AIBN Polymer Group

Available Student Projects

http://www.uq.edu.au/polymer-chemistry/available-student-projects

The lead researchers in the Polymer Chemistry Group are Prof Andrew Whittaker, Assoc Prof Idriss Blakey, Dr Kris Thurecht and Dr Hui Peng. These four researchers have independent research themes but because of their complementary skills work in close collaboration.

The Group Leader, Professor Whittaker is an ARC Australian Professorial Fellow at the Australian Institute for Bioengineering and Nanotechnology and the Centre for Advanced Imaging, and holds an adjunct appointment in SCMB and the Queensland Eye Institute. His research interests include the fields of nanotechnology, biopolymers and polymer hydrogels, polymer degradation, polymer devices, and the application of spectroscopic (especially NMR) methods to polymer research.

The Polymer Chemistry Group consists of over 40 researchers, with two academic staff (Andrew Whittaker and Dave Hill), Research Fellows and PhD and Honours students and support and administrative staff. The group is very active, holding weekly group meetings, and encourages students to travel to national and international conferences to present their work. We have outstanding links with national and international polymer groups. Our aim is to provide a supportive and stimulating environment for the training of young scientists. The projects listed below are all highly collaborative and we aim in all of the projects to impart detailed knowledge of important chemical systems, and train the student in modern analytical techniques.

POLYMERS FOR TISSUE ENGINEERING

Project 1: Nanofunctional Surfaces for Control of the Biological Interface

Biomaterials support, repair or protect the human body. The surface of the biomaterial interacts with the body's immune system, or for external devices with pathogens. Control of the surface and how it interacts with the biological system is essential for effectiveness in its intended application. This project aims to develop innovative strategies for surface functionalisation using polymers that can either augment or attenuate the body's response to the material. Two focus applications, namely anti-microbial surfaces and functional titanium alloys have been identified for the development of the novel surface treatments. The projects will build effective pathways from materials science to pre-clinical evaluation, and will provide training in synthetic chemistry, biomaterials science and pre-clinical testing.
Responsible scientist: Hui Peng

POLYMER DEVICES

Project 2: Novel Biologically-Responsive MRI Agents

The development of MRI imaging agents has been central to the rise of MRI as a leading medical diagnostic tool. An MRI imaging agent is a molecular adjunct which enables enhanced image definition and reduced imaging times, as well as mapping of specific cell types. In this project new imaging agents will be developed which respond to specific biological triggers relevant to diseases, for e.g. changes in pH, ionic strength, oxygen tension, redox environment and temperature. The project will involve synthesis of novel functional polymers using controlled radical polymerisation methods and testing of these molecules as imaging agents in animal models. The project is supported by the Australian Research Council and the National Health and Medical Research Council and involves extensive national and international collaboration. The student will receive training in polymer chemistry, NMR and MRI and biomedical sciences. This project is suitable for PhD and Honours students. *Responsible scientist: Andrew Whittaker*

Project 3: MRI Imaging Agents for Disease Detection

The aim of this project is to develop new magnetic resonance (MR) molecular imaging strategies that will enable the in vivo monitoring of biological processes. Specifically we shall develop novel polymers for imaging of early markers of diseases such as melanoma, prostate cancer, malignant glioma and Alzheimer's disease. Specifically the project involves the synthesis of new partly-fluorinated polymers having controlled architecture for the rapidly developing field of 19F MRI. The project aims to relate the structure of the macromolecules, determined carefully using advanced techniques such as NMR, light scattering, GPC, AFM and electron microscopy, to the performance as imaging agents. The agents will be tested in small animal (mouse) models of disease already developed by this group and our collaborators. *Responsible scientist: Andrew Whittaker, Kris Thurecht, Idriss Blakey and Hui Peng*

Project 4: Polymer Theranostics: Imaging a Treatment *in vivo*

Molecular imaging has had a profound influence on modern diagnostics and has helped drive the evolving field of nanomedicine. "Theranostics", the *portmanteau* of therapy and diagnostics, is one sub-section of nanomedicine and offers the opportunity to monitor the effectiveness of a therapy using molecular imaging techniques - this may be achieved by monitoring drug release from a polymeric carrier, defining tumour boundaries or quantifying necrosis. In this project we will develop biocompatible polymeric devices that target a specific disease state *in vivo*, and subsequently deliver a therapy to treat that disease using various biological stimuli. The effectiveness of treatment will then be monitored using molecular imaging. This will involve utilising advanced chemistries for both the synthesis of the polymer-drug composites, and subsequent ligation of cell-targeting and imaging moieties. The polymeric architecture will be investigated by techniques such as NMR, GPC-MALLS, DLS, HPLC, UV-VIS etc. The polymeric device will incorporate imaging components for modalities such as magnetic resonance imaging (MRI), positron emission tomography (PET), computed tomography (CT) and optical imaging to definitively locate and monitor tumour regression. *Responsible scientist*: *Kris Thurecht and Andrew Whittaker*

