SYMPOSIUM Z

Bio-Inspired and Bio-Derived Materials and Processes

November 29 - December 2, 2004

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SESSION Z1: Biopolymer Engineering/Bio-Derived and Bio-Inspired Polymers
Chair: Joseph McAuliffe
Monday Morning, November 29, 2004
Room 304 (Hynes)

8:30 AM *Z1.1
Bio-Inspired Functional Repeat Sequence Protein Polymers.
Manoj Kumar[1], William Cuevas[2], Nicole Chow[3] and Kathy Collier[1]; [1]BioChemistry Department, Genencor International Inc., Palo Alto, California; [2]Fermentation & Microbial Physiology, Genencor International Inc, Palo Alto, California; [3]Protein Science, Genencor International Inc, Palo Alto, California.

Natural protein polymers such as silk fibroins have been utilized to make high performance fibers for a very long time. In the 19th century, development of man-made fibers was inspired by the desire to mimic silk, the only natural, continuous fiber then available. Renewed interest in repeat sequence protein-based biopolymers1, 2 has arisen because this new class of biomaterial will simulate natural fibers, can be modified for desired function and has many advantages over conventional petroleum-based polymers. Protein-based biopolymers are made using recombinant DNA technology and fermentation3. The former offers the ability to screen for desired properties utilizing the tremendous potential diversity of amino acid combinations and the latter allows for large-scale manufacturing with familiar technology. Using recombinant DNA methods, one can precisely control and incorporate the molecular weight, size, stereochemistry, and functional distribution of actives in the biopolymer to create composite functional biopolymers simulating natural fibers. Using the twenty natural amino acids, one can create a repeat sequence protein polymer (RSPP) designed for a specific function. Subsequent chemical/biological modifications of amino acid side chains with a variety of functional groups further offers a mean for conveying specificity and variety in function. Multifunctional bioengineered biomaterials can be created that serve as new paradigm for a composite biomaterial system. This presentation will describe the design of innovative functional RSPP technology platform that is ready for vast application opportunities. References: 1) Designing materials for biology and medicine, Langer R, Tirrell DA; Nature, 428, 487-92, 2004. 2) Stretching the limits, Alper J, 2002, Science 297, 329-331. 3) Biosynthesis of protein polymers, Ferrari F, Cappello J, 1997, Protein-Based Materials, Chapter 2, Birkhauser: Boston.

9:00 AM *Z1.2
Genetically Encoded, Stimulus Responsive Biopolymers.
Ashutosh Chilkoti, Biomedical Engineering, Duke University, Durham, North Carolina.

Elastin-like polypeptides (ELPs) are biopolymers composed of a VPGXG repeat (V = Valine, P = Proline G = Glycine, X = any amino acid except Pro), which undergo a thermally reversible phase transition. Below a characteristic inverse transition temperature (Tt), ELPs are soluble in aqueous solution, but when the temperature is raised above Tt, they desolvate and aggregate in solution. The phase transition of ELPs is entirely reversible. The Tt of ELPs can be modulated by the choice and mole fraction of the fourth residue (X) and the molecular weight of the polypeptide. ELPs can also be crosslinked to create hydrogels that exhibit desolvation and stiffening of the hydrogel as a function of temperature. A primary focus of our research in ELPs is the development of new applications, which exploit the inverse transition behavior of this class of polypeptides. These applications include: (1) thermal purification of recombinant proteins by fusion with an ELP expression tag, a method we term inverse transition cycling; (2) thermally targeted delivery of anticancer therapeutics to solid tumors by thermally responsive ELP carriers; (3) dynamic patterning of ELP fusion proteins for application in biosensors and BioMEMS, which exploits their reversible adsorption on micropatterned surface templates as a function of the inverse transition; (4) crosslinked ELP hydrogels for application as injectable tissue engineering scaffolds; and (5) design of hybrid biomolecular actuators, in which ligand binding to an ELP fusion protein triggers the inverse transition of the ELP, transduced by the conformational changes in the protein that accompany ligand binding. In this talk, I will first provide a brief overview of the synthesis, properties and characterization of these biopolymers, followed with a brief review of these different applications in biotechnology and medicine.

9:30 AM *Z1.3
New Materials Via Control of Fibrous Protein Assembly and Structure.
Ung-jin Kim[1], Jaehyung Park[3], Hyong-Joon Jin[1,3], Peggy Cebe[4] and David L. Kaplan[1,3]; [1]Biomedical Engineering, Tufts University, Medford, Massachusetts; [2]Biomedical Engineering, Tufts University, Medford, Massachusetts; [3]Chemical & Biological Engineering, Tufts University, Medford, Massachusetts; [4]Physics, Tufts University, Medford, Massachusetts.

Silk fibroin has been extensively studied for its novel material properties as well as its polymorphic behavior. Of particular interest is the control of chain-chain interactions leading to the traditional silk II crystalline structure responsible for both aqueous insolubility as well as structural integrity of materials formed from this protein. This includes transitions that occur during silk fiber spinning by silkworms and spiders. In our recent studies we have explored new ways to manipulate the structural assembly of this protein via a combination of osmotic stress, salt-induced transitions and water vapor annealing. In these studies, we develop a fundamental basis for control of the transitions of the protein into structures that form water-stable materials, in some cases even in the absence of a significant content of beta sheet. For example, films formed from aqueous solutions of silk fibroin and subsequently annealed in water vapor, are extensible and stable in water, and consist of a low content of beta sheet. In a new all-aqueous process 3D porous silk fibroin matrices are formed via salt leaching, with control of structural and morphological features, such as pore size and distribution. The result of this process are scaffolds with controllable porosity that fully degrade in the presence of proteases, unlike silk fibroin materials traditionally processed with methanol, thus containing a high content of beta sheet that subsequently hydrolyze to much a more limited extent in the presence of proteases. Mechanisms are proposed for these new processes that impart physical stability via hydrophobic interactions but avoid significant formation of -sheet. Importantly, these processes offer entirely new windows of materials properties when compared with traditional silk fibroin-based materials. These features are due to the decreased content of -sheet and are particularly intriguing with respect to the mechanical behavior and enzymatic susceptibility of the materials.

10:30 AM Z1.4
Structural evolution of regenerated silk films during thermal treatment.
Lawrence F. Drummy, David M. Phillips, Robert A. Mantz, Barry L. Farmer, Morley O. Stone and Rajesh R. Naik; Materials and Manufacturing Directorate, Air Force Research Labs, WPAFB, Ohio.

There has been longstanding interest in spiders and silkworms because of their sophisticated fiber processing capabilities. Spider and silkworm silks are also of current interest for use in biocompatible, optically clear thin films. Precise control of the microstructure in natural silk fibers is maintained by the sequence of amino acids in the fibroin molecule and the processing conditions during spinning inside the silkworm. Here we demonstrate control over the secondary structure of silk films and natural silk cocoon fibers using heat treatment. The structure of thin films cast from regenerated solutions of Bombyx mori silkworm silk dissolved in hexafluoroisopropanol (HFIP) is studied by synchrotron x-ray diffraction during heating. A solid-state phase change from an alpha helical, silk I-type crystal structure to the well known beta-sheet, silk II structure occurred at a temperature of 140°C. The transition appears to be homogeneous as both phases do not co-exist within the resolution of the current study. Modulated differential scanning calorimetry (MDSC) of the films showed an endothermic melting peak followed by an exothermic crystallization peak both superimposed on top of a glass transition near 140°C. Data from thin films was compared to x-ray data collected from natural silk cocoon fibers that were also heated. The as-spun fibers did not show a phase change, as they were already in the stable silk II structure. A significant increase in the intensity of the diffracted peaks, but minimal peak narrowing, was seen for temperatures above 150°C. These observations indicate that existing crystallites in the fibers did not increase in size, but more crystals nucleated and grew. Heat treatment of silk fibers and films at temperatures well below the silk degradation temperature (200-220°C) offers a controllable route to materials with well-defined structures and presumably superior mechanical behavior.

10:45 AM Z1.5
Nanoparticle Interfaces to Biomolecular Systems.
Kimberly Hamad-Schifferli, Mechanical and Biological Engineering, MIT, Cambridge, Massachusetts.

Nature has created biomolecular machines that function with remarkable efficiency and precision. In recent years, science has attained an unprecedented understanding of the mechanisms of biological "machines." This has inspired utilization of Nature's engineering for applications in computation, self-assembly, and mechanics. Truly useful manipulation of biomolecules demands a means of control that is compatible with the complex and highly disordered environments of real biological systems. Nanoparticles linked to a biomolecule can serve as an "antenna" for control. The nanoparticle is heated by an external alternating magnetic field. The linked biomolecule denatures slightly, halting its activity. Once the alternating magnetic field is switched off, the biomolecule rapidly dissipates heat into solution and relaxes to its native state, resuming activity. Due to nanoparticle size, heat is localized enough to permit

selectivity and reversibility. The distinct advantage of this technique is that it is universally applicable because it targets general the property of heat denaturation in biomolecules. Furthermore, this technique holds promise for implementation in vivo, since nanoparticle solubility permits incorporation into living cells and organisms and the excitation can permeate tissue. Consequently, nanoparticles have great potential to serve as a tool for controllable, tunable manipulation of a wide range of biomolecular machines in biologically relevant environments. Heating of nanocrystals linked to DNA oligonucleotides in solution has been shown to dehybridize the DNA in a manner that is both reversible and specific. Studies of the heating mechanism and also applications of the technique will be described.

11:00 AM Z1.6
Investigating the Interactions of Peptides and Proteins with Biomineral Surfaces through their Effects on Calcium Oxalate Crystal Morphology and Growth Kinetics. S.R. Qiu[1], J.J. De Yoreo[1], C.A. Orme[1], J.R. Hoyer[2], A. Wierzbicki[3], G.H. Nancollas[4] and A.M. Cody[5]; [1]Department of Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; [2]The Children's Hospital of Philadelphia, University of Pennsylvania, Pennsylvania, Pennsylvania; [3]Department of Chemistry, South Alabama University, Mobile, Alabama; [4]Natural Sciences Complex, University of Buffalo, Amherst, New York; [5]Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa.

Biomineralized structures exhibit shapes containing facets or pseudofacets not expressed in crystals grown from pure solutions. An understanding the physical principles that drive shape modification can shed light on biomineral processes and point to strategies for design of modifiers to control synthetic crystal shapes. In develop that understanding, we are using in situ atomic force microscopy and molecular modeling to investigate growth modification at surfaces of calcium oxalate monohydrate (COM), a common biomineral. By investigating the effects of Asp-rich polypeptides, the naturally occurring control protein osteopontin (OPN), and citrate, a common peptide-like inhibitor, we are deciphering the roles of chain-length, amino acid composition, and protein conformation. For all additives investigated, we observe step-specific modifications whose magnitude and specificity depend on these factors. The step-specifcity is demonstrated by citrate, which dramatically alters the growth rate and morphology of one face, but leaves steps on the adjacent face unaffected. Moreover, even on the affected face, the steps in one direction are impacted ten times more than those in the opposite direction. Molecular modeling reveals that the source of these differences is both electrostatic and steric in nature. The importance of peptide composition is illustrated by the case of two similar peptide chains, (Asp3Gly)6Asp3 and (Asp3Ser)6Asp3, which have been chosen to mimic the acidic portions of OPN. We find they induce effects differing by over an order of magnitude. Finally, the role of protein conformation is shown by the effect of OPN. While this protein is also highly acidic, on the face where the peptides and citrate additives are most effective, it has little effect, though it clearly adsorbs to the facet itself. On the adjacent face, it exhibits a strong interaction with precisely those steps unaffected by citrate. We attribute this to an element of COM crystal symmetry leading to quadruple height steps on this face, making them comparable in height to that of the protein. A generalization of these observations towards underlying principles is discussed.

11:15 AM Z1.7
Biomimetic Encapsulation of Inorganic Nanoparticles. Melanie M. Tomczak[1], Heather R. Luckarift[2], Jim C. Spain[2], Morley O. Stone[1] and Rajesh R. Naik[1]; [1]Materials and Manufacturing Directorate, MLPJ Biotechnology Group, Air Force Research Laboratory, WPAFB, Ohio; [2]Airbase Technologies Division, Air Force Research Laboratory, Tyndall Air Force Base, Florida.

Sol-gel silica encapsulation of enzymes has been widely used, but the conditions under which the sol-gel reaction occurs often irreversibly damage the enzymes. We show that the silica matrix formed using a biomimetic approach can be used to encapsulate enzymes and inorganic nanoparticles at neutral pH and room temperature. Enzymes encapsulated in the biomimetically synthesized silica have levels of activity similar to the free enzymes, have an extended shelf-life and can be used several times without significant loss in enzyme activity. We also show that inorganic nanoparticles can be co-encapsulated with the enzymes. The entrapment of enzymes along with magnetic nanoparticles results in the formation of a catalytically active silica matrix that can be magnetically separated.

11:30 AM Z1.8
Structure-Based Design and Synthesis of Helical Glycoproteins. Robin S. Farmer[1,2], Jared D. Sharp[2], Ying Wang[1] and Kristi L. Kiick[1,2]; [1]Department of Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Delaware Biotechnology Institute, Newark, Delaware.

Multivalent protein-saccharide binding events mediate many biological processes such as inflammation, toxin pathogenesis, and metastasis. Although it is known that the nature of the scaffold and the number and spatial distribution of saccharides are critical in controlling binding, the structure-based design and chemical synthesis of polymeric materials for controlled presentation of saccharides has been synthetically challenging. We have therefore produced, via protein engineering methods, multiple families of alanine-rich, helical protein polymers that are equipped with glutamic acid residues that permit chemical attachment of saccharides in specific positions on the polymer chain. The alanine-rich helical protein polymers have been designed to present glutamic acid groups on a helical face at distances of approximately 17Å, 35Å, and 65Å; these distances are commensurate with the receptor spacing of a variety of toxins and lectins and therefore provide architectures that may show target-specific binding. Proteins from all three families are easily expressed and purified from cultures of E. coli and are shown via circular dichroism and infrared spectroscopy to be highly helical over a range of pH values and temperatures. Differential scanning calorimetry and CD investigations demonstrate that the conformational behavior of the macromolecules can be purposefully manipulated by varying temperature and solution conditions, which presents additional opportunities for controlling their structure and function. The helical conformation of the protein polymers is retained upon chemical modification with amine-functionalized monosaccharides, and the binding of glycosylated helical proteins to toxin targets has been characterized via immunochemical assays. These polymers have enormous potential not only in the construction of novel toxin inhibitors and cell signaling activators, but also in the design of macromolecules for other materials and device applications.

11:45 AM Z1.9
Renewable Resource Based Glycolipids: Assembly and Nanostructures. George John, Department of Chemistry, The City College of New York, New York, New York.

The self-assembly of low molecular weight building blocks into nanoscale molecular objects has recently attracted considerable interest in terms of the bottom-up fabrication of nanomaterials The building blocks currently used in supramolecular chemistry are synthesized mainly from petroleum-based starting materials. However, bio-based organic synthesis presents distinct advantages for the generation of new building blocks since they are obtainable from renewable resources. This study is an effort to combine the philosophies of green chemistry and supramolecular chemistry, making use of renewable plant-derived resources as the starting materials (an alternate feedstock) for the noncovalent synthesis of meso- and nanoscale structures. The use of cardanol (obtained from Anacardium occidentale L, a renewable resource and by-product of cashew industry) and its derivatives for various applications is well known. However its use in the synthesis of aryl glycolipids and their self-assembled nanostructures are new to the literature. The glycolipids are self-assembled to form a variety of well-defined nanostructures including liquid crystalline phases (thermotropic&lyotropic), vesicles, nanofibers, low-molecular weight gelators and nanotubes under suitable conditions, which could be of use in material applications. These results will lead to efficient molecular design of supramolecular nanostructures and nanomaterials based on green chemicals, otherwise under-utilised. Also address the advances that have led to the understanding of chiral behaviour and the subsequent ability to control the structure of glycolipid nanostructures-derived from renewable resources-and the resulting impact of this on future material applications.

SESSION Z2: Biomimetics/Biointerfaces/Bio-Inorganic Interfaces
Chair: Phillip Messersmith
Monday Afternoon, November 29, 2004
Room 304 (Hynes)

1:30 PM *Z2.1
Molecular and Mechanical Gradients in Structural Materials from Marine Organisms. Herbert Waite, Marine Science Institute, UCSB, Santa Barbara, California.

Most organisms consist of a functionally adaptive assemblage of hard and soft tissues. Despite the obvious advantages of reinforcing soft protoplasm with a hard scaffold, such composites can lead to tremendous mechanical stresses where the two meet. Although little is known about how nature relieves these stresses, it is generally agreed that fundamental insights about molecular adaptation at hard/soft interfaces could profoundly influence how we think about biomaterials.

Based on two noncellular tissues, mussel byssus and polychaete jaws, recent studies suggest that one natural strategy to minimize interfacial stresses between adjoining stiff and soft tissue appears to be the creation of a fuzzy boundary, which avoids abrupt changes in mechanical proper ties. Instead there is a gradual mechanical change that accompanies the transcendence from stiff to soft and vice versa. In byssal threads, the biochemical medium for achieving such a gradual mechanical change involves the elegant use of collagen-based self-assembling block copolymers. There are three distinct diblock copolymer types in which one block is always collagenous, whereas the other can be either elastin-like (soft), amorphous polyglycine (intermediate), or silk-like (stiff). Gradients of these are made by an incrementally titrated expression of the three proteins in secretory cells the titration phenotype of which is linked to their location. Thus, reflecting exactly the composition of each thread, the distal cells secrete primarily the si lk- and polyglycine-collagen diblocks, whereas the proximal cells secrete the elastin- and polyglycine-collagen diblocks. Those cells in between exhibit gradations of collagens with silk or elastin blocks. Spontaneous self-assembly appears to be by pH tri ggered metal binding by histidine (HIS)-rich sequences at both the amino and carboxy termini of the diblocks. In the polychaete jaws, HIS-rich sequences are expanded into a major block domain. Histidine predominates at over 20 mol % near the distal tip an d diminishes to about 5 mol % near the proximal base. The abundance of histidine is directly correlated to transition metal content (Zn or Cu) as well as hardness determined by nanoindentation. EXAFS analyses of the jaws indicate that transition metals su ch as Zn are directly bound to histidine ligands and may serve as cross-linkers..

2:00 PM *Z2.2
Metal-Protein Bonding in a Biological Adhesive Produced by Marine Mussels. Jaime T. Weisser, Mary J. Sever, Jennifer Monahan and Jonathan J. Wilker; Department of Chemistry, Purdue University, West Lafayette, Indiana.

The oceans abound with organisms producing a wide array of fascinating materials. For many of these biomaterials, detailed pictures of the bonding contained within remain to be discovered. We are working to understand the adhesives used by marine mussels for affixing themselves to surfaces. Mussels create their glue by surface application of a protein matrix followed by cross-linking of the proteins to yield a hardened material. The final, cured adhesive is rich in metals such as iron, zinc, and copper. We are performing experiments with adhesive collected from live mussels, protein extracted from the animals prior to curing of the material, and synthetic models representing potential bonding schemes in the glue. Each system is examined by multiple spectroscopic methods. Reactivity studies and materials testing techniques are also used to better understand the material. Our results suggest that iron begins the cross-linking process by chelating multiple protein strands. Subsequent iron-induced oxidation then yields a protein-based radical. This radical may be present to generate further protein-protein cross-links or possibly protein-surface adhesive bonds.

2:30 PM Z2.3
The adhesive role of DOPA in mussel glue proteins: single molecule force measurements. Haeshin Lee, Bruce P. Lee and Phillip B. Messersmith; Biomedical Engineering, Northwestern University, Evanston, Illinois.

Although most manmade adhesives do not form strong bonds in the presence of water, Nature has solved this problem in a number of species by utilizing specialized adhesive proteins for attachment to underwater surfaces. One such example is the protein bioadhesive of the marine mussel, which is secreted as a liquid that rapidly hardens into a solid adhesive used for securing rigid fixation of mussels exposed to mechanical forces in the intertidal environment. The unusual amino acid 3,4-dihydroxyphenylalanine (DOPA), which appears in concentrations above 20% in certain mussel adhesive proteins (MAPs), has been widely speculated as being responsible for the adhesive as well as the cohesive properties of these proteins. Unfortunately, current understanding of the role of DOPA in interfacial adhesion is based primarily on macroscopic mechanical measurements, often conducted under conditions which make it difficult to isolate the adhesive and cohesive contributions of DOPA. In fact, conclusive molecular-level experiments demonstrating the adhesive role of DOPA are lacking, and the nature and strength of interactions between DOPA and surfaces are largely unknown. In order to interpret existing data and provide some guidance into the rational design of synthetic MAP mimetic adhesives, we are utilizing single molecule force spectroscopy to measure the strength of interaction between a single DOPA residue and surfaces. Amine terminated silicon nitride tips were functionalized by conjugation of Fmoc-poly(ethylene glycol)-N-hydroxy succinimide, followed by deprotection of the Fmoc groups, and conjugation of N-Boc protected DOPA (Boc-DOPA) to the amine terminated PEG.. Force measurements arising from interactions between a single DOPA molecule and a titanium oxide (TiO2) surface were measured using atomic force microscopy. An average interaction force of 0.84 nN (n=50) was observed for interaction with TiO2, which is approximately four times larger than that of the avidin-biotin rupture force. In contrast, functionalization of the tip with tyrosine and phenylalanine resulted in low rupture forces, indicating the adhesive significance of the hydroxylation of tyrosine residues during formation of MAPs, and suggestive of chemical bonding specificity between TiO2 and DOPA. The relatively infrequent (1 in 10) measurement of adhesive force upon pull-off, in conjunction with clearly observed elastic chain extension of PEG (35 nm for 3.4k), support the conclusion that measured forces represent interaction between a single DOPA molecule and the surface. In conclusion, this study establishes a methodology for systematic investigation of adhesive interactions between DOPA and surfaces. The DOPA-TiO2 interaction is much stronger than noncovalent biological interactions, and approaches the strength of a covalent bond.

2:45 PM Z2.4
New Peptidomimetic Polymers for Antifouling Surfaces. Andrea Statz[1], Robert J. Meagher[2], Annelise E. Barron[2] and Phillip B. Messersmith[1]; [1]Biomedical Engineering, Northwestern University, Evanston, Illinois; [2]Chemical and Biological Engineering, Northwestern University, Evanston, Illinois.

Preventing biological fouling of surfaces is important for numerous health care technologies, since cell and protein adsorption can impair the function of medical devices or even cause catastrophic failure. Surface modification with poly(ethylene glycol) (PEG) has led to improved protein and cell resistance in a number of *invitro* studies; however, PEG has shown less desirable results in long term *invivo* studies, can be difficult to anchor onto certain biomaterial surfaces, and may be susceptible to enzymatic or chemical degradation *invivo*. Thus, significant motivation exists for the development of new polymers that exhibit resistance to protein and cell fouling, and which are resistant to degradation for long periods of time *invivo*. We are investigating poly-N-substituted glycine oligomers (polypeptoids), which are non-natural mimics of polypeptides that have a protein-like backbone with side chain derivatization at the amide nitrogen instead of the alpha-carbon. Unlike natural polypeptides, polypeptoids are protease-resistant and exhibit a low-level immune response *invivo*, which suggests that these biomimetic polymers may be useful medical materials. In this study, we report the synthesis and characterization of a novel chimeric peptidomimetic polymer consisting of a polypeptoid nonfouling segment coupled to an adhesive peptide designed to provide robust anchoring of the polypeptoid onto surfaces. The polypeptoid was composed of (N-methoxyethyl) glycine repeat units, chosen so as to resist protein and cell fouling as well as provide improved immune response and protease resistance over natural polypeptides. For anchoring onto surfaces, the polypeptoid was coupled to a mussel adhesive protein (MAP) mimetic peptide enriched in 3,4-dihydroxyphenylalanine (DOPA) and lysine, mimicking the adhesive proteins Mefp3 and Mefp5 of *Mytilusedulis*. The peptidomimetic polymer was found to adsorb strongly to titanium oxide surfaces upon exposure to an aqueous solution of the polymer, and the ability of modified surfaces to resist cell attachment was examined by culturing 3T3 fibroblasts on the surfaces. Modified TiO2 surfaces exhibited a significant reduction in cell attachment and spreading when compared to control surfaces after 4 hours of culture, and low cell adhesion for up to 10 weeks in culture. These results indicate that the nonfouling properties of polypeptoid modified surfaces are not compromised by long term contact with serum-containing fluids. The low cell adhesion results can be explained in part by minimal nonspecific adsorption of human serum components, as indicated by optical waveguide lightmode spectroscopy (OWLS) experiments conducted on DOPA-polypeptoid modified surfaces. The general utility of chimeric peptidomimetic polymers for preventing biological fouling of surfaces has been demonstrated, and may lead to new strategies for preventing *invivo* fouling of surfaces by proteins and cells.

3:30 PM Z2.5
Engineered Peptides for Directed Nanomaterial Synthesis. Erik David Spoerke, James C. Voigt and Bonnie B. McKenzie; Sandia National Laboratories, Albuquerque, New Mexico.

Proteins exert critical influences over the form and function of natural inorganic materials ranging from calcium carbonate in the aragonite of abalone shells to iron oxides in magnetotactic bacteria. Following Nature's example, we have taken advantage of the chemical function, charge, and hydrophilic or hydrophobic character of the amino acid building blocks composing these biomolecules to synthesize designer peptides for technological applications. We have used these engineered peptides to influence the growth of technologically important materials such as cadmium sulfide, zinc oxide, and zinc sulfide. Applying these engineered molecules under aqueous conditions, inorganic crystal growth was regulated and directed on nanometer

length scales. In addition, these peptides were used to integrate these nanostructured materials into multi-component heterostructures with potentially unique materials properties. We report here on the design and synthesis of these biologically-derived molecules and the results of their applications to hard nanomaterials. This bio-inspired approach to materials synthesis intercepts biological molecular chemistry with hard materials synthesis to create powerful tools for complex materials development.

3:45 PM Z2.6
Protein-directed self-assembly of metal nanoparticles.
Alexey A. Vertegel[1], Jonathan S. Dordick[3] and Richard W. Siegel[1,2]; [1]Rensselaer Nanotechnology Center, Rensselaer Polytechnic Institute, Troy, New York; [2]Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy, New York; [3]Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, New York.

Many proteins and peptides are known to form self-assembled structures. Use of protein-directed self-assembly provides exciting opportunities for creating nanostructures due to the diversity of possible forms (wires, rings, catenans) that can be achieved and the possibility to control the assembly/disassembly process *insitu*, since proteins are extremely sensitive to minor changes in such parameters as pH, Ca^{2+} concentration, presence of ATP, etc. In addition, protein-protein interactions are characterized by very high specificity. In the present work, we employ the highly specific interaction between lectin protein concanavalin A and glycoprotein horseradish peroxidase for assembly of colloidal gold and silver nanoparticles. The proteins were attached to the corresponding nanoparticles by either physical adsorption or by covalent binding to self-assembled monolayers on Au and Ag nanoparticles. The conditions were optimized so that only one protein molecule was attached to each nanoparticle. The conjugates were then visualized by atomic force microscopy and characterized by surface enhanced Raman spectroscopy. Attempts were also taken to assemble nanowires using the ability of another protein, tubulin, to form uniform microtubules with 25 nm diameter. In this case, gold nanoparticles were covalently attached to tubulin dimers in aqueous solution, and labeled tubulin was allowed to polymerize in the presence of ATP. Thus formed microtubules were treated by paclitaxel to avoid depolymerization of tubulin. The tubulin-Au composites were characterized by atomic force microscopy. We believe this approach may prove useful, not only for the formation of the assemblies of nanoparticles with bio-inspired structures, but also for probing/visualizing the structure of various protein-protein complexes. The materials synthesized by protein-directed self-assembly may find applications in drug delivery or as biosensors. This work was supported by the Nanoscale Science and Engineering Initiative of the National Science Foundation under NSF Award No. DMR-0117792.

4:00 PM Z2.7
Biomimetic Catalysts of Silica Synthesis for Encapsulation of Proteins and Cells at Neutral pH. Kristian M. Roth[1,3,2], Yan Zhou[2], Wenjun Yang[2], James Weaver[2], Jan Sumerel[2] and Daniel E. Morse[1,2,3]; [1]California Nanoysystems Institute, University of California Santa Barbara, Santa Barbara, California; [2]Marine Science Institute, University of California Santa Barbara, Santa Barbara, California; [3]Institute For Collaborative Biotechnologies, University of California Santa Barbara, Santa Barbara, California.

Silicatein is an enzyme isolated from the biosilica produced by the marine demosponge Tethya aurantia. The enzyme apparently catalyzes the synthesis of silica needles in vivo which the sponge then uses for structural support. Once isolated from the sponge, silicatein can be used in vitro to catalyze the hydrolysis and direct polycondensation of a wide variety of alkoxide, ionic and organometallic precursors to yield the corresponding chalcogens at standard temperature and pressure and neutral pH. Site-directed mutagenesis of the cloned DNA encoding silicatein revealed that two specific amino acids, serine26 and histidine165, are essential for catalysis. Based on these results, an array of small molecules that mimic the unique physiochemical environment found in the enzyme active site were investigated for catalytic activity. A number of biomimetic small molecules have been screened for catalytic activity towards silica formation from tetraethylorthosilica at neutral pH. The most successful catalyst was used to encapsulate firefly luciferase and E. coli cells expressing green fluorescent protein (GFP) in a silica matrix. The benign process used in the synthesis of these silica composites does not impair the inherent function of the encapsulated proteins as shown by fluorescence measurements. By using encapsulation in conjunction with micro-contact printing, patterned arrays of silica nanoparticulate composite materials can be fabricated. Micromolded silica-encapsulated firefly luciferase and E. coli cells expressing GFP were deposited on a silicon wafer to highlight the utility of this technique.

4:15 PM Z2.8
Binding and Specificity of Engineered Polypeptides on Functional Inorganics. Eswaranda Venkatasubramanian, Memed Duman, Turgay Kacar, Daniel Heidel, Emre E. Oren, Candan Tamerler and Mehmet Sarikaya; Materials Science and Engineering, University of Washington, Seattle, Washington.

In biological hard tissues, proteins control inorganic materials assembly, morphogenesis and formation through molecular recognition and specific binding. Instead of natural proteins which may be large and complex, hard to isolate and purify and difficult to use in reconstruction of the hybrid structures, one can use molecular biology technologies, such as directed or forced evolution to obtain inorganic-binding polypeptides. Combinatorial techniques such as cell-surface and phage display have been used to select short polypeptide sequences (7-12 amino acids) that bind to noble metals (Au, Pt, and Pd) and oxide semiconductors (ZnO, Cu2O, and Al2O3) [1]. These polypeptides are used as molecular erectors in assembly or immobilization of nanoparticles, and as agents in bionanofabrication. The understanding of the nature of molecular recognition and binding characteristics of these engineered polypeptides need to be well understood to further engineer their molecular structure and, thereby, utilize them more effectively as molecular biomimetic building blocks in nano- and bionanotechnology. Here we present the binding characteristics of gold binding protein (GBP) that was selected using cell surface display and post-selection engineered to assemble and form ordered nanostructured molecular films. We use a combination of surface plasmon resonance (SPR), quartz crystal microbalance (QCM), and atomic force microscopy (AFM) quantitative binding, assembly and formation on oriented gold surfaces The GBP was used in single repeat and 3, 5, 6, 7, and 9 repeats of the single sequence of MHGKTQATSGTIQS. While AFM provided molecularly ordered structural information, both QCM and SPR were used to examine adsorption processes and provided quantitative binding information under controlled solution environments (such as composition, pH, temperature) as well as kinetic parameters such as binding rates, equilibrium constants and binding energies. The experiments, e.g., in the case of 3repeat-GBP, were carried out in the concentration range of 0.5 to 4 microgm/mL (QCM) and 0.2 to 0.43 microgm/mL (SPR). The data was fit to a simple Langmuir 1:1 adsorption model to obtain kon and koff for both techniques. The kinetics was well described by a single exponential in the case of QCM while distinct biexponential kinetics was observed for the data from SPR. The two-step adsorption in SPR is explained as being due to surface heterogeneity of the substrates. The binding energies obtained using the two techniques were comparable within the range of experimental error and were much higher than those for thiol adsorption to gold from an ethanolic solution. The results show promise for using such genetically engineered protein as molecular scaffolds and also as an alternative to thiols with significant advantages as discussed in specific applications discussed in this presentation.

