SYMPOSIUM H

H: Biological and Bio-Inspired Materials Assembly

December 1 - 2, 2003

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*Invited paper
SESSION H1

8:30 AM H1.1 Structural DNA Nanotechnology, Nadrian C. Seeman, Chemistry, New York University, New York, New York.

Structural DNA nanotechnology uses reciprocal exchange between DNA double helices or hairpins to produce branched DNA motifs, like Holliday junctions, or related structures, such as double crossover (DX), triple crossover (TX), paranemic crossover (PX) and DNA parallelogram motifs. We combine DNA motifs to produce specific structures by using sticky-ended cohesion. The strength of sticky-ended cohesion is that it produces predictable adhesion combined with known structure. From simple branched junctions, we have constructed nanostructures such as a cube and a truncated octahedron, several deliberately designed knots, and Borromean rings. We have used two DX molecules to construct a DNA nanomechanical device by linking them with a segment that can be switched between left-handed ZDNA with right-handed B-DNA. PX DNA has been used to produce a robust sequence-dependent device that changes states by varied hybridization topology. A central goal of DNA nanotechnology is the self-assembly of periodic matter. We have constructed micro-sized 3-dimensional DNA arrays from DX, TX, DX triangle and DNA parallelogram motifs. We can produce specific designed patterns visible in the AFM from DX and TX molecules. We can change the patterns by changing the components, and by modification after assembly. In addition, we have generated 2D arrays from DNA parallelograms. These arrays contain cavities whose sizes can be tuned by design. In studies complementary to specific periodic self-assembly, we have performed algorithmic constructions, corresponding to a DNA Turing OR operations. The key challenge in the area is the extension of the 2D results obtained so far to 3D systems. We expect to be able to produce high resolution crystals of DNA host lattices with heterolegous guests, leading to well-ordered bio-molecular systems amenable to drug delivery. Other challenges are how to incorporate DNA nanomechanical devices in periodic and aperiodic lattices and to use the lattices to organize nanoelectronic components. Self-assembling structural systems present a further exciting avenue to be pursued. Biology provides some intriguing analogies for the physical sciences. The existence of living systems with nanoscale structural components represents an existence proof that autonomous systems can build up and function on this scale, systems capable of energy transaction and replication. The overall challenge that biology presents to the physical sciences is to move from biologic to biomimetic to abiological systems that perform in this same manner. Supported by grants from NIGMS, ONR, NSF and DARPA/AFOSR.

9:00 AM H1.2 DNA-directed assembly on dual-functionalized microparticles, Manish Bajaj* and Paul E. Laibinis**, Chemical Engineering, MIT, Cambridge, Massachusetts, *Chemical Engineering, Rice University, Houston, Texas.

The bottom-up assembly of functional devices requires novel building blocks to facilitate the incorporation of functional and structural hierarchy. Analogously, building blocks can substantially influence the creation of self-assembled devices with unique properties because of the morphological and/or chemical asymmetry. In this regard, we have developed microparticles with one hemispherical face exposing silan and the other exposing gold. These microparticles were formed by the shadow deposition of gold onto silica microparticles. They are two different surfaces allowed the use of different surface chemistries - silane chemistry for the silicon side and chl chemistry for the gold side to immobilize different oligo sequences on the two faces. These dual-functionalized microparticles were used for the selective orthogonal assembly of fluorophore-tagged target oligonucleotides.

This DNA-directed assembly was confirmed by confocal microscopy of the microparticles. We have also used the unique recognition capabilities of DNA molecules to assemble gold nanoparticles of different sizes on the two sides of the dual-functionalized microparticles. In essence, emptying DNA as the linker molecule, these 'Janus' particles can be assembled into various novel 1-D, 2-D, and 3-D structures, which are difficult to realize using symmetrical building blocks.

9:30 AM H1.3 Biomolecular Functionalization and Organization of Nanoparticle, Christoph M. Niemeyer, Uni Dortmund, Dortmund, Germany.

We have developed self-assembled oligonuclear networks consisting of streptavidin (STV) and dsDNA, which are applicable as model systems for immunosorbable nanoparticle networks and nanometer-scaled "soft material" standards for scanning probe microscopy. Moreover, conjugates of single-stranded DNA and STV have been utilized as biomolecular ligands for the immobilization of biotinylated macromolecules at solid substrates via functionalized amine coupling. This "DNA-directed immobilization" allows one for the reversible and site-selective functionalization of solid substrates with metal and semiconductor nanoparticles, or, via, e.g., the DNA-directed functionalization of gold nanoparticles with proteins, such as immunoglobulins and enzymes. This approach is applicable for the detection of chip-immobilized antigens. Moreover, the valuable DNA-directed conjugate allows for the selective conjugation of biotin-derivatives components along a single-stranded nucleic acid molecule. Examples include the fabrication of functional bio-metallic nanostructures from gold nanoparticles and antibodies, applicable as diagnostic tools in biosciences.

10:30 AM H1.4 Helical and Random Coil Protein Scaffolds for Building Design of Macromolecules, Robin S. Farmer*,1 Brian D. Polizotto*1 and Kristi L. Kieckbisher*1,2,1Department of Materials Science and Engineering, University of Delaware, Delaware, Delaware; 2Delaware Biotechnology Institute, Newark, Delaware.

We are capitalizing on the structural and sequence control of protein biosynthesis, combined with the novel chemical reactivity of non-natural amino acids, to create new polymeric materials with exceptional architectural control and targeted function. There are various areas we are exploring in which such macromolecules could be uniquely useful, including the presentation of saccharides, peptides, pharmac wakeup molecules, and cellulosic materials. Our research has focused on the controlled presentation of saccharides, as multivalent protein-saccharide binding events mediate many biological processes such as inflammation, toxin pathogenesis, and metastasis. Although it is known that the length and spatial and spatial distribution of saccharides are critical in controlling binding, these variables cannot be controlled simultaneously in synthetic polymers. Therefore, we have produced a series of artificial proteins, helical and random coil, in which the position of glutamic acid residues has been varied systematically; these sites provide points for attachment of saccharides. Alamine-rich helical polymers have been designed to present glutamic acid residues on a helical face with a distance between glutamic acids of approximately 17, 33, and 65 Angstroms; these distances are commensurate with receptor spacing of a variety of toxins and lectins. Proteins from this family are easily expressed from E.coli and are highly soluble over a range of pH values and temperatures. Glutamic acid containing random coil peptides and proteins have also been synthesized by both solid-phase and genetically directed methods. These molecules can be readily modified with saccharides to yield artificial glycopeptides and glycoproteins, and the binding of these molecules to relevant toxins, such as the cholera toxin, has been investigated by immunological assays. We have also started to explore the chemistry of non-natural amino acids in order to create protein scaffolds decorated with saccharides and other molecules; recent progress in these areas will be briefly discussed. These polymers have enormous potential not only in the construction of novel toxin inhibitors and cell signaling agents, but also in the design of macromolecules for other materials and device applications.

11:00 AM H1.5 Chemical Self-Assembly of Textured Peptide Tapes with Nanoscale Order, Rogina Valenzuela, Hyung-Joon Jin*, and Jaxo van Beek,*,1 Chemical and Biological Engineering, Tufts University, Medford, Massachusetts; 1Chemistry, INHA University, Incheon, South Korea; 2Chemistry, University of Sheffield, Sheffield, United Kingdom.

Multilayered amorphous mm to cm long "tapes" can be precipitated from several designed peptides with amphiphilic sequences. Acid blocks on the outside allow the formation of multilayered crystalline structures. These "tapes" have been used to functionalize the "tapes" with inorganic ions. The peptide tapes are self-limiting in width and thickness, but grow lengthwise to form long coils. A hierarchical, or multilevel, pattern of undulations and ridges is observed on the surface of the tapes, and is correlated to the birefringence observed for the tapes. This suggests a structural origin for the texture - molecular or nanocrystal order - rather than a purely topographic or environmental origin. Even though the sequences are locally based on ills, and "ills-like" crystalline structures have been obtained for these molecules under different conditions, no ills-like crystal structures are observed in the tapes. FTIR data suggest a "ills" F-like secondary structure. Strong X-ray scattering at positions corresponding to several nanometers suggests a folded supersecondary structure suggested by these data. Tapes resembling the folded structures in viruses and pigments belong to the hexaamide chain and crystalline ideal order are missing. The
occurrence of the tapes under conditions very close to those required for beta-sheet crystallization suggests a "crapped" precursor to the folded beta-sheet structure.

11:30 AM *H1.6 From Biomimetic Membranes to Active Materials.
Jacob Schmidt, Bioengineering, UCLA, Los Angeles, California.

We are developing a new family of active materials which derive their functional properties from membrane proteins. These materials have two primary components, the proteins and the lipids themselves. I will discuss our recent work directed toward development of a generic platform for a "plug-and-play" philosophy of membrane protein engineering. Building a single biomimetic polymer membrane is a single molecule monolayer thick, we will enable the exploitation of the function of the membrane protein, from pores and pumps to sensors and energy transducers. Our initial work has centered on the creation, study, and characterization of the biomimetic membranes. We are attempting to make large areas of these membranes using Langmuir-Blodgett film formation as well as through arrays of microfabricated black lipid membrane-type servos. A number of techniques allow the insertion of protein into the membranes. As a benchmark, we have been employing a model system of voltage-gated pores, which have electrically controllable porosities. I will report on the progress of this work, the characterization of the membranes, protein insertion processes, and the yield and functionality of the composite. What we learn in this work is being applied to other proteins, such as the mechanosensitive channel protein Mac1, and the water-specific pore AqpZ, directed toward compact devices for mechanical sensing and water purification.

SESSION H3
Chair: Anneline E. Barron, Timothy Deming and Harn-Anton Klok
Monday Afternoon, December 1, 2003
Back Bay B (Sherron)

1:30 PM *H2.1 Phenylenes Ethynylenes as Amphiphilic Beta-Sheet Bionitromes.
Greg Tow, university of mass-amherst, Amherst, Massachusetts.

New amphiphilic poly(phenylene ethynylene) s have been synthesized. These polymers have non-polar alkyl side chains and positively charged amines that extend from opposite sides of the backbone. The polymers have been shown to form monolayers at the air/water interface on a Langmuir trough with an estimated area per repeat unit of 45 square angstroms. This is important because many proteins have been shown to have an amphiphilic nature, a property that aids in membrane binding. In addition, these polymers are found to self-organize in aqueous solution into bilayers which resemble amphiphilic beta-sheets. The newly synthesized polymers have potential applications as antimicrobial agents and surface modifiers. In addition, their self-assembly properties are being explored.

2:00 PM *H2.2 Bio-inspired Synthesis and Solution Assembly of Linear-Dendritic Copolymers for Nanotechnology Applications.
Kris Stokes, Kris C Wood, Phuong Nguyen and Paula T. Hammond; Chemical Engineering Department, Massachusetts Institute of Technology, Cambridge, Massachusetts.

A large amount of knowledge has been obtained on the modification of spherical dendrimer systems for specific binding[13-16], and their use as unimolecular micelles, with emphasis on drug delivery and encapsulation applications. In all cases, the size and functionality of these nano-delivery vehicles are limited by the size of the dendrimer; further, it is difficult to tune the density and functionality of groups without additional synthesis, which requires a great deal of synthetic effort and financial cost. By creating linear-dendritic block copolymers which can act as phospholipids in solution, much larger nanostructures can be constructed through the formation of micelles containing N chain aggregates of dendritic species, while the high functional density of the dendrimer system is utilized more efficiently. The synthesis and the solution behavior of hydrophilic block poly(ethylene oxide)-b-PAMAM and the hydrophobic poly(ethylene oxide)-b-PAMAM systems will be addressed as model systems of assembly behavior. The high functionality of dendritic aggregates, as well as the incorporation of biocompatible blocks and targeting ligand will be discussed, as well as examples of gene/drug delivery using these designed macromolecule systems.

2:30 PM *H2.3 Synthetic Analogs of Natural Macromolecules: A General Approach to Biomimetic Polymers.
Heather D. Maynard, Jungseon Hwang, Joyce E. Szebeh and Sung Jung Hong; Department of Chemistry & Biochemistry, UCLA, Los Angeles, California.

Synthetic analogs of natural macromolecules, such as the extracellular matrix protein fibronectin, can serve as modulators of cellular processes. We have developed general synthetic strategies to provide rapid access to polymers of this description. For example, we have prepared novel block copolymer scaffolds with sequences of orthogonally reactive groups and have prepared using this approach, many biopolymers with diverse functionality could be generated from a single polymer precursor, that can be further modified to meet the requirements of each synthetic condition. This strategy should be valuable in the rapid creation of materials, for example, for drug delivery and sensors. Synthesis, characterization, and applications will be discussed.

3:30 PM *H2.4 Bio-Inspired Self-Assembly Approaches to Multifunctional Hybrid Materials.
Ulrich Wirsch; Department for Material Science and Engineering, Cornell University, Ithaca, New York.

The study of polymer-based self-assembly ("bottom-up") approaches to multifunctional polymer-inorganic hybrid materials is an exciting emerging research area, especially in solid state and soft materials. We have shown that the self-assembly of macrocycles and inorganic nanoparticles can be induced by the presence of a single chemical species. Tailoring of the polymer-inorganic interface is of key importance. The structures generated on the nanoscale are a result of a fine balance of competing interactions, a typical feature of complex biological systems. The potential for new multifunctional materials lies in the versatility of the polymer chemistry as well as that of the inorganic chemistry that can be exploited in the materials synthesis. In the present contribution, the synthesis and characterization of inorganic hybrid materials will be presented with potential applications ranging from microelectronics to nanobiotechnology. In all cases, the self-assembly of organic and inorganic species is induced through block copolymers. Besides amorphous and crystalline oxide materials, novel hybrid systems toward high temperature stable SiCN and SiC structures are introduced. Examples will include the preparation of mesoporous materials and superparamagnetic mesoporous materials with pore sizes ranging from 5 to 100 nm for separation technology and catalysis. Solaperichrome polymer electrolytes for battery applications, the synthesis of nanoparticles with controlled shape, size, and composition for applications in the life sciences, as well as thin film materials with potential applications in microelectronics and nanobiotechnology.

4:00 PM *H2.5 Tethered Nanoparticles: A New Class of "Macromolecule" for Bio-Inspired Materials Assembly.
Sharon C. Gotke, *2, Zhenli Zhang, *1, Charles (X) Zhang, 1, Monica H Linm, 1, Miek A Hersch 1 and Elaine R Chan 1; Department of Chemical Engineering, University of Michigan, Ann Arbor, Michigan; Department of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan.

An impressive variety of nano building blocks, including nanospheres, nanorods, nanowires, nanofibers, nanotetrupods, and nanorods, and continues to grow with breakthroughs in synthesis techniques. Increasingly, synthetic chemists are turning their attention to the biomimetic functionality of nano building blocks (both macromolecules and supramolecular entities) to direct their self-assembly into complex structures for novel materials and devices. Inspired by these recent advances, we seek to develop an intuitive and general framework for predicting the assembly of nanoparticles functionalized at specific locations with oligomeric tetters or biomimetic "handles" into complex one-, two- and three-dimensional structures. In this regard, molecular simulations of model nano building blocks can yield insight into the conditions under which various structures may be achieved, and can be used to map out phase diagrams of assembled structures. As a first step toward this goal, we use molecular simulations to study the self-assembly of biologically functionalized nanoparticles (e.g. quantum dots) and nanostructured molecules (e.g. cubic isoschissoctahedra and fullerences) in solution. We show how tuning thermodynamic parameters and architectural features of model nano building blocks can control aspects of local and global ordering of the nanoparticles. We further demonstrate that for certain of these novel nano building blocks the simulated morphologies obtained emulate those occurring in natural systems and may be predicted using concepts from block copolymer morphology and self-assembly. For other categories of the unique packing constraints introduced by molecular specificity, very unusual block topology lead to structures far richer than those found in conventional block copolymer, surfactant, and liquid crystal systems, including nanowires, nanocylinders, and nanotubes. Our results suggest the potential usefulness of considering synthetic nanoparticle materials as a new class of "macromolecules" for bio-inspired materials assembly. This work is supported by grants from the...
H3.5
AFM / SEM Investigation of Nano to Micron Scale Structures Formed on Gold during Enzymatic Copolymerization of the Biomimetic Monomers- Amphilic Decyl Ester of L-Tyrosine and Tyrosinamide- by Qian Wu, I-Cheng Hung, Ming-Kun Liu, Changmo Sung1, Kyousung Oh2 and Kenneth A. Marx3. Center for Advanced Materials, University of Massachusetts, Lowell, Massachusetts; 2Department of Chemistry, University of Massachusetts, Lowell, Massachusetts; 3Center for Intelligent Biomaterials, University of Massachusetts, Lowell, Massachusetts.

The pure amphiphilic decyl ester of L-tyrosine (DELT) and DEIT (D-erythro) monomers above their cone each form long rod-shaped aggregates (~10 μm) 3.3 microns in diameter. Diameters were unchanged following enzymatic polymerization but their stable lengths increased (> 100 μm) following polymerization [1]. These self-assembling monomers bind the gold quartz crystal microbalance (QCM) surface at increasing pH [2], and can be electropolymeterized at gold and Pt QCM electrode surfaces [3]. We followed the course of enzymatic polymerization in these optical and optical-surface solutions in QCM parameters that resulted from increases in the aggregates viscoelastic properties during polymerization [2]. In the current study, we copolymerized two monomers, DELT (below its cone) and tyrosinamide, both derivatives of the amino acid tyrosine, in a 1:1 molar ratio (both 0.3 mM) with horseradish peroxidase and hydrogen peroxide, in buffered solution. Gold coated micra substrates were chemically coated in the solution immediately after copolymerization began and the resulting oligomers adsorbed to the gold coated substrates in a time dependent fashion, varying times up to 30 hr after the initiation of polymerization. Using XPS measurements of an independent set of gold coated substrates, the surface of the gold was found to be completely covered by 24 hr, in agreement with previous work [2]. We then examined with SEM and AFM the lytic spherical spherical aggregates below and above 1 μm diameter were observed bound to the gold covered micro-substrates. With AFM, we observed that the spherical aggregates grew from much smaller nanoscale aggregates early in the polymerization process to a point where the surface density was tightly packed. The copolymerized structures were more regular when compared to the unpolymized mixture of monomers that formed similar but less regular spherical shaped and sized structures on the surface. The copolymerized structures also attained a measured surface roughness that was 4-fold greater and a mean height that was 7.5-fold greater than the unpolymized monomer mixture. These results agree with thebehavior observed for DELT above its cone in the QCM experiments that we already discussed [2].