Project 5: Polymeric Vectors for Gene Delivery

One of the most promising routes for cancer therapy that has evolved in the last decade is the

use of small-interfering RNA (siRNA) and gene therapy as a means of switching off genes that are responsible for tumour development. However, while siRNA and gene/antisense therapies provide alternatives to conventional chemotherapies, significant hurdles related to the delivery and efficacy of treatment must still be overcome before this technology can be used as a universal treatment of cancer and other diseases. These problems include the instability of RNA/DNA in serum due to the presence of degrading enzymes, poor cellular uptake, limited endosomal escape (following uptake) and in the case of gene therapy, nuclear trafficking in cells. This project involves the development of biocompatible polymeric carriers that act as carriers for the RNA/DNA. Such a carrier must incorporate a mechanism for binding the therapy, directing the therapy to the site of interest in the body, and a means of releasing the therapy when it is in the correct region of action. Thus, the project will involve synthetic polymer chemistry (for development of the carrier vehicle) as well as development of a series of ligation strategies for attachment of cell-targeting ligands and nuclear-penetrating peptides as well as the RNA/DNA gene of interest. Advanced characterisation techniques such as GPC, NMR, PAGE, HPCL and UV-VIS will be used. *Responsible scientist: Kris Thurecht*

Project 6: Targeted Contrast Nanoparticles for Imaging of Thrombosis and Vulnerable Plaques

This project aims to develop targeted contrast nanoparticles (NPs) that can image cardiovascular diseases (CVD) associated with activated platelets such as thrombosis and vulnerable plaques. Such agents can significantly enhance the accuracy and sensitivity of non-invasive imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI). The main limitation of commercially available contrast agents for imaging is that they are not targeted to specific cells and do not localize at a specific area for any length of time. Since they are rapidly cleared from the body, a high dose is required. Furthermore, in imaging of CVD, typically only the vessel lumen is imaged, therefore not providing sufficient information on clots or the existence of vulnerable plaques in the arterial wall. Hence there is a strong clinical need for agents that specifically target markers of these diseases. *Responsible scientist: Hang Ta*

Project 7: Bifunctionalised Nano-Agents for Simultaneous Diagnosis and Treatment of Cardiovascular Diseases

Cardiovascular disease (CVD) is the major cause of mortality and morbidity in developed countries. Unstable vulnerable atherosclerotic plaques can rupture and cause thrombosis, resulting in acute coronary syndromes, myocardial infarction and stroke. Currently, the detection of this disease is limited due to the lack of sensitive imaging methods and it usually involves invasive procedures. This project aims to develop targeted smart nano-agents that can image vulnerable plaques and thrombosis; and simultaneously provide anti-thrombotic activity. The conjugation of therapeutics with targeted imaging agents provides treatment simultaneously with diagnosis and also provides direct monitoring of success or failure of the therapy. *Responsible scientist: Hang Ta*

Project 8: Theranostics for Inflammatory Diseases

Inflammation is part of the complex biological response of vascular tissues to harmful

stimuli, such as pathogens, damaged cells, or irritants. Chronic inflammation might lead to a host of diseases, such as hay fever, periodontitis, atherosclerosis, rheumatoid arthritis, and even cancer. In atherosclerosis, inflammation plays a key role in all stages from initiation of plaque development to transition of a plaque from stable to a rupture-prone state. Therefore, inflammatory cells are highly promising targets for molecular imaging of vulnerable plaques and inflammation reactions. This project will investigate novel approaches which combine both therapeutic and diagnostic capabilities for atherosclerosis and inflammatory diseases in one dose. *Responsible scientist: Hang Ta*

Project 9 : Development of Ionic Liquid/polymer "Iono-gels" as Conducting Materials

Ionic liquids are a novel class of solvent that exhibit interesting physiochemical properties, most notably are the negligible vapour pressure, high ionic conductivity and electrochemical stability. These properties have led to investigations into the use of ionic liquids in applications for fuel cells, lithium battery electrolytes and solar cells. Central to the advancement of this technology, is the requirement that the ionic liquids become immobilised or incorporated within a solid matrix. This project will investigate the development of novel (co)polymer matrices incorporating ionic liquid-based monomers. The phase behaviour, micro-structure and mechanical and physicochemical properties will be investigated. In addition to polymer synthesis, this project will involve developing an understanding of a number of characterisation techniques such as solid-state NMR, FTIR, TEM, as well as mechanical and conductivity measurements. *Responsible scientist: Idriss Blakey, Kris Thurecht and Andrew Whittaker*

