth of a composition graded doped lateral WSe2/WS2 heterostructure by ambient pressure chemical vapor deposition in single heat-cycle.

Through Raman and photoluminescence spectroscopy, we demonstrate that the monolayer heterostructure exhibits a clear interface between two domains and a graded composition distribution in each domain. The coexistence of two distinct doping modes was verified experimentally. Electrical transport measurements reveal that this lateral heterostructure has representative characteristics of a photodiodes. The optoelectronic device based on the lateral WSe2/WS2 heterostructure shows improved photodetection performance in terms of a good responsivity and large photoactive area.

Notes
Mode-selective phonon excitation using pulse-shaped intense ultrashort optical pulses

Yo Iida
University of Tokyo

Ultrashort optical pulses with a broad frequency component are able to excite phonons having a wide variety of phonon modes in solids through impulsive stimulated Raman scattering (ISRS). When phonons are excited effectively, atoms in the lattice vibrate intensively. This large displacement of atoms are expected to cause changes in phase of materials among solid, liquid and vapor. These ultrashort-pulse induced phase transitions are expected to cause non-thermal effects in solids on the time scale of sub-ps. These phenomena are quite different from the conventional models in phase transition and have gained attention for view point of not only physics but also various potential application, such as in laser material processing and ultrafast switching devices.

Conventional ISRS using Fourier transform-limited pulses excites phonons with different modes at the same time and it is difficult to characterize the contribution of each phonon mode to the phase transition. It is expected that the selective excitation of each phonon mode enable us to understand how each phonon mode modifies the property of the material. To excite a single phonon mode selectively, a pulse shaping technique has been used in the past. The phonon mode resonating to the polarization-twisting frequency of the excitation laser pulses is selectively excited. Up to now, the polarization twisting pulses have been achieved by using a spatial light modulator (SLM). However, the damage threshold of most SLMs limits the pulse energy of the order of sub-micro J.

To generate polarization-twisted pulses with a high pulse energy without a SLM, I developed a new technique using grating pairs, a Michelson interferometer and a quarter-wave plate. Using this experimental setup, the energy of polarization-twisted pulses could reach up to 270 μJ which is enough to break down conventional dielectrics such as quartz with a moderate focusing. We successfully demonstrated the excitation of the specific phonon mode which is resonant with the twisting frequency of the laser pulses in quartz. We are now working for the control of ferroelectric polarization through mode-selective excitation of phonons for applications in, for example, ultrafast memory devices.

Notes
Future electronic devices will evolve from current 1st generation rigid system to 2nd generation invisible and stretchable electronics. However, it remains challenging to achieve ultrahigh electrical stretchability, ultrathin device dimensions and optical transparency into a single type of device.

Practical applicability of soft sensing devices is still restricted, mainly due to traditional conductive materials are too rigid to achieve high stretchability. Novel nanomaterials should be a pathway to achieve both good conductivity and stretchability. This talk mainly introduce a general, low cost fabrication method to fabricate highly sensitive and wearable sensing devices with ultrathin gold nanowires for bio-monitoring applications.
Study of optimal multijunction solar cell designs with uniform luminescent coupling for higher energy conversion efficiency

Yu Jeco, Bernice Mae Fetalvero

University of Tokyo

In photovoltaic solar cells, the multijunction solar cell (MJSC) has achieved the highest solar energy to electric power conversion efficiency. The highest MJSC conversion efficiency attained so far was 46%. This value is getting close to 50%, which is the future target for photovoltaics (PV) community.

To reach the target conversion efficiency though, more refinement needs to be done to minimize losses in solar cells such as thermal loss, carrier thermalization and electron-hole pair (EHP) recombination resulting to light emission. Among these, recycling of light emission due to EHP recombination in MJSCs can enhance the efficiency increase by 1.0%. This is called the luminescence coupling (LC) effect. This is described as the absorption of photons emitted from a higher bandgap subcell to a lower bandgap subcell.

However, preliminary measurements show that the LC current distribution is spatially non-uniform, with decreasing current generation towards the cell edges, causing inherent reduction in energy conversion efficiency. This can be possibly solved by implementing novel GaAs/Ge dual junction solar cell (2JSC) designs can improve the MJSC conversion efficiency which may result to energy cost reduction from solar power generation.