H3.6
Abstract Withdrawn

H3.7
Session Toward Er-α b00 Collagen Synthesis, Sergey E Paramonov and Jeffrey D. Har거inkel, Chemistry, Rice University, Houston, Texas.

Collagen is the major component of almost any connective tissue in a multicellular organism. The structure of collagen is represented by a triple helix, which consists of three left-handed polyproline-II-like
chains. The chains are wound around one another forming a right-handed superhelix. The primary structure of collagen single chains contains 3 types of amino acids: proline (Pro), glycine (Gly), and hydroxyproline (Hyp). A large proportion of the sequence is Pro-Gly-Hyp repeats, which contributes to the right-handed superhelical structure. The repeating sequence of Pro-Gly-Hyp has a secondary structure of the collagen triple helix. The triple helix is stabilized by non-covalent hydrogen bonds between the α-helical secondary structures of the collagen chains. The triple helix is further stabilized by hydrophobic interactions between the side chains of the amino acids. The stability of the triple helix is critical for the mechanical properties of collagen.

3.3 Exploring Molecular Diversity of Repetition Proteins

3.3.1 Frame Shuffling

Kenji Kashiwagi and Yoko Inoue

We have developed a novel protein creation system, MoCraft, in which repetition proteins are created through polymerization of a designer microsequence (PNAS 24.38.05, 1997). Artificial proteins created by this method often show properties of self-assembly [Protein Eng. 16.57, 2003] or self-propagation. [EMBO Reports 4:148, 2003], which are attractive features for protein-based materials. To explore the potential of the MoCraft system in the material science field, we have developed a new method that can increase the molecular diversity of the proteins created from MoCraft. In a standard MoCraft protocol, polymers of an amino acid, which is devoid of the terminal codon, can exist in one of its three reading frames, is prepared by the microsequence polymerization reaction (MPR) method. In MPR, nucleotide insertions or deletions randomly occur at junctions of the microsequence units, resulting in the random transfer of translational frames at the junctions. Proteins created from a standard MoCraft, therefore, are combinatorial polymers of three peptides that are coded from a single microsequence. To increase the molecular diversity of the microsequence polymers, we have developed the MoCraft protocol containing a novel extension of the translation codon. This new method is called "frame shuffling" method. In our poster, we also describe the physicochemical properties of the proteins created by this "frame-shuffling" method.

3.4 A Study of the Self-Assembling Morphology in Peptide Nanorods and Nanotubes

Hajime Okamoto, Takamitsu Tamaoki, and Kentaro Hasegawa

Inhibiting the binding of toxins or pathogenic organisms to the nanotubes on mammalian cell surfaces is a potentially attractive therapeutic strategy. Toxins and pathogens achieve a strong binding through multivalent interactions facilitated by relevant oligosaccharide structure. In such cases, the binding of multiple toxin receptors to a single receptor site on the cell can be significantly enhanced. The development of new molecular scaffolds is known to be critically important in binding to multivalent ligands. For this reason, it has been essentially impossible to design specific molecular materials that exhibit control over both binding affinity and selectivity between different classes of molecules.

3.5 Design and Synthesis of Helical Protein Polymers for Controlled Presentation of Multiple Ligands

Kazuyuki Yamada, Masayuki Uchida, and Ei-ichi Uemura

Recently, numerous biological supramolecules have been artificially synthesized using the process of self-assembling. Scientists have mimicked the specific self-assembly of supramolecular nanomaterials used in nature, such as tailor-made biomolecules and nanotubes. These peptide nanotubes are one of those exciting nano-biomaterials constructed by the self-assembly of peptide nanomaterials. Because the number and kind of amino acids are independently controlled, both the outer diameter and internal diameter of the peptide nanotube can be controlled at will. Therefore, the peptide nanotube is expected to have a wide range of potential applications, such as medicine, chemistry, materials science. Several important experiments and theoretical works have been carried out to study the electronic and functional properties of peptide nanotubes. However, to go one step further and apply them in various areas, one should strive to understand and control their inteme self-assembly morphology. Especially, to determine the difference in the film thickness of amino acids changes their morphology is crucial. Thus, we here target four peptide nanotubes of cyclo-[D-Ala-L-Glu]4, [D-Ala-L-Glu-Gln]4, [D-Ala-L-Glu-Gln-Glu]4, and cyclo-[L-Glu]4, and study their self-assembling form by scanning probe microscopy. For this purpose, we synthesized the above four peptides by the Fmoc solid-phase method and identified them by mass spectrometry and FT-IR spectroscopy. Successively, we carried out the atomic force microscopy, several observed the self-assembling forms on gold or mica substrates. The resulting images of the former three DL-peptides showed not only their straight tubular forms but also some bundles of these nanotubes. The number and size of the observed bundles were rather different among those three peptides, and we discussed this difference based on our theoretical consideration. In contrast to the DL-peptides, the resulting image of the L-peptide nanotubes provides an excellent model for the structure-function design of multivalent ligands. Polypeptides displaying glutamic acid side chains at regular intervals were synthesized by solid-phase techniques and genetically directed methods. The peptides were glycoconjugated with various functionalized saccharides via HBU-activated saccharides and purified by high-performance liquid chromatography (HPLC). 

The complete derivatization of the glycopeptides was confirmed by nuclear magnetic resonance spectroscopy (NMR) and matrix-assisted laser desorption ionization time of flight mass spectroscopy (MALDI-TOF). The potential for these glycopeptides and glycoconjugates as high-affinity inhibitors of the cholera toxin is now a reality. These studies are currently in progress and will be presented in the next meeting.
Multivalent protein-anachorect binding events play a prominent role in disease by exaggerating such as inflammatory responses and bacterial pathogenesis. Although a variety of synthetic glycopolymers have shown improved binding, relative to monosaccharides, to targets such as lectins, viruses, and cell surface receptors, these effects were directed at high concentrations of carbohydrate. In addition to the effect of ligand spacing, ligand number, and polymer concentration on binding events. Here we report the genetically directed synthesis of aliphatic-rich peptides with the general composition [arginine]-x [-arginine]-y [-alanine]-z. Variations in this monomer sequence allow specification of the spacing between glutamic acid residues, which provide chemically reactive sites for the attachment of ligand molecules, such as carbohydrates or small peptides, along the polymer backbone. The differences in the constructs were designed to yield functional groups of spacing of approximately 17A, 35, 5A, and 53A; these distances are commensurate with receptor spacing of a variety of toxins and lectins. Protein polymers comprising these monomers were expressed from E. coli, and the proteins were characterized by HPLC, MALDI-TOF, and amino acid analysis to discern their composition. Circular dichroism spectroscopy shows that the proteins are highly helical over a range of pH values and temperatures, as expected for aliphatic-rich sequences. Because of the potential control over ligand spacing, these proteins are excellent candidates for studies aimed at determining the effect of ligand spacing and number on binding. The a-helical conformation of the aliphatic-rich proteins aids a new dimension to such investigations by introducing the effect of backbone conformation on the ligand-receptor interaction. These novel polymers therefore have enormous potential for mediating protein binding and cell signaling events.

H3.12 In vitro Incorporation of Fluorinated Amino Acids into Hydrogels. Souoni Sen, Ping Wang and David T. Willard, Division of Chemistry & Chemical Engineering, California Institute of Technology, Pasadena, California.

Protein biosynthesis using traditional recombinant DNA technology confines us to the incorporation of the 20 naturally occurring amino acids and the limited functionality that they provide. In an effort to expand the versatility of protein engineering, unnatural amino acids have been incorporated into a protein scaffold, a process that can alter the biochemical, chemical, and physical properties of biopolymers. Recently, 5,5-trifluorocyclooctatetraene (5TF) and 4,4-difluorovinylene (4TF) have been incorporated into a model target protein in an isocitrate-valine aspartic acid E. coli host strain grown in 5TF or 4TF-supplemented minimal medium, respectively. Result-specific incorporation of 5TF and 4TF has been confirmed to be over 90% complete as evidenced by MALDI-MS and amino acid analysis. Previous studies have demonstrated resistance of the unnatural amino acids incorporated into the proteins, such as in the case of trifluorocyclooctatetraene incorporation in the hydrophobic cores of leucine-zipper peptides. In light of this result, we are investigating the stabilizing effects of 5TF and 4TF incorporation into hydrogels and peptides derived from the yeast transcription factor GCN4. Effects of fluorination are also being explored in the context of oligomerization states and DNA binding activity of these mutant zip peptides.

H3.13 Micro-Nano Structure and Viscoelastic Properties of Hydrogels Formed Via Intramolecular Folding and Self-Assembly of Amphiphilic β-Hairpin Molecules. Burak Ozkan1, Karthik Rajagopala2, Lisa Pakstis1, Matthew S Lam1, Juliana Kratzer1, Lisa Haines1, Joel P Schneider1 and Darrin J Pochapsky1,1 Materials Science and Engineering, University of Delaware, Newark, Delaware; 2Chemical and Biomedical Engineering, University of Delaware, Newark, Delaware.

Here we studied the formation of hydrogels via the intramolecular folding and consequent self-assembly of 20 amino acid long β-Hairpin peptide molecules. These hairpin molecules are amphiphilic in nature with an alternating sequence of hydrophobic valine and hydrophilic lysine amino acids surrounding a tripertide turn sequence. These molecules are known to form hydrogels at low peptide concentrations (~1 wt%) rich in β-sheet secondary structure due to intramolecular folding induced at either high pH (>9), high salt concentration (~150 mM), or temperature jumps. The effects of β-Hairpin molecule chemistry and β-hairpin aggregation condition on the structure and viscoelastic properties are discussed. The micro- and nano-structure of the self-assembled hydrogels are studied by laser scanning confocal microscopy, transmission electron microscopy, and neutron and x-ray scattering. At the molecular scale, the structure is heterogeneous with water channels in the order of 10 nm. The self-assembled regions consist of interconnected fibrillar/tubular networks. The viscoelastic properties of the hydrogels are measured by dynamic oscillatory strain measurements. Kinetics of gel formation is studied to understand the effects of peptide sequence on folding and self-assembly and consequence gelation. The storage moduli (G') are on the order of kPa at low concentration of peptide (~<1 wt%) indicating significant increase in modulus number, and backbone conformation in the binding event cannot be fully explored or optimized with these heterogenous polymers.

H3.14 Self-Assembling Physical Polymer Matrices Based on Affinity Interactions Between Peptides and Polysaccharides. Brandon Seal and Alyson Panitch, Huntington Department of Bioengineering, Arizona State University, Tempe, Arizona.

Self-assembling polymers with affinity-based controlled release properties were developed based upon interactions between heparin-binding peptides and heparin. This hydrogel-like system mimics an extracellular matrix environment and also can sequester growth factors, peptides, and drugs with affinity for polysaccharides. These therapies then can be released at rates dependent on heparin affinity. A heparin-binding peptide (PBD1) derived from the heparin-binding domain of urokinase plasminogen activator was synthesized and conjugated to 4-arm polyethylene glycol) terminated sulfonated poly(ethylene glycol) (PEG, 10,000 g/mol) such that four PBD1 molecules were bound to each PEG molecule. Heparin (~18,000 g/mol) was added to PEG:PBD1 (~18,000 g/mol) in a 1:3 molar ratio to create 10% (w/v) solutions in PBS. The release of heparin-like materials from 25 to 150 Pa. In addition, the mixtures recovered quickly following thermal denaturation and mechanical testing. The initial release rates ranged from 80% per day for a peptide with low heparin affinity to 0.6% per day for a peptide with high heparin affinity. By altering the affinity of peptides to heparin, a series of peptides can be developed to yield a range of release profiles useful for controlled delivery of multiple drugs. Due to the physical nature of the bonds within this system, these gel-like materials are conductive to in situ assembly and to direct application, via spraying, onto a tissue or surface of interest.

H3.15 Self-Assembling Protein Hydrogels via Engineered Coiled-Coil Domain Aggregation. Lian M, Brian Chang, Stephen Fisher and James L. McFarland, Chemical and Biological Engineering, Johns Hopkins University, Baltimore, Maryland.

Coiled-coils have been one of the major structural motifs studied in de novo protein design. In particular, many previous studies have used coiled-coils as a molecular recognition motif for the self-assembly of inter- and intra-molecular structures, such as helix bundles. We have utilized such coiled-coil design strategies to develop multiblock proteins that self-assemble into hydrogels with tailored microstructure and topology. These fibrous, telechelic designs consist of hydrophilic random coil (denoted R) flanked by amphiphilic coiled-coil end domains (denoted A, B, C). In this presentation, we will discuss a series of proteins with complimentary assembling end blocks that preferentially form heterotrimeric aggregates of A, B, and C domains. Both diphilic structures (AR, BR, and CR) and triblock structures (NRV with X=Y=A, B, or C) have been studied. Circular dichroism measurements indicate that the helical and random coil blocks of these designs are structurally independent, and that the helical content and stability of the coiled-coil domains may be controlled by solution conditions such as pH and ionic strength. More comprehensive characterization and analytical ultracentrifugation studies also reveal that equimolarmixtures of AR, BR, and CR proteins preferentially form heterotrimers in dilute solution. Analogous mixtures of symmetric diblock ARB, BRC, and CMB in more concentrated solutions self-assemble into viscoelastic network structures, which we have characterized using dynamic light scattering techniques. Such
Hydrogels have wide potential applications in tissue engineering and drug delivery, which are currently being developed.

**H3.16**

**SNPs assay of unlabeled lepton DNA based on biofunctional-modified surface.** He-Yeon Lee and Taejoo Kun. Osaka University, Osaka, Japan.

Numerous electrochemical sensors have been developed for use in the medical and biotechnology industries. The development of disposable sensors has been facilitated by our knowledge gained in electron transfer processes. In the area of medical diagnostics, DNA biosensor protocols should allow for the rapid, sensitive, and precise determination of DNA hybrids or proteins. Furthermore, it is also highly desirable to control these DNA biosensors in an array to achieve a high throughput. We have developed a new electrochemical DNA chip protocol for the detection of unlabeled lepton DNA. Using an oligonucleotide consisting of a biofunctional-modified surface, electrodes, and a probe lepton oligonucleotide were attached through the application of a direct electric field. Electrochemical response changes originating from the hybridization of nucleic acids to proteins bound to nucleic acids using soluble mediators in K4Fe(CN)6 solution could then be observed. The electrochemical signal protocol developed showed high sensitivity and good reproducibility in the detection of DNA hybridization. Significant changes in electrochemical signals were also observed when using target DNA with a single base mismatch, indicating the applicability of this method to SNPs (single nucleotide polymorphism) detection. Recently we are extending this work to multi-channel electrochemical DNA microarray protocols, and will present some preliminary results of the novel DNA chip based on biofunctional-modified surface. The research has significant implications for the application of DNA in electronic devices and DNA-based electrochemical biosensors.

**H3.17**

**Abstract Withdrawn**

**H3.18**

**Molecular Assembly of Amphiphilic Peptides on Membrane-Associated Nano-Magnetite Particles for Protein Display.** Tatsuya Tanaka and Toshiki Matsunaga. Tokyo University of Agriculture & Technology, Koganei, Japan.

Magnetospirillum magnetico AML-1 synthesizes intracellular magnetite particles covered with lipids and membranes. The membranes and magnetite particles (magnetite/membrane particles, BMP) have been used as magnetic carriers in immunoassays and DNA detection by conjugation of antibody and DNA. Until now, in vitro integrations have been successfully achieved using membrane protein-lipid complexes, obtained from recombinant Escherichia coli. Recently, we have developed a novel technique for assembling hybrid proteins on BMP membrane using an amphiphilic peptide. An efficient insertion of amphiphilic peptides into membrane-associated magnetite particles was confirmed by novel molecule substitution here as novel nanomaterial supermagnetic particles. And we incubated BMP and magnetic particles to eukaryotic membrane, were synthesized as controls. The N-terminus of the peptides was labeled with a fluorescent dye, 4-fluoro-5-nitrobenzylimidazol (NBD). Each peptide was added in 10 mM HEPES buffer containing BMPs, and incubated for 1 h with pulsed sonication. The effect of the insertion of NBD-peptide into BMP membrane was investigated by measuring the fluorescence of BMPs. The BMPs associated with Temporin L showed the highest fluorescence as compared with the derivatized and controls. Therefore, the peptides were expected to insert into BMPs via an electrostatic interaction and hydrophobic interaction. Furthermore, the orientation of the peptide on BMPs was also investigated.

**H3.19**

**Controlled Assembly of Dendrimer-Like DNA.** Young Li, Yohsada Tseng, Sung Kwon, J. Scott Allan, and Dan Liu. Biological and Environmental Engineering, Cornell University, Ithaca, New York; Laboratory of Atomic & Solid State Physics, Cornell University, Ithaca, New York.