4:30 PM Z2.9
Artificial Bone Synthesis Based on Hydroxyapatite Binding Protein Template. Seung-Wuk Lee[1,2], Jie Song[1,2] and Carolyn R. Bertozzi[1,2]; [1]Molecular Foundry, Lawrence Berkeley National Lab, Berkeley, California; [2]Chemistry, University of California, Berkeley, California.

Hydroxyapatite binding peptides were selected using combinatorial phage library display. The phage library contained one billion different amino acid sequences which were expressed on pIII coat proteins of M13 bacteriophage, then screened to find specific binding moieties against single crystalline hydroxyapatite surfaces. After fourth round of selection, pseudo-repetitive consensus amino acid sequences possessing periodic hydroxyl side chains in every two or three amino acid sequences were obtained. These sequences resembled the (Gly-Pro-Hyp)x repeat of human type I collagen, a major component of extracellular matrices of natural bone. In addition, a consistent presence of basic amino acid residues was also observed. These peptides were synthesized and then used to template the nucleation and growth of hydroxyapatite nanocrystals. Various electron microscopy techniques (TEM, SEM and EDS) were used to characterize the shape and orientation of mineral growth of the peptide-mineral composites. These mineral binding peptides are expected to be further incorporated into 3-dimensional biomimetic bonelike materials.

4:45 PM Z2.10
Biotechnology and Biomimetics Opens New Routes to the Fabrication of Silica and Metal Oxide Semiconductors.
David James Kisailus[1,2,3], Mark Najarian[1,2,3], James C. Weaver[1,2,3], Yosuke Amemiya[1,3], Joon Hwan Choi[2], Wenjun Yang[1,3], Jan L. Sumerel[1,3], Kristian Roth[1,3], Meredith Murr[1,3,4], Youli Li[1] and Daniel E. Morse[1,3,4]; [1]California NanoSystems Institute, University of California at Santa Barbara, Santa Barbara, California; [2]Materials Research Laboratory, University of California at Santa Barbara, Santa

Barbara, California; [3]Institute for Collaborative Biotechnologies, University of California at Santa Barbara, Santa Barbara, California; [4]Dept. of Molecular, Cellular, and Developmental Biology, University of California at Santa Barbara, Santa Barbara, California.

Working with silica needles produced by marine sponges, our laboratory discovered that the proteins we named silicateins, catalyze and structurally direct the polymerization of silica from silicon alkoxides at neutral pH and low temperature. The silicateins are true enzymes, closely related to a well-known family of hydrolases. Site-directed mutagenesis (genetic engineering) of the cloned recombinant DNAs coding for the silicateins has allowed us to confirm the mechanism of catalysis we postulated for the enzymatic polycondensation of siloxanes from the alkoxide substrates. These studies enabled the synthesis of self-assembling biomimetic catalysts that incorporate essential functionalities we identified for catalysis in the natural enzymes, yielding new nanostructure-directing catalysts of polymerization. Most recently, we discovered that the silicateins also catalyze and structurally direct the hydrolysis and polycondensation of the molecular precursors of such metal oxides as gallium oxide, titanium dioxide, zinc oxide, and cobalt hydroxide. These are the first reported examples of enzyme-catalyzed, nanostructure-directed synthesis of these materials and the first such syntheses at low temperature and neutral pH. Interestingly, interaction with the template-like protein surface is capable of stabilizing polymorphs of these materials that otherwise are not normally observed at low temperatures. Thus, for example, nanocrystallites of anatase titanium dioxide, gamma-gallium oxide and gallium oxohydroxide are formed on the protein at room temperature. Perhaps most remarkably, in some of these cases the interaction between the condensing metal oxide and the protein results in preferential alignment of the resulting nanocrystallites of the mineral, suggesting an epitaxial-like relationship between the mineral crystallite and specific functional groups on the templating protein surface. Recent results confirm our suspicions that the underlying protein has a crystalline structure capable of producing a repetitive crystalline template upon which the metal oxide may order. Biomimickry is currently being used to catalyze and template the growth of various metal oxides. We are incorporating analogs of the critical amino acid residues found in silicateins catalytic active site, anchoring these functional groups (via self-assembled monolayers on gold) adjacent to one another to facilitate catalytic activity by the same mechanism exhibited by the enzyme. Results have shown that biomimetics of the active site in silicatein are capable of producing silica from alkoxide precursors at neutral pH. We presently are attempting to extend the genetic engineering approach described above to identify and then harness the natural structure-directing determinants of the protein. Potential uses of this low-temperature, neutral pH route for nanostructure-directed synthesis are under investigation for optical and electronic applications, sensors, and pharmaceuticals.

SESSION Z3: Poster Session: Biopolymers, Biomimetics, Nanostructures, Biophotonics
Chair: Phillip Messersmith
Monday Evening, November 29, 2004
8:00 PM
Exhibition Hall D (Hynes)

Z3.1
Conformational Behavior of Alanine-Rich Protein Polymers with Varying Functional Group Placement. Robin Farmer[1,2], Lindsey Argust[3], Jared Sharp[2], Christopher Roberts[3] and Kristi Kiick[1,2]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Delaware Biotechnology Institute, University of Delaware, Newark, Delaware; [3]Chemical Engineering, University of Delaware, Newark, Delaware.

The synthesis of protein-based polymers with controlled conformational properties and functional group placement offers many opportunities for the design of advanced materials. In this work, protein engineering methods have been used to produce three new classes of repetitive alanine-rich proteins with the general sequence $[(AAAQ)_xAAAE(AAAQ)_x]_y$. These sequences were designed on the basis of the high helical propensity of alanine, and may mimic architectural features of certain alanine-rich helical sequences found in natural proteins such as the antifreeze proteins. Variations in this sequence allow for variations in both the spacing and the number of chemically reactive glutamic acid residues along the protein backbone. The three families of alanine-rich proteins have been designed to display glutamic acid residues at nominal distances of 17Å, 35Å, and 65Å, and members of each family can be easily expressed from E. coli. Circular dichroism spectroscopy (CD) characterization of these proteins demonstrates that purified proteins of all three families are highly helical, and both CD and infrared spectroscopic methods indicate that the helical character of the proteins can be altered with increasing temperature and protein concentration. Thermal analysis via differential scanning calorimetry (DSC) and CD indicates that the conformational behavior of the proteins from the three families differs at elevated temperatures and can be manipulated depending on solution conditions. The demonstrated control of the conformational properties of these artificial proteins suggests that they may be excellent candidates for use in nanotechnology and biological applications.

Z3.2
Abstract Withdrawn

Z3.3
Characterization of Elastin-Like Polypeptide Block Copolymers. Matthew R. Dreher[1], Karl Fischer[2], Manfred Schmidt[2] and Ashutosh Chilkoti[1]; [1]Biomedical Engineering, Duke University, Durham, North Carolina; [2]Institut f. Physikalische Chemie, University of Mainz, Mainz, D-55099, Germany.

Amphiphilic macromolecules that self-assemble into supramolecular structures such as micelles and gels have numerous applications in drug delivery and tissue engineering. Stimuli-responsive amphiphilic macromolecules are an especially interesting class, in that their self-assembly can be triggered by an external signal. Elastin-like polypeptides (ELPs) are temperature sensitive biopolymers composed of a Val-Pro-Gly-Xaa-Gly pentapeptide repeat (where the guest residue, Xaa, is any amino acid except Pro) derived from a structural motif found in mammalian elastin. These biopolymers undergo an inverse temperature phase transition; i.e. they are soluble at temperatures below their transition temperature (T_t) but become insoluble and aggregate at temperatures above their T_t. In this study we have synthesized and characterized ELP block copolymers that are highly water soluble biopolymers at room temperature but become amphiphilic and self-assemble in response to an increase in solution temperature. An ELP block copolymer consists of two separate ELP genes ligated together by recursive directional ligation. One gene that encodes block A is designed to have a high T_t (>70 °C), while the other gene has a lower T_t (35 °C), and is termed block B. Therefore, at low temperatures the biopolymer is highly water soluble but upon an increase in solution temperature, above the T_t of the B block, the ELP block copolymer becomes an amphiphile as the B block undergoes its inverse temperature phase transition and becomes more hydrophobic. The structures that form at this intermediate temperature are determined by the ratio of the hydrophilic to hydrophobic segments (A:B) and molecular weight (MW) of the ELP block copolymer. We have systematically varied the hydrophilic to hydrophobic ratio of these ELP block copolymers and examined their assembly process with UV-vis spectrophotometry and both static and dynamic light scattering. When the ratio is 1:1, 2:3 or 3:2 the ELP block copolymers form micelles (coordination number $\approx$ 64) at intermediate temperatures; however, when the ratio is 1:3 a micelle is not formed. The initial increase in optical density when raising the solution temperature occurs 4 °C higher for the block copolymer than for the parent ELP that comprises the B block, potentially due to influences from the A block. Upon a further increase in temperature, the A block undergoes its inverse temperature phase transition and a bulk gel is formed. The gelation temperature appears to be independent of MW (T_t is normally dependent upon MW for pseudorandom copolymers of ELPs) potentially due to the close proximity of the A blocks in the corona of the micelle. Presently we are investigating additional ELP block copolymers over a wider range of hydrophilic to hydrophobic ratios and MWs to better define a common set of rules that govern the self assembly of these novel biopolymers.

Z3.4
Biomimetic Modeling of Spider Silk Fiber Spinning. Gino De Luca and Alejandro Daniel Rey; Chemical Engineering, McGill University, Montreal, Quebec, Canada.

Spiders' silks are fiber materials with outstanding combination of toughness, strength, lightness and flexibility. High performance fibers mimicking spiders' silks have many possible applications including medical sutures, biodegradable fishing lines, soft body armor and unique composite materials. The precursor material in the biospinning process of spiders is a liquid crystalline phase that greatly affects the microstructure of the drawn silks and therefore is outstanding physical properties. At present time there is a great interest in developing a fundamental understanding of the precise role played by liquid crystallinity in biospinning process. Development of this fundamental knowledge will lead to the development of environmentally sound, novel and more efficient bio-inspired spinning routes. In this work, a model is being developed to simulate the evolution of the liquid crystalline material during the biospinning process leading to the silk thread. The simulations capture the main micro-structural changes in the duct

of the silk spinning apparatus between the spider's gland and spinneret.

Z3.5
Similarity Analysis of Genetically Engineered Polypeptides for Inorganics. Ersin Emre Oren, Deniz Sahin, Candan Tamerler and Mehmet Sarikaya; Materials Science and Engineering, University of Washington, Seattle, Washington.

There is a rapid increase in the number of identified short peptide sequences selected by using combinatorial biology protocols, such as phage display and cell surface display. There are now genetically engineered polypeptides for inorganics (GEPI) selected for inorganic materials such as noble metals (Au, Pt, Pd, and Ag), other metals (Co and Ti) Oxides (SiO2, Al2O3, Cu2O, Fe2O3, Cr2O3) and semiconductors (PbS, ZnO, GaAs and GaN). In biomolecular sequences (DNA, RNA, or amino acids), high sequence similarity usually implies major functional or structural similarity. Sequence alignment, which is an essential tool in molecular biology, is used to compare two or more sequences by searching for a series of individual components that are in the same order in both sequences. In this study, we developed an approach to obtain a correlation between the substrate material and their identified specific sequences in terms of their binding specificities and affinities via multiple sequence alignment analysis. Here, the basic idea, which is analogous to homology of proteins in different organisms, is to create a logical method in order to define a similarity score of sequences in a given set of binders. Sequences that are very similar probably have a similar structure and/or function such as binding to the specific inorganic surfaces. The results indicate that the self-similarity score of a set of peptides for a given inorganic is relatively higher, especially if only the strong binders is used, than the cross-similarity scores between different sets of peptide groups specific to different inorganic materials. Our goal is to develop a modeling protocol to categorize master sequences of different affinity binders for a given materials surface or a group of materials.

Z3.6
Application of an Analytical N-Particle Stochastic Technique to Protein Folding. Arun K. Setty, Bioengineering, University of Illinois at Chicago, Chicago, Illinois.

An analytical technique is presented to study protein folding. The technique is based on a solution of an N-particle Fokker-Planck equation using a novel path-integral approach. An N-particle configurational probability distribution function has been obtained in closed form for a system of N particles which are interacting via harmonic interactions. This makes it possible to study the evolution of the system along the folding trajectory as a function of time. The probability distribution peaks at the most probable configurations at any given time; consequently multiple pathway information is obtained from analytically studying the probability distribution evolution from a single unfolded starting point. Freedom of choice of the interaction constants makes it possible to explore different parameterization schemes. Results for proteins showing the pathway information and reaction rates, and candidate intermediate states will be presented. The N-particle approach makes it possible to incorporate increasing structural complexity without prohibitive time constraints. This technique has promise for comprehensive studies (within the limits of the interaction potential) of large protein systems, making large scale protein engineering studies possible.

Z3.7
Molecular Biomimetics: Engineered Polypeptides for Nano and Nanobio-Technology. Candan Tamerler[1,2] and Mehmet Sarikaya[2,1]; [1]Materials Science and Engineering, University of Washington, Seattle, Washington; [2]Molecular Biology and Genetics, Istanbul Technical University, Maslak-Istanbbul, Turkey.

Physical and chemical functions of organisms are carried out by a very large number (billions) of proteins through predictable and self-sustaining interactions. Using biology as a guide, we design, synthesize, genetically tailor and utilize short polypeptides for potential molecular linkers in self-assembly, ordered organization, and fabrication of nanoinorganic materials and molecularly hybrid systems in nanotechnology (molecular electronics and photonics) and nanobiotechnology (bio-sensors, -assays, and -materials). Our objectives are accomplished in four task areas:1,2 Task-I: Selection of inorganic-binding short (7-15) polypeptides (genetically-engineered proteins for inorganics, GEPI) using adapted combinatorial biology protocols using metals, oxides and semiconductors; Task-II: Quantitative assessment of the nature of binding and assembly of GEPI on inorganics using experimental (SPR, QCM, AFM, NMR, TOF-SIMS) and modeling (e.g., molecular dynamics) approaches; Task-III: Nanoassembly using GEPI-functionalized designer proteins (e.g., chaperonins, phages, and S-layer proteins), DNA/DNA-binding protein complexes, and electrochemically prepared nano-patterned substrates; Task-IV: Creation of synthetic/biological molecular hybrids and inorganics using GEPI as molecular erectors in functional materials and systems for potential utility in a wide variety of applications in engineering and biotechnological fields. 1. M. Sarikaya, C. Tamerler, A. Jen, K. Schulten, & F. Baneyx, Nature-Mater., 2(9) 577-85 (2003). 2. M. Sarikaya, C. Tamerler, D. Schwartz, & F. Baneyx, Ann. Rev. Mater. Res., 34, 375-408 (2004). Supported by SPO-Turkey and ARO-DURINT, AFOSR, NSF, Murdock, and NICDR, of USA.

Z3.8
The Morphological Aspects and 3D-Architecture of Air-Dried Gel Films of Biological Materials for THz Spectroscopic Characterization. Vladimir P. Oleshko[1], Irina N. Oleshko[2], Tatiana B. Khromova[2] and James M. Howe[1]; [1]Materials Science and Engineering, University of Virginia, Charlottesville, Virginia; [2]Electrical and Computing Engineering, University of Virginia, Charlottesville, Virginia.

THz-frequency spectroscopic studies of various biomaterials using Fourier Transform Infrared spectroscopy demonstrate the existence of multiple dielectric resonances at frequencies varying from 10 cm^{-1} to 25 cm^{-1}, thus indicating the potential to provide reliable structural characterization of biopolymers. In addition to a high sensitivity to conditions of sample preparation and aging, THz-spectral features for various biomaterials, such as natural and artificial DNA and proteins, exhibit significant orientation dependence. The alignment of the material can facilitate mode detection and can be used to evaluate macromolecular orientation and anisotropy. In order to better understand the causes for such spectral variability, we have investigated the texture, morphology and 3D-structural arrangement of air-dried gel films deposited onto polycarbonate membrane filters for THz spectroscopic analyses of biomaterials, Bacillus globigii (Bg, spores and lyophilized cells) and white chicken egg albumin, or ovalbumin (Ov). Digital light microscopy (LM) in reflection and polarization modes revealed a macrostructure texture of red- and yellow-brown gel Bg films and a surface relief that are influenced by the texture of the polycarbonate membranes as well as large irregular pores on the surface up to 5 μm in size. Further examinations of the film micro- and nanostructures by high-resolution field emission scanning electron microscopy (FE-SEM, x1,000-x300,000) in secondary electrons provided much more details on the multi-row (ranging from 10 to about 40 layers) structural arrangement of the Bg films comprising 2-10 μm-sized ordered domains. These domains usually consist of 5-15 uniformly aligned cylindrical spores embedded in the matrix and numerous preferentially elongated fine pores with sizes starting from about 100 nm. Single amorphous-like spores of 300-450 nm in diameter and of 1.4-1.5 μm in length and 20-30 nm-thick continuous shells were identified on the surfaces of the Bg gel films by high-resolution FE-SEM. For lyophilizied Bg cells, individual spores of the same sizes were observed by FE-SEM and FE-transmission electron microscopy (FE-TEM, x10,000-1,200,000) in conjunction with ultradispersed agglomerated intracellular material exhibiting various sphere-like nanostructures of 20-40 nm in size. For fragile green-yellowish Ov films, local variations in the reflection LM contrast have been revealed due to the presence of a surface relief caused by oriented fragments of 10-30 μm in length. On the contrary to the Bg films, most of surface areas in the dense Ov films examined by FE-SEM showed a preferentially smooth largely structureless relief and cracks with no appearance of any individual structural elements. SEM images of cross-sections demonstrated local uniformity of the Ov films about 20 μm in thickness. The structural variations observed in gel films of biomaterials may help to understand and control the THz spectral signature variability.

Z3.9
A High-Throughput Investigation of the Processing Conditions for Ultra-Thin Silk Films. David M. Phillips, Lawrence F. Drummy, Barry L. Farmer, Robert A. Mantz, Richard A. Vaia, Morley O. Stone and Rajesh R. Naik; Materials and Manufacturing Directorate, 3005 Hobson Way, Air Force Research Laboratory, Wright-Patterson AFB, Ohio.

As a natural material, silkworm (*Bombyxmori*) silk is an interesting material that is the subject of much research. The remarkable properties of silk depend on both the protein sequence and the processing conditions imposed by the silkworms during the silk spinning process. In this work, we divert from trying to replicate the natural silk spinning process and employ a flow coating technique to produce optically clear, smooth films with an average thickness near 100 nm. The flow coating technique is especially geared towards high-throughput processing, as the local film thickness is related to the shear rate. Coupled with a temperature gradient that is orthogonal to the shear field, the effect of both film thickness and drying/annealing temperature on the film properties is analyzed. This high-throughput technique allows for rapid analysis of the process parameter space. For the flow coating process, three types of solution were examined: natural gland solution from dissected silkworms,

regenerated silk in 1,1,1,3,3,3-hexafluoroisopropanol, and regenerated silk in a saline buffer. In addition, the gland and saline-based solutions are adjusted for pH to mimic the pH decrease of the gland solution as it moves towards the spinnerets.[1] The film properties resulting from these three solutions and their relationships to the processing conditions are compared and contrasted. [1] Magoshi, J.; Magoshi, Y.; and Nakamura, S., In Silk Polymers: Materials Science and Biotechnology; Kaplan, D.; Adams, W.W.; Farmer, B.; and Viney, C.; Eds.; ACS Symp. Ser.; American Chemical Society: York, PA, 1994; Vol. 544; pp. 292-310.

Z3.10
Abstract Withdrawn

Z3.11
Preparation of Apatitic Calcium Phosphates Stable at 1500C.
Cuneyt Tas, Kenneth Michael Evans and Sarit B. Bhaduri; Materials Sci. and Engineering, Clemson University, Clemson, South Carolina.

Hydroxyl ions located along the unit cell edges of calcium hydroxyapatite [HA: Ca10(PO4)6(OH)2] are suspected to be the cause of poor flexural strength and fracture toughness of synthetic calcium phosphate-based bone substitute and dental implant materials. The goal of this study was to develop a robust synthesis protocol in preparing apatitic calcium phosphate implant materials whose hydroxyl ions were to be fully replaced with oxygen (i.e., oxyapatite or dehydrated apatite). Apatitic (i. e., Ca/P ratio 1.67) calcium phosphate samples of superior thermal stability were prepared by solid-state reactive firing of the powder mixtures of finely ground ammonium dihydrogen phosphate (NH4H2PO4) and calcium acetate monohydrate (Ca(CH3COO)2H2O) under a flow of oxygen gas. The powder mixtures conformed to the Ca/P molar ratio of 1.67 in all the samples. Entire heating and cooling process was performed in flowing oxygen over the temperature range of 300 to 1500C. Starting powder mixtures, when fired under an oxygen atmosphere over the temperature range of 25 to 1200C, displayed only about 1% total weight loss. The products of this new synthesis procedure were also found to be stable against decomposition even after firing at 1500C. Thermal evolution of the precursor calcium phosphate phases, as well as the eventual, dehydrated apatite formation, was monitored by thermogravimetry (TG/DTA) and infrared spectroscopy (FTIR) analysis. X-ray diffraction (XRD) was used for phase identification at each and every stage of sample preparation. Surface morphology of the samples was investigated with scanning electron microscopy (SEM). Vickers hardness and fracture toughness measurements were performed to assess the mechanical properties of these new biomedical implant materials.

Z3.12
Characterization of Biologically Synthesized Titania.
Laura A. Sowards, Melanie M. Tomczak, Lawrence F. Drummy, Augustine M. Urbas, Timothy J. Bunning, Morley O. Stone and Rajesh R. Naik; Air Force Research Laboratory, Materials and Manufacturing Directorate, WPAFB, Ohio.

A biomimetic approach towards synthesis of inorganic nanoparticles, using peptides as templates, has been successful with several inorganic substrates. Here, we used a combinatorial peptide library to identify peptides that bind to and form titania nanoparticles. To simplify this process, we used the water-soluble titanium precursor Titanium (IV) bis(ammonium lactato)dihydroxide (Ti-BALDH) in the formation of the nanoparticles. The reactions have been performed at several different temperatures and/ or have been annealed at several temperatures after the reaction components have been mixed. X-ray diffraction revealed that different crystal structures were formed under different experimental conditions.

Z3.13
Synthesis and Processing of Ceramic Films Using an Organic Template.
Guangneng Zhang[1], Kaustubh Chitre[1], Quan Yang[1], Tolulope Salami[2], Scott Oliver[2] and Junghyun Cho[1]; [1]Mechanical Engineering, SUNY Binghamton, Binghamton, New York; [2]Chemistry, SUNY Binghamton, Binghamton, New York.

A low-temperature solution technique is employed to deposit the ceramic/self-assembled monolayer (SAM) bilayer coatings for surface protection of base materials (e.g., Si, polymers). Specifically, phosphonate-based (diethyl phosphatoethyl triethoxy silane) SAM is used as a template, onto which a ceramic layer is grown *insitu* in a precursor solution. This process mimics a biological synthesis of inorganic films ('biomimetic' synthesis). It is shown that surface functionality of the SAM plays a crucial role in the ceramic film growth due to: i) providing surface nucleation sites for the ceramic film, ii) promoting electrostatic interaction between the bulk precipitates and SAM surface. The resultant ceramic films consist of sub-micron sized spheres that are formed by an enhanced hydrolysis of zirconium sulfate ($Zr(SO_4)_2{\cdot}4H_2O$) solutions in the presence of HCl at $\approx 80^{\circ}$C. The reactions to grow the ceramic film are pH sensitive. The mechanism of film formation is systematically studied by tailoring the film structure and processes from various deposition conditions and solution chemistries. Further, microstructure and microchemistry of the films are characterized via XRD, AFM, SEM/EDS and nanoindentation. This study will thus provide a fundamental understanding for the formation of the ceramic (inorganic) film on an organic template.

Z3.14
Mimicking Gecko's Foot-hairs Using Anodic Aluminum Oxide Templates.
Chun-Wen Kuo[1,2], Jau-Ye Shiu[1], Kung Hwa Wei[2] and Peilin Chen[1]; [1]Research Center for Applied Sciences, Academia Sinica, Taipei, Taiwan; [2]Department of Material Science and Engineering, National Chiao Tung University, Hsin Chu, Taiwan.

It has been discovered recently that the amazing climbing ability of geckos can be attributed to their nanometer-size keratin hairs, which can produce 10^{-7} N adhesion force each and 10N/cm^2 with million of them. It was suggested that both van der Waals force and capillary interaction played important roles in the adhesion mechanism. In order to mimic the adhesion behavior of gecko's foot-hair, we have utilized anodic aluminum oxide (AAO) as templates for spin-coating of Teflon solution (AR 1601). After removal of the AAO templates, the Teflon nanofibers can be produced. The diameter and length of these nanofibers were about 200 nm and 60 μm, respectively. The water contact angle measured on these nanofiber surfaces was about 160 degree. One square centimeter of these nanofibers were capable of holding 40 g weight.

Z3.15
Processing and Morphology for Bio-Inorganic Nanohybrid Containing Polyurethane-g-Gelatin-co-PMMA and Metal Oxide.
Ken Heng See, Michael E. Mullins and Patricia A. Heiden; Chemical Engineering, Michigan Technological University, Houghton, Michigan.

With the aim of developing an ideal biodegradable and flexible nanohybrid in the application of tissue engineering and biomedical field, a bio-inorganic material was developed using polyurethane-g-gelatin-co-PMMA and aluminum isopropoxide. Gelatin, a natural protein, is obtained by thermal denaturation or physical and chemical degradation of collagen. In this chapter, the processing, structure and properties of polyurethane-g-gelatin-co-PMMA/aluminate nanohybrid are discussed. Also the influence of processing conditions on the structural characteristics of this nanohybrid, and the relationship between the physico-thermal properties of the nanohybrid are discussed. The polyurethane-g-gelatin-co-PMMA/aluminate nanohybrid was analyzed for its physicochemical properties by fourier transform infrared spectroscopy, differential scanning calorimetry and thermogravimetric analysis, and transmission electron microscopy.

Z3.16
A Physical Elution Approach to Selection Inorganic-Binding Polypeptides Using Ultrasonication via Phage Display.
Senem Donatan[1], Hilal Yazici[2], Hakan Bermek[2], Mustafa Urgen[1], Candan Tamerler[2,3] and Mehmet Sarikaya[3,2,1]; [1]Materials Science and Engineering, Istanbul Technical University, Maslak-Istanbul, Turkey; [2]Molecular Biology and Genetics, Istanbul Technical University, Maslak-Istanbul, Turkey; [3]Materials Science and Engineering, University of Washington, Seattle, Washington.

Genetically engineered polypeptides for inorganics (GEPIs) offer novel molecular linkers for use in nano- and bionanotechnology [1]. Phage Display is a combinatorial based molecular library method adapted from molecular biology for the selection of polypeptides with a specific binding affinity to a given inorganic material. Recently GEPIs have been selected for noble metals, oxides and semiconductors using both phage and cell surface display methods, each of which have advantages and disadvantages. For example, phage display method has certain limitations such as being time consuming and error prone protocol. In addition, several cycles of chemical elution are used during the biopanning process for the removal of bound and, presumably, specific phages to the material. An often limiting factor at this stage is inability of removing all specific binders. Here we introduce a physical elution step based on ultrasonication, that increases the removing efficiency of surface specific binders and, at the same time, shorthens the time of biopanning. We used a natural mineral, mica, for screening using the Ph.D.-C7C library and developed the optimum conditions for ultrasonication with respect to power, time and duty cycle. Immunofluorescence microscopy analyses of the screens indicate that higher affinity phages are removed and more efficiently from the mica surface by the use of physical after chemical elution compared to binders obtained by chemical elution alone. 1. M. Sarikaya, C. Tamerler, D. T. Schwartz, and F. Baneyx, Ann. Rev. Mater. Res., 34, 373-408 (2004).

Z3.17
Water-soluble Iron Oxide Nanoparticles Derived from Iron Storage Protein. Lingyan Wang, Li Han, Masato Tominage and Chuan-Jian Zhong; Chemistry, SUNY-Binghamton, Binghamton, New York.

Ferritin is an iron-storage protein found in most animals, plants and bacteria. This paper reports novel findings of an investigation of the formation of water-soluble iron oxide nanoparticles from iron-storage protein ferritin. The strategy couples thermal removal of the protein shell on a planar substrate and subsequent sonication in aqueous solution under controlled temperature. With different thermal treatment conditions and sonication temperatures, iron oxide nanoparticles in the size range of 5-20 nm diameters were produced. The nanoparticles were characterized using TEM, UV-Vis, FTIR, TGA, and XPS techniques, and were also compared with iron oxide nanoparticles prepared by wet chemical synthesis. This simple preparation method has important implications to the design of composite nanoparticles for potential magnetic, catalytic, biomedical sensing and other nanotechnological applications.

Z3.18
Understanding the Kinetic Impact of Peptide Modifiers on the Growth of Calcite. L.E. Wasylenki[2], J.J. DeYoreo[1], P.M. Dove[2], D.S. Wilson[2] and N. Han[2]; [1]Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California; [2]Department of Geosciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

The central role of the organic component in biologically controlled mineralization is widely recognized. This component is characterized by proteins containing a high proportion of acidic amino acid residues, especially aspartate, Asp. At the same time, biomineralization takes place in the presence of a number of naturally-occurring, inorganic impurities, particularly Mg and Sr. In an attempt to decipher the controls on calcite growth imposed by both classes of modifiers, and to understand the physical principles underlying growth modification, we have used in situ AFM to investigate the dependence of calcite growth morphology and step kinetics in the presence of a wide suite of Aspartic acid-bearing polypeptides, as well as Sr. In all cases, we observe a distinct, step-specific modification in both morphology and kinetics. While the morphological impacts have been and continue to be the subject of significant research, in this talk we focus on the kinetic impacts. For all peptides investigated as well as for Sr, we find that the step kinetics exhibit a characteristic dependence on additive concentration not predicted by traditional models of growth modification. While all of the impurities clearly induce the appearance of a dead zone where no growth occurs, neither the width of that dead zone nor the dependence of step speed on Ca activity or additive content can be explained by invoking the Gibbs-Thomson effect, which is the basis for the classic Cabrera-Vermilyea model of impurity poisoning. Common kink-poisoning models also fail to explain the observed dependencies. Here we propose a kinetic model of peptide-step interactions based on a cooperative effect of adsorption at adjacent kink sites. The model is in qualitative agreement with the experimental results in that it predicts a non-linear dependence of dead zone width on peptide concentration, as well as a sharp drop in step speed above a certain peptide content. However, a detailed model of peptide adsorption kinetics that gives quantitative agreement with the data has yet to be developed

Z3.19
Multilayer Bioinorganic Protein Structure by Spin Self-Assembly. Sang-Hyon Chu[1], Sang H. Choi[2], Glen C. King[2], Peter H. Lillehei[2], Jae-Woo Kim[3] and Yeonjoon Park[3]; [1]National Institute of Aerospace, Hampton, Virginia; [2]NASA Langley Research Center, Hampton, Virginia; [3]Science and Technology Corp., Hampton, Virginia.

The focus of the present study is to develop a multilayer bioinorganic protein structure by employing spin self-assembly (SA) and to implement structural characterization of the protein layers using variable angle spectroscopic ellipsometry, scanning probe microscopy, and scanning electron microscopy. Multilayered protein arrays can be an essential element of future applications such as bio-nanobatteries, bio-fuel cells, bio-sensors, etc. The bioinorganic protein of interest in this study is ferritin, an iron storage protein that exists naturally in most biological systems. The ferritin protein consists of a hollow segmented protein shell with an outer diameter of 12.5 nm and an inner diameter of 7.5 nm, containing up to 4500 Fe^{3+} atoms as $Fe(OH)_3$. By the reconstitution process of site-specific biomineralization, ferritins can be loaded with different core materials: cobalt, manganese, nickel, cadmium sulfide (CdS), etc. Biological molecules can form ordered nanostructures under specific conditions. Using the spin SA, the ferritin proteins can be assembled into well-organized arrays of single or multilayers. The spin SA method has been shown to produce very thin films that are highly ordered, flat, and stable and to do it more quickly than Langmuir-Blodgett or dipping deposition. The spin SA procedure involves an alternating deposition of oppositely charged layers so that the fabrication process is accelerated and produces a uniform structure. When the spin SA method is employed for ferritin multilayer fabrication, electrostatic forces hold the ferritin particles and strengthen the ferritin adsorption on the substrate surface during the spin-coating process. At high spinning speeds, the centrifugal force and the air drag force acting on the film surface remove the loosely-attached ferritin particles. Once the first layer is formed on a substrate, the second layer of a ferritin array with the opposite charge can be built on the top of the first layer to form a bilayered structure. By repeating this process, a uniform multilayer of ferritins can be created. In the present study, we demonstrate the fabrication of multilayered ferritin arrays for bio-nanobattery electrodes using a spin SA method. The spin SA deposition successfully produced well-organized ferritin arrays. The successive deposition of ferritin layers with opposite charges was exploited to organize and strengthen the three-dimensional ferritin arrays. Ellipsometric analysis allowed a precise and easy determination of protein array thickness, showing a linear increase in thickness with the repeated spin SA processes.

