

Session H – Chemical Engineering (Alphabetical)

Analysis of Thermal and Structural Mechanisms of Silica Microcavity Formation

Bamini Balaji

Mentors: Andrea Armani and Hong-Seok Choi

High quality factor optical resonators are of growing importance in diverse scientific fields and come in various geometries and materials. Of specific interest in this project are the silica microsphere and microtoroid structures. Their widespread relevance calls for a more theoretical understanding of the thermodynamic and structural mechanisms that lead to their formation. We observe that when silica is irradiated with a high intensity CO₂ laser beam, it melts and reflows to form the microcavity. This reflow process is presented and solved using the finite element method with Comsol Multiphysics 3.5a. A combination of the heat equation, fluid properties and thermally induced stress factors are used to analyze the way the silica structure melts and deforms. This analysis gives way for further research on methods for precise and large-scale microcavity syntheses.

Forced Rayleigh Scattering: A New Approach to Studying the Molecular Motion of Leucine-Zipper Hydrogels

Justine X. Chia

Mentors: Julia A. Kornfield, David A. Tirrell, and Brad Olsen

Understanding the dynamics of cell-material interaction has important implications for the fields of tissue engineering and drug delivery. We employ a powerful technique called Forced Rayleigh Scattering (FRS) to measure the diffusion process in polymeric liquids with slow mass transport. Our objective is to build an instrument that allows us to write an optical grating and then monitor the time-dependent intensity diffracted from that optical grating decay. This is done by observing the diffusion and spatial randomization of two forms of a dye attached to the protein of interest: a strongly "colored state" of the photochromic or photobleachable dye and its colorless photoproduct. We apply this instrument to study the diffusion coefficients of a new class of genetically engineered associative Leucine zipper proteins that form physical hydrogels with desirable extreme shear thinning. For massive molecules like Leucine zipper proteins, the average translational diffusion coefficient from the walking mechanism is higher than that of a free floating molecule (Rouse diffusion). Theoretical predictions suggest that a positive slope on a plot of the diffusion coefficient against molecular weight indicates walking, whereas a negative slope correlates to Rouse diffusion. If we understand the mechanism that underlies the molecular motion of these proteins, we can tune and control cell-material interaction, and improve materials for safe, efficient delivery of drugs as well as tissue engineering.

Fabrication of a Proof-of-Concept Electrophoresis Device

James Dama

Mentor: Richard Flagan

Electrophoresis is a dominant small-scale separation method in biology laboratories, but difficulties in scaling up existing methods have prevented widespread industrial use. Problems exist both in scaling up typical electrophoresis devices and in making electrophoresis a continuous process as opposed to a batch process. An electrophoretic technique under consideration by the Flagan lab may be capable of operating on larger scales than existing methods. We fabricated a device meant to demonstrate the principles governing this proposed variant and with which to estimate the resolving power that can be achieved by this method. Subsequent characterization of the device revealed problems with the initial design, suggesting that significant rework is needed before it can be used as intended.

Generation of Induced Pluripotent Stem Cells from Adult Cells Using Non-Viral Transfection of mRNA

Diana R. Dou

Mentors: Mark E. Davis and Christopher Alabi

Previous research has established that the ectopic expression of four transcription factors, Oct3, Sox2, c-Myc and Klf4, are sufficient to reprogram fibroblasts back to a pluripotent state *in vitro*. However, most current techniques used to deliver the necessary genes employ viral vectors, that present concerns for use in humans such as immunological responses and the unpredictability of the insertion site that can lead to unwanted expressions (e.g., can cause cancer). To bypass the problems associated with viral delivery, we propose to develop and optimize a non-viral method to deliver mRNAs from the necessary genes rather than the genes themselves for the time interval required for reprogramming and maintenance of the induced pluripotent stem cell (iPSC) state. To test the concept of delivering mRNAs in a manner not toxic to cells, we use a relatively non-toxic, non-viral delivery system based on cyclodextrin polymers (CDPs)

and a chloroquine analogue we denote CQ7a to transfect HeLa cells with YFP-mRNA. The optimal charge ratio of CDP to nucleic acids for viability and transfection efficiency is determined to be +5. An agarose gel confirmed CDP-mRNA encapsulation at this charge ratio. Ongoing experiments to confirm and quantify YFP-mRNA expression include emission scans and fluorescence imaging. After the mRNA transfection protocol is optimized in the HeLa cell line, future experiments will involve the transfection of mRNA into other differentiated cell lines with the end goal of transfecting the four reprogramming mRNAs into fibroblast cells.