DNA molecules possess many desirable chemical and physical properties as a polymeric material besides their genetic properties as inheritance information carriers. Furthermore, many tools have been available to manipulate DNA molecules (enzymes from molecular biology, for example). Therefore, great potential exists for using DNA as a generic material of a genetic material. Although much progress has been made in DNA computing and DNA nanotechnology recently, the full potential of DNA-based materials has not been achieved. This is in part due to the fact that almost all DNA molecules, natural or synthesized, are either in linear or circular forms, which severely restrict their usefulness in molecular design and construction. We have created branched Y-shaped DNA (Y-DNA) as novel building blocks and assembled, for the first time in a controlled fashion, highly branched, tree-shape DNA dendrimers (termed "dendrimer-like DNA"), or DL-DNA in short) from Y-DNA. The yield and the purity of higher generation DL-DNA did not seem to decrease even in the process of purification, suggesting that the synthesis of Y-DNA and controlled assembly of DL-DNA were robust and efficient. The resulting DL-DNA molecules were stable and almost monodisperse. We also examined the 4th generation DL-DNA by atomic force microscopy (AFM) with both a standard tip and a single-walled carbon nanotube (SWNT) tip, which revealed DL-DNA's highly branched dendritic nanostructure. TEM images also confirmed the nanoscale dendritic structure of DL-DNA. These DNA nanostructures are water soluble, highly monodisperse, and easy to synthesize. In addition, multivalent DNA dendrimers can be either isotropic or anisotropic, providing the possibility for conjugating other chemical entities including proteins and inorganic particles. Furthermore, the strategies and assembly approaches presented here can be easily employed to construct other non-linear, non-circular DNA building blocks that can be incorporated into even more complicated nanostructured material, thus providing great potential for applications in nanotechnology as well as in the rational design of novel, hybrid, nuclear acid-based nanomaterials.

**H3.20**


We have developed a method for patterning receptor-populated lipid domains at the micrometer scale. The receptors contained in these domains are functional and can bind toxic fragments, thus serving as biosensors. To pattern the lipid domains, we have made use of a novel micro-patternning technique, which involves the etching of a polymer coating to expose specific areas of a silicon substrate (Ilic and Craighead, 2005). The chip is then incubated with lipid vesicles, which fuse down on the silicon surface and form lipid bilayers as described by Orth et al. (2003). Polymer lift-off following lipid deposition, reveals lipid patterns on the exposed areas of the silicon chip. The lipid domains range in size from 1-50 μm in diameter and rectangles. Toxin binding has been detected by epifluorescence down to 1 nM concentration making this a suitable technique for the detection of pathogenic proteins below infection levels. Microfluidic network integration allows for preparation of independent lipid domains with different receptors to achieve simultaneous detection of several toxins in one chip.

**H3.21**


Cystic Fibrosis (CF) mucus is a complex fluid consisting of mucin (a glycoprotein), lysozyme (a cationic antibacterial polypeptide), water, salt, as well as a high concentration of a number of monomeric biological polyelectrolytes such as DNA and F-actin. The interactions governing these components are poorly understood, but may have important clinical consequences. For example, electrostatic self-assembly of these components into complex gels contributes significantly to respiratory distress, as well as to mucus sequestration, which leads to long-term infections. In this work, we investigate the structure of sputum collected from CF patients, as well as simulated model systems in vitro, using synchrotron small angle x-ray scattering. Preliminary results indicate the formation of lysozyme-actin complexes, and an unusual dependence of such self-assembly on KCl concentration and actin filament length. This work was supported by NSF DMR-0071261, the Beckman Young Investigator Program, and the Cystic Fibrosis Foundation.

**H3.22**

**Spatial organization of fluorescent dye molecules using biospeckle-lipid-lipid self-assembly.** Huangyong Wang, Jiawen Wang, Dan Liu, and Gerald C. Li. Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

Oppositionally charged lipid and biopolymers can self-assemble into a polymorphism of phases, due to entropically-controlled electrostatic
interactions. For example, cationic lipid and anionic DNA can spontaneously organize into a multimamellar structure with a 1-dimensional parallel DNA chains from 2-dimensional lipid sheets. The inter-DNA spacing can be reversibly tunable between 2.5 nm and 6 nm, which essentially defines a nanoscopic complex with a tunable pore size. These nanoscopic DNA-membrane complexes have been recently used to organize metal ions for Cds templating. In this work, we use biopolymer-lipid complexes to organize charged fluorescent dye molecules, in order to generate nanoscopic coupled arrays with novel optical properties. A number of biopolymers of different charge densities, diameters and persistent lengths have been employed to optimize the self-assembly. Preliminary results will be presented.


While the ability of proteins to self-assemble has made them a powerful tool in nanotechnology, in biological systems protein-based structures ultimately depend on the context in which they form. We combine the self-assembling properties of synthetic diblock copolymers and proteins to construct intrinsically ordered, three-dimensional polymer/protein structures with the ultimate goal of forming nano-scale devices. This hybrid approach takes advantage of the capabilities of organic polymer chemistry to build ordered structures and the capabilities of genetic engineering to create proteins that are selective for inorganic or organic substrates. Here, microphase-segregated block copolymers coupled with genetically engineered proteins are used to produce nanoscale patterning that maximizes the potential for both increased structural complexity and integrity.

H3.24 Abstract Withdrawn


We have recently been investigating the interactions and reactivities of thiol-containing amino acids with metal nanoparticles. This investigation is important for exploring potential applications of metallic nanoparticles as advanced materials in biomedical fields. For example, rapid and reproducible assays of plasma levels of homocysteine are essential for understanding its pathogenic role. This presentation describes recent studies of the reactivity and optical properties of gold and silver nanoparticles capped with various thiol-containing amino acids. The interface reactivity of gold nanoparticles in the presence of a variety of self-assembling thiol-containing amino acids has been systematically investigated. The relative concentration and chain length of thiol-containing amino acids have been found to affect the size and interparticle spatial properties of the nanoparticles. Implications of the findings to the development of biomedical materials for screening of thick or soluble-containing amino acids will also be discussed.


Sol-Gel technology provides a facile, intrinsically low temperature approach to the immobilisation of either inorganic or organic species and has recently been extended to include immobilisation of active biocatalysts as proteins primarily for bioensor applications. Application to biocatalysis is in its infancy and the key to success lies in the characterisation of the relationship between gel structure, maintenance of active state of the proteins and cells and optimisation of catalytic activity. The application of small angle neutron scattering (SANS) to characterisation of solgel based biocatalysts offers the opportunity to examine this relationship. Enzymes such as Candida antarctica lipase B (CALB) have been found to have dramatically increased activities when immobilised in solgel hosts and are applied in a variety of industrial processes, making them suitable candidates for SANS structure/activity studies. Contrast variation studies enable the structures of the biocatalysts and the solgel host to be explored independently, giving information about the interaction between them and the roles of the inorganic/biological interface in mediating bioactivity. Characterising both the solution state and the immobilised form of an enzyme, as well as their respective activities, enables both the conformational and biocatalytic effects of solgel encapsulation to be assessed. Here we determine the contribution of the activities of the free and encapsulated forms of CALB and its conformation in dilute solution. Gels were produced by flavanone (4-hydroxyisopropyl) 2-(2-methoxyethyl) trimethyl ammonium chloride (TMOS) and methyltrimethylsilane (MTMS). Phase separation between the enzyme and the evolving solgel matrix was minimised by incorporating glycerol into the solgel precursor solution. Incorporation of glycerol appeared to enhance the stabilisation and biocatalytic activity of the encapsulated enzyme. The protective effect of the sodium fluoride catalyst upon the enzyme was also investigated. The deduction of structure/property correlations and a rigorous understanding of the effects of solgel encapsulation upon biological entities are being developed. The application of neutron scattering techniques and activity studies to elucidating the effects of solgel biocatalysis on structure and bioactivity will be discussed.

H3.27 Novel Method for the Investigation of the Morphologies of Biological Self-Assembled Monolayers, Arun A. Yu, Julie Norville7, Marc Bald7, Barry D. Bruce1 and Francesco Stellacci1, 1Materials Science and Engineering, MIT, Cambridge, Massachusetts; 2RLF, Department of Electrical Engineering and Computer Science, MIT, Cambridge, Massachusetts; 3Department of Biochemistry and Cellular and Molecular Biology, University of Tennessee, Knoxville, Tennessee.

Recent advances in the development of advanced biological sensors. Many of these sensors (e.g. microarray, biosensors) are based on self-assembled monolayers of molecular clusters such as proteins or protein receptors. The role of the molecules bound to the surface is to react with other bio molecules (such as proteins) present in solution and attract or bind them to the surface. This produces a change in the environment that is detected as signal. In order to maximise such effect it is desirable to control the morphology of the protein on the surface to have, for example, all of the receptor groups pointing out toward the solution. Unfortunately, there is not an efficient method for probing the conformation of a monolayer of proteins or complex bio-SAMs on surfaces. We introduce here a new method for imaging proteins present on electronic driven phase imaging in tapping mode Atomic Force Microscopy (AFM). The method is relies on the detection of differences in AFM phase images obtained when applying various voltages on the AFM tip. It is known that phase images of organic materials depend on the dissipative part of the oscillating probe, i.e. its viscoelastic properties. The applied electric field activates new dissipative channels just in the polar parts of the sample. Consequently it is possible to distinguish polar parts in a non-invasive manner. A quantitative analysis of the phase shift as a function of the polarity of the monolayer will be discussed. Results that help understand the conformation of a monolayer composed of a polyamine substrate will be presented. This will show that in this manner it is possible to make conclusion about the conformation of the protein assembly on the gold surface.


Cationic liposomes are one of the most promising types of non-viral gene delivery vectors. However, their ionically-strength-dependent DNA-binding properties have been shown, in some cases, to cause vehicle reorganization and loss of surface bioactivity. We will show here that peptide liposomes can overcome these effects by binding DNA via hydrogen bonding interactions. The peptide utilized in our studies is peptide nucleic acid (PNA), a synthetic mimic of DNA that replaces the negatively charged sugar-phosphate backbone with a charge-neutral, highly flexible peptide backbone. PNA has been shown to bind to complementary nucleic acid sequences with higher affinity and specificity than traditional oligonucleotides. By using these shorter, heterogeneous sequences of PNA on the surface of liposomes, we are able to non-specifically target multiple short regions of the DNA strand, thus protecting bound DNA against the action of nucleases. Furthermore, DNA binding properties have been shown, in some cases, to cause vehicle reorganization and loss of surface bioactivity. DNA adsorption to peptide liposomes using UV measurements and size
exclusion chromatography, we have quantified the extent of PNA incorporation in the liposomes, as well as the extent of DNA binding under various conditions. Through these measurements, we found that DNA binding occurs with 95% efficiency up to a critical amount of PNA, after which liposomes undergo morphological changes. This critical surface concentration varies for different PNA molecules depending on their backbone type, charge, and the arrangement of each molecule. To determine how each of these variables affects vesicle reorganization during DNA binding, we have been using Langmuir-Blodgett monolayers and fluorescence microscopy to analyze the surface arrangement of the peptides at various stages of the binding process. Maintaining vesicle morphology upon DNA binding allows cell-surface receptors to retain their biological activity, which is important for essential applications, such as gene therapy and biosensing. We will also discuss efforts to selectively bind and release DNA by taking advantage of phase transition through external stimuli (i.e., temperature, pH).

H.3.20 Biological Muscle as Self-Assembled Actuator, Yehuda Ben-Zvi1,2, Lev Boas3 and Denia Balukova2,3; 1Faculty of Electrical Engineering, Czech Technical University, Prague, Czech Republic; 2Institute of Sport Medicine, Charles University, Prague, Czech Republic.

Skeletal muscles are built of micro-sized contractile units called sarcomeres, which contain two filament types: thin and thick. Thin (actin) and thick (myosin) protein filaments together with the myosin heads attached to the myosin filaments are recognized to play a central role in contraction. Swinging of the myosin head drives the thin filaments toward the center of the sarcomere, thereby shortening both the sarcomere and the muscle. One of our most interesting results is that the myosin heads have a multiplex function. The myosin heads seem to be predominant elements that control the evolution of the sarcomere-from the individual to the whole muscle. The mechanism describes the effects of both van der Waals forces and electrostatic repulsive forces on the self-organization of internal structure of the sarcomere. In the state of sarcomere contraction, there is a secondary minimum in the interaction energy determining the equilibrium distance between the myosin heads. The sarcomere contraction is interpreted as calcium induced rearrangement and swing of myosin heads, which result in relative actin-myosin sliding. Application of the process can provide the engineer and physicist with a simple analogy to nano-actuators of highest performance.

H.3.30 Macromolecular-Crystal Binding in Calcium Oxalate Biominalization, Xiaoqin Sheng1, Jeffrey A. Wescott1 and Michael D. Ward1, 1Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota; 2Medical College of Wisconsin, Milwaukee, Wisconsin.

Kidney stones are crystal aggregates, most commonly containing calcium oxalate monohydrate (COM) crystals as the primary constituent. These stones have subunits known as macromolecular or macromolecules with substantial anionic functionality (e.g., carboxylate) play an important role in the crystal growth of calcium oxalate, its aggregation, and the attachment of these crystals to renal epithelial cells. We have therefore focused our effort on the molecular analysis of the effects of these polyanionic additives on the crystal growth and directly measured the interaction between macromolecules and COM crystals using atomic force microscopy (AFM) studies. These studies allow the determination of the influence of specific additives of the complexation of the crystal growth and the selective binding of each polymer and its impact on the growth of different crystal faces were deduced by in situ dynamic AFM imaging in the presence of the polymeric additives, including synthetic macromolecules (poly aspartic acid (polyD) and poly gulmic acid (polyE)) and native protein (osteopontin (OPN)). PolyD exerts greater influence on growth in the [001] direction, while OPN and polyE suppress the growth along the [010] direction. The concentration dependence indicates polyE has an overall weaker effect on the growth than polyD, which has weaker effect than OPN. The evaluation of interference forces between tip-immobilized molecules on the COM (100) surface in aqueous media supports an important role for the carboxylate group in processes responsible for kidney stone formation, specifically macromolecular-mediated adhesion of COM crystals to cells and crystal aggregation. The comparison of the adhesion forces for COM (100) and COM (010) directly proved the preferred binding of carboxylates on COM (010). The presence of polyD or polyE during force measurements results in a reduction in the adhesion forces for carboxylated tips, consistent with blocking of binding sites on the COM (100) surface by the carboxylate-rich polymer. Several native proteins were examined to describe their ability on mediating the adhesion force between crystals and COM surfaces. The experimental microscopic events observed by AFM reveal some of the critical phenomena associated with protein-crystal interactions responsible for regulating the physiological behavior of calcium oxalate biominalizers.

H.3.31 How Organic Monolayers Control the Shape of Growing Nanorods, Dorothy M. Duffy1 and John H. Hasting1, 1Physics and Astronomy, University College London, London, United Kingdom.

Living organisms can control the size, shape and structure of materials. Attempts to reproduce this biological control in the laboratory often use Langmuir monolayers of long-chain carboxylic acids. We use a combination of large-scale molecular dynamics simulations and the Wulff-Kirchhoff theorem to predict the morphology of calcite crystals grown on monolayers of (carboxylic) acid monolayers and find good agreement with experiments. To achieve this, it is essential to go beyond models of the monolayer as a substrate providing a pattern that the growing crystal must fit. Organic monolayers are not rigid structures—when they are flexible, chemically active surfaces in contact with water. Our simulations demonstrate that the nucleation of calcite crystals on organic substrates is controlled by competition between the interactions of the crystal and water with the substrate. Fully ionized substrates have stronger adhesion to the crystal surfaces than neutral substrates and are therefore better at promoting nucleation. The pH of the solution salt promotes nucleation and controls crystal shape since the ionized and neutral monolayers stabilise different surfaces, (10.4) for the neutral case, (10.0) or (00.1) for the ionised case. The density of the surface ions also controls the nucleation of surfaces on ionised substrates. This must be low enough to permit the substitution of each ion by charge groups of the substrate to create a neutral interface. The commonly observed (01.2) interface has a reduced density of calcium ions at the interface to satisfy this constraint. Detailed stereo-chemical matching is of minor importance; the availability of the template is therefore of unique importance. Many of the organic monolayers can be fitted to a given template. The competition with water molecules already present, the state of ionization of the monolayer and the density of surface carbonate ions are much more important.

H.3.32 Molecular Modulation of Calcium Oxalate Crystallization by Osteopontin and Citrate, Roger Quin1, Andrew B. Walsh2, 1Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; 2Department of Chemistry, University of South Alabama, Mobile, Alabama; 3Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa; 4The Children's Hospital of Philadelphia, University of Pennsylvania, Philadelphia, Pennsylvania; 5Chemistry Department, University of Buffalo, State University of New York, Buffalo, New York; 6Department of Chemical Engineering and Materials Science, University of California, Davis, California.

Understanding molecular mechanisms of biological control over calcium oxalate crystallization is crucial for development of effective stone disease therapies. Moreover, extension to other systems may suggest strategies for synthesis of biologically inspired materials. Calcium oxalate monohydrate (COM), which plays a critical role in plant physiology, is a source of pathogenesis in humans, causing kidney and renal stone disease. Despite extensive research on COM modification by proteins and small molecules, the control mechanisms remain unknown. In addition, the mechanism by which these proteins do not inhibit have been identified and sequenced, it provides a realistic system for general physicochemical investigations of biominalization. Here we report the first molecular-scale picture of COM modification by both osteopontin - a naturally occurring protein - and citrate - a commonly used therapeutic agent. Combining force microscopy with molecular modeling, we show that controls growth habit and kinetics by pinning step motion on different forces through specific interactions where both size and structure determine the effectiveness. Moreover, this suggest synergistic effects of simultaneous action by both modifiers. This work demonstrates the utility of combining molecular imaging and modeling tools to understand mineral crystallization in disease. This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405ENG-48, and was supported in part by grants DK56162 and DK33501 from the National Institutes of Health.

H.3.33 Electrostatic and Hydrodynamic Fields Influence In Vitro Polyionic Peptide-Mediated Silica Biominalization, Francisco Rodrigues1,2, Dina D. Glahe1, Rajesh R. Nalk2,4, Kevin P. Hallinan2 and Morley O. Stone1, 1Materials Directorate, Air Force Research Laboratories, Wright-Patterson AFB, Ohio; 2Department of Mechanical and Aerospace Engineering, University of Dayton, Dayton, Dayton, Ohio; 3Department of Engineering Physics, Texas A&M University, San Antonio, Texas; 4Materials Directorate, UES, Inc., Dayton, Ohio.