Z3.20
Control of Polymorphism, Orientation, and Morphology of Calcium Carbonate Film, Using Simple Chitosan-Poly (Acrylic Acid) System. Akiko Kotachi, Takashi Miura and Hiroaki Imai; Department of Applied Chemistry, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan.

Sophisticated architectures found in biominerals are generally suggested to be produced by coexistence of two kinds of organic polymers, such as a soluble agent and a substrate. By mimicking biomineralization, formation of calcium carbonate films was achieved by using synthesized organic polymers with carboxy group, and insoluble polyalcohol substrate. The remaining issues in the biomimetic formation of calcium carbonate films are control of polymorphism and orientation of crystalline grains in the thin films. We developed the film formation technique of calcium carbonate, using a chitosan-poly (acrylic acid) (PAA) system to control the polymorphism and orientation. Calcite films commonly grow on a chitosan substrate in the presence of PAA molecules. We varied the baking temperature of a chitosan substrate, molecular-weight (2k, 90k, and 250k), and concentration of PAA. Aragonite and vaterite film were selectively appeared on a 260 °C-baked chitosan substrate with a specific amount of 90k or 250k molecular weight of PAA. An increase in the concentration of the PAA moleculres promoted the formation of a vaterite film rather than that of aragonite. According to XRD analysis, these films were estimated to be composed of iso-oriented crystalline grains. The c axis of vaterite grains in the film was parallel to the substrate, although the orientation of the aragonite film was relatively weak. In the presence of PAA2k, only calcite films were obtained on a chitosan substrate regardless of baking temperature. However, the orientation of the calcite grains in the films was influenced by the baking temperature of the chitosan substrate. The c axis of the crystalline grains grown on the chitosan substrates baked at 100 and 260 °C were parallel and perpendicular to the substrate, respectively. Since an ordered structure of anhydrous chitosan is formed at a temperature above 240 °C, the conformation of the chitosan molecules was deduced to affect the arrangement of adsorbed PAA, and then control the polymorphism of calcium carbonate grown on the substrate. We fundamentally obtained calcite, aragonite, and vaterite films having almost the same morphology, using the chitosan-PAA system. The microscale morphology of the films was evolved by an additional growth technique. An assembly of rhombohedral microblocks, a forest of microstyluses, and an alignment of thin plates were produced on the mother films of calcite, aragonite, and vaterite, respectively. In consequence, we succeeded the total control of polymorphism, orientation, and morphology of calcium carbonate crystals, using a simple system containing two kinds of polymeric organic molecules.

Z3.21
The Jaws of Nereis: Metal Reinforcement of Biopolymers. Chris Broomell[1], Henrik Birkedal[4], Nelle Slack[5], Rashda Khan[2], Helga Lichteneggar[6], Frank Zok[3], Galen Stucky[2] and Herbert Waite[1]; [1]Molecular, Cellular, and Developmental Biology, UC Santa Barbara, Santa Barbara, California; [2]Chemistry, UC Santa Barbara, Santa Barbara, California; [3]Engineering, UC Santa Barbara, Santa Barbara, California; [4]Chemistry, University of Aarhus, Aarhus, Denmark; [5]Veeco Metrology, LLC, Santa Barbara, California; [6]Materials Science and Testing, Vienna University of Technology, Vienna, Austria.

The marine worm Nereis sp. is an errant rapacious polychaete equipped with two jaws, which it uses for grasping and tearing food. As Nereis lives and feeds in the sediment its jaws must be optimized for durability, wear resistance, and density. While other organisms,

such as mammals or the related marine polychaete Glycera, use mineral to strengthen biting structures, Nereis appears to utilize non-mineralized zinc to optimize the mechanical properties of its jaws. The hardness of Nereis jaws exceeds that of all current engineering polymers and approaches that of Glycera. This enhanced robustness is accomplished by combining the non-mineralized inorganic component with an organic ionomer. Compositionally, the organic moiety of jaws is proteinaceous with the zinc approaching 10% by weight and being directly correlated to hardness. Amino acid analysis of hydrolyzed jaws reveals a composition abundant in histidine with molar percentages following a gradient from jaw tip to base of roughly 25% to 5%. Given the ability of imidazole to coordinate metal ions it is tantalizing to postulate a structural role for histidine-rich proteins in the optimization of the mechanical properties of these jaws. Focus will be on recent progress in characterization of the histidine-rich proteins isolated from the jaws of Nereis.

Z3.22

Electromechanical Coupling Response of Mussel Byssal Threads. Matthew James Harrington[1], Philip Tavernier[5], J. Herbert Waite[1,2,3] and Tom Hyongsok Soh[4]; [1]Graduate Program in Marine Science, UCSB, Santa Barbara, California; [2]Graduate Program in Biomolecular Science and Engineering, UCSB, Santa Barbara, California; [3]Molecular Cell and Developmental Biology Department, UCSB, Santa Barbara, California; [4]Mechanical and Environmental Engineering Department, UCSB, Santa Barbara, California; [5]Materials Research Laboratory, UCSB, Santa Barbara, California.

Mussels attach to the hard substratum of rocky intertidal zones through the use of byssal threads. The byssus has been shown to function as an extracellular shock absorber against the relentless forces of cyclic wave stress through unique properties of stress softening and self healing, but recent evidence suggests that the threads may play another role as part of a piezoelectric sensor of flow direction and magnitude. At this point, physiological utility is speculative, but we have been able to show that hydrated threads will produce a small electrical charge when deformed. Voltage measurements of 5-50 mV/N have been recorded in the distal portion of threads from Mytilus californianus tested in air and submerged in distilled water and buffered solutions.

Z3.23

Controlled Cell Attachment and Patterning Using Mussel Adhesive-Inspired Heterotelechelic Poly(ethylene glycol). Jeffrey Lawrence Dalsin and Phillip B. Messersmith; Biomedical Engineering, Northwestern University, Evanston, Illinois.

Control of biological interactions at the material/fluid interface, particularly non-specific fouling by proteins and cells, is critical for the success of many therapeutic and diagnostic devices. A common method of preparing non-fouling surfaces is the deposition of a monolayer of poly(ethylene glycol) (PEG), which is typically anchored onto the surface by physisorption or chemisorption. In nature, marine and freshwater mussels are able to anchor themselves to a wide range of substrate materials on which they reside by secretion of unique adhesive proteins. These proteins contain an unusually high concentration of the amino acid 3,4-dihydroxyphenylalanine (DOPA), which is believed to be largely responsible for their profound adhesive characteristics. Inspired by the versatile and tenacious bonds that mussels form with surfaces in nature, we have developed linear PEGs end-functionalized with DOPA peptides which are capable of conferring protein and cell resistance to a variety of substrate materials. In the present study, we examine the ability of bio-inspired heterotelechelic PEGs anchored with DOPA and terminated with a bioactive ligand (e.g. RGD, IKVAV) to promote specific cell attachment at the biomaterial surface whilst deterring non-specific adsorption. Furthermore, we are investigating the ability of these novel polymers to be patterned on surfaces to gain spatial control of specific and non-specific bio-adsorption. In addition to standard cell adhesion assays, we are utilizing time-of-flight SIMS and optical waveguide lightmode spectroscopy to characterize the distribution and availability of bioactive PEG on the surfaces being studied.

Z3.24

Surface-Initiated Polymerization: Design of A Biomimetic Anchor for Grafted Polymers. Xiaowu Fan, Lijun Lin and Phillip B. Messersmith; Biomedical Engineering, Northwestern University, Evanston, Illinois.

Surface-initiated polymerization (SIP) provides a useful strategy for grafting of polymers to solid surfaces. Typically, SIP involves the immobilization of an initiator molecule onto a substrate via specific covalent or noncovalent chemical interactions, after which polymerization proceeds from an initiating functional group contained within the immobilized molecule. As such, the nature of the chemical interaction between initiator and substrate is crucial in determining the properties of the polymer-substrate interface after polymerization. SIP has been performed from a variety of surfaces with many different polymers, including those relevant to therapeutic and diagnostic healthcare applications, in which initiator molecules capable of robust adhesion under aqueous environments are desirable. In this study, a biomimetic initiator was designed and synthesized using inspiration from water-resistant mussel adhesive proteins (MAPs), which contain a high concentration of the unusual amino acid 3,4-dihydroxyl-L-phenylalanine (DOPA). The catechol side chain of DOPA has been speculated to be important to adhesive as well as cohesive properties of the natural adhesive. Therefore, we designed a bifunctional DOPA mimetic initiator consisting of an alkyl halogen for atom transfer radical polymerization (ATRP), coupled to a catechol moiety for surface anchoring. The initiator was synthesized and immobilized onto Ti substrates by chemisorption from aqueous solution. Aqueous surface-initiated ATRP (SI-ATRP) of methylmethacrylate macromonomers with oligo(ethylene glycol) (OEG) side chains of different lengths was performed at room temperature. X-ray photoelectron spectroscopy, surface FT-IR, and contact angle analysis confirmed the adsorption of initiator and formation of polymer layers. Polymer layer thickness was measured by spectroscopic ellipsometry, which showed rapid graft polymerization kinetics and a dry thickness saturation limit of about 100 nm. Cell adhesion experiments were performed by culturing 3T3-Swiss albino fibroblast cells on the polymer modified surfaces. Short-term (4 hours) results revealed dramatically decreased cell adhesion to the grafted substrates compared to the unmodified ones. Our results also suggested that short-term cell resistance did not significantly depend on polymer layer thickness and the length of OEG side chains. However, preliminary long-term cell culture studies indicated that after two weeks, cell resistance depended on thickness of the polymer coatings.

Z3.25

Processing of Mussel Adhesive Protein Analog Thin Films by Matrix Assisted Pulsed Laser Evaporation. Timothy M. Patz[1,7], Rodica Cristescu[2], Roger Jagdish Narayan[1], Nicola Menegazzo[3], Boris Mizaikoff[3], Dan Mihaiescu[4], Phillip B. Messersmith[5], Ioan Stamatin[6], Ion N. Mihailescu[2] and Douglas B. Chrisey[7]; [1]Materials Science & Engineering, Georgia Institute of Technology, Atlanta, Georgia; [2]National Institute for Lasers, Plasma and Radiation Physics, Bucharest-Magurele, Romania; [3]School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia; [4]University of Agriculture Sciences and Veterinary Medicine, Bucharest, Romania; [5]Biomedical Engineering Department, Northwestern University, Evanston, Illinois; [6]University of Bucharest, Bucharest-Magurele, Romania; [7]US Naval Research Laboratory, Washington, District of Columbia.

Mussel adhesive protein analogs possess unique biocompatibility, bioactivity, and adhesion properties. These materials have numerous medical and technological applications including use in wound closure, nerve reconstruction, and electronic devices. We have demonstrated successful thin film growth of DOPA modified- PEO-PPO-PEO block copolymer, a mussel adhesive protein analog, using matrix assisted pulsed laser evaporation. To study the effects of varying MAPLE deposition parameters, films were deposited using a spot size of .025-.035 cm2 at .39-.62 J/cm2, from 20,000 to 57,000 shots at a target to substrate distance of 7 cm. Fourier transform infrared spectroscopy has verified that the main functional groups (aromatic ring, C=O and C-N bonds) of the mussel adhesive protein analog are present in the transferred film. Atomic force microscopy has revealed 50-100 nm ripple-like structures on the surface of the film. We have demonstrated that the scale of these ripple-like structures decreases with diminishing polymer molecular weight. Adhesion bonding tests have confirmed the excellent adhesive properties of these mussel adhesive protein analog films. Possible medical and technological applications for these novel films will also be discussed.

Z3.26

Characterization of Biopolymer Hydrogels. Elena Loizou[1], Jaime T. Weisser[2], Gudrun Schmidt[1] and Jonathan J. Wilker[2]; [1]Chemistry, Louisiana State University, Baton Rouge, Louisiana; [2]Chemistry, Purdue University, West Lafayette, Indiana.

The structure and network properties of cross-linked mussel protein hydrogels is investigated by means of rheology, microscopy and small angle scattering. The length scales covered by these techniques provide information about short range structure as well as long range correlations. Rheological measurements showed substantial increase in viscosity and change in modulus as function of cross-linking concentration. Surprisingly the shape of the small angle scattering intensity curve is not much affected by the cross-linking process but measures nm size aggregates present in the sample. Optical and Scanning Electron Microscopy show differences in materials texture on a micron length scale. The cross-linked hydrogel is much more structured with large aggregates while the raw material seems to be more porous and loose. Structural information is important in

tailoring physical, mechanical and biological properties of our hydrogels. We compare mussel protein hydrogels with chitosan type hydrogels and highlight some similarities and differences.

Z3.27

Aqueous Synthesis, Photoluminescence Properties and Biomedical Application of Quantum Dots. Hui Li, Melissa Schillo, Wan Y. Shih and Wei-Heng Shih; Department of Materials Science and Engineering, Drexel University, Philadelphia, Pennsylvania.

Quantum dots (QDs) are semiconductor nanocrystals that exhibit distinctive photoluminescence properties due to the quantum confinement effect. We have developed a new aqueous synthesis route to produce highly luminescent CdS QDs capped with carboxylated molecules in one single step. The obtained CdS QDs 4 nm in size exhibited a sharp photoluminescence peak, less than 20 nm in peak width at half the peak height, in the wavelength range 400 to 500 nm. The absence of the broadband emission at higher wavelengths indicated that the aqueous process was effective in producing a clean CdS surface. The pH value and concentration of precursors affected the wavelength and intensity of the emitted light. By controlling the particle size and dopant concentration, it was possible to obtain luminescence at different wavelengths. The carboxyl-capped CdS QDs were stable in suspension and ready for immobilization of antibodies or other biomolecules. QDs of different colors can act as imaging markers for different antigens or diseases in biomedical applications.

Z3.28

Quantum Dot Based Fluorescence Resonance Energy Transfer Nanosensors. Igor Langier Medintz[1], Aaron R. Clapp[2], Jeffrey R. Deschamps[3], John H. Konnert[3], Harry Tetsuo Uyeda[2] and Hedi Mattoussi[2]; [1]Center for Bio/Molecular Science and Engineering, U.S. Naval Research Laboratory, Washington, District of Columbia; [2]Division of Optical Sciences, Code 5611, U.S. Naval Research Laboratory, Wasington, District of Columbia; [3]Laboratory for the Structure of Matter, Code 6030, U.S. Naval Research Laboratory, Wasington, District of Columbia.

We have employed quantum dot (QD) -protein conjugates in fluorescence resonance energy transfer- (FRET) based assays to study the photophysical properties of QDs as FRET donors.1 We found that the readily tunable QD emission over a wide range of wavelengths permitted effective tuning of the degree of energy overlap between the QD donor and the acceptor for a fixed dye, thus allowing control over the rate of FRET in these complexes(1). These results were further exploited to design a prototype of a FRET-based QD nanosensor(2). We utilized E. coli maltose binding protein (MBP) and targeted its preferred substrate, maltose in the nanosensor(2). We extended this QD-protein format to demonstrate that QD photoluminescence (PL) can be reversibly modulated using a protein located photochromic dye. We further demonstrate that the QD-protein architecture can be extended to surface-based assemblies and still function in FRET. The orientation of the MBP relative to the QD surface is elucidated by using a strategy analogous to a nanoscale global positioning system determination. By attaching a series of site-specifically dye-labeled proteins to the QD surface and the intra-assembly distances determined from the resulting FRET measurements in conjunction with the MBP crystallographic coordinates and a least squares approach we arrive at this structure. The insight gained from these studies suggests that this sensing format can be applied to other receptor proteins or bio-recognition units to facilitate development of a new generation of hybrid QD-based biosensors. (1) Clapp, et al., J.A.C.S. 126:301-310 2004. (2) Medintz, et al., Nat. Mat. 2:630-638 2003.

Z3.29

Biocompatible Rare Earth Oxide Nanocrystals as Fluorescent Biolabels. Ling-Dong Sun, Chun-Hua Yan, Liu-He Wei and Yi-Qun Zhang; Peking University, Beijnig, China.

Inspired by the recent advances in nanomaterials which have produced a new class of fluorescent labels by conjugating semiconductor quantum dots with bio-recognition molecules, we developed another kind of rare earth oxides nanocrystals with strong emission. The luminescence wavelength can be tuned by doping different kinds of rare earth ions as luminescent centers, which can give off visible photon radiation with f-f transition. The excitation wavelength is host composition dependent, and ranged from near UV to IR. The rare earth oxides are prepared in water and surface capping with different kinds of functional groups which makes them water-soluble and biocompatible. By combining sodium citrate and phospho-containing polymer together, the rare earth nanocrystals are obtained with desired fluorescent intensity and colloidal stability even in buffer systems. The as-prepared nanocrystals were conjugated with biomolecules such as BSA and goat anti-human IgG by the formation of amide bond through the reaction of the carboxylic acid on the surface of the nanocrystals and the primary amine groups of the proteins. SDS- PAGE gel-electrophoresis characterization revealed that covalent bonds were formed between the nanocrystals and the proteins. CD measurement showed that the spectra of the protein and the nanocrystal-protein conjugates were similar, indicating that the protein keeps unchanged in the conjugates. Owing to its outstanding stability against photobleaching, high quantum yield, narrow emission band, large Stokes shift and long fluorescent life time, these water-soluble and biocompatible fluorescent rare earth oxide nanocrystals may be a promising candidate in ultrasensitive detection of biological species, immunoassay, and medical imaging, as an alternative to the presently used fluorphores.

Z3.30

Tunable Index Polymers for Biomimetic Optics. Marie Sandrock[1], Michael Wiggins[1], James S. Shirk[1], Eric Baer[2], Anne Hiltner[2], Yi Jin[2] and Huiwen Tai[2]; [1]Optical Sciences Division, Naval Research Laboratory, Washington, District of Columbia; [2]Macromolecular Science and Engineering Department, Case Western Reserve University, Cleveland, Ohio.

Biological optical systems are comprised of complex nanostructured materials. Some of the unique capabilities found in these systems derive from an ability to alter the shape, the refractive index, and the refractive index gradient. New nanolayered polymeric lenses with the structure and properties of biological lenses are described at this meeting.[1] Within these systems, elastomers can provide tunability to polymer-based biomimetic optics. However, in order to design such systems, knowledge of both the optical and mechanical properties of the elastomers is necessary. There is recent experimental and theoretical evidence that the properties of thin and ultra thin polymer films are appreciably different from those in the bulk. The nature of the deviations from bulk behavior is not well understood and is the subject of this paper. We have designed an apparatus for simultaneously determining the optical and mechanical properties of thin films. The film thickness, refractive index and effective Young's modulus of poly(ethylene-octene) (EO), an elastomeric polymer, were determined as a function of applied compressive forces. We found that the modulus of uniaxially compressed EO depends upon the thickness of the material. As the film gets thinner, the observed modulus increases. For example, a 100 micron film has a modulus of 37 $\pm$ 5 MPa whereas a 65 micron film has a modulus of 98 $\pm$ 5 MPa. A variation in effective modulus with sample shape is well known in rubbery materials.[2] The increasing modulus is due to the increasing constraints in the direction perpendicular to the applied stress. Thin films, whose surface to volume ratio is quite large, cannot expand to compensate for the strains induced by the force applied to the film. In the limit of very thin films, the experimental modulus approaches the bulk modulus of the material.[3] The variation of the refractive index (n) with applied pressure (P), dn/dP, was also found to depend on film thickness. A linear and reversible refractive index change of $\Delta n = 0.02$ at an applied stress of 9 MPa was found for a thin film of EO. For thin samples, dn/dP could be modeled by assuming that the density of the material varies with pressure. These effects are found in micron-thick elastomer films. Additional effects of layer thickness on the modulus were also found in nanolayer films used in biomimetic optics. Elastomers are promising biomimetic materials since they can be exploited to achieve desired mechanical and optical properties. We must understand how to control these properties on the micrometer and nanometer level in order to mimic biological optical systems. References: 1. E. Baer, Invited lecture presented at *SymposiumZ : Bio − InspiredandBio − derivedMaterialsandProcesses*, MRS Fall Meeting, Boston, MA (2004). 2. A.N. Gent, P.B. Lindley, Proc. Inst. of Mech. Eng., 173, (1959) 111-112. 3. J. M. Horton, G.E. Tupholme, M.J.C. Gover, Transactions of the ASME, 69 (2002) 836-843.

Z3.31

Design, Synthesis & Characterization of Novel Electronic BioMolecular Materials. Ting Xu[1], Shixin Ye[1], Sophia Wu[1], Joseph Strzalka[1], Michael Therien[1] and Kent Blasie[1]; [1]Department of Chemistry, University of Pennsylvania, Philadelphia, Pennsylvania; [2]University of Pennsylvania, Philadelphia, Pennsylvania.

The design of artificial proteins with synthetic non-biological cofactors could lead to peptide based systems with novel properties not exhibited by biological systems. For example, extended pielectron systems can now be designed and tailored, with appropriate donors, acceptors and constituents to exhibit selected nonlinear optical responses and light-induced electron transport and or proton translocation over large distances. One attempt to achieve this end was performed with a-helical amphiphilic peptides, which assemble into 4-helix bundles with welldefined hydrophilic and hydrophobic domains and orient vertically at the air-water interface. The binding between a non-biological metalloporphyrin Zn cofactor and the helix bundles at selected locations was shown. This may lead to potential bioinspired materials with novel electron transfer properties.

Z3.32
Optical Characterization of Nanostructured Polymer GRIN Lenses. Michael Wiggins[1], Marie L. Sandrock[1], James S. Shirk[1], Eric Baer[2], Anne Hiltner[2], Huiwen Tai[2] and Yi Jin[2]; [1]Optical Sciences, US Naval Research Lab, Washington, District of Columbia; [2]Department of Macromolecular Science and Engineering, Case Western Reserve University, Cleveland, Ohio.

A novel technique to make graded index (GRIN) lenses from polymers with out the use of complicated thermal diffusion processes has been developed at Case Western Reserve University (CWRU) and will be described at this meeting.[1] The technique utilizes extruded multilayer polymer films where individual layer thicknesses are on the order of 10's of nanometers. The use of nanolayers has allowed polymer GRIN lenses to be designed and built with a hierarchical layered structure mimicking the structure of the lens in the human eye. This process has the distinct advantage over the diffusion technique of allowing for more control over the index gradient and has fewer restrictions on the size of lenses than can be easily manufactured. In this paper, we report the results of optical characterization of these lenses at U.S. Naval Research Lab. The initial lenses have a diameter of 18 mm, focal lengths ranging from 20 mm to 500mm, and are bi-planar, plano-convex, or bi-convex. The initial GRIN lens prototypes, fabricated at CWRU, were characterized by different optical techniques. For example, a bi-convex graded refractive index (octopus) lens with a 20 mm focal length was measured to have a focal spot size was about 1.5 times as large as a comparable traditional glass lens. The polymer GRIN lens was substantially thinner and lighter than the comparable glass lens. As might be expected, the aberrations in the biomimetic lenses differ from those seen in traditional lenses. Shack-Hartmann wavefront sensing (SHWS) allows a determination of the type of aberrations present in prototype lenses. In bi-planar lenses, it is also possible with SHWS to directly measure the index gradient and confirm the expected index gradient. There is the potential for substantial control over the focal properties of these lenses because a wide range of lens shapes and GRIN profiles can be fabricated. The index gradients in the polymer lenses are currently about 0.09, much larger than typically available in glass radial gradient (RGRIN) or axial gradient (AGRIN) lenses. Furthermore, since the index gradient in the polymer lenses is not constrained by the thermal diffusion of species through glass, gradients can be defined independently. Initial prototypes have been designed with a spherical index gradient. It is expected that such a spherical GRIN profile can be optimized to reduce spherical aberrations that typically occur in lenses with small f/#'s. The shape of the outer surfaces can also be controlled to minimize aberrations. 1. E. Baer, Invited lecture presented at *SymposiumZ : "Bio − InspiredandBio − derivedMaterialsandProcesses,"* MRS Fall Meeting, Boston, MA, November 29 - December 3, 2004.

Z3.33
Synthesis and AFM visualization of 3-dimentional DNA nanostructures. Rika Mizuno[1], Kazuhiro Yoneda[1], Hirotaka Haruta[1], Takashi Morii[1], Takao Okada[1], Takeshi Asakawa[2], Tomoko Tahira[2] and Kenshi Hayashi[2]; [1]Tech Develop Dept, Research Institute Biomolecule Metrology co., Ltd., Tsukuba, Japan; [2]Research Center for Genetic Information, Medical Institute of Bioregulation, Kyushu Univ., Fukuoka, Japan.

In recent years, DNA comes into use of nanotechnology's devices and materials. We propose a bottom-up approach for the fabrication of various desired nanostructues, based on self-assembly of oligonucleotides governed by Watson-Crick base pairing. Using this approach, we have suceeded in constructing 2-dimentional structures − Y shaped, H shaped and Hexagon [1]. Since branched parts included in these structures were flexible, they were not rigid enough. Here, we have tested novel triangle-based design to construct more rigid and stable structures. New structures, which we reffered to as 'Almost Anything Made of Triangles (aamoT)', is designed with a novel designing strategy, which is based on triangles. We can design many kinds of structures with this strategy. We started from a regular tetrahedron, which consists of four triangles. The structures were autonomously fabricated simply by mixing equimolar solutions of oligonucleotides and performing hybridization. After synthesis of the structures, we confirmed their validity by agarose gel electrophoresis and atomic force microscopy (AFM) visualization. We detected bands of the desired molecular sizes in gel electrophoresis and observed the desired structures by AFM analysis. This work is supported by New Energy and Industrial Technology Development Organization (NEDO). [1] R. Mizuno, H. Haruta, T. Morii, T. Okada, K. Nakashi, T. Asakawa and K. Hayashi, Transactions of the Materials Research Society of Japan 29 [2] 439-441 (2004)

Z3.34
Biologically-Based Synthesis of CoPt and FePt Nanoparticles, Their Structure and Properties. Melanie M. Tomczak[1], Lawrence F. Drummy[1], Zafer Turgut[2], Morley O. Stone[1] and Rajesh R. Naik[1]; [1]Materials and Manufacturing Directorate, MLPJ/Biotechnology Group, Air Force Research Lab, WPAFB, Ohio; [2]Propulsion Directorate, Air Force Research Laboratory, WPAFB, Ohio.

Conventional methods for the synthesis of magnetic (CoPt, FePt) nanoparticles require harsh reactions conditions and extremely high temperatures in order to obtain the desired magnetic properties. We investigated a biologically-based route towards synthesis of these metallic nanoparticles using benign reaction conditions, in an attempt to biomimetically synthesize magnetic nanoparticles. To this end, peptides, identified from a combinatorial peptide library, were used as templates in the synthesis of CoPt and FePt nanoparticles at room temperature and neutral pH. The crystal structure and morphology of the nanoparticles were characterized by transmission electron microscopy, scanning electron microscopy and x-ray diffraction.. The magnetic properties of the nanoparticles were studied by superconducting quantum interference device (SQUID).

Z3.35
DNA-Mediated Phase Behavior of Microsphere Suspensions. Valeria Tohver Milam[1], Paul Louis Biancaniello[2], John C. Crocker[2] and Daniel A. Hammer[3,2]; [1]Materials Science & Engineering, Georgia Institute of Technology, Atlanta, Georgia; [2]Department of Chemical & Biomolecular Engineering, University of Pennsylvania, Philadelphia, Pennsylvania; [3]Department of Bioengineering, University of Pennsylvania, Philadelphia, Pennsylvania.

We have constructed phase diagrams for DNA-modified bead suspensions based on experimental and theoretical studies. The suspension system is comprised of 1-um red fluorescent beads functionalized with identical oligonucleotide sequences and 1-um green fluorescent beads functionalized with the complementary sequence. Keeping the suspension composition and temperature fixed, we studied the phase behavior of colloidal mixtures as a function of ionic strength, surface density of oligonucleotide available for hybridization, and oligonucleotide length. For suspensions containing eight base-pair matches between particle surfaces, we observed a fluid phase of dispersed singlets at low salt concentration and low DNA densities. We attribute this fluid phase behavior to the unfavorable conditions for DNA hybridization. With increasing salt or DNA densities, we observed a phase transition from fluid -> fluid + aggregates -> aggregates. We attribute this destabilizing transition to DNA-mediated attractions between particles. This phase transition shifted to lower ionic strengths and DNA densities for suspensions containing longer sequences with 12-base pair matches.

Z3.36
Novel Motion of Water Droplet on Biomimetic Ultra Water-repellent Surface. Takai Osamu[1,2], Wu Yunying[1], Kouno Masao[2], Saito Nagahiro[3,2] and Inoue Yasushi[1]; [1]EcoTopia Science Institute, Nagoya University, Nagoya, Japan; [2]Department of Materials, Physics and Energy Engineering, Nagoya University, Nagoya, Japan; [3]Department of Molecular Design and Engineering, Nagoya University, Nagoya, Japan.

We had been successfully to fabricate biomimetic ultra water-repellent (UWR) surface through microwave plasma enhanced chemical vapor deposition (MWPECVD) and thermal CVD in our previous works. This UWR surface was made of SiOx film covered with hydrophobic self-assembled monolayer (SAM). We found that the motion of water droplet on the UWR surface was extremely specific trough the researches. In this study, we focused our target on the motion of water droplet on the UWR surface since the motion control is important in the field of micro-TAS and windshield. The water droplet on UWR surface was observed by high-speed charge-coupled device video camera. In order to reveal the effect of functional group on the motion of water droplet, the UWR surfaces with CH_3- and CF_3-groups were prepared. The CH_3- and CF_3-groups were introduced by fabricating CH_3- and CF_3-terminated SAMs onto SiOx films. The backside of substrate was brushed with piece of cloth to generate static electricity. A water droplet was placed on the UWR surface with CF_3-group inclined at 30 degree angle, and it leaped up or run uphill at high speed defying gravity. On the other hand, the water droplet on the UWR surface with CH_3-group was nearly pined at point of fall. These indicates that even a type of functional group in SAM have a great effect on the motion of water droplet on the UWR surface. We report on various motions of water droplet and the origin.

Z3.37
Bio-scaffolds for Plasmonics: Metal Nanoshells from Viral Capsids. Corey Radloff[1], Richard A. Vaia[1], Rajesh Naik[1] and Vernon Ward[2]; [1]Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson, Ohio; [2]Department of Microbiology and Immunology, University of Otago, Dunedin, New Zealand.

Rational design of the optical and electrical characteristics of 'nano-units' is founded in novel synthetic approaches that result in

nanostructures with functionalities tailored to specific applications. Recent efforts have focused on increasing the flexibility of nanostructure fabrication by using bio-derived templates, specifically virus particles. This work investigates the impact of bio-scaffold facilitated assembly of metal nanoshells. Metal nanostructures and the associated strong electromagnetic field at the surface provide possibilities for plasmonic enhancement of various nonlinear optical properties of organic materials. Numerous metallic nano-architectures have been envisioned, however metallodielectric nanoshells have a suite of beneficial characteristics, including facile and systematic tunability of the plasmon resonance by varying the relative dimensions of the core and shell layers. We report on recent approaches to develop techniques for the electroless deposition of a gold shell around a virus core, including both Chilo and Wisenia Iridovirus and Cow Pea Mosaic virus-like particles. Small gold nanoparticles electrostatically or covalently attached to the capsid surface are used to grow a continuous metal shell around the virus unit. Multi-valent presentation is also investigated as a surface preparatory technique. Additionally, the ability to engineer the protein surface is investigated to increase the feasibility to incorporate gold reduction sites, various chemical moieties at specific sites within the core-shell nanostructure, and facilitate directed fabrication of nanoshell assemblages.