One solution for non-uniform LC current generation can be a Plateau GaAs/Ge 2JSC (P-2JSC) design. Having the Ge bottom cell area to be larger than that of the GaAs top cell may compensate for the non-uniform current generation in the edges of its unexposed area. Because the side portions of the bottom cell area are directly exposed to the sun, it can receive more sunlight. Another is by embedding colloidal quantum dots (CQDs) into the selected area near the edges of a 2JSC GaAs top cell. This is to allow larger amount of light emission towards the edges of the Ge bottom cell. This then may yield larger LC current generation near the Ge bottom cell edges. These structures may improve the MJSC conversion efficiency.

Higher GaAs-to-Ge subcell LC efficiency increases conversion efficiency reduction of the limiting cell due to non-uniform LC current generation. At 69% LC efficiency, the conversion efficiency is found to reduce by 1.3%. This reduction implies that the same amount of efficiency can be gained if the LC current generation is made spatially uniform.

Notes
Real-space observations of polaritons in layered 2D materials exposed by s-SNOM

Zhigao Dai
Monash University

Layered two-dimensional materials assembled from atomically thin crystalline layers are emerging as a new paradigm for optical physics. Surface plasmon polaritons, oscillation of group electrons, in graphene and layered topological insulator, have attracted great attention in recent years.

There are a few types of polaritons, including those formed by atomic vibrations in polar insulators, excitons in TMDs, cooper pairs in layered superconductors. In the persistent pursuit for exploration of polaritons, scattering-type scanning near-field optical microscope (s-SNOM) has an exceptional impact. A sharp tip of an atomic force microscope is used as an optical antenna, allowing one to detect how incident light is scattered at the apex of the tip in the nearness of the studied sample. The obtained signal is governed by the local electric field of the polariton wave launched by the tip, rendering nanometer spatial resolution as the tip is raster-scanned over the sample.

Here I would like to give an example to show how we used the s-SNOM to investigate the plasmonic properties of edges in well-defined graphene nanostructures, including sharp tapers, nanoribbons and nanogaps. Using the infrared nanoimaging technique, greater plasmon broadening was observed in the zigzag edge than in the armchair edge.
2-dimensional transition metal dichalcogenide (TMD) nanomaterials have been focused on in recent years because of their intriguing properties that are different from bulk materials. Unlike graphene, there is an intrinsic band gap in TMD nanomaterials, which further becomes direct gap in their monolayer forms. As a representative of TMD nanomaterials, monolayer molybdenum disulfide (MoS2) has a direct band gap of ~1.9 eV, and thus opens its exciting prospects for a variety of optoelectronic applications, especially for solar cells.

In this research, monolayer MoS2 has been synthesized by chemical vapor deposition. The as-synthesized large-area MoS2 film (cm level) shows high quality through the characterizations of Raman and photoluminescence spectroscopy. The monolayer MoS2 film has been further applied to heterojunction solar cells using single-walled carbon nanotube (SWNT) film as hole transport layer. MoS2 film functions as light-absorbing and electron-hole pair generation layer. The properties and mechanisms of MoS2-SWNT solar cell will also be discussed.
Rapid Prototyping of Nano Channels using the Nanofrazor

Srinivas Mettu
University of Melbourne

“Nanofrazor” is a new nano chiselling tool available at Melbourne Centre for Nanofabrication (MCN) for making rapid prototypes of 3D nano scale patterns for use in microchips, sensors and devices for quantum computing. Nanofrazor is an alternative tool for users who rely heavily on E-beam lithography. Nanofrazor works by scanning and pushing a hot silicon tip (~5nm) into polymeric material to chisel (and evaporate) a nanoscale pattern over a very large area (50 microns square) within 1 or 2 minutes. Each of the 50 microns square patterned areas can be stitched together to create the pattern on whole wafer. All we need is grey scale image to make nano pattern.

The Nanofrazor also reads the patterns on the fly while it is writing thereby eliminating an extra metrology step required in conventional nano patterning tools (what we see is what we have just made!!). The depth resolution is in subnanometers whereas length and width resolution is about 10 nm. Once the nano pattern is made in the polymeric material, the pattern transfer to silicon by conventional etching techniques is possible.