The ability to physically influence polyionic peptides-mediated silica
biomineralization morphologies resulting in a series of complex 3D and 3D silica networks is demonstrated. Overall silica morphologies are shown to differ from the silica-like dispersed particles normally obtained in vitro. Two forms of external force fields were imposed on the biomineralization process, namely electrostatic and hydrodynamic fields. These findings suggest that the future development of bio-inspired composite materials and 3D silica using microfluidic composite materials is possible. For example, silica-based micro/nano-composite materials formed using precisely controlled external force fields could lead to the directed deposition of silica, where size and morphologies are controlled. The materials in material with unique mechanical, electrical, magnetic, and optical properties.

H.3.34
Heterogeneous Nucleation of Calcium Oxalate Dihydrate on Amorphous Calcium Phosphate: Implication to Kidney Stone Formation. Prabhu B. Amalnerkar, Sneha M. Patil, Runkhaliya S. Shrivastava, Suhas S. Deshpande, and Umesh S. Deshpande. All authors are from the Department of Pathology, University of Florida, Gainesville, Florida.

The role of calcium phosphate on the nucleation of calcium oxalate (CaOx) on crystalline calcium phosphate, e.g., hydroxyapatite (HA) and brushite. In this study, an alternative route to the synthesis of CaOx/calcium phosphate composite is explored through nucleation of CaOx on amorphous calcium phosphate (ACP) spherical particles. ACP is prepared through polymer-induced liquid precursor (PILP) process. Images from scanning electron microscopy reveal that the calcium oxalate grown on ACP in the presence of polyvinyl phosphonic acid and polyaspartic acid produce mushroom-shaped spherules that are not seen in the homogeneous nucleation of calcium carbonate. The spherules appear to have ACP-rich cores and CaOx overgrowths. Diffraction from x-ray diffraction reveals that the CaOx is in the dihydrate form. This CaOx/ACP composite structure is consistent with the structure of typical urinary stones with the exception that kidney stones normally have CA core. However, we have seen that the ACP particles transform into HA over a period of time which likely occurs in the central core of these synthetic composites as well. This system might serve as a useful in vitro model for examining the complex mechanism in kidney stone formation. (Gower LB, Odom DJ. J CRYSTAL GROWTH 210 (4): 719-723 MAR 2000.)

H.3.35
The Chemical Inhomogeneity of Fhkl-Inclusions and Shell Calcite Matrix - A Combined Micro-Raman, Microthermometric and LA-ICP-MS Investigation. Erika Greisshaber1, Reinhard Job1, Thomas Petkie1 and Allison van den Kerkhof1, Department of Geology, Mineralogy and Geophysics, University of Bochum, Bochum, Germany; Department of Electrical Engineering and Information Technology, University of Hagen, Hagen, Germany; Institute of Isotope Geochemistry, ETH Zurich, Zurich, Switzerland; University of Technology, University of Gottigen, Gottigen, Germany.

In a combined micro-Raman, microthermometric and Laser-ICP-Mass-Spectrometry investigation the chemical inhomogeneity of shell calcite and fluid-inclusions incorporated within the calcite matrix has been analysed. For the assessment of vital effects and signatures of recrystallization processes the measurements were performed on both modern and fossil brachiopod shells derived from distinct marine environments. The here presented study should be regarded as an example for the possibility to analyse very small amounts of material with a spatial resolution of 3 to 8 μm. The combined application of these high-resolution analytical methods enables the investigation of current problems of bio material and biomineralization science as well as of paleo-geochemistry.

A comprehensive laser optical microscopy investigation of the shells is given by Schmahl et al. [1]. Micro-Raman analyses show that the shells are penetrated from both margins along punctae by sea-water. LA-ICP-MS analyses along outer - inner transsects of the shell matrix chemical inhomogeneities, especially within the valve region. Trails of ancient seawater seems to be preserved in fluid-inclusions of both, modern and fossil samples. Microthermometric analyses indicate that most inclusions are filled with a highly NaCl-rich solution. Nacell solution, NaCl concentration than modern seawater, although NaCl solutions in fluid-inclusions along the mantle margin are less concentrated than at the sea wall margin. Thus a fingerprint of ancient seawater is preserved within fluid inclusions. ( job R, Job R, Neuser R, and Meijer (2013): The formation of brachiopod shell calcite - a combined technique and chemical analysis. Abstract submitted to the MRS Full Meeting, Boston 2013.)

H.3.36
The Microstructure Of Brachiopod Shell Calcite - A Combined Textural And Chemical Investigation. Wolfgang W. Schmahl1, Erika Greisshaber1, Christoph Korte1, Reinhard Job1, Jan Meijer3 and Rolf Neuser1, 1Department of Geology, Mineralogy and Geophysics, University of Bochum, Bochum, Germany; 2Department of Electrical Engineering and Information Technology, University of Hagen, Hagen, Germany; 3Department of Physics, University of Bochum, Bochum, Germany.

The architecture of inorganic bio-materials is of interest as prototypes for the design of optimized materials. Furthermore, an understanding of biomineralization - the biologic control of crystal growth - may lead to new fabrication techniques. Apart form the work on molluscs by Chateigner et al. [1], which concentrated on aragonitic shells, the present study will focus on shell carbonates. Using the microstructural component of the secondary layer (Santelben et al. 2011) consists of fibrous calcite single crystals. They show both, a shape and a crystallographic preferred orientation. The morphological fibres are 5 to 10 μm wide and up to 100 μm long, possibly even longer. The fibres are stacked in parallel to complex-shaped blocks of about 100 μm diameter, and the direction of the fibre axis changes from block to block, frequently into perpendicular direction, presumably enhancing the strength of the structure. Although the crystal fibres are curved, the orientation of the crystallographic axes is constant along a single fibre, while changes between neighboring fibres. Locally, the crystallographic texture is a strong [100] axis texture with no preferred orientation of the c100 shear directions. The [001] hex directions of the crystallites point perpendicular to the outer walk of the shell. The morphological fibre axis, however, is parallel to the shell wall, and its crystallographic direction is arbitrary in the plane perpendicular to [001]. In conclusion, x-ray and high-resolution PAXE analysis show large chemical inhomogeneities between the primary and the secondary shell layer as well as within the hingeregion. While Sr, Mn and Fe concentrations decrease from the outward margin towards the mantle margin Ca concentrations increase complementarily. (1) Chateigner D., Hadgdon C. and Wenk H.-R. (2000): Mollusc shell microstructures and crystallographic texture for ventuses. J. Struct. Geol., 22, 175-185. (2) Santelben C., Munro C., Beckert T. and Patrich J. (2001): Shell succession assembly and species dependent effects on the C/0 isotopic composition of brachiopods - examples from the Shurian of Gotland. Chem. Geol., 176, 61-107.

H.3.37

Calcium carbonate-polymer composites have been of recent interest by the biomimetics community because of the outstanding mechanical properties of mollusk nacre. Advancements have been made towards making mineral thin-films, which can be used to fabricate a sequential deposition to create multilayered organic-inorganic composites. However, there has been a lack of control of the polymorph of the mineral film in these synthetic composites. This project could be important for regulating both the morphology and mechanical properties of the mineral phase, as is the case in biominerals, which have a high degree of control over crystal polymorph. Here, we have used crosslinked polylvinylic alcohol (PVA) films as substrates to study the crystallization of calcium carbonate films formed by the addition of acidic polymer, which is used to induce the polymer-induced liquid precursor (PILP) process (Gower & Odom, 2010). In the first system, vapor diffusion of ammonium carbonate was used to supersaturate a calcium carbonate crystallization solution. In the second system, dropwise addition of calcium chloride or ammonium carbonate into each other was used to raise supersaturation. We systematically examined the following factors with respect to polymer-based PILP thin films deposited on PVA substrates: supersaturation degree and stoichiometric ratio of CaCO3/CO2 -; Mg-ion impurity, concentration and location of acidic polymer (polyvinyllic or polycrylic acid); vapor diffusion time; and time of substrate introduction. By carefully adjusting these factors, we were able to selectively synthesize thin films of calcite, vaterite, aragonite, and mono-hydrocalcite. A discussion of the mechanisms governing the polymorphic selectivity will be presented. (Gower, D. J., Gray, S. A., & Odom, D. J. (2010). Calcium carbonate films by a polymer-induced liquid precursor (PILP) process. J. Crystal Growth 210:4, 718-734.)

H.3.38
Biominetic Mineralization of Collagen with Calcium.
Phosphorylase by a Polymer-Induced Liquid Precursor (PILP) Process, Mounimy Sivasakam, Matt J. O'Kane and Laurie B. Gower, Materials Science and Engineering, University of Florida, Gainesville, Florida.

The mineralization of collagen in vivo is of great interest for understanding the mechanisms underlying the mineralization of bone in vivo, as well as for the biomimetic fabrication of synthetic bone graft substitutes. Natural biocomposites such as bone exhibit a nanostructured architecture of hydroxyapatite crystals well arranged within the collagen fibrils, to form a unique interpenetrating composite. In this study, in situ mineralization of collagen with hydroxyapatite was carried out under simulated physiological conditions using acidic macromolecules, such as poly(SARC) acid) and poly(vinyl phosphonic acid), to induce an amorphous liquid-liquid-like mineral precursor. The novelty of our approach is that the polymer-induced liquid-precursor (PILP) phase can be drawn by capillary action into the gaps and grooves of the collagen matrix. The PILP phase then spontaneously crystallizes into hydroxyapatite as the waters of hydration are thermodynamically driven off, leaving the collagen embedded with nanocrystals, and generating a highly mineralized composite that mimics the nanostructured architecture of bone, as revealed by FT-IR spectroscopy, X-ray diffraction and electron diffraction. Etching studies reveal that the mineral phase is generated both on and within the collagen fibrils, leading to an interpenetrating network of mineral and collagen. We hypothesize that this in vitro model system is simulating the intracellular mineralization of collagen that occurs in secondary bone formation, and offers a promising approach for the development of new hard-tissue implant materials such as bone and teeth.

H3.30
Biomimetic synthesis of novel composite materials. Suresh Valliyoorpillai, Chemistry, National University of Singapore, Singapore, Singapore.

Hard material synthesis in Nature is believed to be controlled by biomacromolecules such as proteins and play an important role towards the survival of the species. Recent advances in biomimetic mineralization process is beginning to show some light on this fascinating process of bulk material synthesis. Often, the observed morphologies and the control exerted by the biomacromolecules on the structure and orientation of the biocements are difficult to reproduce in the laboratory conditions. We have been interested in unlocking the molecular mechanisms for the formation of highly structured architectures such as spherulites (JBC 268, 178 (1), 2929-36; PNAS 2002, 99, 5115-20). This presentation will highlight our various approaches to understand this process and translate that knowledge towards developing unique composite materials.

H3.40
Organic Template-Directed Hydroxyapatite Crystallization: Evaluation with IR External Reflection Spectroscopy. Kiyoyasu Tamaura1,2, Roni Weisz3, Joji Takada1,2.
1Ceramic Research Institute, National Institute of Advanced Science and Technology, Nagoya, Japan, 2CREST, Japan Science and Technology Corporation, Nagoya, Japan, 3Biomaterials Center, National Institute for Materials Science, Tsukuba, Japan.

Organic template-directed crystallization of hydroxyapatite was studied in situ via Fourier transform IR external reflection spectroscopy. Langmuir monolayer of arachidic acid was formed on a surface of immobilized body fluid, which possesses ion concentration and a pH almost equal to those of human blood plasma. Owing to the chemical interactions between inorganic ions and carbonyl group, heterogeneous nucleation of hydroxyapatite occurred under the monolayer. The absorbance of the antisymmetric and symmetric methylene stretching bands increased during the crystallization process, which means that conformational change of hydrocarbon chain occurred. Interfacial interactions between organic templates and induced crystals are often discussed only through comparisons of two-dimensional spacing of organic headgroups with that of phosphatidyl in arrangements in the crystals. However, the present study implies that the Langmuir monolayer changes its structure to optimize the geometrical fit to the induced hydroxyapatite crystals.

H3.41
Molecular imprinting of biomineralized CaS nanostructures: Crystallographic control using self-assembled DNA-membrane templates. Hongjun Li1, Thomas E. Angelini2, Paul V. Braun3 and Gerard C.I. Wong1,2,3. 1Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, 2Department of Bioengineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, 3Department of Bioengineering, University of Illinois at Urbana-Champaign, Urbana, Illinois

A wide range of biomineralization and templating methods exist for organizing inorganic materials at a wide range of length-scales. Here, we show how the crystallographic control of the inorganic matrix is possible using synthetic biomolecular templates comprised of arionic DNA and cationic membranes, which self-assemble into a multi-junction structure where a periodic one dimensional (1D) lattice of parallel DNA chains is formed between stacked (2D) lipid sheets. We have organized Cd+2 ions within the interhelical pores between DNA strands, and subsequently reacted them with H2S to form CdS nanorods of controllable width and crystallographic orientation. The strong electronic interactions align the templated CdS (002) planes parallel to the negatively charged sugar-phosphate DNA backbone, which indicates that molecular details are DNA molecule are imprinted onto the inorganic crystal structure. The resultant nanorods have (002) planes tilted by 60º with respect to the rod axis, in contrast to all known ILV-semiconductor nanorods.

H3.42

The presence of biopolymers strongly affects mineralization form solution, through processes which are poorly understood but are important in biomimetic and biomimetic materials science. We have found that the presence of acidic polypeptides, such as poly(SARC) acid) or poly(SARC) acid), can drive mineralization of calcium carbonates through an amorphous precursor phase, in some cases, with a stage of liquid-liquid phase separation that allows CaCO3-rich droplets to form and subsequently crystallize. Here we present the first in situ submicroscropic observations of this polymer-induced liquid-precursor (PILP) process by laser light scattering. Static and dynamic light scattering data were obtained from CaCl2 solutions containing poly(SARC) acid) and exposed to the decomposition products of ammonium carbonate. The measurements probe the average scatterer mass and apparent hydrodynamic radius R(h, app) of the droplets as they nucleate and condense. The data reveal three stages of the PILP process: an early stage of droplet growth to R(h, app)≈550 nm, a mid-stage of fluctuation and polydispersity in particle size, and finally growth period where R(h, app) increases from 550 nm to the micron scale. We will discuss possible models of nucleation, aggregation, and dehydration that occur in the presence of the polymer.

H3.43
Equilibrium Hydration Structure and Protein Resistance. Manfred P. Heuberger, Tanja Drobek and Nicholas D. Spencer, Department of Materials, Swiss Federal Institute of Technology (ETH), Zuerich, Zuerich, Switzerland.

It is known that certain liquids have finite compressive loads when confined between two surfaces at separations of few molecular diameters. The commonly accepted interpretation of these observations involves liquid structuring. Similar structural forces in water are found in conjunction with the phenomenon of hydration. In biological systems, the structure of water and the related hydration forces play a crucial role determining the specific bio-molecular functionality. The adsorption of proteins on surfaces is of high relevance for drug delivery and the design of bio-materials. Polyethylene glycol (PEG)-based surface grafts are known for their capability to render a surface resistant to non-specific protein adsorption. The steric repulsion that originates from the flexible PEG chains is commonly invoked as theoretical basis for this protein-resistance. Yet, both PEG and proteins are highly hydrated structures. In fact, the extraordinarily water-solubility of PEG is commonly attributed to an exceptional structural fluidity of PEG and water. We present the first direct force measurements that indeed show the existence of such equilibrium hydration structures in hydrated PEG brushes. High-resolution measurements obtained with the extended surface force apparatus reveal structural forces that are superimposed to the known steric repulsion. The fundamental relevance of these results for the phenomenon of protein-resistance is discussed.
The design of polymers that mimic the complex structures and remarkable biological properties of natural proteins is an important endeavor. Recently, a number of non-natural peptides with designed sequences have been elaborated to produce biologically active structures; in particular, facial amphiphilic peptides built from beta-amino acids have been shown to mimic both the structures as well as the biological function of natural antimicrobial peptides such as magainin and defensins. These natural peptides, as well as their beta-peptide analogues, are expensive to produce and difficult to produce on a large scale, limiting their use in materials as well as pharmaceuticals. We report herein on the design of a series of oligomers and polymers that capture the physical and biological properties of this class of antimicrobial peptides, but are easy to prepare from inexpensive monomers. This new class of amphiphilic polymers may find application in situations where inexpensive antimicrobial agents are required.


Antimicrobial peptides are ubiquitous natural antibiotics that are diverse in amino acid sequence. Despite their diversity, these peptides share several common features, including: a large net positive charge, a disordered structure in solution, and the potential for forming amphiphilic structures under certain environmental conditions. Killing activity of these peptides has been linked to their ability to transition from random coil structures in solution to amphiphilic secondary structures upon lipidation. We have previously shown that lipidation of peptides can increase the formation and stability of their secondary structure. We lipidated a series of three peptides and tested the effect on their structure, net-antimicrobial activity, and eukaryotic cell toxicity. When lipidated, all of the peptides showed increased antimicrobial activity as measured by MBC and/or ONPG assays. The CD spectra of the lipidated samples showed a corresponding increase in their alpha-helical content in a phospholipid containing solution, which mimics bacterial membranes. In the presence of PC vesicles, which mimic the cell membrane of eukaryotic cells, two of these peptides showed little change in their structure upon lipidation. The corresponding hemolytic activity of these peptides remained low. One peptide showed a large increase in hemolytic activity upon lipidation and also showed a marked increase in helical content in the presence of PC vesicles. These results support the theory that activity of antimicrobial peptides, either hemolytic or antimicrobial, is linked to the change in secondary structure when introduced to lipid membranes. Lipidation of peptides may improve their usefulness as antimicrobial agents by enhancing their ability to form the necessary secondary structure to interact with target membranes.