Z3.38
Numerical Simulations of Liquid Droplets Dynamics on Surfaces with Bio-Inspired Nanotextures. Florin Andrei Nae[1], Nagahiro Saito[2], Yasushi Inoue[1], Yunying Wu[1] and Osamu Takai[1]; [1]EcoTopia Science Institute, Nagoya University, Nagoya, Japan; [2]Department of Molecular Design and Engineering, Graduate School of Engineering, Nagoya University, Nagoya, Japan.

Present research addresses the dynamic behavior of liquid droplets impinging surfaces with bio-inspired nanotextures. The wettability of a solid surface with a certain liquid is mainly determined by the chemical compositions of the surface and liquid, and the surface texture. Recent advances in nano fabrication allow controlling the surface roughness as well as patterning the surface of a solid substrate with regions of different wettabilities. Such nanotextured surfaces provide a model system for studying the wetting and dewetting processes and can also act as a template for self-organization of liquids. Since the wettability processes have an intrinsic dynamic character characterized by a very short time span, numerical simulation can be useful to investigate these processes in order to capture features that are otherwise difficult to quantify experimentally. Three cases were considered in the present research: hydrophobic patterned surfaces with regular roughness, hydrophobic irregular surfaces with random roughness, and almost flat hydrophobic-hydrophilic patterned surfaces with regular nanometer level roughness. Numerical simulations performed using a computational fluid dynamics package were compared with experimental data collected using a high-speed CCD camera. Presented results can have numerous applications such as in fabrication of self-cleaning surfaces, printing applications, DNA chips, microfluidic devices, or micro lens arrays.

Z3.39
Conductance Measurement of a DNA Network in Nano-Scale by Point Contact Current Imaging Atomic Force Microscopy. Hidekazu Tanaka, Ayumu Terawaki, Yoichi Otsuka, Hea-Yeon Lee, Takuya Matsumoto and Tomoji Kawai; ISIR-Sanken, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka, Japan.

We have visualized the conductivity of DNA network as spatial resolved current image at high humidity by using Point-contact Current-Imaging Atomic Force Microscopy (PCI-AFM). Deoxyribonucleic acid (DNA) has attracted considerable attention as an important and promising molecule not only because of its inherent ability to manage genetic code, but also due to its potential application in the development of molecular devices. The DNA duplex can be thought of as a molecular nano wire whose diameter is about 2nm, and has the potential to exhibit electrical conduction through the pi -stacked network of its constituent base molecules. Recently, we found that DNA molecules could form a self-assembled network structure [1], potentially useful in the generation of nano-scale devices, so that its electronic properties are also interesting. Simultaneous observation of topography and current image by PCI-AFM enable us to reveal electrical property for biological and/or soft materials in nano-scale [2]. Applying this technique to DNA network, in the high humidity of 60%, electrical current along DNA network is larger than that of mica surface by 20pA at bias voltage of 5V, whereas they have no difference at dry condition (humidity of 0%). [1] T. Kanno, Hiroyuki. Tanaka, N. Miyoshi, and T. Kawai, Appl. Phys. Lett. 23, 3848 (2000) [2] Y. Otsuka, Y. Naitoh, T. Matsumoto, and T. Kawai, Appl. Phys. Lett. 82(2003)1944-146

Z3.40
Novel Synthesis of Water-Soluble Conducting Copolymers. Ferdinando F. Bruno[1], Ramaswamy Nagarajan[2], Jayant Kumar[2] and Lynne A. Samuelson[1]; [1]Material Science, U.S. Army RDECOM Natick Soldier Center, Natick, Massachusetts; [2]Physics and Chemistry, University of Massachusetts, Lowell, Massachusetts.

A novel biomimetic method for the synthesis of a conducting copolymer of polypyrrole and of Poly(3,4 ethylenedioxythiophene) (PEDOT) in the presence of a polyelectrolyte, such as polystyrene sulfonate (SPS) is presented. A poly(ethylene glycol) modified hematin (PEG-Hematin) was used to catalyze the polymerization of pyrrole and of 3,4 ethylenedioxythiophene in the presence of SPS to form Polypyrrole $-co-$PEDOT/SPS complex. UV-vis, FTIR, NMR spectroscopy, X-ray diffraction and conductivity studies indicate the formation of a stable copolymer with enhanced electrically conductivity (as compared with the homopolymers). The presence of SPS in this complex provides a unique combination of properties such as conductivity, processability and water-solubility.

Z3.41
Characterization of Surface Interactions in Gold Nanocrystal DNA Conjugates. Katherine A. Brown, Sunho Park, Andy Wijaya and Kimberly Hamad-Schifferli; Biological Engineering, Massachusettes Institute of Technology, Cambridge, Massachusetts.

Recent studies have detailed synthesis and characterization of Au nanocyrstal DNA conjugates for use in biological and nanotechnological applications. The use of such conjugates requires an understanding of the interactions between DNA nucleotides and the nanocrystal surface. Surface nucleotides interactions can affect the size and conformation of the conjugates, as well as the availability of DNA to hybridized to its complement. The affinity of individual nucleotides and poly(N) strands have been investigated and reveal a range of affinities, however sequence dependant behavior of mixed character oligonucleotides have not been studied. A detailed investigation as to the effects of surface-nucleotide interaction and DNA coverage ratios will afford useful insights into the interactions of DNA with gold surfaces and allow predictions of the potential of a given sequence for various applications. Here we present an electrophoretic mobility study of the effects of DNA oligo sequence on the nanocrystal nucleotide interactions.

Z3.42
Gold Nanoparticle Labeling of Active Proteins on Specific Amino Acids. Marie-Eve Aubin[1] and Kimberly Hamad-Schifferli[2,1]; [1]Biological Engineering Division, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Mechanical Engineering Department, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Ribonuclease S and Cytochrome c were site-specifically labeled with 2-3nm gold nanoparticles. Protein labeling was achieved by covalent linking to a specific cysteine surface residue through a thiol bond. Structural and thermal characteristics of the nanoparticle-protein conjugates were explored by circular dichroism and UV-Vis absorption spectroscopies. Enzymatic activity of the Ribonuclease S-nanoparticle conjugate was measured by substrates with FRET pairs.

Z3.43
Synthesis of hydrophobic peptide and peptide nanowire in supercritical water. Takanari Togashi, Hiroyuki Tsuchizaki, Mitsuo Umetsu, Satoshi Ohara, Seiichi Takami and Tadafumi Adschiri; Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai, Japan.

Solid-phase organic synthesis is most utilized for generating polypeptide, while the hydrothermal synthesis of peptide has been studied on spontaneous generation of polypeptide in the origin of life. The critical matter in hydrothermal synthesis is that the temperature at which amide bonds are hydrolyzed is below the temperature at which amide bonds are formed. Exceedingly-rapid quench of temperature is strongly dependent on the yield of polypeptide. Here, we significantly suppressed the hydrolysis by application of solid-liquid phase separation, and made a nanowire from the synthesized products. A 100 mM phenylalanine solution was heated at 220 C for 10 min, and then rapidly cooled to 100 C by mixing water. We expected polyphenylalanine to be precipitated above the hydrolysis temperature because of its hydrophobicity. In fact, more than 5 % weight of added phenylalanine was precipitated in the reacted solution. Recent study has reported that dipeptide of phenylalanine formed a nanowire with amyloid structure by re-precipitation in water after dissolution in hexafluoropropanol (1). The application of the same procedure to the solid product formed in hydrothermal reaction resulted in the formation of nanowire with the length of about 30 m. This suggests the formation of polyphenylalanine. (1) Meital Reches, and Ehud Gazit, Science 300, 625-627 (2003)

Z3.44
Impact of Water Droplets on Ultra Water-Repellent Surfaces: Their Shape and Energy Dissipation. Yunying Wu[1], Masao Kouno[2], Nagahiro Saito[3,2], Yasushi Inoue[1,2] and Osamu Takai[1,2]; [1]EcoTopia Science Institute, Nagoya University, Nagoya, Japan; [2]Department of Materials, Physics and Energy Engineering, Nagoya University, Nagoya, Japan; [3]Department of Molecular Design and Engineering, Nagoya University, Nagoya, Japan.

When a falling water droplet impact on an ultra water-repellent (UWR) surface, the water droplet spreads or is transformed up to a moment when kinetic energy is dissipated by viscosity of water. A particular shape of water droplet on the impact can be observed on the UWR surface. The kinetic energy was approximately stored as elastic deformation energy. From the result, perfectly elastic collision can be observed on UWR surface. In order to understand this phenomena, instantaneous shape of water droplet on the impact would be important information. In this research, we studied the static and dynamic behavior of water droplets fallen on various UWR surfaces using a high-speed charge-coupled device video camera and an environmental scanning electron microscope (ESEM). UWR plant leaves with water contact angle of more than 150° were used as the surface. Moreover, various paper and metal mesh sheets were also used. The paper and metal mesh sheets were coated with UWR films. In the case of UWR surface without the metal mesh sheets, we found out that surface nano-structure has a great influence on the dynamic contact behaviors. In the case of metal mesh sheets, rather than surface nano-structure, the interval of metal wires had a great effect on the dynamic behavior. We believe that such understanding about water droplet lead to the dynamic control on the UWR surface.

Z3.45
Abstract Withdrawn

Z3.46
Resonance-Assisted Hydrogen Bonds Stabilize Guanine Quartet Networks on Solid Surfaces. Roberto Otero Martin, Maya Schoeck, Luis Miguel Molina, Erik Laegsgaard, Ivan Stensgaard, Bjork Hammer and Flemming Besenbacher; Interdisciplinary Nanoscience Center (iNANO) and Department of Physics and Astronomy, University of Aarhus, Aarhus, Denmark.

Hydrogen bonding between DNA bases is one of the main interactions that control the conformation and hence the biochemical function of nucleic acid molecules [1,2]. Apart from the Watson-Crick model for base pairing [1], DNA bases can form other hydrogen-bonded complexes that lead to different DNA structures, like G-quadruplexes [3] or i-motifs[4]. In spite of the increasing evidence for the existence and in vivo function of these DNA structures [5], a convincing biophysical model for their stability is still missing. By combining high-resolution, variable-temperature Scanning Tunneling Microscopy (STM) and state-of-the-art Density Functional Theory (DFT), here we show that the DNA base guanine (G) deposited under ultra-clean conditions onto a suitably inert substrate such as Au(111) self-assembles into a hydrogen-bonded network of G-quartets, whose structure corresponds perfectly with the quartet structure of telomeric DNA [3] determined by X-ray crystallography. The strong preference of G molecules to form quartets can be explained by a cooperative effect that strengthens the hydrogen bonds within the G-quartet network over the hydrogen bonds in isolated dimers. This result underlines the necessity of going beyond the picture of isolated hydrogen bonds in order to properly describe the interactions between biomolecules. [1] Watson, J. D. & Crick, F. H. C. A structure for deoxyribose nucleic acid. Nature 171, 737-738 (1953). [2] Sinden, R. R. DNA Structure and Function (Academic Press, San Diego, 1994). [3] Sundquist, W. I. & Klug, A. Telomeric DNA dimerizes by formation of guanine tetrads between hairpin loops. Nature 342, 825-829 (1989). [4] Gehring, K., Leroy, J.-L. & Guéron, M. A tetrameric DNA structure with protonated cytosine-cytosine base pairs. Nature 363, 561-565 (1993). [5] Kipling, D. The telomere (Oxford University Press, Oxford, 2002).

Z3.47
Electrical Conductivity of Ferritin Immobilized Multi Wall Carbon Nanotubes Mat. Sanjib Bhattacharyya, Paolo Martins, Romain Fleurier, Jean-Paul Salvetat and Marie-Louise Saboungi; CRMD, CNRS, Orleans, CEDEX 2, France.

Novel nanomaterials for bioassay applications represent a rapidly progressing field of nanotechnology and nanobiotechnology. To explore the possibility of using carbon nanotubes as the nanoscale building blocks in bionanotechnology, we have to study the electrical properties of these systems. We have successfully immobilized ferritin protein molecules onto the sidewalls of Multi wall carbon nanotubes (MWNT) through covalent bonds. Ferritin immobilized MWNT mat was obtained by vacuum filtration of these materials through nanoporous filter paper. Electrical conductivity measurements were done by two-probe methods after evaporating two metal electrodes onto the mat. The room temperature conductivity shows a one order of magnitude difference between the pure MWNT mat and ferritin immobilized MWNT mat. The temperature dependence of the conductivity is also different in ferritin immobilized MWNT from that of pure MWNT, suggesting a different conduction mechanism in protein immobilized MWNT mat.

Z3.48
Production of Nanoscale Biomolecular Crystals.
Joshua C. Falkner[1], Ali Al-Somali[1], Jennifer Jamison[1], Junyan Zhang[1], Tushar Prasad[1], Stephanie Adrianse[1], Jayashree Soman[2], Rhoniese Simpson[1], Michelle Calabretta[2], Tianwei Lin[3], John Johnson[3], Wilson Radding[4], George Phillips[4] and Vicki Colvin[1]; [1]Chemistry, Rice University, Houston, Texas; [2]Biochemistry, Rice University, Houston, Texas; [3]Molecular Biology, Scripps Research Institute, La Jolla, California; [4]Biochemistry, University of Wisconsin - Madison, Madison, Wisconsin.

Protein crystals are useful tools in materials chemistry that facilitate the creation of three dimensional architectures on the nanometer scale. These materials offer distinct advantages over other porous materials due to both the tunable pore size and heterogeneous nature of the pore walls. Here we discuss methods for controlling the crystal size and forming nearly monodisperse cross-linked crystals useful for specific applications. Protein nanocrystals, for example, allow for the generation of highly porous biomolecular substrates. Such systems provide fast diffusion rates and high accessibility in catalytic reactions.

Z3.49
Control of Oligonucleotide Conformation on Nanoparticle Surfaces by Modification with a Self-Assembled Monolayer.
Sunho Park[1], Katherine A. Brown[2] and Kimberly Hamad-Schifferli[1,2]; [1]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Biological Engineering Division, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Nanoparticle labeling of DNA oligonucleotides has many applications in sensing, programmable assembly of nanostructures, and control. The linking of nanoparticles to oligos has been explored and the most common route is to use a thiol or other functional group on the 5' or 3' end of the oligo, leaving the bases unobstructed for hybridization to its complement. However, it has been found that oligos can adsorb to gold nanoparticle surfaces through the bases on the nucleotides and thus inhibit hybridization by preventing base pairing. We use chemical modification of the nanoparticle surface with 6-mercapto-1-hexanol (MCH) to control oligo conformation oligo via SAMs chemistry so that the DNA can achieve a conformation that facilitates hybridization. The Ferguson plot method is used to evaluate the change in effective size of Au-DNA samples upon MCH reaction. Experimental results clearly show that the effective size increases upon the reaction with MCH, but decreases at high MCH concentrations due to different electrophoretic behaviors of the conjugate as well as the loss of surface DNA. In addition, hybridization ability of surface modified Au-DNA can be achieved by labeling the complement DNA with fluorescent molecule. By considering both effective size change and hybridization property, we can predict the real conformation of the Au-DNA conjugates at each MCH reaction condition.

Z3.50
Novel Polypeptide-Based Silicate Layered Nanocomposite: Effect of Poly(L-lysine) Molecular Conformation on Material Properties. Rohan Hule[1], Vahik Krikorian[1], Jeffrey Thompson[2], Timothy Deming[2] and Darrin Pochan[1]; [1]Materials Science and Engineering and Delaware Biotechnology Institute, University of Delaware, Newark, Delaware; [2]Materials and Chemistry, University of California at Santa Barbara, Santa Barbara, California.

The formation of nanocomposites from poly(L-Lysine) (PLL), a semi-crystalline polypeptide, as the matrix is discussed. Cationic PLL.HBr is reinforced by sodium montmorillonite (MMT) clay via solution intercalation technique. By varying solution conditions such as pH, temperature and concentration in the presence of clay platelets, the secondary conformation of the polypeptide was controllably altered into α-helical and β-sheet. Investigations were made into the secondary structure of PLL using Fourier Transform Infrared (FTIR) spectroscopy, Small Angle X-ray Scattering (SAXS) and Circular Dichroism (CD) spectroscopy. Material properties of the nanocomposites, relative to the secondary conformation, were observed and compared with random coil nanocomposites made earlier. The formation of nanocomposites and the degree of intercalation is further discussed. Mechanical testing experiments on reinforced polypeptides revealed significant enhancement in elastic modulus over neat polypeptides, with values comparable to traditional engineering polymers.

Z3.51
Molecular Recognition in 2D Binary Mixtures of DNA-Base Molecules Studied by STM. Maya Schoeck, Roberto Otero Martin, Luis Miguel Molina, Erik Laegsgaard, Ivan Stensgaard, Bjork Hammer and Flemming Besenbacher; Department of Physics and Astronomy, University of Aarhus, Aarhus, Denmark.

Molecular recognition events between complementary nucleic acid bases are fundamental for many biological processes, like DNA replication, and is currently being exploited for self-assembling DNA-based nanostructures. The DNA replication fidelity in living organisms is maintained by a complex molecular machinery of polymerases, exonucleases, etc. On the other hand, in the case of replicating NA molecules in the prebiotic soup, the basic physico-chemical mechanism to steer the replication process is the hydrogen-bonding between DNA bases. The fidelity of this replication process implies that Watson-Crick pairing must be favored over others, like "wobble" or "deviant" pairing. By means of a combination of STM experiments and DFT calculations, in this contribution we compare the 2D molecular networks formed on Au(111) upon deposition of the binary mixtures G-C (purine-pyrimidine pair of complementary bases) and A-C (purine-pyrimidine pair of non-complementary bases). We show that, after a gentle annealing to 80 C the non-complementary bases segregate into islands of pure A and a network of pure C, whereas the complementary bases G and C form a network that cannot be separated by annealing up to the desorption temperature for C. High-resolution STM images allow us to identify the structures for these enhanced thermal stability as structures that contain G-C bonds possibly with the same structure as the Watson-Crick pairs in DNA molecules. This result shows that the hydrogen-bonding interaction alone can steer the molecular recognition process necessary for high-fidelity DNA replication even in the absence of polymerases, exonucleases, etc.,a result that could be relevant to understand the origin and nature of the first self-replicating molecules in the prebiotic soup.

SESSION Z4: Protein Self-Assembly/Nanostructures/Polymer Design and Synthesis
Chair: Morley Stone
Tuesday Morning, November 30, 2004
Room 304 (Hynes)

8:30 AM *Z4.1
S-Layer Based Nanostructures. Uwe B. Sleytr, Dietmar Pum, Margit Sara and Bernhard Schuster; University of Natural Resources and Applied Life Sciences, Vienna, Center for NanoBiotechnology, Wien, Austria.

The study of biological self-assembly systems is a new and rapidly growing scientific and engineering field that crosses the boundaries of existing disciplines. The attractiveness of such bottom up processes lies in their capability to build uniform, ultrasmall functional units and the possibility to exploit such structures at meso- and macroscopic scale. In this context, two-dimensional bacterial surface layer proteins (S-layer proteins) represent very versatile assembly systems with unique features as structural basis for a complete supramolecular construction kit. S-layers are the most commonly observed cell surface structures in prokaryotic organisms (bacteria and archaea). They are composed of a single protein or glycoprotein species (Mw = 40 to 200 kDa) and exhibit either oblique, square or hexagonal lattice symmetry with unit cell dimensions in the range of 3 to 30 nm. S-layers are generally 5 to 10 nm thick and represent highly porous protein meshworks with pores of uniform size and morphology in the 2 to 8 nm range. One of the key features of isolated S-layer proteins is their intrinsic tendency to self-assemble into two-dimensional arrays in suspension and at various interfaces. The wealth of information accumulated on the general principles of S-layers led to a broad spectrum of potential applications in many areas of both life and materials sciences. The possibility to change the natural properties of S-layer proteins by genetic manipulation opens a new horizon for the tuning of their structural and functional features. Functionlized S-layer proteins that maintain their propensity for self-assembly have led to new affinity matrices, diagnostic tools, biological templates for the controlled binding of molecules and nanoparticles and targeting or delivery systems. For review see: Sleytr, U.B., M. Sara, D. Pum, B. Schuster, P. Messner, C. Schaeffer. 2002. Self-Assembly Protein Systems: Microbial S-Layers. pp. 285-338. In: A. Steinbuechel, S. Fahnestock (eds.) Biopolymers, Vol. 7, Wiley-VCH, Weinheim, Germany. Sleytr, U.B., M. Sara, D. Pum, B. Schuster. 2001. Characterization and use of crystalline bacterial cell surface layers. Progr. Surf. Sci. 68:231-278. Sleytr, U.B., M. Sara, D. Pum, B. Schuster. 2001. Molecular nanotechnology and nanobiotechnology with two-dimensional protein crystals (S-layers). pp. 333-389. In: M. Rosoff (ed.) Nanosurface Chemistry, Marcel Dekker, New York, Basel.

9:00 AM *Z4.2
Using proteins from extremophiles as tools for nano-technology. Jonathan D. Trent, Robert Andrew McMillan and Chad Paavola; Bioengineering, NASA Ames Reseach Center, Moffett Field, California.

One of the most basic problems in nanotechnology is how to manipulate matter on the nano-scale and one of the most straight-forward solutions to this problem is to utilize systems that self-assemble. There are no more sophisticated self-assembling systems than those found in biology. Biology provides self-assembling architectures that are controlled and constructed at the molecular level. Our group at NASA Ames Research Center is using biomolecules from organisms known as "extremophiles" to create structures on the nano-scale. Extremophiles are organisms living in harsh environments that produce some of the most robust biomolecules known. We are exploring how proteins from extremophiles can be gentically modified to be used as tools to manipulate and order nano-particles. I will discuss our work with a genetically engineered 60 kDa extremophile proteins that self-assemble into double-ring structures, which we are using for both electronic and medical applications.

9:30 AM Z4.3
Protein self assembly on patterned surfaces.
Karthikeyan Subburaman[1], Nadine Pernodet[1], Miriam Rafailovich[1] and Nan-Loh Yang[2]; [1]Materials Science & Engineering, State University of New York at Stonybrook, Stonybrook, New York; [2]Department of Chemistry, City University of New York, Staten Island, New York.

We have shown that Fibronectin (Fn) fibrillogenesis can be induced when the protein is adsorbed onto charged polymer surfaces [1]. Furthermore, we have shown that the protein fibers self assemble into a large lattice whose period spans several tens of microns. Here we explore the morphology of the lattice when it is confined on a patterned surface whose scale changes gradually from microns into the nanometer regime. We find that the lattice transforms to form long wires running longitudinally to the patterns. Since these morphologies can be explained in terms of minimizing the deformation of rigid crystalline structures, we co-adsorbed fironectin with elastin, which is a more flexible protein. The modulus of the new fibers was measured as a function of the pattern scale using Scanning Modulation Force Microscopy. In this mode, we were able to visualize the location of the harder Fn and the elastin in the fiber. We find that the Fn now forms the backbone of the fibers while elastin forms the outer sheath. Since the patterns were formed by deposition of Au wires on a Si chip, we are able to apply external voltages to different segments of the chip and explore the effect of external fields on the ordering of the charge protein molecules. Supported in part by the NSF-MRSEC program and the DOE References: 1. Pernodet, N., Rafailovich, M. Sokolov, J. Xu, D., Yang, N.L. and McLeod, K.J. (2003) Fibronectin fibrillogenesis on sulfonated polystyrene surfaces. J. Biomed. Mat. Res. 64A:682-692.

9:45 AM Z4.4
Virus-Based Toolkit for the Directed Assembly of Nanoscale Devices. Daniel J. Solis[1], Chuanbin Mao[2], Brian D. Reiss[1] and Angela M. Belcher[3]; [1]Chemistry/DMSE, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]University of Texas at Austin, Austin, Texas; [3]Massachusetts Institute of Technology, Cambridge, Massachusetts.

The utilization of biological factors in the design, synthesis and fabrication of nano-scaled materials and devices presents novel, large scale solutions for the realization of future technologies. In particular, we have genetically modified the M13 Filamentous Bacteriophage for its use as a biological scaffold in the peptide-controlled nucleation and patterning of nanoscale semiconducting and magnetic materials. Through evolutionary phage display screening of ZnS, CdS, CoPt, and FePt, functional peptides that influence material properties such as size, phase and composition during nucleation have been identified. The incorporation of these specific, nucleating peptides into the generic scaffold of the M13 coat structure provides a viable linear template for the directed synthesis of semiconducting and magnetic nanowires. Through further modification of the remaining proteins on the virus scaffold, other functionalities can be incorporated such as the directed patterning of the virus/nanowires assemblies into nanoscaled devices with tunable properties as determined by the genetic information carried within the virus scaffold. Multi-functional viruses provide a truly self assembled system for the design and execution of a myriad of nanoscaled devices in a green, scalable and cost effective manner.

10:30 AM *Z4.5
Biomimetic Strategies for Nanomaterials Chemistry.
Rajesh R. Naik, Melanie M. Tomczak, Ryan M. Kramer, Lawrence F. Drummy, Laura A. Sowards and Morley O. Stone; Materials and Manufacturing Directorate, Air Force Research Laboratory, Dayton, Ohio.

The diversity of catalytic reactions in biology is astounding. While much effort has been directed at understanding the catalysis of organic compounds, there is a growing appreciation for nature's incredible control over the nucleation and growth of inorganic structures. Biomolecules as well as biomolecular architectures, have been shown to control the growth of inorganic nanoparticles. Our research efforts have been directed at utilizing biomimetic approaches to control nucleation and growth of inorganic materials. We have directed our effort towards the fabrication of composite organic/inorganic nanomaterials, using nature's master of silica, the diatom, as our model system. We have extended this effort by utilizing specific peptides coupled to supramolecular bioassemblies to control nucleation, growth and deposition of inorganic nanomaterials. In this talk, I will cover our efforts directed at selecting inorganic-binding peptides, patterning these novel peptides and exploiting the self-assembling properties of biomolecules for nanoparticle synthesis.

11:00 AM *Z4.6
Biologically-active Nanostructures Derived from Functionalized Polymerization Initiators and Incorporating Dendritic Macromolecules via "Click" Chemistry.
Craig Hawker[1], Rachel K. OReilly[1,2], Matthew L. Becker[2], Maisie J. Joralemon[2], Dipanjan Pan[2], Kai Qi[2], Jeffrey L. Turner[2] and Karen L. Wooley[2]; [1]IBM, San Jose, California; [2]Department of Chemistry, Washington University in St. Louis, St. Louis, California.

Introduction Nanoscopic particulate materials present great promise for use as carriers and reporters for biomedical applications with applications ranging from imaging contrast agents, drug delivery vessels, to scavengers of toxins, etc. Although a significant amount of effort has been dedicated to the preparation and study of nanostructured materials for medical development, a key challenge toward directing the transport, delivery and clearance of these materials, i.e. their biodistribution, has not been solved. The distribution of materials in vivo is a complex process that relies upon interfacial interactions between, in this case the nanoparticle, and varied biological tissues. This requires an understanding of the supramolecular and multivalent interactions at the molecular level over nanoscopic dimensions (the size of the nanostructured material) and control over the surface chemistry of the nanoscale material. Because this is a complex and dynamic process, there is significant fundamental and applied understanding that needs to be developed. One of the immediate challenges is the development of synthetic methodologies that allow for the preparation of well defined nanostructures having surface chemistry and internal structure, each of which can be controlled and modified accurately. We have focused over the past several years on shell crosslinked (SCK) polymer micelles, which are robust core-shell nanoparticles that allow for tuning of the internal core and external shell compositions and properties. In this presentation, several synthetic routes for the introduction of biologically-active surface moieties will be described, and the characterization of the materials will be detailed, from in vitro model studies to in vivo biodistributions. The development of SCKs for targeting to selective tissues will also be discussed. Details of the Presentation The preparation of well defined SCK nanostructured materials that present biologically-active moieties emanating from their surfaces has been accomplished by several synthetic approaches. This presentation will detail two diverse and unique synthetic approaches. One approach incorporates the biologically-active moiety at the initiator stage of the synthesis to ensure placement at a polymer chain terminus. Supramolecular assembly and covalent crosslinking of the polymer chains then yields the SCK nanostructures. In a second, quite different approach, the SCKs are produced via supramolecular assembly of amphiphilic block copolymers that contain "Click" reactive functional groups, followed by crosslinking upon reaction with dendrimers carrying multiple compatible "Click" reactive functionalities. This process provides for the crosslinking stabilization and also incorporates excess functionality via the dendritic multi-functional units, which allow for conjugation of biologically-active ligands post-SCK preparation.

11:30 AM Z4.7
Phenylene Ethynylene is a Versatile Backbone for Biomimetic Design.
Greg N. Tew, Polymer Science, University of Massachusetts, Amherst, Amherst, Massachusetts.

The design of simple molecules and polymers that capture the shape and biological function of natural biopolymers remains an important goal. We will discuss the use of phenylene ethynylene backbones to design facially amphiphilic beta-sheet like sheets as well as tight helices. Many peptides, such as the Magainins and Defensins, are amphiphilic in nature and known to fold into specific conformations responsible for their antimicrobial activity. Recently, a number of non-natural peptides with designed sequences have been elaborated to provide biologically active structures; in particular, facially 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. However, these natural peptides as well as their beta-peptide analogues, are expensive to prepare and difficult to produce on large scale. The design of polymers and oligomers that mimic the complex structures and remarkable biological properties of proteins is an important endeavor and would provide attractive alternatives to the difficult synthesis of natural peptides. We therefore have designed a series of facially amphiphilic polymers that capture the essential physical and biological properties of antimicrobial peptides, but are easy to prepare from inexpensive monomers. These polymers adopt structure very reminiscent of amphiphilic beta-sheets and have good activity with minimal inhibitor concentrations at 24 h as measured by the Hancock method in the low microgram per mL range (uM to nM). They are active against a broad spectrum of bacteria including gram-postive and negative as well as antibiotic resistant strains. Structure-activity relationships are being developed and experiments relating to the amphiphilic nature of the polymers will be discussed. In addition, we have designed helical systems giving us access to the two most important secondary structural elements in protein folding. We will describe the synthesis and characterization of these new helical structures.

11:45 AM Z4.8
Mechanical Response and Adhesion of High Strength, Physically Associating Polymer Gels.
Kenneth R. Shull[1], Rebecca E. Webber[1], Bruce P. Lee[2] and Phillip B. Messersmith[2,1]; [1]Department of Materials Science and Engineering, Northwestern University, Evanston, Illinois; [2]Department of Biomedical Engineering, Northwestern University, Evanston, Illinois.

We examine the mechanical properties and adhesive response of two types of bio-inspired, physically crosslinked gels. The first of these is an alginate polysaccharide that forms a strong hydrogel in the presence of divalent cations. The second system is an acrylic triblock with poly(methyl methacrylate) (PMMA) endblocks and a poly(n-butyl acrylate) (PnBA) midblock. Gelation of the alginates occurs by the addition of Ca2+ ions to aqueous solutions of sodium alginate, whereas gelation of the acrylic triblock copolymers occurs via thermally reversible aggregation of the PMMA endblocks when the copolymers are dissolved in any of a variety of alcohols. The rheological and mechanical behaviors of both types of gels were studied using an axisymmetric probe tack apparatus with stress relaxation and cyclic movement capabilities. The alginate hydrogels behave elastically at small strains and become viscoelastic at large strains, a result that is responsible for the excellent mechanical strength of the gels. The acrylic polymer gels also have very high strength, with adhesion that can be controlled by adding specific functional groups to the PnBA midblock. The viability of this approach was demonstrated by using 3,4-dihydroxyphenylalanine (DOPA), an important constituent of naturally occurring adhesive peptides, as the adhesive functionality.

SESSION Z5: Biophotonics/Bio-optics
Chair: Morley Stone
Tuesday Afternoon, November 30, 2004
Room 304 (Hynes)

1:30 PM *Z5.1
Biologically Formed Microlens Arrays with High-Tech Features.
Joanna Aizenberg, Bell Labs/Lucent, Murray Hill, New Jersey.

Nature provides a whole host of superior multifunctional structures that can be used as inspirational systems for the design and synthesis of new, technologically important materials and devices. This presentation describes the exceptional optical performance of natural microlens arrays formed by light-sensitive brittlestars, their structural and compositional features, and advantageous properties. We show that brittlestars form a nearly perfect optical device with micron-scale, lightweight, mechanically strong, aberration-free, birefringence-free, individually-addressed lenses, which offer a unique focusing effect, signal enhancement, intensity adjustment, angular selectivity, and photochromic activity. We believe that these biological structures provide new ideas for the fabrication of improved optical systems, constructed using a bottom-up approach.