Assessment of Nonspecific Protein Adsorption Resistance of Zwitterionic Polymers via Optical Microcavities

Steve He

Mentors: Rick Flagan and Jason Gamba

Recent research by the Jiang group at the University of Washington has produced zwitterionic polymers capable of inhibiting protein adsorption. Moreover, it has been shown that passivation of the polymer coatings with antigens for targeted protein adsorption is realizable. This technique would prove invaluable for biosensing applications; however, current adsorption measurement methods using Surface Plasmon Resonance are limited in resolution and sensitivity. Optical microcavity toroids synthesized via laser reflow of silica disks are known to exhibit ultra-high quality resonance modes. The concomitant increase in detection sensitivity makes them ideal for high resolution sensing, capable of detecting binding events on the single-molecule level. Here we probe the nonspecific protein adsorption characteristics of the Carboxybetaine Methacrylate polymer using high quality microcavity toroids ($Q \sim 10^8$).

Machining and Molding Polydicyclopentadiene (pDCPD): On the Microtechnology Potential of a Young Plastic

Ning-Jiun Jan

Mentor: Julie Kornfield

Polydicyclopentadiene (pDCPD) may enable the manufacture of microscopic optical and mechanical components quickly and effectively at low cost. Many of these emerging technologies require high aspect ratio features, where interfacial forces, shrinkage, and dimensional stability make it difficult to create and maintain the desired structure. The polymer pDCPD is a cheap material with low interfacial tension, high fidelity, dimensional stability, high durability, short curing time and is transparent for fast and easy quality control. Machining and molding high aspect ratio hexagonal pyramids into pDCPD evaluates the potential of pDCPD as a material for microtechnologies. These pyramids are 5 mm deep with 15 degree angles, demonstrating an instance where there are great interfacial forces as well as a situation where shrinkage and dimensional instability cannot be tolerated. Machining is done with a programmable Computer Numerical Controlled (CNC) milling machine. The molding is done by curing pDCPD within the desired mold. The molds and machined parts are observed under microscopic cameras to evaluate fidelity. It has been found that pDCPD can be easily removed from metal molds, as well as from a commonly used silicone, polydimethylsiloxane (PDMS) while maintaining high fidelity, supporting the use of pDCPD for microtechnologies.

Linear and Cyclic Polycyclooctene: Differences in Crystallization

Nathan D. Morison

Mentors: Julie Kornfield and Iman Hajimorad

Polymers have become a giant of industry since WWII, which has led to extensive scientific study of how polymers are affected by different processing methods, molecular structures and other variables. The current work explores the effect of a small set of cause and effect relationships including how linear polymers crystallize differently from ring polymers, particularly the difference between high molecular weight linear polycyclooctene (PCO or PCOE) cyclic polycyclooctene (CPCO or CPCOE). One structural variable for these olefin based polymers is the stereochemistry of the double bond. We determined this cis:trans ratio using H-NMR. We explored differences in crystalline structure using differential scanning calorimetry. The molecular weights are determined immediately after synthesis, again after some storage time, and a third time after differential scanning calorimetry. On the basis of the molecular weight measurements the polymer did not degrade during storage or testing. The DSC results are compared to draw some conclusion about the differences in crystallization between linear and cyclic polymers.