1Biomedical Engineering, the University of Texas at Austin, Austin, Texas; 2Bioengineering, Massachusetts Institute of Technology, Massachusetts, Massachusetts.

The rapid growth in the use of synthetic polymers in medicine and biotechnology has prompted the development of advanced biomaterials that display both biocompatible and bioactive properties. A large variety of biological functions could be programmed into materials including: ligands that bind cellular receptors, drugs for targeted delivery, and antibodies for detection or binding. In particular, we are interested in the surface modification of existing biomaterials using combinatorial phage display technology to control cellular behavior and to direct tissue formation. Ideally, surface modification techniques should provide an inherent flexibility to permit changes in molecular design for a broad range of applications and should be straightforward to implement. There have been many techniques used to modify the surfaces of biomaterials including protein adsorption and self-assembly, synthesis of novel graft-copolymers with desired functional groups, and direct covalent surface modifications. To address the limitations of these approaches, we are designing a surface that precisely activates specific biological pathways using a new method for biomolecule immobilization. Specifically, we utilize combinatorial phage display technologies to select for unique polymer-specific peptide sequences that have direct binding to the polymer’s surface. We have used a commercially available genetically engineered, random bacteriophage library that displays peptides on the surface of the phage coat protein. This provides a high-throughput method for screening billions of different peptides against a biomaterial of interest. Such peptide libraries have been used for many applications including antibody-antigen binding interactions, mapping of protein-protein interactions, and creation of peptide binding motifs for semiconducting materials such as ZnS, CdS, and GaAs. To our knowledge, this has never been done before for synthetic polymers, and would provide a major contribution to the field of biomaterials. In particular, we have focused on developing an electrically conductive polymer that has shown enhanced nerve regeneration, as a model biomaterial to select for unique peptide sequences for direct surface modification.

10:30 AM *H4.4* Conformational Genomics and Synthetic Biology. Jijiun Deng1,2, Ken K. Lim1,2, Keating Lippsman2, and David G. Lyon1,2.

1Chemistry and Biology, Emory University, Atlanta, Georgia; 2Center for Fundamental and Applied Molecular Evolution, Emory University, Atlanta, Georgia.

Amyloid, best known for its association with degenerative maladies including diabetes, preeclampsia, Parkinson's and Alzheimer's diseases (AD), represents a supramolecular ordered protein assembly seemingly accessible to all polypeptide sequences. Control of the favorable energetics of association of such self-assembling nanoscale materials is critical for disease and applicable to nanotechnology. Here we report that diverse morphologies evolve from peptide solutions of the Alzheimer's Disease related Ab peptides. Different morphologies ranging from fibrils, sheets, helical ribbons, twisted ribbons, and nanotubes, emerge from nucleating clusters that propagate in the presence of free peptide. Physical stabilization of a nucleus or arresting its propagation dictates successful selection of a specific morphology. Nucleation can also drive novel formation, stabilization and further increasing the half-life of a selected structure.

These initial steps towards a synthetic biology suggest a rich diversity of approaches emerging for the construction of supramolecular assemblies that can be selected for desired functional properties.

11:00 AM *H4.5* Pushing The Self-Assembly Envelope To Mimic Biology: Materials And Functions. S. W. Stupp, Materials Science & Engineering, Northwestern University, Evanston, Illinois.

The functionality of biology is based largely on the folding code of proteins which creates nanoscale objects with defined shapes and surface chemistries, followed by further self-assembly among proteins and other biopolymers through noncovalent interactions to create more complex and larger objects. In specific environments these complex structures are able to trigger mineralization to create hard phase-soft phase composites, in . Other biological capabilities include self-limiting assembly, replication, reversibility, and covalent capture without loss of shape. This lecture will illustrate many of these processes in synthetic systems using a toolbox of large molecules that contain blocks with different properties. The types of blocks include, rigid, flexible, dendritic, hydrophilic, or functionalized.

We illustrate with these systems spontaneous mineralization of self-assembled templates, the formation of noncovalent interactions with electronic conductivity, functionalization of carbon nanotubes, and the controlled formation of nanofibers with cell signaling capacity for regenerative medicine.


Understanding of new materials at the molecular level becomes increasingly critical for a new generation of nanomaterials for nanobiotechnology, namely, the design, synthesis and fabrication of nano-devices at the molecular scale from bottom up. Basic engineering principles for microfabrication can be learned by understanding the molecular self-assembly and programmation phenomena. Self- and programmed assembly phenomena are ubiquitous in nature. The key elements in molecular self-assembly are chemical complementarity and structural compatibility through noncovalent interactions. Numerous self-assembling systems have been developed ranging from models to study of protein folding and protein conformational diseases, to surfactant peptides, nano-surface engineering, and nanobiotechnology. Several distinctive types of self-assembling peptide systems have been developed. These self-assembling peptide systems are simple, versatile and easy to produce. These self-assembling systems represent a significant advance in the molecular engineering for diverse technological innovations.

**SESSION H5**

**Chair:** Anneline E. Berne, Timothy Deming and Hana-Antonina Klok

**Tuesday Afternoon, December 3, 2003**

**Back Bay B** (Sheraton)

1:30 PM **H5.1**

**Virus Based Scaffolds for the Peptide Directed Synthesis of Single Crystal Magnetic and Semiconducting Nanoparticles and Liquid Crystals.** Chun-Min Mao, Dan Sohn, Seong-Wuk Lee, Brian Reis, Christian Flynn and Angela Behrle; Department of Materials Science and Engineering, Chemistry, and Biological Engineering, MIT, Cambridge, Massachusetts.

Peptides capable of specific recognition and nucleation of semiconductor and magnetic materials were isolated and engineered into advanced biologically templated and functionalized viral liquid crystal systems. Peptides selected through an evolutionary screening process, which exhibit control of composition, size and phase during nanoparticle nucleation were exploited for these materials-directing structures. The incorporation of specific nucleating peptides into the genomic scaffold of the M13 virus structure provides a viable template for the directed synthesis of semiconducting and magnetic materials. The engineered viruses were exposed to semiconductor precursor solutions, and the resultant nanostructures that were templated along the viruses to form nanowires were extensively characterized using high-resolution analytical electron microscopy and photoluminescence. Removal of the viral template via annealing promotes oriented aggregation-based crystal growth, forming individual single crystal nanowires. We report a virus based scaffold for the synthesis of crystalline ZnS and the first free-standing Li2O2 nanowires. The unique ability to interchange substrate specific peptides into the linear self-assembled filamentous construct of the M13 virus introduces a material tunability not seen in previous synthetic routes. Additionally, liquid crystal systems were used for the fabrication of a highly ordered composite material composed of genetically engineered M13 bacteriophage and inorganic nanocrystals.

2:00 PM **H5.2**

**Controlling Self-Assembly: How Assembly Conditions Affect the Micro and Nanostructure of Amphiphilic Diblock Polypeptides.** Lisa M. Polakowska,1,2 Andrew P. Nowak,3,4 Timothy J. Deming,1 and Darrin Pochan1,5. 1Materials Science and Engineering, University of Delaware, Newark, Delaware; 2 Delaware Biotechnology Institute, Newark, Delaware; 3 Nowak, University of California, Santa Barbara, California; 4Chemistry, University of California, Santa Barbara, California.

Self-assembling amphiphilic polypeptides are being studied as materials for biomedical applications. These low molecular weight amphiphilic polypeptides have a hydrophilic lysine (K) or glutamic acid (E) block and a hydrophobic leucine (L) or valine (V) block. Dissolution in aqueous solution at neutral pH and low fraction of polymer (vol fraction polypeptide ≥ 0.5 wt%) allows the polypeptides to self-assemble into hydrogels. When these polypeptides are dosed in organic solvent and dissolved against water, allowing the molecules to remain in the linear self-assembled filamentous construct of the M13 virus introduces a material tunability not seen in previous synthetic routes. Additionally, liquid crystal systems were used for the fabrication of a highly ordered composite material composed of genetically engineered M13 bacteriophage and inorganic nanocrystals.

2:15 PM **H5.3**


The complex self-assembled structure of the biological cell is unique in its ability to simultaneously carry out multiple reactions in localized regions within the cytoplasm. Understanding how the curvature and physical properties of the cytoplasmic environment influence cellular organization and function opens the door for the possible development of "artificial cells" that could be tailored to carry out specific reactions on a micro or mesoscale. The research in our laboratory utilizes giant unilamellar phospholipid vesicles that have been filled with an aqueous two phase system (ATP), comprised of two reversibly phase separating polymers, to model the cytoplasmic environment of the cell. Using an ATPS as a model cytoplasm allows the position and the reactivity of different biomolecule populations to be controlled within the phase system. The synthesis and characterization of these novel coacervate systems will be discussed as well as the partitioning behavior of the encapsulated polymers used to form the ATPS. The partitioning behavior and reactivity of various macromolecules, including DNA and several different enzymes, will also be presented.

2:30 PM **H5.4**

**Ultrathin Star-Polymer Layers for Protein Receptive and Biofunctional Interfaces.** Martin Moeller; Institute of Technical and Macromolecular Chemistry, RWTH Aachen University of Technology, Aachen, Germany.

We prepare star poly(ethylene oxide) (PEO) hydrogel layers that provide a well-defined biorecognition environment for oriented growth and proliferation of tissue cells. The hydrogels can be assembled molecular layer-by-layer from multifunctional PEO-stars, which allows the formation of a well-defined biologically inert interface that resists nonspecific adsorption of cells and proteins. Furthermore, the combination of the hydrogels with PEO-stars containing specific peptide ligands allows receptor-mediated cell adhesion. By combination of lithographic techniques, block copolymer templating and solid-phase synthesis, the concentration, spatial distribution and clustering of the peptide ligands can be precisely controlled over length scales ranging from several nanometers up to a few micrometers. The result is a unique model system that allows a systematic study of cellular behaviour in response to (bio)chemical, topological and mechanical stimuli.

3:00 PM **H5.5**

**Self-Assembled Peptide Functionalized Hydrogels.** Stefano Pagliuca,1 Hana-Antonina Klok,2 August Berendt,3 Martin Moeller4, Juergen Groll1 and Joachim Spatz4. 1Institut des Materiaux, Laboratoire des Polymères, EPFL, Lusanne, Switzerland; 2Zentrum der Dermatologie und Venerologie, Klinikum der Johann Wolfgang Goethe-Universität, Frankfurt, Germany; 3Deutsches Wissenschaftszentrum, RWTH Aachen, Aachen, Germany; 4Physikalisches Chemisches Institut, Biophysikalische Chemie, Universitaet Heidelberg, Heidelberg, Germany.

Integrin mediated cell adhesion is crucial for proper cell function and plays a major role in the regulation of cell proliferation, differentiation and apoptosis. Integrins also play a major role in the mechanism/sense system, enabling cells to sense the topography and mechanical properties of their environment as well as to detect mechanical stimuli. The main events in the function of this mechanism/sense system are the binding of integrins to extracellular ligands, the clustering of integrins in the plane of the cell membrane and the aggregation of signalling molecules, linker proteins and other transmembrane receptors for extracellular signalling molecules. The resulting protein complexes, known as focal adhesion complexes, transduce the mechanical signal into chemical signals, which results in an alteration of the expression of specific gene products. A systematic investigation of the (combined) effects of (bio)chemical, topological and mechanical stimuli on integrin dependent cellular behaviour requires the use of a well-defined model system. We present a model system which allows the combined effects of topological, mechanical and chemical stimulation on cell adhesion and proliferation. The model system consists of a PEO-PPO hydrogel prepared by self assembly of cross-linkable multifunctional star polymers. A layer of this hydrogel is deposited on an elastic PDMS support resulting in a substrate bearing an intrinsically bioactive surface resistant against non-specific adhesion of cells and proteins and enabling the mechanical deformation of the resulting substrate in elongation experiments. Cell adhesion in response to specific stimuli on this surface can be achieved by functionalizing its surface with peptide ligands acting as recognition motif. In this contribution, we present several complementary approaches, which allow precise control over the concentration, spatial distribution and clustering of peptide ligands over length scales ranging from several nanometers up to a few micrometers.

3:45 PM **H5.6**

**Patterning of two component biological colloidal particle...**

New approaches to pattern biofunctional polymer-colloid templates for selective cell attachment utilizing soft lithography and selective deposition techniques on polyelectrolyte multilayer thin films will be presented. The surface of poly(acrylic acid) (poly(sodium hydroxide)) multilayer films was constructed specifically to prevent cell adhesion; while a cell-adhesive colloidal array was achieved by the chemical modification of colloidal particles with RGD peptides. In this work, two component colloidal arrays including cell-biotin and cell-adhesive colloidal arrays atop polymer multilayer films were also designed to direct cell adhesion. The effects of pattern geometry, surface topography and particle functionality on cell spreading were studied. In order to understand the interactions between swollen cells and colloidal particles, confocal images and fibroblast focal adhesion and actin stress fibers on different colloidal templates were investigated. The control of cell behavior in such microperforated biological material systems can offer the capability to create collobial biosensors, tissue engineered scaffolds, and drug screening devices.

4:00 P.M. #H5.7 Peptide Mediated Surface Modification for Controlling Cell-Material Interactions, Phillip Messersmith, Jeffrey Dakin and Lijun Lin; Biomedical Engineering, Northwestern University, Evanston, Illinois.

Certain marine organisms secrete remarkable protein-based adhesive materials for adherence to the mineral, metal, and wood surfaces upon which they reside. For example, mussel adhesive proteins (MAPs) contain L3,4-Dihydroxyphenylalanine (DOPA), an amino acid that is believed to be responsible for the adhesive characteristics of MAPs. Although the exact role of DOPA in these proteins is not known, recent evidence suggests that interfacial adhesion to substrates is generally believed to involve interactions between DOPA and functional groups at the surface of the solid substrate. In this presentation we will describe our efforts to exploit the adhesive qualities of DOPA-containing peptides to control cell behavior at surfaces. Our strategy for accomplishing this utilizes simple solution modification of material surfaces by conjugates of DOPA-containing peptides and the nonfouling polymer poly(ethylene glycol) (PEG). Characterization of the modified surfaces by XPS, TGA, SMS and other methods indicates that the nonfouling PEG polymer is grafted onto the surface by the DOPA containing peptide. For example, exposure of a variety of material surfaces (e.g. gold, titanium, stainless steel, etc.) to a solution of DOPA-PEG polymer results in deposition of PEG onto the surface as well as significantly reduced protein and cell adhesion to the surface. Obvious applications of this strategy include protein and cell-resistant surfaces for medical applications (biomimetics, corugation-resistant surfaces, etc.). However, there is considerable potential use of this strategy for nonmedical applications as well. Finally, we will also describe our efforts to use this approach to facilitate specific cell-cell interactions, by appending PEG or other ligands for cell surface receptors, to the terminus of the PEG chain.

4:30 P.M. #H5.8 Exploration of Collagen Mimetic Peptide As A Collagen Adhesive Biopolymer For Novel Biomaterials Development, Seungji M. Yu1,2, Allen Yi-Lin Wang and Ching Yao Sun; 1Department of Materials Science and Engineering, Johns Hopkins University, Baltimore, Maryland, 2Department of Chemistry, Johns Hopkins University, Baltimore, Maryland.

Collagen, either alone or in combination with other component, is an important biomaterial that is used in a variety of medical applications ranging from hemostatic materials and biocompatible coatings to drug delivery and tissue engineering. Currently, there are manifest biomedical interests in modifying the structure of natural collagen to improve its biochemical and mechanical properties. As an alternative to the prevalent “chemical” modification method, we have developed a novel “physical” collagen modification technique that is based on collagen’s native ability to fold into triple helix molecular architecture. Here we present that synthetic collagen mimetic peptides exhibit specific affinity to natural collagen under controlled thermal conditions (heat or laser treatment). Such affinity can be exploited as a new targeting method to attach therapeutic drugs to collagens in the living tissues and to biomaterials that incorporate natural collagens.

SESSION H6: Poster Session II

H6.1 Magnetic Nanosensors for the Detection of Molecular Targets. J. Michael Porg, Lee Josephson and Ralph Wender, Center For Molecular Imaging Research, MGH-Harvard Medical School, Charlestown, Massachusetts.

Nanomaterials may be useful for the development of highly-sensitive and high-throughput biosensors required for genomic and proteomic data acquisition in complex biological samples and potentially for in vivo applications. One particular challenge has been to develop bio-available systems that can be miniaturized by high-throughput measurements in turbid/mixed media, c) require minimal sample preparation, d) allow fast sample throughput and e) can potentially be applied for in vivo imaging. We have developed a novel magnetic nanosensor technology fulfilling these prerequisites for molecular target detection in biomedical applications. The technique uses magnetic microparticles that selectively change the spin-spin relaxation times (T2) of surrounding water molecules upon specific magnetic target interaction. In preliminary studies we showed that the monodisperse magnetic microparticles self-assemble into stable nanoassemblies of 300-500 nm, in a corresponding decrease in the spin-spin relaxation times (T2) of surrounding water detectable by NMR techniques. We have found that the technology can be used to detect DNA/RNA, protein, and enzymatic activity without extensive sample purification or amplification from biological samples. The current detection threshold was found to be sub-nanomolar range for DNA with extremely high molecular specificity. The assay is performed in solution and does not require isolation or purification of the sample. Major biomedical and medical applications of the developed technology lie in 1) the development of techniques to simultaneously interrogate RNA and proteins, 2) the development of high-throughput solution phase arrays and 3) the ability to image molecular interactions by magnetic resonance imaging. Furthermore, because the magnetic nanoparticles are biocompatible, the technology may ultimately allow even in vivo sensing. We will present data showing the ability of the developed technology to sense various targets such as GNP (mRNA and protein), telomerase (mRNA and protein and activity) and various agents, proteins and intact viruses (herpes simplex and adenovirus).