2:00 PM *Z5.2
Introduction to Bio-inspired Optics. Leonard J. Buckley[1,3] and Randall R. Sands[2]; [1]Defense Sciences Office, DARPA, Arlington, Virginia; [2]Touchstone Consulting, Brookeville, Maryland; [3]Chemistry Division, NRL, Washington, District of Columbia.

The Defense Advanced Research Project Agency (DARPA) is sponsoring several research efforts aimed at designing, developing and demonstrating bio-inspired optical systems. The inspiration for this research can be found in nature - from the complex graded index of refraction found in the human crystalline lens to the hyper-acuity of an insect's compound eye. Engineering optical systems that posses the capabilities found in animal systems is extremely challenging and requires the development of new materials and materials processing. This article reviews the human vision system with particular emphasis on the crystalline lens. We examine the unique material behavior and structure that give rise to these interesting and impressive optical characteristics. In addition, we will provide a brief overview of the DARPA programs that are currently exploiting innovative optical designs found in nature for use in military imaging systems.

2:30 PM *Z5.3
Bio-inspired Functional Microlens Arrays with Integrated Pore Structures. Shu Yang, Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.

Biology provides a multitude of varied, new paradigms for the development of adaptive optical networks. Here we present a first example of synthetic, biomimetic microlens arrays with integrated pores, whose appearance and function are strikingly similar to their biological prototype - a highly efficient optical element formed by brittlestars. The complex microstructure is created directly by three-beam interference lithography in a single exposure. We show that (i) the microlenses have strong focusing ability and the structure can be, therefore, used as an adjustable lithographic mask, and that (ii) light-absorbing liquids can be transported in and out of the pores between the lenses, which provides a wide range of tunability of the lens optical properties.

3:30 PM *Z5.4
Bio-Inspired Polyelectrolyte Multilayers: From pH-Gated Bragg Reflectors to Superhydrophobic Surfaces.
Michael F. Rubner[1] and Robert E. Cohen[2]; [1]Materials Science and Eng., MIT, Cambridge, Massachusetts; [2]Chemical Engineering, MIT, Cambridge, Massachusetts.

Nature makes extensive use of the pH-dependent behavior of weak acid and weak base groups such as the carboxylic acid and amine functional groups. The pH-gated opening and closing of the carboxylate lined cages of the cowpea chlorotic mottle virus, for example, is an important element of the infection process. By constructing polyelectrolyte multilayers from weak polyelectrolytes like poly(acrylic acid) and poly(allyl amine), we have created a variety of different thin film coatings with pH-triggered properties that mimic some of those found in nature. For example, we have demonstrated a pH-induced porosity transition that can be used to create porous films with pore sizes that are tunable from the nanometer scale to the multiple micron scale. The pores of these films, either nano- or micropores, can be reversibly opened and closed by changes in solution pH. In addition, the highly textured honeycomb-like surfaces created by the formation of micron-scale pores are ideally suited for the creation of superhydrophobic surfaces that mimic the behavior of the self-cleaning lotus leaf. The ability to engineer pH-gated porosity transitions in heterostructure thin films has further led to the demonstration of broad-band anti-reflection coatings, pH-tunable Bragg reflectors, electronic shutters and stable superhydrophobic surfaces.

4:00 PM *Z5.5
Bio-Mimetic GRIN Lens Using Polymeric Nanolayered Film Systems. Eric Baer[1], Anne Hiltner[1], Yi Jin[1], Jiong Yu[1], Aditya Ranade[1], Huiwen Tai[1], James Shirk[2], Michael Wiggins[2] and Marie Sandrock[2]; [1]Macromolecular Science and Engineering, Case Western Reserve University, Cleveland, Ohio; [2]Naval Research Laboratory, Washington, District of Columbia.

The unique capabilities of biological optics arise from sophisticated features such as gradient index (GRIN) lenses and dynamic shape change. These GRIN lenses comprise thousands of layers that vary in protein concentration. It is reported that the human eye comprises greater than 20,000 layers and can change shape to accommodate near and far focus . The refractive index range (Δn) within a spherical lens in a human eye is about 0.03. In other cases like fish eye and octopus eye lenses, larger Δn compensates for an inability to change shape. The refractive index range within octopus eye is about 0.15 and fish eye is about 0.22. The aim of this research is to develop new nanolayered polymeric lenses with bio-inspired designs which have the structure and the properties of biological lenses. Specifically, this paper describes polymeric nanolayered systems that are used to mimic the lens in an octopus eye. In contrast to the well-known concept of self-assembly, layer multiplying coextrusion uses forced-assembly to create thousands of alternating layers of two or more polymers. Each layer can be less than 10nm in thickness. A new class of polymeric layered systems composed entirely of interphase was fabricated by forced-assembly of nanolayers. These nanolayered films were fabricated with systematic variation of refractive index by varying the composition of the constituent polymers. The films were highly transparent since the individual layer thicknesses were significantly below the quarter wavelength of visible light. One hundred films with refractive index changes between each film of one percent were made from poly(methyl methacrylate) and poly(styrene acrylonitrile). Subsequently, GRIN stacks were processed from these films with tailored refractive index distributions dictated by the parabolic distribution reported for the octopus lens. A novel method was developed for preparing biomimetic GRIN lens with a structure similar to octopus eye lens using these stacks. Nanolayered structures, the refractive index profiles and optical characteristics of these biomimetic lenses were studied. Their optical properties were investigated both experimentally and theoretically, and good predictive correlations were obtained. It was confirmed that lenses prepared by this technique are almost aberration free and give a wider field of view than normal curved lenses. Large radial GRIN lenses of various thicknesses were also successfully produced. These have flat surfaces yet still focus light due to the parabolic refractive index distribution along the radius. The relationship between the focal length and lens thickness was studied and successfully compared with theoretical predictions. Acknowledgements: The authors wish to thank Dr. Leonard Buckley for his many technical contributions. This work was generously supported by DARPA.

4:30 PM Z5.6
Signal Multiplexing in QD-based Fluorescence Resonance Energy Transfer. Aaron R. Clapp[1], Igor L. Medintz[2], Harry Tetsuo Uyeda[1], Ellen R. Goldman[2] and Hedi Mattoussi[1]; [1]Optical Sciences Division, Code 5611, Naval Research Laboratory, Washington, District of Columbia; [2]Center for Bio/Molecular Science and Engineering, Code 6900, Naval Research Laboratory, Washington, District of Columbia.

Colloidal CdSe-ZnS quantum dots (QDs) have narrow photoemission bandwidths and broad absorption spectra which suggest that they may be ideal fluorophores for biological 'multiplexing' investigations. Unlike organic fluorophores which require a complex arrangement of excitation sources and filters to generate multiple signals, many populations of QDs can be simultaneously excited with a single excitation source. In a mixed sample, the Gaussian-like emission profile of QDs allows simple deconvolution of the composite signal to yield individual QD photoluminescence (PL) contributions. We have previously shown that QDs function as efficient energy donors in fluorescence resonance energy transfer (FRET) investigations, including a solution phase FRET-based biosensor for maltose.[1,2,3] To determine the feasibility of multiplexed FRET-based sensing, we tested several QD-protein bioconjugates, each having a unique emission spectrum (or "color") functioning as independent signal channels. The various populations of QDs were self-assembled with labeled and unlabeled proteins, mixed in solution and interrogated with a single excitation source. The measured composite spectra were deconvoluted using the known emission profiles to reveal the individual contributions of each QD population (color). QDs coated with dye-labeled protein acceptors showed distinct FRET-induced PL quenching due to the presence of proximal dye acceptors in the conjugates. The quenching of each QD population in the mixture depended on the degree of spectral overlap and the number of dye-labeled proteins immobilized on a single QD. Further, the normalized derived individual spectra were identical to the native spectra (Gaussian-like) of each QD population, indicating that the channels are clearly distinguishable and independent. We will discuss the use of the above findings to develop a functional QD-based FRET multiplex biosensors using a similar strategy, with each QD population having surface-bound proteins that are sensitive to a unique molecular substrate. [1] A.R. Clapp et al., J. Am. Chem. Soc. 126, 301 (2004). [2] I.L. Medintz et al., Nat. Mater. 2, 630 (2003). [3] I.L. Medintz et al., P. N. A. S. 101, 9612 (2004).

4:45 PM Z5.7
Bio-Derived Photonic Crystals for Soft X-Ray Optical Systems. Tushar Prasad[1], Daniel Mittleman[2], Joshua Falkner[1], Mary Turner[1], Tianwei Lin[3], John Johnson[3] and Vicki Colvin[1]; [1]Chemistry, Rice University, Houston, Texas; [2]Electrical & Computer Engineering, Rice University, Houston, Texas; [3]Molecular Biology, The Scripps Research Institute, La Jolla, California.

Fabrication of three-dimensional nanostructures with long range

ordering has always been a challenging task. Use of biological macromolecules as templates to manufacture nanoscale materials provides an easier path for producing patterned nanostructures. Certain protein and virus structures crystallize in the form of a periodic lattice with nanometer range ordering. A non-toxic plant virus, Cowpea Mosaic Virus (CPMV), can be crystallized in body-centered cubic (BCC) form through chemical means. The process starts with the stabilization of biomolecular crystals with crosslinking agents which results in stable, sturdy template materials. The void spaces or interconnected channels in the virus crystal can be infiltrated with metals by electroless deposition. Finally, thin films of virus crystals can be obtained. The unit cell in these crystals comprises of virus particles in close-packed BCC configuration with metal filled void spaces. Characterization of resulting virus crystals by transmission electron microscopy and small angle x-ray scattering shows excellent internal ordering with well-defined lattice planes and confirms very good metal infiltration into the void spaces. From an optical point of view, these crystals can be considered as periodic systems capable of manipulating soft x-ray propagation, since their lattice constant is of the order of nanometers. In other words, thin films of crystals derived from CPMV can act as three-dimensional photonic crystals for soft x-ray optical systems. For wavelengths around 35 nm, calculations based on electromagnetic transfer matrix method predict a reflectivity of about 7% with a peak width of 22%, which can be utilized for mirrors and dispersive elements on synchrotron radiation beamlines.

SESSION Z6: Bio-Inspired Devices, Sensors and Motors
Chair: George Bachand
Wednesday Morning, December 1, 2004
Room 304 (Hynes)

8:30 AM *Z6.1
Engineering Life into Matter. Carlo D. Montemagno, Bioengineering, University of California-Los Angeles, Los Angeles, California.

Recent advances in our ability to manipulate matter at the scale of individual molecules have created an incredible level of excitement in both the scientific community and the general population. The excitement over this new capability, commonly labeled nanotechnology, is vested in the expectation of the development of new materials and systems that offer unparalleled functionality. Materials that autonomously adapt their shape and physical properties in response to the their surroundings, computers that instead of operating by switching the flow of electrons, manipulate information through the management of the ethereal world of quantum states and, molecular sized machines that actively repair damage to our bodies and function as molecular scale prosthetics are all expectations of nanotechnology. While the question of whether or not this vision is truly achievable is still open, the truth is that much of the expectations for nanotechnology are already realized in living systems. Living systems however, are more than a product of matter manipulation at the molecular scale; the richness of functionality associated with living systems is a direct product of the information generated from both the interactions between molecules and the overall supra-molecular structure of the system. In essence living systems are "living" because of the fusion of nanotechnology and informatics. Living systems result from the precision assembly of matter with prescribed modalities for the transport and transduction of information among supra-molecular clusters. Presented is the concept of Integrative Technology, the intersection of the precision assembly of matter, nanotechnology, coupled with the functional building blocks of nature, biotechnology, and fused by the network flow of spatiotemporal information, informatics. The power of Integrative Technology is illuminated through an illustrative example; the engineering of nano-sized excitable vesicles with the ability to intrinsically process information. The fusion of the tools of nanotechnology and biotechnology to produce excitable vesicles is described as is the mechanics of information flow that ultimately lead to the manifestations of emergent higher-order behavior. Finally, the potential of using systems engineered and produced from nanoscale components to create complex systems and materials that manifest embedded functional behavior is discussed.

9:00 AM *Z6.2
Biomolecular Motors as Engines for Nanoscale Transport and Assembly. Henry Hess[1], Christian Brunner[2], John Clemmens[1], Robert Doot[1], Karl-Heinz Ernst[3], Sheila Luna[1], Robert Tucker[1] and Viola Vogel[2,1]; [1]Bioengineering, University of Washington, Seattle, Washington; [2]Department of Materials, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland; [3]Molecular Surface Technologies, Swiss Federal Laboratories for Materials Research (EMPA), Duebendorf, Switzerland.

Active, energy-consuming transport processes on the micro- and nanoscale are widely used by nature to self-assemble complex cellular and subcellular structures and materials. Biomolecular motors, such as the motor proteins kinesin and myosin, play a central role in many of these transport and assembly processes, since they are able to efficiently convert chemical energy into mechanical work using ATP as fuel. Mimicking these biological active transport processes can lead to major advances in nanotechnology by enabling a variety of new approaches to sensor design and materials assembly. However, critical components, such as molecular motors with high functionality, cannot be synthesized at this point. We have chosen to circumvent this roadblock by designing hybrid devices, which integrate nanomachines of biological origin into synthetic environments. For example, we designed 'molecular shuttles', a nanoscale transport system integrating kinesin motor proteins as engines and filamentous microtubules as cargo-carrying units. Critical advances have been made in guiding these shuttles along microfabricated tracks, controlling their speed, and selectively loading them with cargo, and we will describe our progress regarding these technical aspects. These advances allow us to tackle a number of new applications, most notably the bottom-up assembly of new nanostructures and the integration of molecular-scale transport into biosensing. With regard to assembly, our ability to define the trajectories and thus the precise manner of collisions between multiple shuttles combined with a suitable way of cross-linking leads to the formation of non-equilibrium structures, which can then be used as biological templates for a variety of chemical and lithographical procedures. With respect to sensing, we can selectively capture and transport analytes molecule by molecule and implement new approaches to purification and concentration prior to detection. Hybrid devices which seamlessly integrate the most advanced biological and synthetic elements can push out the boundaries of technological possibilities. However, the integration process poses particular challenges, and we will discuss our results regarding the compatibility of biological and synthetic elements and their implications. H. Hess, G. D. Bachand, and V. Vogel. 2004. Powering Nanodevices with Biomolecular Motors. Chemistry - A European Journal, 10:2110-2116. J. Clemmens, H. Hess, R. Doot, C. M. Matzke, G. D. Bachand, and V. Vogel. 2004. Motor-protein "roundabouts": Microtubules moving on kinesin-coated tracks through engineered networks. Lab on a Chip, 4:83-86. H. Hess, C. M. Matzke, R. K. Doot, J. Clemmens, G. D. Bachand, B. C. Bunker, and V. Vogel. 2003. Molecular Shuttles Operating Undercover: A New Photolithographic Approach for the Fabrication of Structured Surfaces Supporting Directed Motility. Nano Letters, 3:1651-1655.

9:30 AM Z6.3
Setting a Foot on the Path to Nanorobotics: DNA Biped Walks Forward and Back. William B. Sherman and Nadrian C. Seeman; Chemistry, New York University, New York City, New York.

DNA is a highly versatile material. Strands 100 bases or shorter can be synthesized routinely with any desired nucleotide sequence. The sequences, in turn, specify structural features of the strands. Single stranded segments are highly flexible. Double helices are fairly rigid molecules with a linear topology and a persistence length of 50nm. Multiply branched motifs can be formed into complex, non-linear structures that can be more rigid than the simple double helix.[1] Further, DNA strands that are partially hybridized can be separated by the introduction of 'fuel strands'[2] that form fully hybridized mates with one of the target strands. This provides a control mechanism that can target a particular strand in a large set of strands and, by removing only that strand, alter the shape of the target structure. We have taken advantage of all these features of DNA to construct a DNA-based device that moves relative to an external structure.[3] The biped itself consists of two double helices connected to each other by three flexible single strands. On the end of each of the two double helices is a 'foot' (a single stranded overhang). The biped walks along a 'sidewalk' molecule, which consists of three double helices rigidly fixed together. Each helical domain in the sidewalk has a sticky ended overhang called a 'foothold.' Since each foot and foothold in the system has a unique sequence, 'set strands' can be introduced into the system that specifically hybridize to exactly one foot and one foothold, thereby setting foot placement. 'Unset strands,' can then be used to remove the set strands and free up one foot or the other. By alternately raising and lowering each foot, the biped marches up and down the sidewalk. Exposing the system to UV light, causes the psoralen molecules attached to the bottom of each foot to form a covalent bond with the neighboring strands. Subsequent denaturing gel electrophoresis can determine the position of the biped by observing the size of the psoralen adducts formed. [1] P. Sa-Ardyen, A. V. Vologodskii, and N. C. Seeman. The Flexibility of DNA Double Crossover Molecules. *Biophys. J.* 2003, 84, 3829-3837. [2] B. Yurke, A. J. Turberfield, A. P. Mills, F. C. Simmel, J. L. Neumann. A DNA-Fuelled Molecular Machine Made of DNA. *Nature*. 2000, 406, 605-608. [3] W. B. Sherman, N. C. Seeman. A Precisely Controlled DNA Biped Walking Device. *NanoLetters*. 2004 In press.

9:45 AM Z6.4
Assembly of Quantum Dots by Ribosomal Molecular Machines. Ioana Pavel[1], Angela M. Belcher[2] and Karen S. Browning[1]; [1]Department of Chemistry and Biochemistry, The University of Texas at Austin, Austin, Texas; [2]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

We developed a method for organizing quantum dots by linking them to chemically reactive amino acids side chains (e.g., cysteine) and then integrating these amino acids into a polypeptide nascent chain through in vitro translation of a mRNA template. This new method for the supramolecular assembly of bioinorganic heterostructures uses mRNA and ribosomes as natural molecular machines. This system also provides a new tool for probing fundamental biological processes (e.g. translation). We developed a novel coupled transcription-aminoacylation system to prepare large amounts of pure aminoacyl-tRNA. The aminoacyl-tRNA is covalently linked to a quantum dot (Monomaleido Nanogold). The result is a novel quantum dot-conjugated-tRNA. Quantum dot-conjugated polypeptides are synthesized in vitro and the presence of nanogold particles is verified by electrophoresis, Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), and high resolution TEM.

10:30 AM Z6.5
Ion Channels Embedded in Synthetic Bilayers: Sensing their Stochastic Ion Translocation. Randy S. Duran[1], Peter Anderson[2], Joanna Long[3], Jun Zhang[1], Ingo Koeper[4], Wolfgang Knoll[4], Chris Williams[2], Frank Raucci[3], Kun Fang[1] and Henk M. Keizer[1]; [1]Chemistry, Univ of Florida, Gainesville, Florida; [2]Whitney Laboratory, University of Florida, St. Augustine, Florida; [3]McKnight Brain Institute, University of Florida, Gainesville, Florida; [4]Max Planck Institute for Polymer Research, Mainz, Germany.

As part of a project centered on functionally incorporating ion channels in non-native and polymer-stabilized lipid bilayers, we are interested in characterizing the ion translocation behavior of the resulting assemblies. We have investigated several mutants of the natural Maxi-K channel and the self-assembling synthetic M2 peptide oligomer from the acetylcholine receptor with a view towards using them in tethered bilayers over microelectronic devices for eventual biosensor applications. The ion channel characteristics and their functional incorporation in bilayers will be presented. Stable, long-lasting, single channel ion current fluctuations were measured by tip dip methods and these data will be discussed.

10:45 AM *Z6.6
Synthesis and Surface Modification of Upconverting Phosphors for Use as a Reporter in Immunochroamtographic Bio-assays. David Cooper and Brent MacQueen; SRI International, Menlo Park, California.

This presentation will discuss the synthesis and surface modification of upconverting phosphors (UCPs) for use in bio-assay systems. UCPs are a unique class of materials consisting of rare-earth lanthanide series elements. These phosphors undergo unique, low-energy, multi-photon excitations (typically in the near infrared region) that results in a higher energy emission (typically in the visible) than that of normal phosphors, which convert high-energy excitation (typically in the ultraviolet) to lower energy emissions (typically in the visible). The phosphors are nontoxic, inorganic (ceramic) crystals made of rare earth ions alloyed into a host matrix. This unique property makes these phosphors ideally suited for use as reporters in lateral-flow bio-assays because they exhibit excellent signal-to-noise ratios. All biological materials generate an emission (autofluorescence) when excited with high-energy photons. In contrast, the upconverting phosphors utilize only low-energy photons to generate an emission signal, with no background autofluorescence generated in the presence of biological materials. Consequently, the limit of detection for the UCP can be lower than that obtained with conventional fluorescent reporters. SRI has demonstrated direct detection of as little as 1 ng of phosphors with hand-held instrumentation. SRI has developed extensive expertise in the synthesis and surface modification of UCPs, as well as the evaluation of assay conditions to optimize the detection limits of its bio-assay system. The synthesis expertise involves optimization of emission wavelength and emission intensity through a high-throughput screening process. Once the composition of the phosphor is optimized, a patented fluidized bed process is used to produce spherical particles in the 300-400 nm range. The phosphor particles are then surface modified by a multi-step process that results in the immobilization of antibodies. Keys to the immobilization process are the surface density of antibodies, percent of immobilized antibodies that remain active, and the ability to minimize nonspecific binding of the functionalized particles to the capture surface. SRI has also developed a hand-held instrument that conducts biological warfare agents to be detected in the field. The instrument uses a lateral-flow immunoassay test strip that can be multiplexed to detect multiple targets simultaneously in 15 minutes. The unit weighs less than 2 lb with batteries and can perform more than 200 tests using a single battery pack. This unit is ideal for environmental use because only the phosphor particles will illuminate. Furthermore, the UCPs provide a permanent record, as they do not degrade over time or photobleach in light exposure (if kept dry).

11:15 AM Z6.7
Bacteriorhodopsin Monolayers for Optoelectronics: Orientation and Photoelectric Response on Solid Support. Tao He[1], Noga Friedman[2], David Cahen[1] and Mordechai Sheves[2]; [1]Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot, Israel; [2]Department of Organic Chemistry, Weizmann Institute of Science, Rehovot, Israel.

Following light absorption the purple membrane (PM) protein bacteriorhodopsin (bR) can pump protons from the cytoplasmic side to the outer medium, accompanied by an immediate charge separation step and an energy gradient across the cell membrane. Photoexcitation can also lead to the formation of a relatively long-lived intermediate (M412), which exhibits a ca. 150 nm spectral shift in its absorption maximum and the highest population of all intermediates. In addition, bR exhibits long-term stability over a wide range of pH values, temperature, humidity, and in a variety of (photo)chemical environments. All of these make it a promising biomaterial for optoelectronic applications. However, before the protein can be incorporated into functional devices, PM fragments should be assembled onto solid support. Moreover, to generate the maximal voltage per absorbed photon, preparation of PM patches with good macroscopic orientation, using simple and practical assembling methods, is a key point. In this work, PM fragments were adsorbed onto the solid support pre-modified with positively charged 3-aminopropyltrimethoxysilane (APS). The dark value of contact potential difference, measured by Kelvin probe, indicates that a well-oriented PM monolayer was obtained. We ascribe this to the electrostatic asymmetry between the two sides of the membrane protein. The observed surface photovoltage is caused by a complicated sequence of events, which starts with the formation of an electric dipole, when a photon is adsorbed by the retinal located in bR protein. The experimental results indicate that this photoelectric response is related to the M412 intermediate. Furthermore, a native bR monolayer can be converted completely to the M412 intermediates under steady state irradiation of green-yellow light, while with multilayers or suspensions mostly only a fraction can be converted to the M412 state. This is related to the extended lifetime of the M412 intermediate in the monolayer, which is assumed to be caused by dehydration in the thin film and by the electrostatic interaction between the positively charged APS and the negatively charged protein.

11:30 AM Z6.8
Microoxen: Microorganisms Move Microscale Loads. Douglas B Weibel, Piotr Garstecki, Declan Ryan, Willow DiLuzio, Michael X. Mayer, Jennifer E. Seto and George M. Whitesides; Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts.

A growing interest in using biological motors to power nano/micro devices has recently emerged. We approach this subject with the perspective that biological motors may be most conveniently harnessed using the whole organism rather than structures that are reconstituted in vitro from their purified components. To test this concept, we have investigated a system for transporting microscale loads using phototactic microorganisms. As "microoxen", we used *Chlamydomonasreinhardtii* ("chlamy"), a unicellular, biflagellated algae capable of swimming at velocities of 150-250 μm/sec. To attach loads to cells, we screened surfaces presenting different chemical functionality for their ability to bind the cell wall of chlamy. We selected poly(4-hydroxyproline) peptide sequences that non-specifically bound to the cell wall with high-affinity. We modified polystyrene beads (1-5 μm diameter) with poly(4-hydroxyproline) peptides and found that cells carrying beads swam at velocities approaching 200 μm/sec. When confined in microfluidic channels containing LEDs, phototaxing cells moved beads along channels in nearly linear trajectories. As the basis for releasing beads from cells, we modified beads with a poly(4-hydroxyproline) peptide that is photocleavable. Beads were released using UV light (365 nm wavelength) that was not noticeably toxic to chlamy. In the present work we demonstrate the phenomenon of microoxen by using chlamy to pick up, carry, and drop off loads with control over their final destination.

11:45 AM Z6.9
Biomolecular Interactions at the Phospholipid-Decorated Surfaces of Liquid Crystals. Nathan Lockwood, Jeffrey Brake and Nicholas Abbott; Chemical and Biological Engineering, University of Wisconsin, Madison, Wisconsin.

The liquid crystalline state is a remarkable phase of matter that combines the mobility of liquids with the long-range organization of crystals. Biological systems have evolved mechanisms to exploit the balance of order and mobility in liquid crystals to achieve a range of biological functions, such as receptor clustering and control of cell signaling. The liquid crystalline nature of biological membranes plays such a pivotal role in biology that synthetic materials in a liquid crystalline state are a natural choice when searching for a means of interfacing with biological systems. Our research exploits the sensitivity of thermotropic liquid crystals to molecular-scale interactions at surfaces for the purpose of imaging adsorption-desorption and molecular recognition events occurring at biomimetic interfaces between liquid crystals and aqueous solutions. We have developed an experimental system in which stable, planar interfaces are formed between aqueous phases and immiscible thermotropic liquid crystals confined within the pores of gold grids. We have used this system to explore and characterize phospholipid monolayers spontaneously assembled at the aqueous-liquid crystal interface from vesicles and mixed surfactant-phospholipid micelles. Phospholipid-laden interfaces formed in this manner consist of a monolayer of phospholipids that have a lateral fluidity characteristic of biological membranes. The orientation of the supporting liquid crystal is sensitive to organization of the phospholipids at the interface. Strong and weak specific-binding events involving proteins at these interfaces drive the reorganization of the phospholipids and trigger orientational transitions in the liquid crystals. Processes involving the lateral organization of the lipid layer (such as the formation of protein- and phospholipid-rich domains) and stereospecific enzymatic events are also readily imaged by the orientational response of the liquid crystal due to the fluid nature of the lipid-laden interface. For example, the specific binding and hydrolysis of phospholipids by phospholipase A2 leads to easily visualized changes in the anchoring of the liquid crystal whereas the non-specific adsorption of proteins is not reported by the liquid crystal. Because many biologically-relevant interactions that occur at phospholipid interfaces lead to the reorganization of the lipid (e.g., binding of viruses, protein toxins, and cell signaling proteins), our experimental system and methods form the basis of a generally applicable technique for studying in vitro mimics of cell membranes.

SESSION Z7/AA7: Joint Session: Biomimetic Surfaces/Cell-Material Interactions/Biofunctional Peptides
Chairs: Phillip Messersmith and Molly Stevens
Wednesday Afternoon, December 1, 2004
Room 304 (Hynes)

1:30 PM *Z7.1/AA7.1
Biointerfaces Mimicking Extracellular Matrices to Engineer Cell Function. Andres Jose Garcia, Mechanical Engineering, Georgia Inst. Technology, Atlanta, Georgia.

Cell adhesion to adsorbed extracellular matrix (ECM) proteins and adhesive sequences engineered on synthetic surfaces plays critical roles in biomaterial, tissue engineering, and biotechnological applications. Cell adhesion to these adhesive motifs is primarily mediated by integrin receptors. In addition to anchoring cells, integrin binding activates signaling pathways regulating cell survival, proliferation, and differentiation. While tethering short adhesive peptides derived from ECM ligands (e.g., RGD for fibronectin) promotes cell adhesion and function in several cell systems, these biomimetic strategies are limited by reduced biological activity compared to the native ligand, lack of specificity among integrins, and inability to bind non-RGD integrins. These limitations are of particular importance to tailoring specific cellular responses since different integrins trigger different signaling pathways. We have engineered surfaces that control the presentation of integrin-binding domains and mimic the primary, secondary, and tertiary protein structure of fibronectin and type I collagen. These surfaces promote specific integrin binding and focal adhesion assembly and signaling as well as osteoblast cell adhesion and bone-specific gene expression, alkaline phosphatase activity, and deposition of a biologically equivalent mineralized matrix. A recombinant fragment of fibronectin spanning the 7th-10th type III repeats of fibronectin and encompassing the PHSRN and RGD motifs was tethered to non-fouling supports to specifically bind alpha5beta1 integrin and trigger focal adhesion assembly and signaling. Binding of this receptor is critical to osteoblast proliferation, differentiation, and matrix mineralization. To target alpha2beta1 integrin, a triple-helical collagen-mimetic peptide incorporating the GFOGER motif was tethered to model non-adhesive supports. These biomimetic surfaces supported alpha2beta1 integrin-mediated adhesion and focal adhesion assembly and directed osteoblast specific-gene expression and matrix mineralization to higher levels than conventional culture supports. Finally, we have engineered mixed ligand surfaces presenting varying fibronectin-/collagen-mimetic ligand densities to independently target alpha5beta1 and alpha2beta1 integrins. These mixed ligand surfaces synergistically modulate cell adhesive activities. These surface engineering strategies provide a basis for the rational design of robust biospecific interfaces that tailor adhesive interactions and elicit specific cellular responses for the development of bioactive implant surfaces, scaffolds for enhanced tissue reconstruction, and growth supports for enhanced cellular activities.

2:00 PM *Z7.2/AA7.2
Interactions of Biomimetic Peptide-Amphiphiles with Their Receptors. Efrosini Kokkoli, Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota.

This study involves the use of a model biomimetic system that allows us to investigate collective and single-molecule forces between receptor-ligand pairs that reveal details of the molecular recognition mechanisms of multiple and individual pairs. An Atomic Force Microscope (AFM) is used to provide high resolution images and direct adhesion measurements at the piconewton level. In this work, bioartificial membranes that mimic the cell adhesion domain of the extracellular matrix protein fibronectin (GRGDSP) are constructed from peptide-amphiphiles. The receptors of choice are the $\alpha_5\beta_1$ integrins that are immobilized onto the AFM tip. The effect of different parameters such as different ions, synergistic effects from other peptides (PHSRN) and the loading rate have been investigated on the dynamics of the $\alpha_5\beta_1$-GRGDSP interaction using the AFM.

2:30 PM Z7.3/AA7.3
Engineering Communication Between Mammalian Cells and Materials Surfaces Via a Novel Cell-Surface Protein. Joel H. Collier[1] and Milan Mrksich[2]; [1]Biomedical Engineering, University of Cincinnati, Cincinnati, Ohio; [2]Chemistry, University of Chicago, Chicago, Illinois.

Establishing communication pathways between cells and materials surfaces is important in the development of cell-based sensors and devices, electronic components, and biomaterials. Here we describe a system in which mammalian cells have been engineered to display a non-native chimeric protein on their cell membranes that enables them to enzymatically process self-assembled monolayer (SAM) substrates. This specific processing produces changes in the redox characteristics of the SAM that can be readily measured with cyclic voltammetry, in short transducing cellular activity into an electrical signal. The functionality of the chimeric protein is endowed by the enzyme cutinase, which catalyzes the hydrolysis of esters on the SAM surface. The cutinase is presented away from the cell membrane by a rigid stalk domain, and the entire construct is anchored by the transmembrane domain and an intracellular fragment of the $\beta 1$ integrin. Transfection with this construct produces cells with a high cutinase activity on their surfaces. We describe the construction of the chimeric protein, transfection of Chinese hamster ovary (CHO) cells, and characterization of a cell line that stably expresses this engineered construct. On the SAM component of the system, we have displayed hydroquinone esters that serve as good substrates for cutinase. In the absence of cutinase activity (e.g. in cultures with untransfected cells) this hydroquinone remains protected, and no redox peaks are detectable with cyclic voltammetry (CV). When these surfaces are exposed to transfected cells displaying cutinase, however, the CV signal increases dramatically. We also monitored this deprotection of the hydroquinone with MALDI-TOF mass spectrometry. This approach constitutes a novel way to transduce cellular activity into measurable electronic signals.