In this talk, we would give a brief introduction of the tool and show the working principle of the Nanofrazor along with its capabilities in pattern transfer to silicon. We also show few examples of rectangular and wavy nano channels that we have fabricated at MCN. We show the comparison of patterns read by Nanofrazor with that of conventional metrology methods to validate its metrology step.

Notes
Graphene coatings have been reported to suppress corrosion of various metal substrates due to their chemical inertness. However, the extent of protection offered depends on the uniformity and defect density of the graphene layers developed on the metallic substrates. Among the various synthesis methods, chemical vapour deposition (CVD) is one of the most promising ones to produce graphene coating on a variety of metal substrates. However, achieving controlled CVD growth of large area, uniform and less defective graphene coating is still challenging.

This study investigates the influence of various CVD growth parameters during the graphene synthesis, such as hydrogen flow, carbon precursor flow, growth temperature and cooling rate used on the uniformity of the resultant graphene coating and its corrosion resistance. The barrier properties of graphene-coated Cu substrates were evaluated using potentiodynamic polarisation and electrochemical impedance spectroscopy (EIS) in 0.1 M NaCl for 1008 h. High graphene growth temperature (1060ºC) and low hydrocarbon flow rate (1 sccm) in the absence of H2 flow were identified to synthesize a uniform graphene coating, which showed durable barrier performance.

During the initial hours of immersion, the graphene coated copper (Cu) specimens showed about one and half order of magnitude improvement in corrosion resistance in 0.1 M NaCl and even after 1008 h, the corrosion resistance provided by the graphene coating was almost five times more than that of bare Cu. The optimized CVD graphene parameters reported here can provide a new direction to achieve long-term durable graphene coating.
Topic 1: Nonlinear Optical Effects in Silicon Waveguides

Tania Moein
Swinburne

Several types of nonlinear optical effects have been studied in past years by employing silicon waveguides. Silicon is very promising to produce nonlinear optical devices due to its transparency at 1.1 μm up to 6 μm, high nonlinear refractive index and it’s compatibility with CMOS technology. Here we experimentally demonstrate the fabrication and characterization techniques of Si waveguides on SOI wafer. Various structures of silicon wire waveguides and ring resonators is presented in this research.

Topic 2: Graphene Bolometer for VIS-IR Spectral Range on Nano/Micro SiN Membranes

Tania Moein
Swinburne

We propose a high sensitive bolometric detectors for visible and infrared wavelengths based on a novel assembly principle of a monolayer graphene on a nano/micro SiN membrane. The basic operating principle of optical detectors relies on the absorption of electromagnetic radiation in a photosensitive element – graphene – where its energy is converted into an electronic signal via Seebeck mechanism due to temperature gradient. Hence, detection efficiency is directly related to the efficiency of the optical absorption process. Two different types of lithography-free and high precision bolometers defined with electron beam lithography and lift-off are demonstrated.

Notes
Serpentine Microfluidic Channels on Polymers for Filtration and Separation of Particles

Arcot Yugandhar
Deakin University

Filtration and Separation of Particles have enormous technological significance in industry and research such as water purification, chemical processes, and separation of particles in bio-fluids like sorting/filtering of blood components. Microfluidic device is a favoured choice to macro scale techniques in terms of scaling-up and intensifying the effects of hydrodynamic forces required for separation of particles in the fluid flow. Serpentine microfluidic channels are an advantageous choice over other channel profiles considering parallelization of channels, foot print, and high throughput. Depending upon the size of particles and technique for separation, the geometry of the serpentine channel plays a significant role in the separation efficiency of the particles.

This research particularly focuses on the geometry and surface roughness of the serpentine micro-channels and their effect on the separation efficiency of the particles. Inertial focusing, Dean’s flow forces, chemical gradient and electric potential forces will be used in the separation of the particles. Inertial focusing and Dean flow forces will be used for equilibrium positioning of the particles in the channels and particularly applicable for particle sizes greater than 3μm. Chemical gradient and electric potential gradient will be used for separation of particles less than 3μm. The research primarily focuses on blood as working fluid which consists of particles of different sizes ranging from ions, proteins to particles of 20μm.

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Seminars at the Melbourne Centre for Nanofabrication

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