Project 10: Novel Block Copolymer for Lithographic Applications

In recent years, block copolymers have created new opportunities as alternative nano-scale pattern templates for lithography applications. Block copolymers are particularly attractive because the self directed assembly of domain structures in thin films can produce an array of template patterns in the range of 5-50nm. It is well established that the ideal block copolymer must exhibit both a high value of polymer-polymer interaction parameter (c) and one highly etch resistant block. We have identified from the structure-property models that we have developed, that the polystyrene-*block*-polyester copolymer is a good candidate. Hence in this project, a range of interesting chemistries will be utilized for the synthesis of the block copolymer including ring opening polymerisation, living radical polymerization and some monomer preparation, in addition to characterization by various advanced techniques such as NMR, GPC, thermal analysis and vibrational spectroscopy. The thin film phase separated morphology will be investigated with respect to the surface interaction between the substrate and block copolymer by using high resolution scanning electron microscopy and XPS. *Responsible scientist: Andrew Whittaker, Idriss Blakey*

Project 11: Responsive Polymers for Dynamic Nuclear Polarisation Spectroscopy and Imaging

Dynamic Nuclear Polarisation (DNP) is an exciting technique that can increase the sensitivity of NMR experiments by several orders of magnitude. DNP is based on the transfer of polarization from unpaired electron spins, such as those on stable free radical species, to the NMR nuclei of interest. The addition of a stable free radical to the analyte system however, can have unwanted effects such as the broadening of NMR resonances and undesirable

relaxation effects. The fast and effective separation of the radical and analyte is a potential strategy for avoiding these issues. This project involves the development of stimuli-responsive polymers which feature stable free radicals at their periphery. On application of a given stimulus, conformational changes in the polymer will lead to precipitation or the internalization of the radical sites in the polymer particle. These systems will be investigated as DNP agents for spectroscopy and imaging applications. The project will initially involve polymer synthesis (ATRP, RAFT) and functionalisation ("click" chemistries). Advanced structural characterization of the polarization systems (e.g. NMR, EPR, GPC, thermal analysis, vibrational spectroscopy) will be followed by the investigation of their DNP capabilities. *Responsible scientist: Kris Thurecht and Andrew Whittaker*

Project 12: Polymeric Halogen Bond Donors: Catalysis, Drug Delivery, Self-assembly

Halogen bonding (X-bonding) is a non-covalent interaction that is rapidly emerging as a powerful tool for directing self-assembly processes. X-bonding shares many similarities with, but is also orthogonal to, hydrogen bonding and is highly directional and tunable, in terms of bond strength. X-bonds form between a halogen electron acceptor site (the X-bond donor) and an electron-rich donor site (the X-bond acceptor). The halogen X-bond donor can consequently be considered a Lewis acid site. Integrating X-bond donor sites, such as iodoperfluorocarbon groups (e.g. 4-iodotetrafluorophenyl), into polymeric systems creates a number of interesting opportunities in the areas of catalysis, drug delivery and polymer self-assembly. Modern controlled radical polymerization methods (ATRP, RAFT) will be used to prepare new polymers functionalised with X-bond donors and their ability to interact with X-bond acceptors will studied. The polymers and their adducts will be characterized using techniques such as NMR, GPC, DLS, thermal analysis, vibrational spectroscopy etc. Projects with a focus on applications in a) Drug Delivery and b) Catalysis and c) Polymer self assembly are being offered. *Responsible scientist: Idriss Blakey*

POLYMERIC MATERIALS

Project 13: Solid-State NMR Investigation of Poly(tetramethylene oxide)-Based Polyureas Polyether-urethanes are an important class of polymer with very broad applications as foams, moldings, coatings (paints), medical devices, protective clothing, etc. The nanoscale-segregated morphology of these materials plays a critical role in determining their physical and mechanical properties. In particular the arrangement of the so-called hard and soft segments determines properties such as stiffness, barrier properties and impact strength. This morphology is difficult to characterize; a combination of methods sensitive to both dynamic and static properties of the polymer is required to obtain a detailed picture of how the structure relates to the material's properties. In this project advanced solid-state NMR methods will be used to characterized the structure and dynamics of poly(tetramethylene oxide)-based polyureas. The work will be conducted with our collaborators at Penn State University (Prof Jim Runt), and will involve both synthesis and detailed characterization of a range of materials with commercially-relevant structures. The student will receive training in materials chemistry, physical chemistry and advanced spectroscopic methods. This project is suitable for PhD and Honours students.*Responsible scientist: Andrew Whittaker*