2:45 PM Z7.4/AA7.4
Self-assembly of Peptide Amphiphiles and its Implications for Bioelectronic Nanostructures. John D. Tovar[1,2] and Samuel I. Stupp[1,2,3]; [1]Department of Materials Science and Engineering, Northwestern University, Evanston, Illinois; [2]Institute for Bioengineering and Nanoscience in Advanced Medicine (IBNAM), Northwestern University, Evanston, Illinois; [3]Department of Chemistry and Feinberg School of Medicine, Northwestern University, Evanston, Illinois.

Supramolecular architectures based upon self-assembling molecules are emerging as powerful tools for bionanotechnology. Our laboratory has used the self-assembly of peptide amphiphile (PA) molecules to form nanofiber networks capable of directing the crystallographically oriented growth of hydroxyapatite and inducing selective differentiation of neural progenitor cells. These systems consist of a hydrophobic alkane tail coupled to an oligopeptide sequence. In their assembled state, the aggregated alkyl tails form a well-defined hydrophobic region within the nanofiber while the exterior of the nanofiber is decorated with bioactive peptide epitopes. We report here on a spectroscopic examination of self-assembled PAs tailored with

rational placement of tryptophan residues and pyrenyl-amidated lysines. Fluorescence measurements with the environmentally sensitive tryptophan probe indicate that the peptidic segments of the PA molecules remain well-solvated regardless of their location within the self-assembled aggregate. Extrinsic fluorescence quenching also confirms that the chromophores are accessible in their aggregated states, although this accessability is expectedly hindered relative to the unassembled state. In fact, we see trends indicating a progression towards increased quencher access within the nanostructures that have chromophores placed closer to the outer fiber periphery. We are currently applying this knowledge to the study of electrically active PA nanofibers designed as novel bioelectronic components. We have synthesized PAs that bear covalently attached electroactive moieties (such as terthiophene) and studied their electrochemical behavior once assembled into nanofibers. We have also demonstrated that the PAs may be used to sequester hydrophobic monomers that then undergo polymerization to form conducting polymers.

3:30 PM *Z7.5/AA7.5

Interfacial Biomaterials. Mark Grinstaff[1] and Daniel Kenan[2]; [1]Departments of Biomedical Engineering and Chemistry, Boston University, Boston, Massachusetts; [2]Department of Pathology, Duke University, Durham, North Carolina.

Advances in implant technology have revolutionized health care practices over the last twenty years, with abundant examples ranging from prosthetic joints to vascular grafts. Yet, today one of the pressing challenges is the development of prosthetic implants or devices that integrate appropriately with tissues. Existing materials can either generate an overly robust inflammatory reaction that compromises function, or fail to integrate appropriately, resulting in suboptimal performance. Thus, new materials, tools, and procedures are needed to promote better integration at the interface between synthetic materials and biologics. We describe a general protocol for the design and preparation of bio-mimetic coatings termed "interfacial biomaterials." Interfacial biomaterials represent a novel coating technology capable of directing biological processes at the interface between a synthetic surface and a biologic. The approach relies on screening combinatorial libraries to identify unique peptides that adhere to a synthetic target such as a plastic or metal, or to a biological target such as a protein or cell. Next, two or more adhesion peptides are synthetically coupled to create an interfacial biomaterial that mediates the interaction of the protein or cell with the synthetic material. Preparation of multi-functional interfacial biomaterials provides one strategy to mediate the biological process at the critical interfacial site between biologics and synthetic surfaces. Importantly, these materials expand the current repertoire available for designing and developing new biomaterials for applications ranging from proteomics to tissue engineering.

4:00 PM Z7.6/AA7.6

Dynamic Assembly of Nanostructures: Exploiting Peptide-Peptide Recognition. Molly M. Stevens[1,2], Nolan T. Flynn[4], Chun Wang[2], David A. Tirrell[3] and Robert Langer[2]; [1]Materials, Imperial College London, London, United Kingdom; [2]Chemical Engineering, Massachusetts Institute of Technology, Boston, Massachusetts; [3]Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California; [4]Chemistry, Wellesley College, Wellesley, Massachusetts.

There is growing interest in the ability to actively direct the assembly of inorganic nanoparticles using biomolecular recognition for the creation of new materials and nanotechnology devices. This area of research exploits the high specificity exhibited by biomolecular recognition systems to achieve assembly. Here we report the coiled-coil peptide based assembly of nanoparticles and demonstrate that the system can be dynamically controlled under mild conditions (near-neutral pH and ambient temperature). The development of new methods such as this to control dynamic nanoparticle assembly may impact on certain applications in medical science such as the generation of novel tunable and/or switchable materials. In particular, the ability to dynamically assemble and dis-assemble such structures under physiologically accessible environmental conditions, as triggered for example by changes in pH would be valuable for materials to be utilized for sensing in vivo and drug delivery. Self-assembly of gold and other nanoparticles was investigated utilizing nanoparticles functionalized with acidic or basic leucine zipper-like peptides. The peptides adopt an alpha-helical conformation when they form a homomer or heterodimer coiled-coil structure, the stability of which is modulated by electrostatic interactions across the interface of adjacent helices. Circular dichroism spectroscopy of the free peptides in solution revealed changes in the helicity of the peptide, which indicates the association or dissociation of coiled-coil structures, as the pH is varied. Reversible pH-induced transitions were observed (e.g. between pH 8.5 and 7 for the acidic peptides). Transmission electron microscopy images of the peptide-coated nanoparticles revealed that well-dispersed populations of nanoparticles could be caused to dynamically assemble in response to mild pH triggers.

4:15 PM Z7.7/AA7.7

Design of Peptides with Collagen High Frequency Triplets Sequence for Templating of Bone Mineralization. Yang Zhang[2,1], Jie Song[2,4] and Carolyn Bertozzi[1,2,3]; [1]Department of Chemistry, University of California, Berkeley, Berkeley, California; [2]Materials Sciences Divisions, Lawrence Berkeley National Laboratory, Berkeley, California; [3]Department of Molecular and Cell Biology, University of California, Berkeley, Berkeley, California; [4]Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, California.

As the main extracellular matrix protein in bone, type I collagen is only thought to serve as the structural scaffold for bone minerlization, while other acid proteins binding to their gap region may play a main role that prompts the nucleation and deposition of bone minerals. By analysing the repeating Gly-Xaa-Yaa triplets sequence of type I collagen molecules, it is found that most of high frequency triplets sequences contain uncharged or positive charged amino acid residues. Therefore, three peptides containing with repeating high frequency triplets sequences in human type I collagen but with different charged side chain (positive, uncharged and negative) of amino acid residues were designed and synthesized to probe their mineral-templating abilities. It shows that peptides with different charged side chain have different behaviors on Ca-P mineralization. And the most interesting thing is that the triplets-sequence with positive charged amino acid residues could facilitate the formation of Ca-P crystals, as observed by HRTEM. This result may display the information of protein-minerals interaction encoded in the sequence information of collagen molecule, and provide a better understanding for that the replacement of one glycine in collagen molecule could present disorder of minerals deposition, which as shown in lots of collagen defect diseases such as osteogenesis imperfecta.

4:30 PM Z7.8/AA7.8

Molecular Modeling of Engineered Polypeptides. Urartu O. S. Seker[1], Ersin Emre Oren[2], Selcuki Cenk[1], Candan Tamerler[1,2] and Mehmet Sarikaya[2,1]; [1]Materials Science and Engineering, University of Washington, Seattle, Washington; [2]Molecular Biology and Genetics, Istanbul Technical University, Maslak-Istanbul, Turkey.

In biological hard tissues, proteins control inorganic materials assembly, morphogenesis and formation through molecular recognition and specific binding. Adapting both cell-surface and phage display protocols, we have selected and isolated short oligopeptide sequences (7-12 amino acids) that bind to noble metals and oxide semiconductors. The understanding of the nature of molecular recognition, binding and kinetics of the inorganic specific peptides is essential for an effective utility of the selected polypeptides in materials assembly and formation. Considering that protein recognition of an inorganic surface may originate both from chemical (e.g., polarity, H-bonding, polarity and charge effects) and physical (structural size, surface crystallography & morphology) interactions, we have developed/modified an array of experimental techniques to quantitatively characterize binding characteristics of the peptides and also to investigate the interactions of the selected sequences with various materials surfaces through computational methods. The initial step in our conformational analysis consists of generating conformers of selected oligopeptides in vacuum. The CHARMM force field has been used to generate the conformers. Next, the most stable conformers have been re-optimized with the same force field. Results obtained are used to compare the hydrogen bonding patterns, which is one of the major factors determining the conformational preference. Our preliminary calculations have shown that there are significant differences in the fully optimized conformers compared to the initial geometries taken from the conformational analysis. The most important part of the modeling bioinorganic hybrid systems is the choice of the force field that will be used to investigate the interactions at the peptide-metal interface. Initially, these hybrid systems have been investigated by using the CHARMM Molecular Mechanics program in vacuum as implemented in HyperChem 7.5. The most stable conformer has been brought onto the metal surface and than the system is fully optimized allowing the interactions of both systems. The same calculations have been repeated for each system by using different force fields implemented in different suit of programs. The similarities and/or differences between the calculated results have been discussed in terms of energies, geometries and electronic properties as well as the nature of the metal surface and the oligopeptides. Since these interactions occur usually under physiological conditions, further calculations will focus on modeling of these systems in solution (in water). The nature of solvent and the solute-solvent interactions could play an important role on the type and strength of interactions between these two components. Research supported by ARO-DURINT and SPO-Turkey.

4:45 PM Z7.9/AA7.9

Controlling Viability and Osteogenic Differentiation of Human Mesenchymal Stem Cells Photoencapsulated in Poly(Ethylene Glycol)-Based Hydrogels.

Charles Raymond Nuttelman[1], Margaret Claire Tripodi[1], Sean Michael Langelier[1] and Kristi Sue Anseth[1,2]; [1]Chemical and Biological Engineering, University of Colorado, Boulder, Colorado; [2]Howard Hughes Medical Institute, University of Colorado, Boulder, Colorado.

Human mesenchymal stem cells (hMSCs) have many properties that make them ideal for tissue engineering applications, including their ease of isolation, high proliferative capacity, and ability to form new tissue. By rationally designing a poly(ethylene glycol) (PEG)-based, photocrosslinkable hydrogel scaffold, we aim to provide a three-dimensional environment that maintains viability of encapsulated cells and actively promotes their osteogenic differentiation. Due to the highly hydrophilic nature of PEG hydrogels and the fact that proteins do not adsorb strongly to this material, encapsulated hMSCs are presented with a blank environment upon encapsulation. As a result, initial cell viability is low. By incorporating either the well-known RGD cell adhesion peptide sequence or charge into the scaffold, cell viability in vitro at least up to four weeks is dramatically improved. Charge is incorporated into the hydrogel network by copolymerizing diacrylated PEG with ethylene glycol methacrylate phosphate (EGMP) or methacrylic acid (MA). In addition to maintaining cell viability in these PEG hydrogels, we also aim to develop an osteogenic scaffold, which induces the differentiation of encapsulated hMSCs in the absence of added osteogenic factors in the surrounding media (i.e., differentiation factors are released from within the gel). Dexamethasone, a synthetic corticosteroid that causes osteogenic differentiation of hMSCs, was conjugated to a photoreactive methacrylate group through hydrolytically degradable ester bonds. During network formation, this molecule is covalently linked into the network, resulting in pendant dexamethasone, which, over time, can release from the network due to hydrolysis of the ester bonds. Released, soluble dexamethasone can then interact with the encapsulated hMSCs, causing osteogenic differentiation as indicated by gene expression using real-time PCR and other techniques.

SESSION Z8: Poster Session: Bioinspired Motors and Devices, Cell-Material Interactions, Biofunctional Peptides
Wednesday Evening, December 1, 2004
8:00 PM
Exhibition Hall D (Hynes)

Z8.1

The Separation of Genomic DNA by Surface. Bingquan Li, Xiaohua Fang, Vladmir Samuilov, Jonathan Sokolov and Miriam Rafailovich; Materials Science, Stony Brook University, Stony Brook, New York.

We have shown that it is possible to separate double stranded DNA chains by using surface interactions rather than topological constraints [1-3]. Even though it can not achieve base pair resolution, this method has the distinct advantage that it can separate chains that vary by five orders of magnitude in length on the same surface. Hence it has the potential of becoming a convenient technique for rapid screening and fingerprinting. Since the method has in theory no limit as to the size of the chains that it can separate, it can in principal be used to separate entire chromosomes. For example, Hatchwell [4] has recently suggested that this technique may be useful in detecting genomic copy defects in individuals with micro-deletion syndromes. Since the resolution of this method is roughly 1% and independent of the chain length, it can in principal identify defective chromosomes without extensive processing needed to identify the specific gene where the problem has occurred. Since human chromosomes are roughly 200 Mega base pairs, it is currently not possible to separate them by any other technique without prior fractionation. Here we present data on the separation of entire E. coli and S. pombe chromosomes and preliminary results on the separation of human chromosome. [1] N. Pernodet, V. Samuilov, K. Shin, J. Sokolov, M.H. Rafailovich, D. Gersappe, B. Chu. DNA Electrophoresis on a Flat Surface, Physical Review Letters, 85 (2000) 5651-5654. [2] Y.-S. Seo, V.A. Samuilov, J. Sokolov, M. Rafailovich, B. Tinland, J. Kim, B. Chu. DNA separation at a liquid-solid interface, Electrophoresis, 23 (2002) 2618-2625. [3] Y.-S. Seo, H.. Luo, V. A. Samuilov, M. Rafailovich, J. Sokolov, B. Chu, Dilip Gersappe, DNA Electrophoresis on nanopatterned surfaces, Nano Letters, 4, 2004, 659-664. [4] Hatchwell, E. 1996. Hypomelanosis of Ito and X; autosome translocations: a unifying hypothesis. J. Med. Genet. 33: 177-183. Sponsored by the Department of Energy

Z8.2

Bacteriorhodopsin Liposomes Doped Silica Material and its Applications. Tzy-Jiun Mark Luo[1], Ricky Soong[2], Esther Lan[1], Bruce Dunn[1] and Carlo Montemagno[2]; [1]Materials Science and Engineering, University of California, Los Angeles, California; [2]Bioengineering, University of California, Los Angeles, California.

A functional, sol-gel material which exhibits photo-induced proton generation was synthesized. Liposomes (proteoliposomes) containing the transmembrane protein, bacteriorhodopsin (bR), maintained their integrity when encapsulated within a polyethyleneglycol-silica matrix while allowing rapid interactions between sol-gel and solution. When light-incubated at room temperature, these proteoliposome-doped gels (proteogels) exhibited 70% of the proton pumping efficiency of proteoliposome solutions. Combined with soft-lithography technique, thin film and waveguide structures were also constructed on fluidic devices to allow direct and indirect sensing. Applications of this sol-gel material for ATP generation were also demonstrated. The ability to prepare the protegels in waveguide structures that are albe to support a proton gradient provides opportunities to use these materials in devices for biologically-based power generation.

Z8.3

Surface Electrophoresis of DNA on Ito Surfaces. Radha Perumal Ramasamy, Vladimir Samuilov, Jonathan Sokolov and Miriam Rfailovich; Materials Science and Engineering, Garcia Center for Polymers at Engineered Surfaces, Stony Brook, New York.

The distribution of electric field in and near the surface of the electrophoretic cell determines the motion of DNA in the buffer and along the surface. This is a complicated problem, influenced by buffer ion concentration, electrode configuration, surface and substrate conductivities. To provied a more uniform field distribution near the walls of the electrophoretic cell, we constructed a cell with walls made of conducting surface of ITO (Indium Tin Oxide) coated upon Poly Yester film (Delta Technologies). The ITO film has a sheet resistance of < 10 Ohms. The electric field distribution in the cell was measured with a point voltage probe in cells containing TBE buffer. Steady state calculations approximating the experimental geometry were made for different arrangements of electrodes using MAFIA (Computer Simulation Technologies) program. The influence on Surface electrophoresis using Lambda - DNA and Hind - III Digest DNA in different buffer concentrations will be discussed. Support from NSF - MRSEC is greatfully acknowledged.

Z8.4

Electrophoretic Separation of Carbon Nanotubes and Nanotube-Based Bio-nano Assemblies. Alexandre Vetcher[1], Tiffany Lin[2], Jun-Huei Fan[1], Mikhail Kozlov[2], Gregg R. Dieckmann[2,3], Inga H. Musselman[2,3], Rockford K. Draper[1,2,3], Stephen D. Levene[1] and Ray H. Baughman[2]; [1]Department of Molecular and Cell Biology and Institute of Biomedical Sciences and Technology, University of Texas at Dallas, Richardson, Texas; [2]NanoTech Institute, University of Texas at Dallas, Richardson, Texas; [3]Department of Chemistry, University of Texas at Dallas, Richardson, Texas.

An electrophoretic procedure has been developed for analysis of carbon nanotube dispersions prepared with the aid of different dispersing agents. We show that a wide range of aqueous dispersions of single-walled and multi-walled carbon nanotubes dispersed using common surfactants, DNA, RNA and peptides can be fractionated by agarose-gel electrophoresis. It was found that in a DC electric field, carbon nanotubes and nanotube-containing biomolecular complexes migrate in the gel in the direction of negative potential forming well defined bands. We determined the distribution of particle mobilities along the direction of electrophoresis by using Raman spectroscopy. The results suggest that separation of metallic and semiconducting nanotubes can be achieved by this procedure. Factors affecting mobility of biomolecular nanotube complexes are discussed and possible analytical applications of the procedure in nanotechnology field are proposed.

Z8.5

Stochastic Frequency Signature for Chemical Sensing using Noninvasive Neuronelectronic Interface. Cengiz Sinan Ozkan, Mechanical Engineering, University of California at Riverside, Riverside, California.

The detection of chemical agents is important in many areas including environmental pollutants, toxins, biological and chemical pollutants. As smart cells, with strong information encoding ability, neurons can be treated as independent sensing elements. A hybrid circuit of a semiconductor chip with dissociated neurons formed both sensors and transducers. Stochastic frequency spectrum was used to differentiate a mixture of chemical agents with effect on the opening of different ion channels. The frequency of spike trains revealed the concentration of

the chemical agent, where the characteristic tuning curve revealed the identity. Fatigue experiment was performed to explore the refreshing ability and memory effect of neurons by cyclic and cascaded sensing. Neuronelectronic noses such as this should have wide potential application, most notably in environmental and medical monitoring.

Z8.6

Fabrication of Nanoscale Biosensor for Pathogen Detection and Identification. Qingrong Huang[1], Chada Ruengruglikit[1], Ho Cheol Kim[2] and Robert D. Miller[2]; [1]Food Science, Rutgers University, New Brunswick, New Jersey; [2]IBM Almaden Research Center, San Jose, California.

The biosecurity of the food and water supply is an imminent concern in light of global events related to terrorism since September 11th. Novel systems are required for the development of fast, reliable, and highly sensitive biosensors for detection of biological agent in food or water post-harvest. Recently, we have developed a novel technique for the creation of thin, highly porous organosilicate films with tunable surface hydrophilicity that can be used as substrates for DNA microarrays. Highly porous methyl silsesquioxane (MSSQ) was produced via the thermosetting of MSSQ, templated by a thermally decomposable pore generator (porogen)-Pluoronic surfactant P123. The hydrophilic patterns on the hydrophobic MSSQ surface were created by exposure of MSSQ film surface to UV/Ozone through a photomask. Oligonucleotides show selective adsorption only to the surface of hydrophilic spots. Specific probes for E. coli and Listeria were tested via hybridization process. Our results from surface plot analysis showed the specificity of rfbE gene to E. coli, not Listeria. In summary, the resulting highly porous patterned films are robust, stable, and easy to make, thus are very promising candidates for the applications in pathogen detection and identification.

Z8.7

Disposable Microchip Intefrated with Capillary Electrophoresis and Indium Tin Oxide Amperometric Detector. Ju-Ho Kim[1], Min-Chul Moon[1], Chi Jung Kang[2] and Yong-Sang Kim[1]; [1]Department of Electrical Engineering, Myongji University, Yongin, Kyunggido, South Korea; [2]Department of Physics, Myongji University, Yongin, Kyunggi-do, South Korea.

We have developed a disposable microchip with microfabricated thin-film electrodes on glass substrate for a capillary electrophoresis and an amperometric detector. The system was realized with polydimethylsiloxane (PDMS)-glass chip and indium tin oxide (ITO) electrode. The injection and separation channels (80 um wide * 40 um deep) were produced by moulding a PDMS against a micro fabricated master with relatively simple and inexpensive methods. ITO electrode was fabricated by patterning the ITO film deposited on a fusion glass. A capillary electrophoresis and a three-electrode electrochemical detector were fabricated on the same chip. Unlike analogous CE/ECD devices previously reported, no external electrodes were required. The surface of PDMS layer and ITO-coated glass was treated with UV-ozone to improve bonding strength and to enhance the effect of electroosmotic flow. For comparing the performance of the ITO electrodes with the gold electrodes, gold electrode microchip was fabricated with the same dimension. The running buffer was prepared by 10 mM 2-(N-morpholino) ethanesulfonic acid (MES) titrated to pH 6.5 using 0.1 N NaOH. The testing analytes are consisted of 1 mM catechol and 1 mM dopamine. Separation of catechol and dopamine was performed using an electric field strength of 60 V/cm after applying an injection electric field of 60 V/cm. The electrochemical detection circuit could mostly decouple the interference of a separation electric field. Electrophoretic measurement of dopamine and catechol mixture is successful in the ITO electrode microchip. Results are indicated convenient and rapid separation and detection of two compounds, with a total time of around 80 sec applying a separation electric field of 60 V/cm. The measured current peaks of dopamine and catechol are proportional to their concentrations. For comparing the performance of the ITO electrodes with the gold electrodes, electropherograms was measured for CE-ECD device with gold electrodes under the same conditions. Except for the base current level, the performances including sensitivity, stability, and resolution of CE-ECD microchip with ITO electrode are almost the same compared with gold electrode CE-ECD device. When we are using disposable microchips, it is possible to avoid polishing electrode and reconditioning, which are required with gold electrodes.

Z8.8

The Stability of Free and Immobilized Liposome Systems as Surrogates for Living Cells in Biosensor Materials. Jianxiu Zhao[1], Banada P. Padmapriya[3], Arun K. Bhunia[3] and Jenna L. Rickus[1,2]; [1]Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana; [2]Biomedical Engineering, Purdue University, West Lafayette, Indiana; [3]Food Science, Purdue University, West Lafayette, Indiana.

The use of living cells in bioengineered materials and devices often creates design constraints that limit performance including long term stability. This paper presents a new approach to material design that mimics cells with liposomes as non-living 'artificial cells'. The goal is to retain the desired biological function while eliminating the constraints of living cells. Here, liposomes are used as surrogate cells to replace the mammalian cells in an existing detection method for the deadly foodborne bacteria, *Listeriamonocytogenes*, which produces pore forming toxin, listeriolysin O (LLO). The methods are based on the binding of LLO to cholesterol in the lipid bilayer resulting in the release of a soluble signaling agent. The new material is an artificial system of lipids, protein, small molecules and inorganic glass designed to mimic the biological features of the living bioassay by presenting the receptor for protein recognition, providing the lipid environment for protein insertion, and simulating the release of intracellular contents. In this work, the stability of the liposomes in both a free and immobilized state is presented. The immobilized liposomes are encapsulated in a sol-gel derived silica glass. A carboxyfluorescein fluorescence quenching assay is used as an indicator of liposome integrity and LLO insertion. The free liposomes are stable for almost one week at room temperature. The impact of sol-gel synthesis conditions on liposome stability is also presented with the goal of achieving improved stability and a means of integration into future biosensor devices.

Z8.9

Microfluidic Platform for Solid Phase Extraction of Biomacromolecules. Catherine Klapperich[2,1] and Arpita Bhattacharyya[1]; [1]Department of Biomedical Engineering, Boston University, Boston, Massachusetts; [2]Department of Manufacturing Engineering, Boston University, Boston, Massachusetts.

The development of on-chip nucleic acid isolation devices represents the ability to shrink conventional bench-top isolation systems into miniature, portable devices with major advantages of cost, time and sample/reagent consumption. These microscale isolation devices used in series with amplification and detection modules would lead to highly effective portable disease surveillance devices. Most of the microfluidic-based isolation devices are being made by photolithographic patterning of silicon or glass, or by curing polydimethyl siloxane (PDMS) in silicon or glass mold. However, silicon and glass fabrication can be too expensive for disposable devices, while PDMS devices lack dimensional stability and have limited shelf life, thus necessitating the use of alternative materials such as engineering polymers. In this work we have used Zeonor, a medical grade cyclic olefin polymer (COP) as our primary chip material. The chip has been fabricated by compression molding of the polymer with an electroformed stamp formed from a silicon master. The cell lysis is done with chaotropic buffer and the nucleic acid is separated from the larger cell lysate using solid phase extraction in the microchannels. The solid phase is made from a photopolymerized polymer impregnated with silica particles. Nucleic acids bind to silica in the presence of the chaotropic agents. After the lysate flows over the solid-phase, sequential wash steps are performed with washing buffer and the isolated nucleic acids are then eluted from the solid phase with a low stringency buffer. Electroosmotic flow (EOF) is used to drive the sample through the channel and a current monitoring system is used to measure the EOF. To prevent the solid phase from being pushed down the channel due to the applied electric field, it is cross-linked to the wall of the channels. We will present data quantifying the EOF generated in these gel filled channels and data describing the separation efficiency of nucleic acids from whole cell lysate.

Z8.10

Nematic Liquid Crystals as Analytical Tools for the Label-Free Detection of Post-Translationally Modified Peptides at Interfaces: New Methods for Evaluating Protein Kinase Activity. Brian Harlan Clare[1,2], Paul J. Bertics[3] and Nicholas L. Abbott[1]; [1]Chemical & Biological Engineering, University of Wisconsin, Madison, Wisconsin; [2]Chemistry, University of Wisconsin, Madison, Wisconsin; [3]Biomolecular Chemistry, University of Wisconsin, Madison, Wisconsin.

Recent work has demonstrated the utility of nematic liquid crystals for the sensing of protein binding events at interfaces. One potential application of this novel surface-based assay is the label-free, high-throughput screening of cancer therapeutics which inhibit protein kinase activity. To this end, we report the synthesis of a peptide-laden interface, and the use of nematic liquid crystals to detect a surface-bound phosphopeptide product after protein kinase modification. In addition, we demonstrate the use of liquid crystals as a tool for imaging spatially-resolved arrays of surface-bound peptides.

Z8.11

Electrophoretic Mobility of Proteins near Surfaces.

Radha Perumal Ramasamy[1], Avtar Singh[2], Miriam Rafailovich[1] and Jonathan Sokolov[1]; [1]Materials Science and Engineering, Garcia Center for Polymers at Engineered Surfaces, Stony Brook, New York; [2]Stuyvesant High School, Stuyvesant High School, New York, New York.

We have attempted to perform surface electrophoresis of Proteins. Droplets of FITC stained Albumin, POly-L-Lysine, Casein purchased from Sigma were deposited on glass cover slips. The droplets were then placed in contact with a TBE buffer solution contained in a cell molded from PDMS. Pt electrodes were inserted into the cell and a voltage was applied. The motion of the protein was then imaged using Leica confocal microscope as a function of buffer concentration, distance from the surface and applied voltage. References: 1) Henzel WJ, Watanabe C, Stults JT.Protein Identification: The origin of Peptite Mass Finger Printing. J.American Society for Mass Spectrometry. 14 (September 2003): 931 - 942 2) Mathesius U, Imin N, Natera SH, Rolfe BG.Proteomics as a functional genomics tool. Methods of Molecular Biology 236: 395 - 414. Work supported in part by NSF - MRSEC Program.

Z8.12
Combining Molecularly Imprinted Polymers and Miniemulsion Polymerization for the Preparation of Higher Sensitivity Aqueous Biomimetic Sensors. Yvon G. Durant, Jerome Claverie, Julien Ogier, Thiruvasagam Ponnuchamy and Glen Miller; Materials Science, University of New Hampshire, Durham, New Hampshire.

The development of a biomimetic sensors targeted to the detection of complex analytes such as saxitoxin, guanosine and peroxyacetyl nitrate (PAN) is of particular interest. To achieve this goal by synthetic means, biomimetic sensors can be designed by molecularly imprinted polymers (MIP). Miniemulsion polymerization was used to prepare nanobeads. Recognition monomers, such as methacrylic acid, 5'-O-Acryloyl esters of guanosine, and acrylamine substituted crown ether have been used for the recognition (imprinting) of analytes such as caffeine, and guanosine. Crosslinking has been achieved using EGDMA, TRIM and oligomeric polyacrylamide-pentaethlyneoxides. No porogenic solvent was used and a high level of surface imprinting was achieved. The nanobead synthesis involved low polymerization temperatures with redox initiation and a specific analyte feed strategy. The templating analytes were recovered by simple dialysis. Nanobeads in the size range of 60 to 200nm have been produced and imaged. This method is more efficient than bulk polymerization as it allows the recovery of a major fraction of the analyte (which is important when working with toxic or expensive molecules) and to have a high number of active site on the surface of the beads with few embedded and inactive sites. The sensitivity and selectivity of the imprinted nanobeads has been measured by equilibrium membrane dialysis and compared to non-imprinted beads and bulk MIPs. Specific adsorption areas per unit mass are significantly larger than for similar bulk imprinted MIPs. Initial transduction results have been done using QCM-D in a flow-through cell assembly.

Z8.13
Nanoscale Properties of Apatite Precipitated onto Synthetic Hydroxyapatite from Simulated Body Fluid. Jennifer Vandiver[1], Delphine Dean[2], Nelesh Patel[3], William Bonfield[3] and Christine Ortiz[1]; [1]DMSE, MIT, Cambridge, Massachusetts; [2]EECS, MIT, Cambridge, Massachusetts; [3]Materials Science and Metallurgy, University of Cambridge, Cambridge, United Kingdom.

Upon implantation of synthetic hydroxyapatite (HA) *invivo* or incubation *invitro* in simulated body fluid (SBF), a bone-like apatite layer forms on the surface which is considered essential for the creation of a strong bond with the surrounding bone tissue, a distinctive property of HA termed bioactivity. The microstructure and composition of this apatite layer is influenced by a variety of variables such as initial surface structure, solubility, surface charge, and the presence of biomacromolecules. A detailed knowledge of the temporal evolution of nanoscale topographical and nanomechanical properties of the precipitated apatite layer is important in understanding the molecular origins and optimizing bioactivity of HA-based implants. Hence, synthetic, phase pure, dense, polycrystalline HA pellets were incubated in SBF (a solution which mimics physiological conditions, pH=7.4, IS=0.155M) for 36 days and resulted in a distinct topographical change of the surface due to precipitation of an apatite layer. Tapping mode atomic force microscopy (TMAFM) showed that the original HA pellet surface was composed of smooth faceted grains with an average maximum dimension, d=1170 +/- 760 nm and an intragrain peak-to-valley feature height, h<1 nm. The precipitated apatite layer was composed of three distinct morphologies; localized regions of hemispherical structures (d=44.7 +/- 12.7 nm, h=3.6 +/- 2.7 nm), regions of elongated, plate-like structures (width, w=31.0 +/- 8.5 nm, d=104.4 +/- 31.1 nm, h=5.0 +/- 3.2 nm), and larger irregularly shaped structures with relatively smooth surfaces (d=640.7 +/- 132.7 nm, h=104.0 +/- 51.7 nm). Height profiles of bare HA regions directly adjacent to apatite regions yielded an apatite layer thickness of 62.4 +/- 46.7 nm and hence, the original HA grain boundaries were still clearly visible. Chemically and spatially specific high resolution force spectroscopy (HRFS) was performed on the precipitated apatite layer in an aqueous buffer solution (pH=5.97, IS=0.01M) using soft cantilever probe tips that had been chemically functionalized with the self-assembling monolayer (SAM) 11-mercaptoundecanoic acid, HS-$(CH_2)_{10}$-COOH. This data was compared to the nonlinear Poisson-Boltzmann-based electrostatic double layer theory to predict the surface charge per unit area of the precipitated apatite layer and yielded an average $\sigma_{apatite}$ -0.031 C/m^2 that varied from -0.007 C/m^2 to -0.056 C/m^2, similar in magnitude to that known for the initial HA surface. A positional variation of surface charge with crystalline facet was observed and suggests a possible relationship between the initial underlying HA facet surface charge and precipitated apatite structure.