H6.2 Self-Assembling Model Lipid Membranes for Investigating Irritation in Skin, Srividya Ramachandran1, David Moore2 and Eilidh Bedford2, 1Unilever Research, Edgeware, New Jersey; 2Unilever Research, Port Sunlight, United Kingdom.

The objective of this work was to identify suitable microstructural biomimetic models for topically induced skin irritation and develop anti-irritation technologies based on this understanding. The outer layer of skin, the stratum corneum (SC), provides the body with a formidable barrier to the ingress of foreign molecules. The SC consists of a complex microstructure of highly ordered lipid mesophases surrounding protein-rich cells. These ordered lipid phases are responsible for the skin’s barrier function. Disruption of the SC’s lipid structure compromises barrier function, often resulting in dermatological irritation. The current study focuses on retinoids, a widely used class of dermatological actives, which can induce irritation when topically applied. A model of the SC lipid matrix containing of the SC’s major lipid species, cholesterol and fatty acids, was used to study the effect of retinoids on the complex microstructure of the SC. Lipid organization was investigated using XRD, DSC, and FTIR spectroscopy. When necessary, concentration dependent FTIR spectroscopy were used to spectroscopically distinguish the ceramide and fatty acid signals in the FTIR spectra. The FTIR results demonstrated that ceramides and fatty acids, in the above-described model, exist in separate orthochnomically packed phases within a complex lamellar microstructural matrix. Consistent with this observation, we observed that the ceramide and fatty acid phases disorder at different temperatures. The addition of retinol to our SC lipid model caused disruption of the lipid bilayers, as evidenced by the lower the disordering temperature of the ceramides and fatty acid, as measured both by DSC. Disruption in lipid microstructure and phase behavior, was dependent on retinol concentration, but was still significant at concentrations as low as 0.5%wt. Similar changes in lipid behavior have been observed in intact porcine SC samples when treated with retinol. We are currently investigating the potential biophysical mechanisms of borage seed oil, a clinically effective topical anti-irritant. Our recent results demonstrate that SC treated with retinol, and subsequently with borage seed oil, recovered its original lipid microstructure, suggesting one possible mechanism for reducing irritation is to control SC lipid microstructure.

H6.3 Bio-Inspired Periodic Microarrays Created by Multi-beam Interference Lithography, Shi Yang1, Mischka Megens1,2 and Joanna Azenberg1, 1Bell Laboratories, Random Technologies, Murray Hill, New Jersey; 2Philips Research.
Laboratories, Prof. Holstian 4, NL 5656AA Eindhoven, Netherlands.

Nature has developed strategies that give biological processes and structures exquisite selectivity and performance. Inspired by the discovery of light-sensitive biotissues, which have microsens arrays with integrated pores, we develop a novel, yet simple approach that uses holographic lithography to create porous silicon arrays that are analogous to the biological structures. In comparison, microstructures fabricated by conventional photolithography do not form such arrays. Further, we will discuss possibilities to tune the optical properties in the artificial microsens arrays.

H6.3
An All-Solid State Electronic Wettability Switch Based on a Combination of Electro-Agile Organic Materials.
Magnus Bengtson, Joakim Imsland and Nate Robinson; ITN, Lankoping University, Norrkoping, Sweden.

Here we report on a solid-state device having an electro-active surface being exposed to the surrounding environment. The surface tension properties of this surface can be updated electronically. This is achieved via an electronically updatable surfactant in a solid-state device. Upon addressing the device electronically, the surfactant exposes a hydrophilic or a hydrophobic molecular constituent outward of the surface. This causes a change in the surface tension of the active surface. We have characterized the electronic wettability switch with surface sensitive analytical tools and simple with water contact angle measurements. The switch in the contact angle is large indicating that the switching mechanism is fairly efficient. Controlling the surface tension is known to play an important role in cell growth, adsorption of biomaterials and for controlling the dynamics of fluids. We will describe the principal function of this device and its possible use as a "control device" of the growth and assembly of liquid and solid state formations.

H6.5
Abstract Withdrawn

H6.6
The design of self-assembled multivalent nanoparticles.
Alvito Castell, and Ravi S. Kane; Chemical Engineering, Rensselaer Polytechnic Institute, Troy, New York.

We describe the synthesis and characterization of self-assembled nanoparticles based on ring-opening metathesis polymerization (ROMP). Biofunctionalized nanoparticles may form the basis of a new class of potent multivalent antagonists, molecules that bind to pathogens or toxins and prevent their attachment to target cells. These antagonists may contribute to therapies for diseases including AIDS, anthrax, and cholera. The formation of colloidal nanoparticles of controlled size is also important for applications in drug delivery and for the control of biological interactions. Hydrophobic and hydrophilic derivatives of norbornene were synthesized as monomers and then polymerized using the Grubbs catalyst (C18Ru(=CHPPh)3PCy3) to form diblock copolymers of controlled composition. The polymers were characterized using nuclear magnetic resonance (NMR) and gel permeation chromatography (GPC). Tuning the composition of the block copolymer enables the tuning of the diameters of the self-assembled nanoparticles in the 5-100 nm range. The nanoparticles were characterized using dynamic light scattering (DLS) and scanning electron microscopy (SEM). The functionalization of the nanoparticles with biological ligands will also be discussed.

H6.7
Biocomposite Nanarchitectures with Gas-Phase Bioactivity.
Jean Marie Wallace1, Anne J. Riche1, Kristin B. Eden1, Rhonda M. Strand2, Jeremy J. Pierson1, Jeffrey W. Long3 and Debra R. Robinson1; 1Surface Chemistry Branch, Naval Research Laboratory, Washington, DC, USA, 2Surface Modification Branch, Naval Research Laboratory, Washington, DC, USA.

Multifunctional composite aerogels-highly porous, high-surface-area materials-can be formed by "nano-sizing" appropriate guests into the network of an aerogel silicon sol. Recent results indicate this biocompatibility can also be engineered into the supercritical-fluid-processed silicon aerogel nanoarchitecture. We encapsulate the hemi-protein, cytochrome c, within a silicon nanoreservoir architecture by nanofilling a protein-protein superstructure (nucleated in the liquid phase by colloidal gold) into the three-dimensional gel. The superstructure provides stability to the protein in solution, as shown by a shift in the pK of unfolding in the presence of a nanochannel architecture. The entrapped cytochrome c is also stabilized to the harsh conditions necessary to produce an aerogel, as evidenced by retention of the Soret band. The protein binds gaseous NO and remains in a stable configuration within the silica matrix for ca. 6 weeks at room temperature, as long as the ambient humidity is kept high. Further investigations are probing the properties of the protein-protein superstructure by varying the size and type of metal colloid and the protein itself. These studies will provide fundamental information on the interactions between biological entities and metal oxide hosts. [1] C.A. Morris, M.L. Anderson, R.M. Strand, C.I. Merzbacher, D.R. Rollison, Science, 284, 622 (1999).

H6.8
Cell Interactions with Polyethylene Thin Films.
Hyo Sook Jung1, J. S. Koo1, Kwanwoo Shin1, Ju Myung Song2 and Joos-Sop Kim3; 1Materials Science and Engineering, Kwangju Institute of Science and Technology, Gwangju, South Korea, 2Polymer Science and Engineering, Chosun University, Gwangju.

Random polyethylene films have been shown to have numerous applications as biomimetic materials. Polymers with relatively low ionic content (less than 30 mole %) have been shown to achieve charge concentrations comparable to those in the extra-cellular matrix. The interaction between the cells and charged surface can be strongly influenced by 1) the presence of ions in a buffer solution due to the electrostatic interactions, and 2) the hydrated surface dynamics due to the present electrostatic surface morphology with varying surface charge densities. Here we report on image ellipsometry and microscopic study where we explore the interactions and in situ dynamics of the fibroblast cells on the polyethylene layer, in this case sulfonated polyethylene (PPSes) and polyethylene acrylic acid (PSAAx). The adsorption/desorption behavior of fibroblast cells are found to be quite different as a function of degree of charge. These results are then correlated with systemic study of the adsorption dynamics of cells as a function of incubation time for various charge densities of the polyethylene. This work was supported by Korea Research Foundation.

H6.9
Modeling the structure and electrostatics of a DNA/carbon nanotube hybrid. Anand Jagota, Steve Lustig and Ming Zheng; DuPont, Wilmington, Delaware.

The recently discovered ability of ssDNA to form a stable hybrid material with single walled carbon nanotubes has proved extremely useful in forming stable dispersions, and in providing routes for their separation according to electronic structure and diameter. The hybrid is stabilized by stacking interactions between the bases and the nanotube surface, and solubilized in water by the exposed phosphate groups. We present detailed molecular modeling of the sequence-dependent structure of the DNA/nanotube hybrid using molecular statics, dynamics, and Monte Carlo simulations. Sequences can stack as single strands, or double strands stabilized by interstrand hydrogen bonds. We have additionally modeled the process of elution of the hybrid material from a charged substrate, the basis of our separation technique, using classical electrostatics. Our model describes the elution process as competition between the bound and eluted state with condensed counter ions, and predicts critical salt concentration within the range of experimental values that is sensitive to the type of carbon nanotube embedded in the DNA warp.

H6.10
Development of Fiber-free Intravascular Lens for Blocking After-cataract with Photochemical Surface Modification.
Kiyotaka Tanizawa, Yuji Sato, Masaharu Miyakawa, Masaaki Murakawa, Electrical Engineering, Tokai Univ., Hiratsuka, Japan.

The hydrophilic and hydrophobic groups were substituted alternately on a PMMA intracural lens (IOL) surface with photochemical reactions of ArF excimer laser and XeCl excimer lamp. Thus, the IOL was developed that is free from fibrin. In operative treatment for cataract, an IOL is generally implanted instead of the cloudy crystalline lens. However, fibrin is stuck onto the IOL surface after long-term insertion, and cells proliferate on it, which makes the IOL surface gets opaque; that is after-cataract. Accordingly, we designed the micro domain structure of hydrophilic and hydrophobic groups on the IOL surface for fibrin-free. Firstly, the IOL was irradiated with XeCl excimer lamp in the presence of perfluoropolyether to be hydrophobic. By this photochemical reaction, the CF3 functional groups were substituted on the IOL surface. Secondly, the ARF laser was projected through the mask pattern in reduced size in the presence of water on IOL surface to be hydrophilic. By this photochemical reaction, the OH functional group was substituted at the exposure part. Micronscopic infrared spectroscopy analysis was carried out to investigate the hydrophilic or hydrophobic groups that had been substituted on the IOL. Therefore, it became clear that CF3 and OH radicals were substituted in the interval of 100μm on the IOL surface. Fibrin sticking test was carried out with PI-IR and SEM. As the result, it is clarified that the fibrin sticking rate of the sample, which treated at the 8 minute irradiation of XeCl lamp for hydrophobic treatment and laser fluence of 20μJ/cm2 with laser shot number of 6000 for patterned hydrophobic treatment, decreased 23% compared with non-treated sample. In these experimental results, the micro
domain structure of hydrophilic and hydrophobic groups inhibits the fibrin sticking rate. In conclusion, the production of the ideal intracellular lens was demonstrated.

**H6.11**

Semiconductor-metal quantum-dot super-molecules: light emission and energy transport. Nicholas Alexander Kotsos, Alexander Gower, Jim Lee, and Ying Wang; Chemistry, Oklahoma State University, Stillwater, Oklahoma; Physics, Ohio University, Athens, Ohio.

Hybrid semiconductor-metal supermolecules have been fabricated by using antigen-antibody and bioin-streptavidin affinity. When the distance between the supermolecule elements is optimized, Au nanoparticles (NP) strongly enhance (5-10 fold) the excitonic light emission of CdTe NP and nanowires (NW). The diameters of NP and NW were chosen to affect the resonance condition between plasmon adsorption of Au NP and excitonic emission of CdTe colloids. The enhancement effect is explained in terms of plasmon-assisted absorption of incident light and plasmon-induced increase of nanoparticle dipole moments. Both experimental and theoretical analysis of this mechanism will be discussed. Calculations show that the enhancement of emission comes from plasmon-enhanced optical fields in the vicinity of semiconductor nanocrystals. Qualitative agreement with experimental data was obtained when single NP/NW is surrounded by several Au-NPs. TEM images demonstrate that that 3-4 and 10-15 Au NP are attached to CdTe NP and NW, respectively. The effect of enhanced luminescence is comparable to the surface enhanced Raman scattering and can be taken advantage of in optoelectronic nanoscale devices and biological sensors.

**H6.12**

Large Scale Thermal Undulations of a Lipid Membrane using an Illuminated Solvent Model. Brendan O'Malley, Federico Meneghini, and Massimo Naro; Uniliter Research and Development, Bellington, United Kingdom; University of Padua, Padua, Italy.

Lipid membranes undergo thermal undulations that influence both their elastic properties and surface tension. Recent theoretical studies have suggested that the effect of these thermal undulations is to stiffen the membrane, while computer simulation studies of lipid membranes at this length level have utilized that the absence of long wavelength undulations in these nanometer scale simulations leads to a larger surface tension than would be expected at a macroscopic level. This study uses the dissipative particle dynamics (DPD) method to simulate simple model membranes composed of one or more different lipid molecules. The influence of the size of the membrane patch simulated on the observed thermal undulations and the effect on reduced macroscopic properties are the main focus of this work. In order to probe length scales on the order of a micron we propose an implicit solvent model in which the effect of the solvent on the lipid molecules is replaced by a many-body lipid-lipid interaction. A dipole-dipole interaction between surfactant molecules is employed to model the dipolar moment of lipid while a simple attractive term between lipid tails is used to produce a stable bilayer. The results of this study and also of complementary DPD studies including solvent will be presented. Lastly the effect of lipid composition on macroscopic properties and surface tension of our simple model membrane will be described.

**H6.13**

Patterned PEG grafted poly(allylamine) for fabrication of bio-array templates. Heeje Kim, Junsang Doh, Darrell Irvine, Robert Cohen, and Paula Hammond; Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Newly designed poly(allylamine)-g-poly(ethylene glycol) polycation graft copolymers have been synthesized in order to combine bio-functionalized wetting ability with stable charged polyelectrolyte multilayer surfaces. Polymer-copolymer stamping (POPS) techniques developed in our group have been used successfully to produce micron scale patterned regions on negatively charged multilayer surfaces by direct stamping of these PEG grafted poly(allylamine) copolymers. Even when the fraction of grafted PEG in the copolymer dominates the composition, as is well known, the long side chains of PEG effectively resist adsorption of antibodies or other proteins, and create a bio-template immersed in polymer. Therefore, when a desired antibody can be covalently attached to the graft copolymer by introducing proper coupling agents at the end-functionalized PEG side chain. In this way, a pattern of a specific antibody can be achieved on the non-specific surface of other proteins. Generation of the antibody pattern can directly lead to fabrication of a patterned cellular array. In this study, we investigated properties of the new graft copolymer and utilized it to make cellular arrays as well as protein arrays.

**H6.14**

Assembly of Polysaccharide-Derivatized Polymer Networks for Protein Delivery. Nuri Yamaguchi and Kristi L. Kieck; Materials Science and Engineering, University of Delaware, Newark, Delaware; Delaware Biotecnology Institute, Newark, Delaware.

The paradigm of modern biomaterials research is the design of polymeric materials that can respond to specific stimuli and provide a desired biological response. Polymeric materials have been produced that can deliver therapeutic molecules in response to stimuli such as pH, temperature, hyaluronic acid, or enzymes, and scaffolds that can direct the proliferation of cells and tissue have become increasingly important in tissue engineering. We propose a novel strategy for the assembly of hydrogel networks and subsequent delivery of polypeptide molecules in response to specific cells, via the use of heparin-functionalized polymers whose assembly, rheological properties, and delivery profile are controlled by specific protein-saccharide interactions. Heparin-decorated polymers, synthesized by reaction of capric acid having terminal malimide poly(ethylene glycol) (MW 10,000) with maleimide-functionalized heparin (MW 3000), have been characterized by 1H NMR spectroscopy, size-exclusion chromatography, and dynamic light scattering; results indicate attachment of heparin with at least 75% efficiency. Hydrogels have been formed on the basis of the interaction of these polymers with heparin-binding micromolecules, and the viscoelastic properties of these hydrogel networks have been measured by optical probe rheometry and bulk rheometry methods. The binding and release of polypeptide growth factors to these heparinized hydrogels has also been demonstrated via immunochemical means. The combination of these results suggests the opportunities for assembling novel networks on the basis of protein-saccharide interactions, and employing these networks for drug delivery applications.

**H6.15**


The cellular cytoplasm is a complex environment in which the micromolecular architecture of the cytoplasm is unknown except for the presence of the nucleus and mitochondria. The mechanism of which is not clear. One theory to explain molecular localization involves aqueous phase separation, a physical phenomenon in which two polymers separate into distinct domains at low weight percent but remain soluble in water. Partitioning of biomaterials into different phases of bulk aqueous two-phase systems (ATPS) has been widely documented towards non-denaturing separation. This work describes the use of mimicking ATPS as a simplified synthetic analog of the cellular cytoplasm. We have observed the temperature-dependent phase behavior of ATPS in bulk and have used this information to encapsulate ATPS within synthetic phospholipid vesicles (typically 5-50 microns). We have found that aqueous phase separation of lipid vesicles does not follow bulk behavior; it is dependent on the lipids used for vesicle preparation as well as the identity and concentration of the external diluent used for microscopic imaging. Lipid vesicles comprised of varying ratios of DOPC:DOPG:PEG 2000 typically do not exhibit aqueous phase separation even when it is predicted from bulk behavior, requiring a hypertonic sucrose solution to display this phenomenon. We have partitioned proteins within bulk ATPS and lipid vesicles, finding that the two exhibit differing behavior. Typically, partitioning within lipid vesicles occurs to a lesser extent than that predicted by bulk behavior.