Synthesis and Assembly of Mucoadhesive R_f-PEG/R_f-PRG-PAA Hydrogel Drug Delivery System

Albert Nava

Mentors: Julia A. Kornfield and Jeremy Wei

We produced polyacrylic acid chains on the end of polyethylene glycol polymers. The tri block polymer is defined as R_f-PEG-PAA. The polymers were prepared using PEG molecular weights of 6000 and 10000. The polymers were synthesized via click chemistry and Atom Transfer Radical Polymerization using R_f-PEG as the macro-initiator. R_f-PEG-PAA and R_f-PEG were then fused together to form a co-hydrogel in water. The

R_f groups of the R_f-PEG-PAA associate with the R_f cores of the R_f-PEG micelles. This was tested using dynamic light scattering to check for bulk heterogeneities. The display of PAA on the surface made it available to interact and interpenetrate with mucin glycoproteins.

Self-Assembled Liquid Crystalline Gels

Lita Yang

Mentors: Julia A. Kornfield and Zuleikha Kurji

Liquid crystals exhibit properties intermediate between a liquid and a crystalline solid. Due to their molecular structure, a liquid crystal can be cooperatively aligned in certain directions. Likewise, polymers respond to even slight mechanical stresses. Thus, polymers can be combined with liquid crystals for unique electro-optic and mechano-optic properties. For this project specifically, we are using end-on coil-SGLCP diblock copolymers (the coil block is polystyrene) and the liquid crystal, 5CB. Our goal is to establish a block copolymer "tool kit" to control the properties of liquid crystals so they may be efficiently used for applications such as optical signal processing and liquid crystal displays. We have found that lower concentrations and molecular weights of polymer are most effective at reorientation. Subsequent work to be taken with this combination include further understanding of the effect of temperature on the system, choosing a different block copolymer to test with, and applying electric and magnetic fields to this system. This project will hopefully give physical insight into the segregation of the coil-liquid crystal block copolymers at the air-liquid crystal interface and produce a suitable system that is bistable when switched in a magnetic or electric field.

Studying the Thermodynamics of Respirable Fragment Release from Pollen

Qinren (Sally) Zhen

Mentors: Richard Flagan and James House

Asthma attacks have been shown to be linked with pollen rupture and the subsequent release of respirable, allergen-containing fragments. While previous studies have shown that atmospheric conditions such as humidity, temperature and electric fields affect the rupturing events, it is of our interest to quantify this effect. Fresh rye grass pollen samples are collected locally and daily. To investigate the influence of relative humidity (RH) in air and water activity in aqueous condition on pollen behaviors, pollen grains in aqueous water, salt solutions of different concentrations and humid air are observed under a light microscope for rupturing events and germinations; generally pollen grains are shown to rupture far more readily in aqueous condition than in air, and in high water activity or RH than low ones. The effect of humidity gradient on the direction of rupture or growth is also briefly investigated, with no statistically significant observations. A controlled-humidity system will be constructed utilizing a virtual LabVIEW PID controller to control, vary and measure the RH to which pollen samples are exposed, for further, more quantifiable studies on how the change of RH over time may affect pollen rupture. As two other thermodynamic variables, temperature is measured during all experiments, and electrical fields may be added to the apparatus.

Solid State NMR Studies on Reaction Intermediates of Metal Borohydrides Hydrogen Storage Systems

Lily Zhou

Mentor: Sonjong Hwang

The quest for sustainable fuels leads researchers to the eye-catching potential of hydrogen gas. While pressurized hydrogen gas can power cars for short ranges, only a more volume efficient storage method will make hydrogen a competitive alternative to fossil fuels. Light metal borohydrides, which contain high amounts of hydrogen by weight, offer an attractive group of volume efficient storage compounds. However, they typically produce stable intermediates in the form of metal dodecaboranes that do not decompose and release hydrogen, rendering part of the storage material ineffective. Thus, it is of great interest to study the motional properties of these reaction intermediates and their associated energies. Using solid state nuclear magnetic resonance (NMR) spectroscopy, the dynamic properties of these intermediate compounds (MB₁₂H₁₂, M=Li, K, Ca) were studied at variable temperatures. The NMR spectra reveal the exchange correlation times associated with atomic jumps in the anion and the activation energy of such motion. Along with other parameters associated with the dodecaboranes' dynamic properties, this information may suggest methods for destabilizing them in order to react into the desired products to power hydrogen fuel cells.