Z8.14
Direct Measurement of Single Cell Adhesion Force to Various Biomaterials Substrates with AFM. Yan Deng[1,2], Carl G. Simon[2], Sheldon M. Wiederhorn[3] and Brian R. Lawn[3]; [1]Unilever Research China, Shanghai, China; [2]Polymer Division, National Institute of Standards and Technology, Gaithersburg, Maryland; [3]MSEL Lab, National Institute of Standards and Technology, Gaithersburg, Maryland.

Cell adhesions to various solid biomaterial substrates were directly measured with AFM in cell medium environment. Three kinds of biomaterials: Polystyrene, bioglass and soda-lime glass (control), in a form of microbead, were glued to AFM cantilever. The de-bonding force of cells to these biomaterials was measured in cell chamber in serum medium. Applying dynamic force on the cantilever, the continuous bonding de-boning events were recorded. The de-bonding forces were compared for individual biomaterial beads in terms of their first, the average and the maximum de-bonding value for 50 cycles of tests. Cells showed the highest adherent force to PS surface and the lowest to soda-lime glass, consistent to their relative bioactivity. The initial de-bonding force is not significant different from the average be-bonding force for 50 counts. Analysis of dynamic cyclic de-bonding cell-materials interaction revealed that the bonding-debonding formation was a non-single event, instead a periodic/multiple bonding behavior was maintained up to hundreds of breaks. By comparing the adhesion force of cells to different biomaterials surface, this technique demonstrates a simple and quick evaluation method for bioactivity or biocompatibility for prospect tissue engineering biomaterials.

Z8.15
Characterization of Heparin-Peptide Interactions and their use in Hydrogel Assembly. Le Zhang[1], Nori Yamaguchi[1], Byeong-Seok Chae[2], Eric M. Furst[2] and Kristi L. Kiick[1]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Chemical Engineering, University of Delaware, Newark, Delaware.

Protein-polysaccharide interactions play important roles in a myriad of physiological and pathological processes. The design of materials in which assembly, mechanical response, and biological properties are controlled by these interactions could therefore mimic the biological environment and find use in a variety of biomedical applications. We and others have previously demonstrated that heparin-peptide interactions can be used in the assembly of noncovalently associated networks, and the identification of additional heparin-binding peptides with various binding affinities will expand the physical properties and uses of such materials. In the investigations reported here, the heparin binding affinity of a variety of heparin binding peptides has been monitored by heparin-sepharose chromatography and surface plasmon resonance (SPR) experiments, and compared with the physical properties of hydrogels assembled via interactions of these peptides with low molecular weight heparin (LMWH). Results from these experiments indicate that a heparin-binding peptide derived from an arginine-rich sequence demonstrates the highest heparin-binding affinity and heparin-association rate when compared to heparin-binding domains of antithrombin III, heparin-interacting protein, and a peptide that mimics the heparin-binding domain of human platelet factor 4. Additionally, the termini of poly(ethylene glycol) (PEG) four-arm star polymers have been chemically modified with these heparin-binding peptides or with LMWH. Hydrogels are immediately assembled upon interaction of the LMWH- and peptide-modified PEG star polymers, and the physical properties of the hydrogels, determined via microrheological methods, correlate well with chromatography and SPR results. The ability to manipulate the physical properties of the hydrogels will provide novel materials for use in controlled drug delivery and other biomedical applications.

Z8.16
Local Adhesion Force Mapping of Living Cells Using Atomic Force Microscopy. Shouren Ge[1], Kaustabh Ghosh[2], Richard Clark[2],

Jonathan Sokolov[1] and Miriam Rafailovich[1]; [1]Materials Science and Engineering, State University of New York at Stony Brook, Stony Brook, New York; [2]Biomedical Engineering, State University of New York at Stony Brook, Stony Brook, New York.

Determining local adhesion of cells is essential to the understanding of many biological processes including migration, differentiation, proliferation, and growth regulation. Fibronectin, a prominent component of the extracellular matrix (ECM), sometimes serves as a general cell adhesion molecule by anchoring cells to collagen or proteoglycan substrates. Fibronectin also can serve to organize cellular interaction with the ECM by binding to different components of the extracellular matrix and to membrane-bound fibronectin receptors on cell surfaces. To investigate the local adhesion properties of dermal cells, an atomic force microscope (AFM) cantilever tip was functionalized with the fibronectin and used to determine the adhesion force on the membrane surface. Living dermal cells were imaged using the AFM operated in force volume mode. A total of 256 force curves per mapping were obtained on a 4 μm2 area. Each force curve was analyzed for specific adhesion events corresponding to the receptor-ligand bond rupture force. A most frequently detected binding force of 110 pN was found at a distance of 220 nm. The adhesion force was detected less frequently for the dermal cells cultured with serum. It indicated that the interaction between the dermal cells and fibronectin molecule was specific.

Z8.17

Polysaccharide-Poly(ethylene glycol) Star Copolymers for the Production of Polymer Networks for Protein Delivery. Nori Yamaguchi[1,2], Byeong-Seok Chae[3], Eric M. Furst[3] and Kristi L. Kiick[1,2]; [1]Department of Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Delaware Biotechnology Institute, Newark, Delaware; [3]Department of Chemical Engineering, University of Delaware, Newark, Delaware.

The design of polymeric materials that can deliver therapeutic molecules and provide a desired biological response has proven critical in drug delivery and tissue engineering applications. Polysaccharide-derivatized polymers offer unique opportunities for the design of such materials, given the importance of polysaccharides in the extracellular matrix and for the sequestration of bioactive proteins. Here we report the synthesis of heparin-modified, PEG-star copolymers that can be used in the assembly of hydrogel networks via multiple strategies and that are also competent for the delivery of bioactive growth factors. Heparin-decorated polymers, synthesized by reacting thiol end-terminated multiarm poly(ethylene glycol)s (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. Both covalently crosslinked and noncovalently assembled hydrogels can be produced from the PEG-heparin polymer. For example, hydrogels have been formed on the basis of the interaction of these polymers with heparin-binding macromolecules, and in this mode of assembly, the rheological properties and delivery profiles can be controlled by the specific protein-saccharide interactions. The viscoelastic properties of these networks have been measured by optical probe microrheology and bulk rheology methods. The binding and release of therapeutically important proteins from the heparinized hydrogels have also been demonstrated via immunochemical assays and are correlated with the erosion of the hydrogel. The combination of these results suggests the opportunities for assembling novel networks on the basis of protein-saccharide interactions, and employing these networks for protein delivery applications.

Z8.18

Comparative and Quantitative Studies of a Spectrum of Biomaterials using Mouse Adult Neural Stem Cells. Fabrizio Gelain[1,2], Andrea Lomander[1], Angelo Vescovi[2] and Shuguang Zhang[1]; [1]Center for Biomedical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]DIBIT, Hospital S.Raffaele, MILANO, MI, Italy.

Neural Stem Cells (NSC), a potential therapeutic source for cellular transplantations in nervous system injuries, are currently studied in cell-based therapy by itself or Tissue Engineering (TE) approaches. They also provide a good in vitro model for developing and regenerating nervous system, helpful in testing for cytotoxicity, cellular adhesion, and differentiation properties of biological and synthetic biomaterials used in TE. In this study, ten biomaterials, including, well-studied and recently produced ones, were tested in vitro for a total of four weeks. Additionally, the outcome of a surface treatment coating with laminin was tested. For each condition, cell viability, differentiation and maturation of the differentiated stem cell progeny (i.e. progenitor cells, astrocytes, oligodendrocytes and neurons) were evaluated. Considering that the most satisfying biomaterial should show an as high amount of living and differentiated cells as possible, it was quantitatively demonstrated that commonly used biomaterials like Collagen I, Fibronectin, PLLA, PCLA and PLGA are inferior to Collagen IV, Matrigel or Laminin. In all cases, the coating protocol dramatically improved the performance of the biomaterials, but without altering their ranking, hence showing the importance of a surface treatment in scaffold transplant procedures. Moreover, the synthetic peptide based self-assembling scaffold hydrogel RADA16 was used as representative of a new class of biomaterials due to its fully defined molecular structure with considerable potential for further functionalization and slow drug release. Because of its comparable performance with those proven biomaterials and its potential to be easily tailor-made, it is promising to be used as a means not only to improve cell adhesion and delivering drugs in vitro but also in future studies as well as clinical trials in vivo.

Z8.19

Morphology Of Amphiphilic Diblock Copolypeptides Self-Assembled Into Hydrogels or Vesicles. Lisa M. Pakstis[1], Andrew Nowak[2], Eric Holowka[2], Timothy Deming[2] and Darrin Pochan[1]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Chemistry and Materials, University of California at Santa Barbara, Santa Barbara, California.

Amphiphilic diblock copolypeptides consisting of a hydrophilic lysine (K) or glutamic acid (E) block and a hydrophobic leucine (L) or valine (V) block self-assemble into stiff, porous hydrogels at low volume fractions of polymer (vol. fraction polypeptide (0.5 wt%). The micro and nanoscale morphology of these materials was characterized using laser scanning confocal microscopy (LSCM), cryogenic transmission electron microscopy (cryo-TEM), and ultrasmall and small angle neutron scattering (USANS and SANS). The microscopy and scattering data revealed the formation of membranes on the nanoscale that interconnect to create an innately porous network on the nano- and microscale. Alteration of the assembly conditions, such as solution pH and ionic strength, led to controllable differences in the bulk materials properties and microscale morphology of the hydrogels. Decreasing the polypeptide chain length to below a degree of polymerization 100 resulted in vesicle formation on the microscale without disrupting the nanoscale membrane formation. Changes in the assembly pathway, such as assembly in pure water vs. assembly upon addition of water to a homogeneous organic solution, resulted in various morphologies, including hydrogels, micelles, and twisted fibrils. These results indicate that the nanoscale assembly of these polypeptides into membranes is intrinsic to this class of molecules whereas any hierarchical, microscale assembly can be controlled through the assembly environment and molecular design.

Z8.20

Nanostructure of β-Sheet Fibrils Constructed by Unfolded β-Hairpin Peptide Self-Assembly. Matthew S. Lamm[1], Karthikan Rajagopal[2], Joel P. Schneider[2] and Darrin J. Pochan[1]; [1]Materials Science and Engineering, University of Delaware, Newark, Delaware; [2]Chemistry and Biochemistry, University of Delaware, Newark, Delaware.

A 20-residue peptide consisting of alternating valine and lysine residues flanking a tripeptide turn sequence has been shown to self-assemble via differing pathways into dramatically different materials, depending on the primary structure of the turn sequence. Under appropriate solution conditions (high pH, high temperature, and/or high ionic strength), β-hairpin peptides with turn sequences designed to adopt a type II' turn intramolecularly fold leading to the reversible assembly of β-sheet rich hydrogels. Alternatively, almost identical peptides differing in only turn sequence that strongly disfavors intramolecular folding adopt an extended β-sheet conformation and irreversibly assemble into fibrillar structures. These fibrillar structures are similar to classic β-amyloid or prion fibrils. This research is focused primarily on the structure and assembly mechanism of the β-sheet fibrils. Fibrils are formed by lateral association of individual β-sheet filaments providing an untwisted, un-branched fibril morphology with dimensions of 5 to 100nm in width and up to a few microns in length. The peptides assemble in 2 dimensions only, resulting in highly anisotropic, ribbon-like structures, with thickness limited only by the number of amino acids in the peptide. The structure and assembly have been investigated with electron and atomic force microscopies and x-ray diffraction. Solution conditions with which one can control the kinetics of assembly and the hierarchical structure of the mature fibrils will be discussed.

Z8.21

Natural and Artificial Bioactive Hydrogels with Interconnected Macroporosity and Robust Mechanical Properties. Agnieszka N. Stachowiak[1], Anna Bershteyn[1], Elina Tzatzalos[2] and Darrell J. Irvine[1,3]; [1]Materials Science & Engineering, MIT, Cambridge, Massachusetts; [2]Chemical Engineering, MIT, Cambridge, Massachusetts; [3]Biological Engineering Division, MIT,

Cambridge, Massachusetts.

Bioactive hydrogels with interconnected macropores combine tissue-like elasticity with superior pathways for mass transport and cell migration, making them attractive tissue engineering scaffolds. However, disordered porous structures require extremely high porosity (> 95%) for adequate interconnectivity, resulting in poor mechanical properties for soft materials. We have thus developed a colloidal crystal templating method to prepare hydrogels with ordered, highly interconnected macrovoids at moderate (70%) void fractions. Poly(methyl methacrylate) microspheres (20-60 μm diameter) were assembled by mechanical agitation into colloidal crystals. Liquid polymer was added to the resulting templates and solidified, after which the spheres were removed by dissolution to form porous scaffolds. We first templated bioactive poly(ethylene glycol) (PEG) gels by photopolymerization of PEG diacrylate and peptide acrylate. Alternatively, PEG diacrylate was copolymerized with monomers containing functional groups to enable later attachment of intact protein. Finally, we directly templated extracellular matrix materials such as collagen, which undergoes thermal solidification, and may be stiffened by cross-linking before extracting the templating spheres. The morphology of the resulting templated hydrogels was characterized by optical and electron microscopy. Scaffolds exhibited long-range hexagonally close-packed voids throughout their cross-sections, accessible porosity on their surfaces, and interconnecting pores 25% smaller than the close-packed void diameters. Compressive moduli of the PEG scaffolds in the hydrated state were 16-22 kPa, comparable to soft tissues. Further, this value is 12 $\pm$ 5 % of the solid PEG gel modulus, which is in good agreement with the Gibson-Ashby theory of porous structure moduli based on the percent porosity and bulk material modulus. In comparison, structures with 95% porosity have moduli only 0.25% of the solid. Hydrogels modified with bioactive groups supported cell attachment and migration through the interconnected structure, as evidenced by studies with fibroblasts and lymphocytes. Due to their open porous nature, these scaffolds mimic reticular tissues such as the T zone of the lymph node. We have thus used these constructs to study interactions of labeled T cells and dendritic cells using time-lapse 3D fluorescence microscopy. The scaffolds are optically transparent and show minimal autofluorescence, making them a useful in vitro model compatible with fluorescence imaging studies. In summary, we have fabricated hydrogel scaffolds with tissue-like compressive strength, and interconnected porosity that allows 3D cell migration. Further, the colloidal crystal templating approach is a general one, in principle applicable to any aqueous solution undergoing a stable liquid-to-solid transition. Properties such as pore size, stiffness, and bioactivity are readily varied by the choice of materials used.

Z8.22

Peptide Intramolecular Folding and Consequent Intermolecular Self-Assembly: Effects of β-hairpin Peptide Turn Sequences on Hydrogel Nanostructure and Bulk Material Properties. Tuna Yucel[1], Bulent Ozbas[1], Karthikan Rajagopal[2], Darrin J. Pochan[1] and Joel P. Schneider[2]; [1]Department of Materials Science and Engineering and Delaware Biotechnology Institute, University of Delaware, Newark, Delaware; [2]Department of Chemistry and Biochemistry, University of Delaware, Newark, Delaware.

Monomeric peptides were designed to undergo reversible intramolecular folding with pH to form β-hairpins that consequently self-assemble into a hydrogel network rich in β-sheet. The β-hairpins are composed of a central tetrapeptide turn sequence flanked by two extended strands containing alternating hydrophilic lysine and hydrophobic valine residues. Oscillatory rheology showed that the exact type of turn sequence used within the peptide significantly affected the ultimate bulk hydrogel mechanical properties[1]. The shear storage moduli (G$\prime$) of 2 weight percent gels varied from 1.2 to 8.5 kPa at 65 °C where the weak turn propensity turn sequences produced the least rigid hydrogels and the strong turn propensity turn sequences produced the most rigid gels. Circular dichroism spectroscopy (CD) and transmission electron microscopy (TEM) were employed to understand the molecular and structural origins of this seven-fold difference in ultimate hydrogel scaffold moduli. CD illustrated that the amount of unfolded (unstructured) peptides present in a final hydrogel is directly correlated to the turn propensity of the turn sequences[1]. TEM revealed that all of the folded hairpins self-assemble into similar fibrilar nanostructures while cross-linking densities differ between peptides of different turn sequences. The idea of controlling supramolecular properties via the control of intramolecular folding as dictated by peptide design will generally be discussed. [1] Rajagopal, K.; Ozbas, B.; Pochan, D. J.; Schneider, J. P., J. Am. Chem. Soc., submitted.

Z8.23

MC3T3-E1 Pre-Osteoblasts Differentiation Through Interactions with Porous Titanium Scaffolds.

Jean-Philippe St-Pierre[1,2], Maxime Gauthier[2], Louis-Philippe Lefebvre[2] and Maryam Tabrizian[1]; [1]Department of Biomedical Engineering, McGill University, Montreal, Quebec, Canada; [2]Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada.

Aimed at improving the healing capabilities of bone, recent efforts in the development of biomaterials for bone regeneration applications have focused on the development of biomimetic structures which promote cellular adhesion, proliferation and differentiation [1]. Specifically, the design of highly porous metals with an interconnected porosity and surface topography capable of providing 3D scaffolds for osteoconduction shows favorable characteristics for this purpose. A powder metallurgy process has recently been developed to produce titanium foams characterized by a unique and promising microstructure [2]. The process is quite versatile and flexible, permitting control over the structure pore size and other microstructural parameters. In previous work, we reported the interactions between MC3T3-E1 pre-osteoblastic cells and titanium foams of various pore sizes with emphasis on the morphology of scaffold-adhered cells. From this study, it was observed that pre-osteoblasts exhibit a polygonal shape with 3D extensions when adhered to the porous materials, in contrast to the spindle-like shape of cells adhered to polished titanium controls [3]. It was hypothesized that these morphological differences would be associated with an increased cell differentiation rate on the porous scaffolds. The work presented in this abstract aims to compare the differentiation rates of MC3T3-E1 cells adhered to three types of titanium foam of differing pore sizes to that of polished titanium controls. This has been achieved through a study of the osteocalcin released in culture medium by differentiating cells adhered to the scaffolds, analyzed using a sandwich ELISA assay (Biomedical Technologies Inc, USA). Osteocalcin is an adequate osteoblastic differentiation marker as it is expressed exclusively by osteoblasts as an extracellular matrix protein. A study has been carried out for up to 17 days after initiation of the pre-osteoblast differentiation process. Preliminary results indicate that the titanium foams promote the release of osteocalcin by cells when compared to polished titanium, in agreement with the literature [4-5]. A study of the alkaline phosphatase (ALP) activity, another differentiation marker which measures the role of ALP in the conversion of pNPP to pNP, is also under way. To complement these results, studies of DNA and protein content, collagen type I production, and calcium deposition are to be completed. In addition to these biochemical assays, differentiated MC3T3-E1 cells and their extracellular matrix are visualized through scanning electron microscopy. REFERENCES: 1) Wen CE et al. J Mater Sci - Mater Med. 13 (2002) 397-401. 2) Lefebvre LP et al. US Publ No US2003/0044301 A1. Pub Date Mar 6, 2003. 3) St-Pierre JP et al. Mat Res Soc Symp Proc. Vol 823 (2004) W12.9.1-W12.9.6. 4) Schmidt C et al. J Biomed Mater Res (Appl Biomater). 63 (2002) 252-261. 5) Y. Yang et al. Biomaterials. 23 (2002) 1383-1389.

Z8.24

Molecular Design of surface-grafted Monomers and Initiators on Flat Substrates and Their Application in 2D-Molecular Imprinting. Abdiaziz A. Farah[1], Raluca Voicu[1], Raluca Barjovanu[1], Kidus Tufa[2], Farid Bensebaa[2] and Karim Faid[1]; [1]National Research Council of Canada (NRC), Institute for Microstructural Sciences, Ottawa, Ontario, Canada; [2]National Research Council of Canada (NRC), Institute for Chemical processing Environmental & Technology, Ottawa, Ontario, Canada.

Surface modification of solid substrates at the molecular level draws an immense research interest in polymer and materials science as it leads to well-defined surfaces with controlled micro and macroscopic properties very different of those obtained by simply coating the surfaces with functional polymers. In this account, self-assembled thin films of initiator, monomers and polymers obtained on chemically modified surfaces will be described. The surface-grafted monolayers were studied by imaging methods such as SEM, AFM and fluorescence microscopy and surface characterization methods such as contact angle, ellipsometry, X-ray photoelectron spectroscopy (XPS), and Fourier transform infrared reflection-absorption spectroscopy (FT-IRRAS)). Preliminary studies of these materials for surface-nanotemplating using 2D- molecular imprinting process will also be illustrated.

Z8.25

Artificial Extracellular Matrices: Polymer Films Modified with Positive Cues to Promote Cell Adhesion and Neurite Extension. Hyun-Kon Song[1], Katherine A. Ahmann[1], Somya Venkataramani[2], Hyo-Young Yeom[1], Diane Hoffman-Kim[3], Arto Nurmikko[1,2], David C. Paine[1] and G. Tayhas R. Palmore[1,3]; [1]Division of Engineering, Brown University, Providence, Rhode Island; [2]Department of Physics, Brown University, Providence, Rhode Island; [3]Division of Biology and Medicine, Brown University, Providence, Rhode Island.

Nerve growth is modulated in vivo by positive (permissive or growth-promoting) and negative (growth-inhibitory) biochemical cues. Neurons of the peripheral nervous system (PNS) are able to regenerate after injury because of the endogenous growth-promoting environment provided by Schwann cells. Traumatic injury to the central nervous system (CNS), however, often results in irreversible loss of function because the neurons in the CNS reside in an environment that contains too many negative cues and too few positive cues. We seek to calibrate the quantity of positive cues relative to negative cues needed for CNS regeneration and thus have fabricated patterned substrates of specific dimensions for this purpose. These substrates consist of a conductive polymer matrix doped and chemically modified with biologically-active molecules in varying spatial relationships. The preparation of these substrates will be discussed, including their spectroscopic, microscopic and immunochemical characterization. In addition, results will be shown that demonstrate how these substrates promote cell adhesion and guide neurite extension of hippocampal neuron cells from embryonic (E19) rats in the presence of both positive and negative cues.

Z8.26

Complex Integration of Nanowires for Introducing Compounds into Mammalian Cells. Daqing Zhang[1], Katarzyna Dziewanowska[1,2], Gregory A. Bohach[1,2], Pam Shapiro[1,3], Christopher Berven[1] and David McIlroy[1]; [1]physics, university of Idaho, Moscow, Idaho; [2]Microbiology, molecular biology & biochemistry, University of Idaho, Moscow, Idaho; [3]Chemistry, University of Idaho, Moscow, Idaho.

The controlled delivery of biologically-active molecules to the inside of mammalian cells has broad and significant applications, such as drug delivery and cell biology research. However, many chemical compounds cannot permeate through cell membrane, i.e., endocytosis into the cell is prohibited. A method has been developed to use nanowires as carriers into cells, which would sidestep this obstacle. The strategy for introducing nanowires into cells is to exploit receptor/ligand interactions employed by inteacellular bacteria. Fibronectin is covalently linked to nanowires/nanotubes for delivery to the inside of cells. Certain microorganisms, coat themselves with fibronectin, a normal protein produced by vertebrate animals. Acting as a molecular bridge, fibronectin links the bacteria with integrins on host cell surfaces. This molecular complex induces cytoskeletal rearrangements and endocytosis into the cell. In this paper, we present recent results of this research.

Z8.27

The Influence of Primary Structure on β-hairpin Peptide Intramolecular Folding and Consequent Self-Assembly into β-sheet Structures. Zhibin Li[1], Lisa Haines[2], Bulent Ozbas[1], Joel Schneider[2] and Darrin J. Pochan[1]; [1]Material Sci & Eng, University of Delaware, Newark, Delaware; [2]Chemistry, University of Delaware, Newark, Delaware.

Designed peptides with 20 amino acids can undergo an intramolecular folding process triggered by ionic strength, temperature or pH to form amphiphilic β-hairpin structures. These facially amphiphilic, folded β-hairpins can further self-assemble to form a hydrogel network structure. In the work presented here, a negatively charged photocage group has been introduced on the hydrophobic face to modify the intramolecular folding and consequent self-assembly process. By taking advantage of the light induced cleavage of the caged compound the negatively charged group can be released from the hydrophobic face at different points during the molecular folding process in order to control nanostructure and network structure, respectively. Using transmission electron microscopy and dynamic light scattering, the detailed self-assembled structures are studied both with and without the photocage group. These structures are correlated with the bulk rheological properties. Importantly, by assembling the peptides with the photocagable groups attached, direct insight into β-sheet fibril intermediate structures, including spherical aggregates proposed as a critical intermediate in the formation of β-sheet fibrils in general, was gained via direct imaging of these intermediate structures. A temperature dependence on the β-sheet fibril, as well as spherical aggregate formation, was also observed. Furthermore, designed peptides are being used to understand the formation of these spherical, possibly intermediate aggregates. For example, by mixing two peptides, one that can form the folded β-hairpin structures and another that cannot fold, the details of the formation of these spherical aggregates is being studied.

Z8.28

Self-Assembling Hybrid Hydrogels from HPMA Graft Copolymers Containing Coiled-coil Domains. Jiyuan Yang[1], Chunyu Xu[1] and Jindrich Kopecek[1,2]; [1]Department of Pharmaceutics and Pharmaceutical Chemistry, University of Utah, Salt Lake City, Utah; [2]Department of Bioengineering, University of Utah, Salt Lake City, Utah.

Hydrogels are water-swollen macromolecular networks which have been widely used for biomedical applications. Hybrid hydrogels are of great interest since the synergistic combination of two types of distinct molecules may lead to new materials that surpass each individual component. Coiled-coils have been one of the major structural motifs utilized to develop materials that assemble based on coiled-coil protein interactions. These materials often undergo a transition in response to external stimuli, such as temperature and/or pH changes. We have designed and synthesized a series of graft copolymers containing coiled-coils of different lengths (denoted CCn, where n represents the number of heptads). A linear hydrophilic polymer of N-(2-hydroxypropyl)methacrylamide (HPMA) was chosen as the backbone. Being stimuli-sensitive physical crosslinking agents, these coiled-coils were attached to the synthetic polymer via pendant functional groups. The coiled-coil containing graft copolymers self-assembled into hybrid hydrogels. Circular dichroism measurements indicated that helical structure existed in these graft copolymers. The swelling ability and the microstructure of the hydrogels were studied. In particular, microrheology was used to evaluate the gel formation. The results revealed that mean-square displacement (MSD) of both CC4 and CC5 were independent to time, whereas that of CC3 changed, which suggested that the length of coiled-coils has decisive influence on the self-assembling process. These studies highlight that a tailor-made responsiveness of the hybrid hydrogels for a specific application may be achieved.

Z8.29

Lateral Mobility of Tethered Vesicle-DNA Assemblies. Jason Joseph Benkoski and Fredrik Hook; Applied Physics, Chalmers University of Technology, Gothenburg, Sweden.

Supported lipid membranes are particularly attractive for use in biochemical assays because of their resistance to nonspecific adsorption and their unique ability to host transmembrane proteins. Although ideal for use in many surface-based detection techniques, supported bilayers can make the incorporation of proteins problematic due to the steric constraints of the underlying substrate. A recently developed strategy overcomes this obstacle by tethering liposomes to supported lipid bilayers via cholesterol-tagged DNA. The DNA tether is formed by first exposing the supported lipid bilayer to a solution of the cholesterol-DNA. The cholesterol then spontaneously embeds itself within the hydrophobic interior of the bilayer, forming a mobile anchor. Finally, a suspension of vesicles decorated with the complementary cholesterol-DNA is added, and the DNA pairs hybridize to complete the assembly. The lateral mobility of the assemblies was measured using florescence recovery after photobleaching (FRAP). Three variables were tested in all: vesicle size, tether length, and anchor size. The diffusion coefficient was measured to be significantly lower than that expected for free vesicles in suspension. It was neither sensitive to the size of the vesicles nor the length of the DNA tether. However, changing the anchor size from one cholesterol to two resulted in a decrease of the diffusivity by a factor of 3. Perhaps even more notable was the fact that hybridized single cholesterol-DNA without vesicles was found to diffuse 18 times faster than the tethered vesicle assemblies and over six times faster than the lipid molecules in the bilayer. The lateral diffusivity of tethered vesicle assemblies appears to be controlled by the diffusion of the cholesterol anchors despite the fact that anchor diffusion is not the slowest process. This discrepancy is believed to arise from the fact that each vesicle is tethered to the bilayer by multiple DNA pairs.

Z8.30

Novel Approaches for Fabrication of Monodisperse Giant Liposomes. Vesselin N. Paunov, Olivier J. Cayre, Chun Xu, Pietro Taylor, Andy Campbell and Paul D.I. Fletcher; Department of Chemistry, University of Hull, Hull, United Kingdom.

We have developed two novel techniques for preparation of giant liposomes. The first technique allows 2D arrays of giant liposomes on solid substrates to be fabricated and is based on a combination of micro-patterning of ITO glass slides with lipid 'ink' and electroswelling. Microcontact printing with silicone elastomer stamps is used with lipid solution 'inks' to produce lipid patterns on electro-conductive solid substrates. We have studied the effect of the lipid ink composition and the pattern features on the size of the liposomes. The average diameter of the giant liposomes produced by electroswelling of the lipid pattern is determined by size of the micro-pattern features. This technique can be used for preparation of monodisperse giant liposomes of diameters from 10 to 300 micrometers. Based on these results we have been able to reveal the mechanism of formation of giant liposomes of similar size. We also report the preparation of novel giant liposome microcapsules obtained by templating of water-in-oil emulsions stabilised by a suitable lipid mixture where the aqueous drops are gelled with a non-adsorbing hydrocolloid. The produced giant liposomes of gelled cores have sizes

varying from several micrometers to several hundred micrometers and demonstrate remarkable stability. We have studied the release kinetics of entrapped species from these capsules by using fluorescence microscopy. Such giant liposomes microcapsules can find application in a number of pharmaceutical, cosmetic and food products as delivery vehicles for drugs, fragrances and food supplements.

Z8.31
Biodegradable Plastics with Low Temperature Formability. Ikuo Taniguchi, Nathan G. Lovell and Anne M. Mayes; Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Biodegradable polymers such as poly(L-lactide) (PLA) are of interest as biomedical materials and environmentally-friendly plastics. However, the degradation temperatures of such polyesters are usually close to their melting point, limiting their melt processability. As a potential solution to this problem, we have prepared biodegradable block copolymers comprising soft and hard components that can be processed at temperatures as low as room temperature by the application of pressure. The pressure-induced flow, or baroplasticity, of these systems is facilitated by pressure-enhanced miscibility of the soft and hard components. Candidate polymer pairs expected to exhibit the desired thermodynamic behavior were chosen based on free energy calculations. Biodegradable block copolymers were synthesized by sequential ring-opening polymerization of lactones and lactide. The composition, molecular weight and chemical structure of the copolymers were well controlled, allowing the physical properties of the resulting materials to be readily tuned. This presentation will describe the synthesis, low temperature processing, structure and mechanical properties of several biodegradable baroplastic compositions.

Z8.32
Preparation and characterization of electrospun hyaluronic acid membranes for tissue engineering. Yuan Ji[1], Kaustabh Ghosh[2], Richard Clark[2], Jonathan Sokolov[1] and Miriam Rafailovich[1]; [1]Materials Science and Engineering, State University of New York at Stony Brook, Stony Brook, New York; [2]Biomedical Engineering, State University of New York at Stony Brook, Stony Brook, New York.