**H6.16**

Select Increased Neuronal Cell Function on Nanoporous Silikon. Janice L. McKenzie, Marian A. Sambito, Nadir M. Kalkhourn and Thomas J. Webster; Biomedical Engineering, Purdue University, Lafayette, Indiana; Stry Biomedical Corporation, Bedford, Massachusetts.

Nanotechnology can be defined as materials whose components exhibit novel properties by gaining control of structures at the atomic, molecular, and supramolecular level. Although many advanced properties of materials with constituent particle sizes less than 100 nm have been observed for traditional science and engineering applications, very few advantages of these materials have been explored for tissue-engineering purposes. It is hypothesized that give researchers control over interactions with biological entities (such as proteins and cells) in ways previously unimaginable with conventional materials. This and because organs of the body are primarily made of micromolecular structures and, as a result, are inextricably interacting with materials which have similar feature sizes. For example, laminin (a protein approximately 70 nm in width and length) is a common extracellular matrix component of neural tissue.
Despite this fact, implants currently being investigated for neural applications (such as silicon) do not possess a large degree of nanostructured surface features. To test the hypothesis of using nanostructured materials as neural implants, in the present study, we synthesized biocompatible layers of nanoscopic silicon using an electrochemical etch process. Furthermore, we utilized these nanoscopic silicon as templates for the growth of aligned carbon nanofibers using chemical vapor deposition. Cell culture experiments were performed with astrocytes (glial scar tissue forming cells) and neurons to test the ability of such materials to serve as neural implants. Remarkably, these studies enhance select functions of neurons on nanoscopic silicon as compared to smooth silicon surfaces. In contrast, the nanoscopic silicon material appeared to show less interaction with nanoscopic rougher silicon. This study thus clearly indicates that nanostructured porous silicon materials can be used to significantly enhance select functions of neurons important for neural tissue engineering applications. This work was supported in part by NSF Grant No. DMI-0922529.

**H6.17**

**Mesoscale simulation studies of chiral self-assembly.**

Rahim Selinger, University of Texas, Austin, Austin, USA; V. Selinger,

**H6.20**

**Novel Colloidal Amphiphilic Chitosan Nanoparticles.**

Rongrong Yokesan, Mitsuaki Akahira, and Shuntaro Chirashida.

The precipitation of CaCO3 is widely occurring process in nature (bioneralization) as well as an important operation in industry. CaCO3 nanocles in three crystalline polymorphs: calcite, aragonite and vaterite. Biological systems control polymorphism by the growth environment. Parameters for microcrystalline calcite polymorphism of inorganic components. Although the effect of experimental variables on the polymorphs has been studied by number of authors, the only conditions for getting each polymorph are generally uncertain. Aragonite is less abundant than calcite and is formed under a very narrow range of physicochemical conditions and is easily transformed into calcite by changes in the environment. Nowadays, the interest in aragonite has increased substantially. Its needle-like crystals are used as fillers for the improvement of mechanical properties of paper and polymer materials. In this work we have studied CaCO3 crystallization using sitting-drop method at different temperatures. The crystallization experiments were done using a chamber consisting of 85 mm plastic Petri having a central hole in its bottom glued to a plastic cylindrical vessel. Inside the chamber, micro-bowls were filled with 3.5 UL of 200mM CaCl2 solution in 200mM TRIS buffer pH 9. The central hole allows the diffusion of CO2 vapor from above to increase into the Caco-C2 solution on the polymorphs of CaCO3. Varying the hole diameter of the CaCL2containing chamber, its distance from the CO2 source and the temperature of the experiments this rate was changed. The hole diameter was varied from 3 mm to 60 mm, the distance between 15 mm to 105 mm and the temperatures from 20 to 70°C. In case of hole diameter of 30 mm a kinetic crystallization experiment at 70°C for variable periods of time (3-48 h) were done. Experiments were carried out increasing the distance from the central Petri dish. It was found that by diminishing the distance the rate of aragonite carbonate and calcium chloride solution, and by increasing the hole diameter and the temperature, the rate increases and the aragonite form is observed. By combining these factors appropriately even vaterite crystals were obtained. Since the kinetic of crystallization is a determinant factor of the morphology, a convenient design of the crystallization chamber can conduct the crystallization of CaCO3 towards a specific crystalline form.

**H6.19**

**Tobacco Mosaic Virus as a Template for Nanotechnology.**

Stacey Jones-Willy 1, Neel R Armstrong 1 and Wei Xi, 1 Chemistry, University of Arizona, Tucson, Arizona; 2Biochemistry and Molecular Biophysics, University of Arizona, Tucson, Arizona.

Virus particles have recently been shown to be good templates for the growth of nanometer-scale objects with either metal or semiconductor coatings. Tobacco Mosaic Virus (TMV) is an excellent candidate for this purpose, given its well-defined structure (wimilies), its dimensions (ca. 3,000 in length and ca. 18 nm in width), and the ease of imaging by electron microscopy (SEM) and/or scanning probe microscopies (SPM). We show here that in addition to these attributes, it is possible to immobilize metal oxide and other materials onto TMV onto freshly cleaved mica substrates, with retention of orientation in the soft-lithography stamp. Optimization of the following parameters: 1) careful choice of solution deposition conditions [pH, TMV concentration], 2) the presence or absence of other proteins to prevent aggregation, 3) incubation of the soft-polymer stamp with the virus solution and careful drying, provide for "stamping" of the virus onto the micro surface with orientation of the virus preferentially along the long axis of the virus. We present this method as a means for the fabrication of nanometer-scale lines. SPM and SEM characterization of these features will be presented, along with preliminary results concerning the metallization of these virus-stamped surfaces.

**H6.21**

**Silk Composites: Apatite Coated Electrospun Silk Fibers.**

Chumee Lee, Hyemyung-Joon Je 1,2, Gregory D. Botsaris, and David L. Kaplan, 1 Department of Chemical and Biological Engineering, Tufts University, Medford, Massachusetts; 2Department of Polymer Science and Engineering, Inha University, Incheon, South Korea.

Human bone is a three-dimensional composite made of inorganic apatite crystals and organic collagen fibers. Mimicking this composite structure and composition has attracted interest for bone biomaterial substitutes and as a material design strategy in general. An attractive strategy to fabricate this kind of composite is to grow a layer of bone-like apatite on polymeric materials to generate osteoconductive features combined with good mechanical strength. Recent interest in the use of silk in biomedical applications is due to the unique mechanical properties, biocompatibility, and biodegradability. For example, we have reported silk protein-based macropores for ligament and bone tissue engineering. Electrospinning offers an alternative approach to protein fiber formation that can potentially generate nanometer scale diameter fibers, a useful feature for some biomedical applications engineering applications. In the present study, we explored the preparation of apatite-silk composites by growing apatite on functionalized nanodiameter silk fibers prepared by electrospinning. Functionalized fibers were spun from an aqueous solution of silk/PEO (80/20, wt/wt) containing poly-L-lactic acid. An alternating melting process was used to grow apatite on the fibers. The deposited apatite was characterized by scanning electron microscopy (SEM), X-ray
H6.25 Bioactivity of Silicon Nanowires. Duttari K Nagesh and Jeffery L Colfer, Chemistry, Texas Christian University, Fort Worth, Texas.

In the last few years, different forms of crystal silane silicon have been extensively researched for use in a variety of fields, ranging from optoelectronics to sensors to biomedical applications. The one-dimensional nature of silicon nanowires (SiNWs) is of special interest due to their high-aspect ratio and unique physicochemical properties.

The presentation focuses on the fabrication of SiNWs and their use as biosensors. The ability to control the size and shape of the nanowires allows for the creation of highly sensitive and specific sensors.


Nanoparticles possess shape and size dependent properties that can be utilized in various applications such as semiconductors, optically active materials, and as catalysts. The structure and properties of these materials are dependent on the synthetic process.

The presentation focuses on the synthesis of silica and germania nanomaterials and their potential applications. The use of these materials in catalysis, sensors, and drug delivery systems is discussed.


Highly ordered silica materials with uniform meso-porous structures (1.8 nm) are of interest for applications in catalysis, adsorption, and separation technologies. The high surface area and uniform pore size of these materials makes them ideal for a variety of applications.

The presentation focuses on the synthesis and characterization of these materials, as well as their potential applications in the field of catalysis.
cm³/g volume and BET surface area 800 - 1500 m²/g. Synthetic variables include pH control during the templating process. We observed that the template alone is also effective in directing the fabrication of silica pore in very low pH (< 3.3) conditions, resulting in the formation of nano-particle silica. Nonionic triblock copolymers such as EO₃PO₃EO₃ are superior templates to mediate the construction of highly ordered silica nanostructures. The approach demonstrated a wide range of possibilities in tailoring the structures of silica synthesized using convenient reagents. Such meso-porous silica materials have application in large-molecule catalysis, chromosomal separation, bio-molecular separations and drug-delivery.

H6.28 Expression and Characterization of G Protein-Coupled Receptors on Nano-Sized Bacterial Magnetic Particles.

Tomoko Yoshino, Haruko Takeda, Masaaki Morita, and Tadashi Masunaga.

Biotechnology, Tokyo University of Agriculture and Technology

Seven-transmembrane proteins, G protein-coupled receptors (GPCRs) play central roles in a wide range of biological processes and are prime target for drug discovery. GPCRs have large hydrophobic domains, thus the processing for purification of GPCRs from the cell membrane are frequently time-consuming and typically result in loss of native conformation. In this study we assembled GPCRs on a nano-sized bacterial magnetic particle (BMPs) surrounded by lipid membrane by genetic engineering using Magnetospirillum magnetotacticum AMB-1. D1 dopamine receptor (D1R) was used as a model GPCR. Expression plasmid of D1R fusion protein gene DNA, D1R-DOR, which is most abundantly produced on BMPs, was constructed and introduced into strain AMB-1. D1R-BMP complexes were simply extracted by magnetic separation from ruptured AMB-1 transformant cell culture medium, and the complexes were ready to use for analysis. D1R expression was confirmed on BMPs by ELISA using anti-D1R antibody, indicating that Mma1-D1R fusion protein was assembled onto the BMP surfaces. Saturation binding analysis was used to assess the affinity of magnesium [²⁵¹H]SC123390 to D1R-BMP complexes. Recombinant BMPs displayed a single affinity for the [²⁵¹H]SC123390 with a Ka value of 9.7 nM. This is in good agreement with the value obtained from D1R prepared from cell membrane of rat striatum used for the development of an in vivo ligand binding screening system using D1R-BMP complexes, competitive binding was also performed using fluorescence ligand. In the presence of body-labeled SC123390, various concentrations of dopamine were added and competitive binding was performed. Fluorescence of BMPs was measured after several washings. As a result, the increase of competing chemical concentrations decreased the fluorescence of BMPs. This system makes possible the convenient acquisition of the native conformation of GPCRs without the need for detergent solubilization, purification and reconstitution after cell disruption. Biomimetic produced by magnetic bacteria are powerful tools for automated applications.

H6.29 Metal Removal by Using Magnetic Bacteria.

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Biotechnology, Tokyo University of Agriculture and Technology

Magnetic bacteria synthesize intracellular magnetite termed bacterial magnetic particles (BMPs) with sizes ranging from 50 - 100 nm in diameter and number over 10 per cell. BMPs are composed of magnetite (Fe₃O₄) or greigite (Fe₃S₄) with a single magnetic domain. We have previously reported the detection of endocrine disrupting chemicals with BMPs displaying estrogen receptor. In this study, we propose a metal removal method by using cell surface display on magnetic bacteria. Collection of cells is one of the major problems in microbiological bioresource. Harvesting cells by centrifugation from bulk cultures is tedious, time consuming and costly. Since magnetic bacteria swim along magnetic filed lines and posses the innate ability to intracellularly accumulate tellurium and cadmium, they are ideal candidates for the magnetization of contaminating metals. Moreover, they exhibit tolerance to lithium, cesium, magnesium, strontium, barium, cobalt and zinc. Cell surface display in the magnetic bacterium Magnetospirillum magnetotacticum AMB-1 was performed by containing membrane ompA (consisting membrane protein gene) or flaA closed from E. coli. Recombinant OmpA or FlaA were designed to display metal-affinity peptides. Metal-affinity peptides and inserted positions were evaluated by measurement of metal recovery amounts. Moreover, various metal ion species were examined with substitution the peptides.

H6.30 Nanostructured bioactive coatings by sol-gel synthesis and rapid thermal processing.

LaKeisha Goins¹, Samuel Holden² and Andrei Samborsky³.
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Bioactive calcium-based coatings like hydroxyapatite (Ca₅(PO₄)₃(OH))₂, and recently CaTiO₃ are of great interest for application in biomedical implants. Several coating parameters such as composition, crystalline grain size, and surface morphology play crucial role in this application field. The nature of the substrate implant material, for example, titanium and its alloys, is also an important factor affecting adhesion, osteointegration, and mechanical strength of the system. It has been observed that nanocrystalline hydroxyapatite coatings demonstrate better bioactivity than a corundic-grained material, or bioceramic titania alayas. We present the results of an investigation of solgel deposition of nanostructured hydroxyapatite (HA) and CaTiO₃ coating systems onto nanocrystalline thin-film substrates including Ti and TiO₂ (both rutile and anatase modifications). Hydroxyapatite coatings were also prepared on CaTiO₃ layer. The calcium - phosphorus ratio and calcium - titanium precursors were spun onto the substrates at 2000 - 4000 rpm. A 30 - 50 nm thick layer was formed after each coating cycle. The 200 - 500 nm thick nanocrystalline coatings were formed by repeating the coating procedure several times followed by rapid thermal processing (RTP) in oxygen or nitrogen. Several multilayer systems of (HA-CaTiO₃)n and (HA· TiO₂)n were also prepared to study the interaction between the layers during the thermal processing. Crystallization of the single phase CaTiO₃ was observed at 600°C, and nanocrystalline HA was observed at 800°C after RTP for 2 minutes. The effect of sintering ambient during the rapid thermal processing on the development of high-quality hydroxyapatite coatings was studied. The formation of the CaTiO₃ interface layer was observed during RTP of HA coating on Ti and TiO₂ substrates, as well as in HA· TiO₂ multilayer system. We discuss in detail the influence of the substrate material and the effect of thermal annealing process on the adhesiveness and properties of the materials. We acknowledge support from the National Science Foundation, Research Experiences for Undergraduates (REU) Site award to the University of Alabama at Birmingham (UAB) under Grant No. DMR-0229360.


Eoin Han and Joseph A. Kiely.

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Control over the nucleation and growth of biologically formed crystals is truly remarkable. We have utilized self-assembled monolayers (SAMs) to understand the principles controlling the formation of calcium carbonates, including their crystallographic orientation, morphology and size. By progressively selecting the SAMs and introducing specialized additives during the growth of these crystals (e.g. Mg ions), we were able to exert the multilevel control of the formation of calcium carbonate. In order to elucidate the mechanisms of the oriented nucleation, morphological modifications and size control, detailed studies of the control of the structure of SAMs and crystal they nucleate, as well as the effect of the additive concentration was performed. We believe that understanding the formation of biominerals will lead to many practical applications.

H6.32 Photoluminescence of a Conjugated Polymer-Polyelectrolyte Assembly and Effective Quenching in Aqueous Solution and on Self-Assembled Thin Film Architecture.

Gabriel Almeida Montenegro, Andrew M. Döring, Jeff W. Werner, Wengang Li, Hsiao-Li Wang and Andrew P. Shepley.

Biotechnology, Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Control of assemblies driven by polyelectrolyte interactions represents a biologically inspired approach to materials synthesis. One means of investigating such assemblies is through photoluminescence spectroscopy of luminescent polyelectrolytes. A photoresponsive polymeric assembly was formed in aqueous solution between polyelectrolyte (2,5-methoxypropyl-sulfonate phenylene vinylene) (MPS-PV) and DAB-Ams(16), a generation 3 polypropylene hexafluorodecanediurethane (DAB). The photoluminescence (PL) intensity from an aqueous solution of MPS-PV was greatly enhanced upon addition of DAB and found to increase, as well as red-shift, with additional DAB. Efficient quenching of MPS-PV photoluminescence has also been observed by using sulfonated-OS6 in aqueous solution and self-assembled on thin film architectures. These results provide a greater understanding of the photoluminescence from polyelectrolyte assemblies and include possible uses in high-sensitivity chemical and biological sensing and in light-emitting displays (LEDs).


Marie Isabelle Lorette da Silva¹, Gabriela Simone Lorette², Shirle N. Dezio², Juan Carlos Gonzalez³, Carlos
Melamins are important pigments found in many organisms and tissues. They have attracted great attention due to their role in photocatalytic and technological applications as ultra-violet light filters, for example. In this work we studied the effect of hydration on the local structural and electrical properties of synthetic melamin thin films. Melamin powders synthesized from L-dopa using either DMSO (Dimethyl sulfoxide) or pure water were pressed into uniform thin films (about 100 nm thick) by evaporating (casting) solutions of these powders on crystalline silicon substrates. After dried out, some of the samples were hydrated in a humid chamber. The obtained samples were analyzed using Atomic Force Microscopy (AFM), Electrical Force Gradient Microscopy (EFM), and Conductive Atomic Force Microscopy (CAFM). TappingMode ultra sharp Si tips were used for AFM and EFM measurements. A-CFM was carried out with a Ag/Co-Ag tip (estimated radius of 40 nm). The surface morphologies were studied with A-CFM. Samples prepared with DMSO presented a continuous film, with good adhesion to the substrate, while more homogeneous films were obtained for water-prepared samples. Extended flat terraces with small round depressions were observed for the DMSO samples. The samples prepared in water, however, exhibited a rougher surface, with larger microstructures. The hydrated DMSO-prepared melamin samples exhibited large agglomerates in the center of the deposits with heights in the range 1.3–3 nm. For the non-hydrated sample, the agglomerates are rarely present at the initial surface but they have been observed to increase significantly in time when the sample is kept at ambient conditions. The roughness equals zero on the surface of the film, and the agglomerate regions, were calculated. The planar regions provide similar exponents for both the hydrated and non-hydrated samples, indicating that the film does not have a surface morphology which was not present in the solution. However, the samples presented large roughness values, closer to those observed for the water-prepared samples. EFM and CAFM were used to study the electrical properties of the samples in correlation with their morphology. An increment of the EFM signal was observed for both samples at the edges of the flat terraces. However, a lower EFM signal was found in the agglomerates. The decrease of the EFM signal indicates a lower free density produced by hydration of the sample. This is indeed confirmed by CAFM data which shows different resistivities in the agglomerate regions. Our results suggest that the thin film is formed by relatively large phase structures which are subsequently spread onto the silicon surface. The agglomerates originate from reaction with water at specific locations on the surface, most likely defects on the planar structure.

**H6.34** Shape Adaptable Water-soluble Conjugated Polymers, bin Liu, Shu Wang, Guillermo C Bazan and Alexander Mikhailovsk; Dept of Chemistry & Materials, Institute for Polymers and Organic Solids, Univ. of California, Santa Barbara, Santa Barbara, California.

Conjugated polymers provide highly responsive optical platforms for chemical and biological detection. Water-soluble conjugated polymers are of particular interest for reporting biological recognition events. Cationic conjugated polymers such as poly(9,9-bis(N,N-trimethylammoniumhexyl)-fluorene phenylene) form part of a DNA-sensing technique which utilize both the optical properties of the cationic conjugated polymer and the complexation of polyelectrolytes with opposite charges. In this contribution we report on a synthetic method for producing cationic conjugated polymers with a range of backbone reactivities. We show that, despite structural differences which affect the average conjugation length, there is facile energy transfer amongst polymer segments and similar emission properties and FRET function. Additionally, the non-linear cationic conjugated polymers are more efficient excitation donors.

**H6.35** Nano-Scale Roughness Inducing Super-Water-Repellency: From Natural to Artificial, Yungui Wu,1,2 Chengqiang Liu,3 Massimo Kondo,1 Hirokuki Sugimura,1 Yassou Inoue1 and Osamu Takan1; 1Takasago Center for Integrated Research in Science and Engineering, Nagoya University, Nagoya 464-8603, Japan; 2Aichi Science & Technology Foundation, Nagoya 460-0002, Japan; 3Department of Materials Processing Engineering, Nagoya University, Nagoya 464-8603, Japan.

Previous studies showed that both micro- and nanoscale hierarchical surface structures (like lotus leaves - branch-like nanostructures on top of the microcapillaries) were the key to produce superhydrophobicity. The height of superhydrophobicity was less important than asperity shape in determining wetting by theoretical calculation and experiment. However, the present work on plant leaves reveals that the superhydrophobic property is mainly affected by these nanostructure although the surface of these leaves consists of both micro and nanoscale microstructures. In addition, the hydropathic property is independent on the shapes of nano-scale asperities. The results from the natural world provide a guide for constructing artificial superhydrophobic surfaces with nano-scale fine roughness by using microwaves plasma enhanced chemical vapor deposition (MWE-CVD) and focused ion beam (FIB) forming. The water contact angle of artificial surface is mainly affected by the asperity height. This would be the results of more air trapped in the pores between higher height asperity if the flat-rough surface was made up of nano-scale submicro-asperity feature. This work is supported by JSPS - RFTF98R1501 and ASTF.

**H6.36** Insoluble Phospholipids as Novel Agents for Controlling Intracellular Trafficking, Andrew B. Holmes, Stuart J. Conway, Melissa K Johns and Christopher Meyer; Chemistry, University of Cambridge, Cambridge, United Kingdom.

Phosphatidyl inositol polyphosphoinositides (PIPs) have emerged as a powerful tool for probing the downstream processes which control intracellular signaling. This paper reports the novel synthesis of simple lipid analogs of many known and novel PIPs and their use to identify new proteins involved in signal transduction. For example attachment through the lipid side chain to affinity columns provides a powerful tool in therapeutic applications for a wide variety of disease states. Even phosphatidic acids are found to bind to important proteins associated with housekeeping and cancer processes. New results with photo-degradable phospholipids will be reported.

**H6.37** Lymphoid Viruses: Assemblies toward photonic crystals, Shane Jahn1, Lynn Waterhouse1, Ryan Kramer1, Richard Vain2, Sam Ha3, Edwin Chan4, Edwin Thomas5, James Kalnins6 and Vernon Ward3; 1AFRL/MELB, Wright-Patterson AFB, Ohio; 2MIT, Boston, Massachusetts; 3University of Otago, Otago, New Zealand.

Natural systems present many opportunities for the advancement of optical materials due to the large number of naturally occurring self-assembled theoretically predicted to exhibit unique photonic properties. In contrast to the homogeneous surface of its non-biological counterpart, polymer colloids, the heterogeneous surface chemistry of the lymphoid protein capsid of virus particles offers a myriad of opportunities to realize non-close-packed structures. The Chik and Wiesner Iridoviruses are grown in waxmoth larvae and are collected through filtration and centrifugation. The iridovirus was used to demonstrate bottom-up assembly of virus particles that exhibit optical reflection in the visible regime. Assembly methodologies investigated include centrifugation, capillary flow, crystallization, flow field, sedimentation, and dielectrophoresis. Bulk virus assemblies exhibit non-close-packed structures, whereas the iridovirus to three layers near a surface exhibits a close-packed arrangement. The lower surface charge of the virus and topological features of the capsid imply that the relative assembly of the particles is sensitive to pair-wise orientation of the iridovirus as well as concentration and pH during assembly. Polymeric virus colloids whose spherical symmetric interaction potential and higher surface charge dominates the inter-particle forces between the colloids restricting the accessible packing geometries.

**H6.38** Engineering viruses for colloidal self-assembly, Kirstin Panday and Seth Fraden; Physics Department, Brandeis University, Waltham, Massachusetts.

Suspensions of colloidal rods self assemble into isotropic, nematic, cholesteric and smectic liquid crystal phases. We study the charged rod-like virus fil whose interparticle interactions are dominated by electrostatics. With increasing solution ionic strength the range of the electrostatic interactions is decreased. By coating the viral surface with functionalized neutral polymers larger in size than the range of electrostatic interactions, we create colloidal rods that interact solely through steric polymer-polymer interactions. By selectively binding to specific sites on the viral surface with these functionalized polymers one of our goals is to create virus-polymer block copolymers. We study the phase behavior of these virus-polymer colloids in solution to quantify the role of shape and interparticle potential in the stability of liquid crystalline phases.

**H6.39** Energy transfer between bio-assembled nanocrystal quantum dots, Sohee Jeong, Mark Achermann, Laurent Balet, Victor I Klimov and Jennifer A Hollingsworth; LANL, Los Alamos, New Mexico.

The ability to construct ordered two- and three-dimensional...

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structures on the nanometer scale is essential for the development of next-generation optical, electronic, and magnetic materials and devices. We use model or protein and model systems, which have evolved to transport cargo at the nanoscale in an energy-dependent manner, for assembly of artificial nanomachines.

Here, semimicellar nanocrystalline quantum dots (NQDs) comprise the cargo. At the surface of NQDs are robust and tunable surface fluorophores, making them ideal candidates for such applications as fluorescent markers in biological imaging. We prepare high-quality (in terms of optical properties and size dispersion) NQDs coated with hydrophilic and hydrophobic shells that incorporate them into functionalized lipoprotein micelles, thereby permitting water solubility and conjugation to target biomolecules. We study assembly of differently sized, micelles-encapsulated NQDs by observing inter-particle energy transfer as NQDs are brought into and out of close proximity with one another. Energy transfer provides a useful and sensitive tool for monitoring active biocomplex assembly of NQDs.

**H6.40**

Biomimetic One-Pot Synthesis of Magnetic Nanomaterials


Biological systems have undergone long evolutionary optimization processes enabling macromolecules to structure inorganic materials to form their skeletal parts. These include the formation of amorphous (colloidal) polymers, crystalline (bone and teeth), and single crystalline metal (copper and gold) structures. These processes are important for the design and construction of technologically important materials. Borrowing from the two concepts, we have observed the formation of crystalline ferric oxide in an amorphous nanophase material in one step via a block copolymer leading to multifunctional materials. Block copolymer-ceramic nanocomposite films were cast through a coassembly-induced self-assembly (EISA) approach from a one-pot solution containing iron-diluminolamine selgel precursors and polyaniline (black-ethylamine oxide). This simple pathway leads to superparamagnetic mesoporous materials and nanoparticles with potential applications in magnetic separation, molecular labeling, and catalysis technologies. Nanoparticles in the shape of spheres, cylinders, and plates were generated from the sphere, hexagonal cylinder, and lamellar reverse mesophases, respectively, by dissolution of the polymer matrix with a selective solvent. Mesoporous materials were formed by pyrolysis of the polymer channels of the inverse hexagonal cylinder and cubic bicontinuous regular mesophases. Calcination of the materials nucleates and grows magnetic ferric oxide particles within the aluminosilicate matrix. Transmission electron microscopy and magnetic properties characterization using a SQUID magnetometer reveal the approximate size of the ferric oxide particles is 5 nm. This approach eliminates the possibility of clogging the pore structure in the mesoporous materials as observed in back-filled systems.

**H6.41**

Noncovalent Immobilization of wild type Phosphotriesterase in Polyelectrolyte Multilayers, Won-Yoon Lee and Alix Singh

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Wild type phosphotriesterase (PTE) catalyzes the hydrolytic degradation of organophosphates. In order to physically stabilize and sustain its activity, PTE were sandwiched between polyelectrolyte layers of opposite charges and held in layers through electrostatic interaction without distorting the enzyme architecture. Silica nanoparticles (30-50 µm in diameter) were used as support for polyelectrolyte layers and the microspheres were evaluated for their catalytic activity in varying humidity environment. Thus, polyelectrolyte multilayers were prepared from branched polyethyleneimine (BPEI) used for embedding PTE and poly(acrylic acid) (PAA) was used for capping the multilayers after constructing five PTE layers. Enzyme and polyelectrolyte deposition was confirmed by employing quartz crystal microbalance (QCM) to demonstrate the stepwise growth of layers under the conditions used in the case of silica microspheres. Enzymatic activity of PTE immobilized was measured as the amounts of P-NO produced from hydrolysis of methyl parathion (MPT) in water. The reusability of the PTE-ENz-MPT was demonstrated by carrying out multiple hydrolytic reactions and also displaying enzyme activity under extreme humidity environment for a period of weeks indicating that enzyme immobilization involving electrostatic interaction is a viable means in building bioactive coatings.

**H6.42**

Super-Hydrophobic Thin Films for Organic Molecular Adsorption

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Various phenomena, such as snow sticking, condensation or evaporation, and current conductions, are expected to be highly dependent on the superhydrophobic surface. Here we report organic molecular adsorption on such a surface. The film deposited onto a quartz crystal microbalance (QCM) sensor, was prepared by microwave plasma chemical vapor deposition (CVD), using trimethylmethoxysilane as raw materials and Ar as additive gas. Such film has a proper nanotexture and a hydrophobic surface terminated with methyl groups, which consequently showed ultra-water repellency. Then we evaluated the amount of organic molecules adsorption by examining resonance frequency, which is sensitive to the mass change. The results showed that organic materials (vapor), such as formaldehyde, methanol, ethanol, acetone, toluene and hexane, preferentially adsorbed on the film, whereas other hydrocarbons were restricted due to the hydrophobic nature of the surface. The amount of the adsorbed organic molecules seemed to depend on the molecular polarity because of a prefer adsorption for some organic molecules with high polarity. The use of this film was crucial to increase the organic molecular adsorption amount through the effective surface areas increasing. The selective organic molecular adsorption properties are expected to serve as environmental materials (i.e. sensor, sorbent) to detect or adsorb toxic organic gases. This work is supported by JSPS - RFTFP9813101 and ASTER.

**H6.43**

Competitive Adsorption at the Air-Water Interface From a Self-Assembling Polymer-Surfactant Mixture.

Young-Soo Seo, Krishnan Chari and Sunil Swaja, 1-CNCR, NIST, Gaithersburg, Maryland; 2-Kodak, Rochester, New York.

A mixture of polymer and surfactant is frequently used in the preparation of colloidal dispersions and emulsions. Typically, the surfactant is needed for reducing interfacial energy whereas the polymer is needed for imparting stability against Brownian coalescence, coarsening, Ostwald ripening, and phase separation. The effectiveness of a polymer-surfactant mixture is dependent on the interplay between self-assembly in the bulk fluid and adsorption at the interface. Here we study the relationship between the air-water interface as a model for more complex cell-oil-water or emulsion-water interfaces. We demonstrate using a combination of neutron reflectivity and surface tension measurements that polymer-surfactant assembly in bulk water enables coexistence of polymer and surfactant at the interface via partial displacement of adsorbed surfactant by polymer. The latter is extremely important in colloidal stabilization. It is widely recognized that surfactant can displace polymer at high enough concentrations but not vice versa.

**H6.44**

Self-Propagating High-Temperature Synthesis of Porous Nickel-Titanium for Bone Engineering Applications

D. L. Belk, 1, 2, R. A. Ayers 1 and J. J. Moore 1, 2.


Porous Nickel-Titanium (NiTi) is a strong candidate material for bone engineering applications because its mechanical properties are within the range of bone and its porosity allows for biologic interlock of the material to the surrounding tissue. Self-propagating high-temperature synthesis (SHS) is one method for producing porous NiTi. Nickel and titanium powders, -325 mesh, were mixed for 34 hours then pressed into cylindrical pellets (0.5 inch diameter, 0.5 inch height) to a theoretical green density of approximately 55%. The pellets were preheated in flowing argon for one hour then ignited using a tungsten coil. Scanning electron microscopy and electron dispersive X-ray spectroscopy show localized differences of stoichiometry suggesting variations in the crystal structure where the Ni to Ti atomic ratio varied between 48.5:51.5 and 50:74.9:3. X-ray diffraction (Philips X-Pert PRO) confirmed the present crystal structure equiaxial NiTi as well as other intermetallic compounds including NiTi2 and Ni3Ti.
Nanoindentation (MTS Nano Indenter XP) of this heterogeneous material indicates a mean range indentation modulus of 83.6 ± 9.4 GPa. This is of the same order of magnitude as bone, which has an elastic modulus range of 14-20 GPa. Ongoing work is examining the effect of green density, combustion temperature and preheat to control NiTi stoichiometry, porosity, and microstructure to optimize this material for bone engineering purposes. It is anticipated that increasing porosity and/or reducing the presence of other intermetallic components will result in a more appropriate mechanical match between the NiTi and bone tissue.

H6.45
Quantitative Analysis on DNA-Grafting Densities for the Assembly of 2-D Opaline Arrays. Sejong Kim1, Erik Geiss2, Harris E. Marcus2 and Potis Papadimitriou3, 1Nanosensor Optoelectronics Laboratory, Department of Chemistry, Polymer Program, Institute of Materials Science, University of Connecticut, Storrs, Connecticut; 2Department of Metallurgy and Materials Engineering, Institute of Materials Science, University of Connecticut, Storrs, Connecticut.

Recently, DNA hybridization has been increasingly adopted in materials sciences due to its capability of specific and reversible molecular recognition. These unique properties of DNA have been used for the realization of 2-D assembly of colloidal particles as a precursor to constructing 3-D photonic crystal in a layer-by-layer manner. In order to precisely understand this DNA-assisted assembly of colloidal particles, in this study, we quantitatively assessed the surface density of grafted and hybridizing accessible DNA oligomers on both substrate and colloidal particles. The DNA grafting densities were determined by UV-VIS of dye-functionalized complementary DNA oligomers, in conjunction with theoretical models. The variations of the concentration of hybridized DNA as a function of parameter such as the number of DNA base pairs, the length of spacer and the size of particle were also investigated to determine the immobilization strength of colloidal particles on various surfaces.

H6.46
Cell Growth on Prestructured Microelectronic Semiconductor Materials. Heinz D. Wartenbock1, Christian Almader1, Christoph Pacher1, Emmerich Bertagnoli1, Michael Wirth2 and Franz Gabor3, 1Institute for Solid State Electronics, Vienna University of Technology, Vienna, Austria; 2Institute for Pharmaceutical Technology and Biopharmacy, University Vienna, Vienna, Austria.

The rapid advance of semiconductor technology has resulted in a size revolution of microelectronic devices. Feature sizes below 200 nm have become standard in many microchips such as DRAMs. The devices fabricated in semiconductor technology can be produced in a magnitude smaller than biological units and hence provide the potential for novel in-vivo sensors, actuators or novel analysis and data collection approaches. The interface between microelectronics and biomaterials serves a central role in future engineering of biomedicinal sensors and functional devices. This study focuses on the material science aspects of the cell-semiconductor interface. The toxicity of materials used in microelectronics for human cells was investigated. Tissue cultures were grown on silicon, silicon oxide, several organic and inorganic dielectrics and a representative selection of metals. Human colon carcinoma cells (Caco-2) were used as exemplary cell line to test the biocompatibility of materials. Caco-2 cells are a widely used in vitro model for studies and are robust under environment stress. The Caco-2 cells were cultured on microchip chips stored in polycarbonate culture plates. The samples were incubated at 37°C for a period of 10-14 days. The growth rate, the cell coverage of the surface after a defined growth time and the cell adhesion were investigated. Results were compared to the growth progress on standard glass slides. Preliminary results showed a well-behaved growth of cells on Au and Si3N4. Patterened substrates of thin Au lines on Si3N4 dielectric layers were also used as support substrate for cells. The grown Caco-2 cells displayed a good adhesion to the substrate. These initial experiments opened the gate to functionalized materials for bioelectronics. Further studies are required to provide the necessary multidisciplinary environment that thoroughly links biology, nanoengineering, and medicine. Potential applications involving cellular processes either in vitro or in vivo will be discussed.