An electrospinning method was introduced to prepare Hyaluronic acid (HA) nanofiber non-woven membranes as a novel scaffold for tissue engineering. Thiolated HA was dissolved in SF-DMEM and electrospun to form non-woven membranes with a porous structure. Then the electrospun HA membranes were crosslinked by adding PEG-diacrylate (PEGDA) with a volume ratio of 4:1. Gel formation was occurred within 5 minutes and the concentrated hydrogels were rehydrated later to form a 3D porous hydrogel structure. By optimizing the processing parameters such as solution concentration, flow rate, deposition time. We can effectively control the fiber diameter and pore size. The structure and morphology of electrospun HA hydrogels were investigated by using Atomic Force Microscopy (AFM) and Confocal Laser Scanning Microscopy. Cell seeding experiments were also performed to elucidate the cell adhesion, migration and proliferation in the electrospun 3D porous HA hydrogels. Results show that this novel biodegradable scaffold has great potential applications in tissue engineering due to its unique 3D porous structure and excellent biocompatibility. Supported by NSF-MRSEC

Z8.33
Self-assembly of positively charged amphiphilic peptides. Alexander Siegrist[1], Fouzia Boulmedais[1], Salvatore Chessari[1], Martin Muller[2], Marcus Textor[1] and Shuguang Zhang[3]; [1]Oberflachentechnik, ETH, Zurich, Switzerland; [2]Elektronenmikroskopie, Inst.f. Angewandte Physik, ETH, Zurich, Switzerland; [3]Center for Biomedical Engineering, Massachusetts Institute of technology, Cambridge, Massachusetts.

The current state-of-the-art biochemical delivery system is largely based on oligofectamine, trans-tKO, and other polymer vesicle-based delivery systems. They are often toxic to cells in cultures and exhibit poor in vivo effectiveness. Moreover, most of alternative delivery systems do not confer both efficiency and specificity for targeted delivery, a key aspect for drug delivery. A new type of surfactant peptide designed to mimic the properties of cationic lipid systems was described recently (von Maltzahn et al. 2003). In this work, we study the self-assembly of four different amphiphilic peptides by Cryo-Transmission Electron Microscopy and Dynamic Light Scattering. These peptides have approximately 2nm in length with a cationic, hydrophilic head followed by a hydrophobic tail. The difference between these peptides is the hydrophobicity and hydrophilicity of amino-acids composing them. In pure water depending of their formula, they adopt two different self-assemblies : nanotubes (diameter between 10 nm to 50nm) and platelets (with diameter between 30 and 110nm). We study the influence of ultrasonication, extrusion and salt on self-assemblies of the peptides. The formation of vesicles or nanotubes seems to depend of the size of the hydrophobic tail compared to the size of the hydrophilic head. von Maltzahn, G., et al. (2003). "Positively charged surfactant-like peptides self-assemble into nanostructures." Langmuir 19: 4332.

Z8.34
Optimization of Electrospinning Process Parameters for Tissue Engineering Scaffolds for Bioactive Bandages. Ming Chen[1], Prabir Patra[3], Steve Warner[3] and Sankha Bhowmick[1,2]; [1]Biomedical Engineering and Biotechnology, University of Massachusetts Dartmouth, North Dartmouth, Massachusetts; [2]Mechanical Engineering, University of Massachusetts Dartmouth, North Dartmouth, Massachusetts; [3]Textile Science, University of Massachusetts Dartmouth, North Dartmouth, Massachusetts.

Electrospinning has been used a tool for creating three-dimensional scaffolds for tissue engineering applications. During electrospinning, the biomaterial of choice (which can range from polymer to various mixtures of copolymers) can be spun to form fibers ranging from several microns down to 100 nm or less in diameter. By optimizing the parameters governing the electrospinning process, one can engineer controlled features in the scaffold in accordance to the specific tissue engineering application. While several studies have demonstrated the success of electrospinning as a tool for forming 3-D scaffolds, quantitative data showing the relationship of process parameters to cellular viability and proliferation is lacking. In the current study, we use polycaprolactone (PCL) as a biomaterial of choice for creating tissue engineered scaffolds for bioactive bandages. PCL is an ideal biopolymer because of its lack of toxicity, low cost and slow degradation. While previous studies have proven that PCL could be electrospun, we optimize the process parameter space for PCL electrospinning based on voltage, biomaterial concentration and the distance between capillary and collection screen. Using scanning electron microscopy (SEM), we measured the fiber diameter and also studied the growth and migration of NIH 3T3 fibroblasts into the PCL electrospun scaffolds at various time points post seeding of cells. Other quantitative assays including laser scanning fluorescence microscopy have shown that PCL electrospun scaffolds are suitable as bio-active bandages.

Z8.35
Tribology of Self-Assembled Peptide Layers. Daniela Silvano[1], Andrzej Kulik[2], Wolf-Peter Ulrich[1] and Horst Vogel[1]; [1]Laboratory of Physical Chemistry of Polymers and Membranes, Swiss Federal Institute of Technology of Lausanne, Lausanne, Switzerland; [2]Laboratoire de Nanostructures et Nouveaux Materiaux Electroniques, Swiss Federal Institute of Technology of Lausanne, Lausanne, Switzerland.

Hydrophobic and amphipathic polypeptides can form densely packed, highly organized self-assembled monolayers at water-solid interfaces. Here we investigate how the amino acid sequences of the polypeptides and external parameters like temperature and ionic composition of the surrounding aqueous medium influence the structure and finally the tribological properties of the self- assembled monolayers at solid supports. The general goal of this work is the design of surfaces with controlled chemical and physical properties which could be used for medical and bioanalytical applications and microelectromechanical systems. Fourier transform infrared spectroscopy, surface plasmon resonance and scanning force microscopy are used to investigate the molecular structure and the tribological properties of the following self-assembled polypeptide layers at solid supports. i. Polypeptides comprising N-terminal cysteines can be easily assembled at gold surfaces via Au-S covalent bonds. In the case of Ac-Cys-$(Ala)_x$-$CONH_2$ (x = 3-10) we investigated how the polypeptide chain length influences the mentioned properties of these layers. Starting from random coiled peptides in solution, it is possible to induce a regular and stable secondary structure by self-assembly on gold. Scanning probe microscopy shows that the layer structure provides a way to control tribological properties of the layers. ii. Functional groups included in the peptide sequence allow specific binding to complementary groups on solid surfaces. Here we use the reversible, Ni^{2+} ion modulated binding between poly-histidine peptide sequences and NTA on the support. Amphiphilic helices whose surface is half hydrophilic (histidine residues) and half hydrophobic (alanine and leucine residues) are used to reversibly switch between two helix orientations by modifying external parameters such as ionic composition of the aqueous phase. Dramatic changes in the tribological properties of the peptide layer for the two different helix orientations are expected.

Z8.36
Engineering Titanium Surfaces for Specific Interactions with Integrin Receptors through Poly(L-Lysine)-g-Poly (Ethylene Glycol) Adlayers Functionalized Collagen Derived Mimetic Peptide. Salvatore Chessari[1], Samuele Tosatti[1], Milvia Lepre[2], Falko

Schlottig[2] and Marcus Textor[1]; [1]Materials, ETH, Zurich, Switzerland; [2]Synthes AG, Oberdorf, Switzerland.

Previous studies have shown that engineering surfaces for specific integrin-ligand interaction and signaling cascades provides a biomolecular strategy for optimizing cellular responses in biomaterials applications. Integrin-mediated cell adhesion to extra-cellular matrix (ECM) proteins anchors cells and triggers signals that direct biological response such as cell differentiation, wound healing, immune response and tissue function through specific and dynamic regulation of cell behavior. The integrin ?2?1 recognizes a specific amino acid binding sequence that is present on type I collagen. Integrin recognition is entirely dependent on the triple-helix conformation of the ligand similar to that of native collagen[1]. This study focuses on engineering ?2?1-specific bioadhesive surfaces by immobilizing a triple-helical collagen-mimetic peptide, incorporating the specific binding sequence, onto model nonadhesive substrates. Metal oxide surfaces can be made protein-resistant through spontaneous assembly of poly-(L-lysine)-g-poly-(ethylene glycol) (PLL-g-PEG) grafted co-polymers. This copolymer is used as a basis for developing special surfaces with controlled specific biological properties[2], e.g. through grafting the binding sequence of type I collagen to part of the PEG-chains to induce a direct interaction of the peptide ligands at controlled surface density with cell receptors. Three different peptide versions have been synthesized and their conformation analyzed by Circular Dichroism. The polymer functionalized surfaces were characterized by Optical Waveguide Lightmode Spectroscopy (OWLS) and Ellipsometry. References 1. Reyes, C.D. and A.J. Garcia, Engineering integrin-specific surfaces with a triple-helical collagen-mimetic peptide. Journal of Biomedical Materials Research Part A, 2003. 65A(4): p. 511-523. 2. Tosatti, S., et al., Peptide functionalized poly(L-lysine)-g-poly(ethylene glycol) on titanium: resistance to protein adsorption in full heparinized human blood plasma. Biomaterials, 2003. 24(27): p. 4949-4958.

Z8.37

Artificial Integral Membrane Proteins for Vectorial Electron Transfer Across Soft Interfaces. Joseph Strzalka[1], Shixin Ye[1], Bohdana M. Discher[2], Christopher C. Moser[2], P. Leslie Dutton[2] and J. Kent Blasie[1]; [1]Dept. of Chemistry, University of Pennsylvania, Philadelphia, Pennsylvania; [2]Dept. of Biochemistry and Biophysics, University of Pennsylvania, Philadelphia, Pennsylvania.

Naturally occurring oxidation-reduction protein complexes have a proven ability to insert vectorially into membranes and generate potential differences across these membranes, but also have complicated architectures and a fragility that make them difficult to adapt to materials applications. Given the ease of solid phase peptide synthesis and the robustness of simple structural motifs, synthetic peptides show promise as components of novel biomolecular materials, provided that the functions of these individual molecules can be translated into materials properties by organizing the peptides into macroscopically ordered ensembles. We have developed amphiphilic alpha-helical bundle peptides, analogous to membrane proteins, with the exterior of one end of the bundle hydrophilic and the exterior of the other end hydrophobic, in order to promote the organization of these peptides at interfaces. Just as in previously developed water-soluble helical bundle peptides, the inclusion of histidines in the sequence of these amphiphilic peptides provides sites for bis-His ligation of metallo-porphyrin prosthetic groups (e.g. heme) in the core of the bundle, letting them serve as a scaffold for the arrangement of donors and acceptors in an electron transfer chain. However, in amphiphilic peptides the chain may bridge the interface between polar and non-polar media and so generate a potential difference across a host lipid monolayer or bilayer. We have designed and characterized a series of amphiphilic four-alpha-helical bundle peptides with the hydrophilic end based on the earlier water-soluble peptides, with the helices extended by sequences derived from a proton channel analog or from part of the transmembrane domain of the cytochrome bc1 complex. The purified peptides are highly alpha-helical, assemble into 4-helix bundles when detergent solubilized, and can bind heme groups in either the hydrophobic or hydrophilic end of the bundle, with binding affinities in the 10-100 nM range. The hemes, whether bound in the hydrophilic or hydrophobic end of the bundle, exhibit oxidation-reduction midpoint potentials in the range of -140 to -100 mV. X-ray reflectivity and grazing incidence diffraction studies of Langmuir monolayers show that as surface pressure is applied at the air/water interface, the peptides assemble into four-helix bundles oriented with the helical axes perpendicular to the interface. X-ray studies of the inclusion of these peptides into phospholipid vesicles are also underway. This work supported by the NIH (GM55876) and the MRSEC program of the NSF (DMR00-79909). Synchrotron x-ray sources at Brookhaven and Argonne National Laboratories supported by the Department of Energy.

Z8.38

Tether Length Effects on Cell Adhesion to Amphiphilic Comb Copolymers Presenting Tethered RGD. William Kuhlman[1], Anne M. Mayes[1] and Linda G. Griffith[2]; [1]Materials Science, MIT, Cambridge, Massachusetts; [2]Biological Engineering, MIT, Cambridge, Massachusetts.

Amphiphilic comb copolymers having poly(methyl methacrylate), PMMA, backbones and polyethylene glycol, PEG, side chains have demonstrated considerable promise as materials for biomedical applications (1,2,3). These systems show good resistance to protein adsorption, resulting in a benign biological response. Where specific biological signaling is desired, the ends of some PEG chains can be selectively functionalized with a biological ligand of interest, creating a surface consisting of two types of PEG chains: inert "blocking" chains that impart protein adhesion resistance and functionalized "active" chains that mediate specific cell-surface interactions. This study seeks to examine the effects of the relative lengths of such blocking and active chains on cell signaling. Two possible effects of chain length are considered: screening of cell receptor interactions with active chains by longer blocking chains, and reduction of receptor crowding effects on ligand-receptor interactions using longer active chains. The latter is of particular interest where receptor clustering plays a critical role in cell response, such as with integrin-mediated focal contact formation. If clusters of ligands are attached by tethers that are small relative to the receptor dimensions, then a bound receptor may block remaining ligands, making them inaccessible even at low overall surface concentrations of ligand. In this study these effects are examined using the adhesion peptide RGD as a model ligand for active chains, by evaluating cell attachment and spreading on amphiphilic comb copolymers where tether length, peptide density and peptide clustering are systematically varied. 1) Irvine, D. J., Mayes, A. M., Griffith, L. G. Biomacromolecules, 2 (2001) 85-94 2) Irvine, D. J., Ruzette, A. V., Mayes, A. M., Griffith, L. G. Biomacromolecules, 2 (2001) 545-556 3) Koo, L. Y., Irvine, D. J., Mayes, A. M., Lauffenburger, D. A., Griffith, L. G., J. Cell. Sci. 115 (2002) 1423-1433

Z8.39

Rate of Diffusion-influenced Ligand Binding to Receptors on a Cell Surface: Effect of Receptor Shape. Olga K. Dudko[1], Alexander M. Berezhkovskii[1], Attila Szabo[2] and George H. Weiss[1]; [1]Center for Information Technology, Mathematical & Statistical Computing Laboratory, National Institute of Health, Bethesda, Maryland; [2]Laboratory of Chemical Physics, NIDDK, National Institute of Health, Bethesda, Maryland.

The theory of the kinetics of ligand binding to receptors on a cell surface is extended to account for receptor shapes more general than the usually assumed circular shape. The full time dependent behavior of the rate of diffusion-influenced ligand-receptor binding is expressed analytically in terms of geometrical parameters of the receptor. The analytical results are supported by Brownian dynamic simulations. The results are potentially useful in ligand- and receptor-based drug design.

Z8.40

Direct Immobilization and Patterning of Hyaluronic Acid on Hydrophilic Substrates. Kahp Y. Suh[1], Ali Khademhosseini[2], Jen Ming Yang[3], George Eng[4], David Berry[2,5], Thanh-Nga T. Tran[5] and Robert Langer[2,4,5]; [1]School of Mechanical and Aerospace Engineering, Seoul National University, Seoul, South Korea; [2]Division of Biological Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [3]Department of Chemical and Materials Engineering, Chang Gung University, Kwei-Shan, Taiwan; [4]Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [5]Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Hyaluronic acid (HA) was directly immobilized onto hydrophilic substrates without any chemical manipulation, allowing for the formation of an ultra-thin chemisorbed layer. It is hypothesized that HA is stabilized on these surfaces through hydrogen bonding between the hydrophilic moieties in HA (such as carboxylic acid (-COOH) or hydroxyl (-OH) groups) with silanol (-SiOH), carboxylic acid or hydroxyl groups on the hydrophilic substrates. Despite the water solubility, the chemisorbed HA layer remained stable on glass or silicon oxide substrates for at least 7 days in phosphate buffered saline. HA immobilized on silicon and other dioxide surfaces in much higher quantities than other polysaccharides including dextran sulfate, heparin, heparin sulfate, chondroitin sulfate, dermatan sulfate, and alginic acid. This behavior is related to the molecular entanglement and intrinsic stiffness of HA as a result of strong internal and external hydrogen bonding as well as high molecular weight. These results demonstrate that HA can be used to coat surfaces through direct immobilization, which provides simple routes to patterning HA without resorting to surface modifications. Motivated by the result, HA was patterned using two soft lithographic

methods on various substrates including glass, silicon dioxides, poly (hydroxyethyl methacrylate) [poly (HEMA)], polystyrene cell culture dishes, and biodegradable polylactic glycolic acid (PLGA), without the use of chemical modification or with slight modification with NaOH or oxygen plasma treatment. Such versatile use of soft lithographic methods would be potentially useful for many biomedical applications of HA.

Z8.41

Membrane on a Chip. Applications of Tethered Lipid Bilayers. Ingo Koper[2], Randy Duran[1], Wolfgang Knoll[2], Peter Anderson[3], Andreas Offenhausser[4], Sven Ingebrandt[4], Nikolaus Knorr[2], Vladimir Atanasov[2], Jing Li[2] and Renate Naumann[2]; [1]Chemistry, University of Florida, Gainesville, Florida; [2]Max Planck Institute for Polymer Research, Mainz, Germany; [3]Whitney Laboratory, University of Florida, Marineland, Florida; [4]Julich Research Center, Julich, Germany.

Tethered membranes have been shown to be a powerful platform for the study of membrane properties and to monitor the incorporation of functional biological units. Compared to other model membrane systems they provide enhanced stability. Within a DARPA-funded international project between the University of Florida and the Max Planck Institute for Polymer Research, Mainz we are using bilayer membranes tethered to the gate-oxide of field effect transistors as a bio-FET platform. Incorporated ion channels will be used in order to construct a novel type of biosensing device. Electric properties of the immobilized ion channels will be read out and analysed for changes in the presence of analyte molecules. The membrane systems developed at the Max Planck Institute show also extremely high electrical resistances enabling the study of ion translocation through membrane proteins embedded in the membrane matrix. The Maxi-K ion channel has been successfully incorporated into a tethered membrane system. A novel 16 channel FET design and read-out system has been developed in a cooperation with the Research Center Julich and it has been adapted to the membrane system. Tethering of membrane system, historically established on gold surfaces, to the silicon surface has been shown.

Z8.42

Surface Interfacial Properties of Modified Planar and Porous Silicon Studied via Protein Adsorption. Li-Lin Tay[1], Nelson L. Rowell[1], Daniel Poitras[1], David J. Lockwood[1] and Rabah Boukherroub[2]; [1]National Research Council, Ottawa, Ontario, Canada; [2]Interdisciplinary Research Institute, IEMN-IRI, Villeneuve d'Ascq, France.

Light emission in nano-porous silicon has captured considerable scientific attention. The large surface area coupled with its luminescence properties has been utilized as a transducer element in many biosensor applications where the interaction between the bio-molecule and porous substrates is of paramount importance. Here, we present results from our study of the serum albumin protein interaction with the acid modified nanoporous and planar silicon surfaces. By tailoring the terminal functional group, one can control the surface interfacial properties of planar and porous Si materials, changing them from the hydrophobic surfaces into the more biologically favorable hydrophilic ones. The 3.8 μm thick porous silicon films were fabricated through electrochemical anodization of single crystalline silicon in hydrofluoric acid. The hydrogen terminated porous and planar silicon surfaces were modified through a thermally induced hydrosilylation process to generate an organic monolayer covalently attached to the silicon surfaces through Si-C bonds. These attached molecules bear the acid terminal group. Bovine serum albumin (BSA) was adsorbed onto the modified surfaces. The resulting surfaces were characterized using scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). SEM images showed micron-sized BSA aggregates on both planar and porous surfaces. More interestingly, SEM-EDS (energy dispersive spectroscopy) analysis indicated that the protein had penetrated more than 1 μm into the porous structure despite the small pore diameters (10 nm). SEM also revealed that the porous films were damaged and had partially lifted off the silicon substrate after prolonged BSA adsorption. This is likely due to the BSA penetrating deep into the porous structure and anchoring itself tightly through strong electrostatic interaction with the acid-covered pSi sidewalls. A change in surface tension during BSA film formation then causes the pSi layer to buckle and lift-off the underlying Si substrate. Single bounce attenuated total reflection FTIR of the planar and FTIR of the porous Si surfaces after BSA adsorption showed strong characteristic Amide I, II and III vibrational bands. Protein penetration into the porous surfaces, its interaction with the acid modified surfaces and with other alkyl-terminated hydrophobic surfaces will also be discussed.

Z8.43

UV-Photon Induced Photo-chemical Surface Modification of Silicone Rubber for Biocompatible Intraocular Lens. Nobuhiro Sato, Yuji Sato and Masataka Murahara; Electrical Engineering, Tokai Univ., Hiratuka, Japan.

The silicone intraocular lens surface was selectively modified to be hydrophilic by UV irradiation before vulcanizing in the process of heat curing of the silicone rubber; which resulted in the development of a soft and highly biocompatible intraocular lens. Silicone rubber, which has a high transparency, resistance to hostile environments and oxygen permeability, is clinically used as an intraocular lens. The silicone lens, however, gets out of place due to its water repellency and low tissue affinity when implanted in the eye. Then, we have modified the silicone rubber surface selectively into hydrophilic by irradiating the Xe_2 excimer lamp through the pattern mask in the air. The plasma and ion beam irradiation methods are employed in order to modify the material surface into hydrophilic. These methods, however, damage the surface physically, destroying the original characteristics of the material. In our study, the hydrophilic property was generated on the desired area of the surface while making use of the original characteristics of silicone rubber by the photochemical substitution of hydrophilic groups. The Xe_2 excimer lamp was vertically irradiated on the photo-oxidized intraocular lens made of silicone rubber through the pattern mask again in an atmosphere of reaction liquid having OH groups. The reaction liquid was photo-dissociated to produce OH radicals. The sample surface was photo-excited at the same time, and the OH radicals were substituted on the surface. In this manner, the OH functional groups were substituted on the part excited by the lamp to develop the hydrophilic property. The microscopic infrared spectroscopy analysis [microscopic ATR-FTIR] was carried out to investigate the modified samples. As a result, it was confirmed that as the time of lamp irradiation extended, the absorption peak of the CH_3 groups at 2900 cm^{-1} decreased, but the absorption peak of the OH groups increased. The contact angle with water was also measured. Of the non-treated sample, the contact angle was 110 degrees; of the treated sample, the contact angle improved to 22 degrees with the Xe_2 lamp irradiation for 25 minutes. Furthermore, the protein adsorption of the non-treated or treated sample was evaluated with fibrin [FIB] solution as a protein index. The results revealed that the fibrin adsorption rate increased while the OH substitution density become higher.

Z8.44

Superhydrophilic Patterns on Superhydrophobic Surfaces. Lei Zhai[1], Fevzi C. Cebeci[1], Robert E. Cohen[2] and Michael F. Rubner[1]; [1]Department of Material Sciences and Engineering, MIT, Cambridge, Massachusetts; [2]Department of Chemical Engineering, MIT, Cambridge, Massachusetts.

The lotus leaf structure has been mimicked by creating a honeycomb like polyelectrolyte multilayer surface overcoated with silica nanoparticles. Superhydrophobicity was achieved by coating this highly textured multilayer surface with a semifluorinated silane. The surface maintains its superhydrophobic character even after extended immersion in water. Superhydrophilic patterns have been generated on the superhydrophobic surfaces. Their applications in planar microfluidic channels and sensors are demonstrated.

Z8.45

Synthesis of Hydroxyapatite Thin Films Prepared by Pulsed Laser Deposition Method. Hiroharu Kawasaki[1], Tamiko Ohshima[1], Yoshiaki Suda[1], Shouta Nakashima[1], Tetsuya Toma[2] and Shinichi Kawasoe[2]; [1]Electrical Engineering, Sasebo National College of Technology, Sasebo, Nagasaki, Japan; [2]Japan Nanotech. Co. Ltd., Omura, Nagasaki, Japan.

Hydroxyapatite (HAp) has attracted a great deal of attention because its chemical composition is similar to that of natural bone tissues. It promotes rapid bone growth and bonding between bony tissue and implant surfaces. HAp is also utilized for various fields of environment purification with titanium dioxide photocatalyst, because it absorbs bacteria, virus, ammonia and organic materials. In this paper, HAp thin films were prepared using pulsed laser deposition (PLD) method. Crystalline structure of the HAp thin films prepared using pure HAp target was analyzed by X-ray diffraction (XRD). The result suggests that there are many small peaks indexed to hexagonal lattice of Ca_10(PO_4)_6(OH) _2 (002), (201), (211), (300), (202) crystal, and no impurity other than HAp is detected in those films. The composition ratio of the film was characterized by X-ray photoelectron spectroscopy (XPS). XPS spectra of the P2p_3/2, O1s, Ca2p_3/2, peaks can be observed from the prepared films. Depth profiles of XPS measurement suggest that the film thickness of HAp prepared by PLD method is about 400-500nm at the deposition time of 30 min. Therefore, the deposition rate of the film is about 0.2-0.3 nm/s. HAp coatings on TiO_2 thin films have been prepared using HAp(10%)+TiO_2 targets. XRD measurement suggest that both of TiO_2 (TiO_2 (101: anatase), TiO_2 (110: rutile)) and HAp crystalline peaks can be prepared on the same Si substrate. XPS spectra of the

Ti2p_3/2, O1s, Ca2p_3/2, P2p_3/2 peaks can be observed from the prepared films. These results suggest that crystalline HAp+TiO_2 thin films can be prepared by the PLD method using HAp(10%)+TiO_2 targets. Surface morphology of the film observed by transmission electron microscopy, shows that the mean grain size is about 50-100 nm.

Z8.46

Fibrin Free Intraocular Lens with V-UV Photon Induced Photochemical Surface Modification for Making Micro Domain Structure with Hydrophilic and Hydrophobic.

Yuji Sato and Masataka Murahara; Electrical Engineering, Tokai Univ., Hiratsuka, Japan.

The hydrophilic and hydrophobic groups were photo-chemically substituted in minute pattern on the polymethylmethacrylate [PMMA] surface by the Xe_2 excimer lamp and the ArF excimer laser; consequently, the intraocular lens [IOL] that is free from fibrin has been developed. PMMA has been used as an intraocular lens [IOL] because of its high transmittance in the visible region and superb mechanical modifiability. However, protein and fat are stuck onto the lens surface after a long-term insertion, where cells proliferate; which causes the surface to get opaque, namely after-cataract. In order to inhibit the fibrin sticking, the PMMA has been coated with the heparin or polyethylene oxide. It is, however, weak in compatibility with heparin or polyethylene oxide because of its repellency, so the method works for only a short period. On the other hand, the PMMA surface has been modified into hydrophilic by the plasma or ion irradiation method to improve the biocompatibility. But the method not only damages the sample surface but also makes it easy for fibrin to stick. An IOL is required to inhibit protein sticking and to have high biocompatibility: the hydrophilic and hydrophobic surfaces are needed to improve the biocompatibility and to avoid protein or fat adhesion, respectively. No materials that have both hydrophobic and hydrophilic groups have reported before. Thus, we demonstrated to pattern the micro domain structure with hydrophilic and hydrophobic groups on the IOL surface. Firstly, the IOL was irradiated with Xe_2 excimer lamp in the presence of perfluoropolyether to be hydrophobic. By the photochemical reaction, the CF_3 functional groups were substituted on the IOL surface. In order to substitute hydrophilic groups in matrix-form on the surface. The ArF laser light was then irradiated on the hydrophobic surface in the presence of water through the $150\mu m\Phi$ dot-patterned negative mask and the lens to project the pattern reduced to $50\mu m\phi$ dots. With this selective photochemical surface modification, the hydrophilic and hydrophobic groups were arrayed alternately on the sample surface. The modified IOL was soaked in fibrin [FIB] water solution, and the fibrin-sticking rate was measured by using an infrared spectroscopy [FT-IR]. The results showed that the fibrin-sticking rate of the sample substituted with hydrophilic groups increased while that of the sample substituted with hydrophobic groups decreased. Moreover, the fibrin-sticking rate of the sample with the micro domain structure of hydrophilic and hydrophobic groups was reduced to one-fifth that of the non-treatment sample. The results confirmed that the micro domain structures with hydrophilic and hydrophobic groups inhibit the fibrin sticking. In conclusion, the ideal, fibrin-free intraocular lens has been produced.

Z8.47

Assembly of Glycoconjugate Polymers on Hydrophobic Templates on Silicon.

Hajime Sato[1], Miura Yoshiko[2], Nagahiro Saito[1], Osamu Takai[1] and Kazukiyo Kobayashi[2]; [1]Material Engineering, Nagoya University, Nagoya, Aichi, Japan; [2]Molecular Design and Engineering, Nagoya University, Nagoya, Aichi, Japan.

The immobilization and the micro-patterning of biomolecules on the solid surfaces are paid much attention for the application of biomaterials, biosensors, and microarrays. Micro-patterned carbohydrates on solid surfaces are expected to analyze carbohydrate protein interactions and to fabricate the scaffolds of cell cultivation, because carbohydrates on cell surfaces play important roles in numerous intercellular recognition processes. Since carbohydrate-protein interactions are usually weak and amplified with multivalent effects, it is important to exploit a strategy for micropattering of carbohydrate on solid surfaces with the multivalency. The glycopolymers have been reported to show the strong multivalent effects to lectins (saccharide recognition protein). We investigated the micro-patterned saccharide displays through the self-assembly of glycoconjugate polymers onto the hydrophobic-hydrophilic template. The micro-patterned hydrophobic structures were prepared by the formation of self-assembled monolayer of octadecylsilane (ODS-SAM) and photolithography using vacuum ultraviolet light. The micro-patterned ODS-SAMs were immersed in aqueous solutions of glycoconjugate polymers. The self-assembled membranes of glycoconjugate polymers were formed onto the ODS-SAM based on the amphiphilicities. The thicknesses of the polymer layers estimated by ellipsometry were increased with the immersion to reach 15-20 angstrom after 5-6 h irrespective of the polymer backbones and sugar structures, and the time courses of the polymer adsorption were followed by the Langmuirfs equation. SEM suggests that the glycoconjugate polymer was adsorbed on ODS-SAM region. XPS spectra of the polymer-coated substrates on the ODS-SAM indicated that the intensities of C-O peaks and C=O on the photodegraded region were almost 10 % of those on ODS-SAM. Glycoconjugate polymers were specifically adsorbed on the hydrophobic ODS-SAM by the interaction between the polymer backbone and substrate, in which the saccharide moieties of the polymers were exposed to the surface. The lectin recognition of the micropatterned carbohydrates was visualized by fluorescence microscopy using FITC-labeled lectin. Fluorescence images were observed along the micro-patterns, and the patterning was specific to the combination between carbohydrates and lectins. The combination of the top down material processing (lithography) and the bottom-up processing (self-assembly of the biomacromolecules) is one of the key methodologies for the nano-materials. Carbohydrate microchips and patterned cell cultivations using this strategy are currently under way.

Z8.48

Responses of MC3T3 Cells to Crystallographic Texture of Titanium Alloy.

Shahabeddin Faghihi[1], Mohammad Reza Bateni[2], Fereshteh Azari[3], Jerzy A. Szpunar[2], Hojatollah Vali[3] and Maryam Tabrizian[1]; [1]Biomedical Engineering, McGill University, Montreal, Quebec, Canada; [2]Mining,Metals and Materials Engineering, McGill University, Montreal, Quebec, Canada; [3]Anatomy and Cell Biology, McGill University, Montreal, Quebec, Canada.

Understanding cell-biomaterial interactions is crucial for osseointegration, which is a requirement for short- and long-term stability of metallic implants. Titanium and its alloy are increasingly used in orthopedics and dentistry, even though, cellular interactions with these materials is not well understood. The aim of this study was to investigate the effects of substrate crystallographic texture on mouse osteoblast (MC3T3-E1) responses. Samples of Ti6Al4V having different textures and grain morphology were used as a substrate. All samples had equal surface area and were polished under the same conditions for identical surface roughness. X-ray diffraction (XRD), optical microscopy, and atomic force microscopy (AFM) were used to identify phase composition, preffered orientation, and microstructure. Topography and mean surface roughness were measured by tapping-mode AFM. To study the effect of crystallographic texture of Ti6Al4V on short- and long-term cell response, the samples were cleaned with solvents in an ultrasonic bath, autoclaved, and then cultured with osteoblasts. Cell attachment, proliferation and morphology were assessed. For attachment evaluations, cells were cultured for 30 min, 1, 2, and 4 hours. Cell morphology on different substrates was studied by scanning electron microscopy (SEM) after three days. To determine the effects of substrate texture on cell growth, proliferation rates were evaluated after 3, 8, and 11 days. Results show a texture dependency on both cell attachment and proliferation. A significant correlation was established between the number of attached cells and the texture of the substrates. In samples with (010) fiber texture more cell attachment and proliferation rates were observed compared to samples with (110) texture. Cell morphology was not significantly affected by sample texture.

Z8.49

Novel 3D NiTi-TiC composites as potential bioactive scaffolds for bone tissue-engineering applications.

Guglielmo Gottoli[1,2], Douglas E. Burkes[1,2], John J. Moore[1] and Reed A. Ayers[1,2]; [1]Metallurgical and Materials Engineering, Colorado School of Mines, Golden, Colorado; [2]Center for Commercial Applications of Combustion in Space, Golden, Colorado.

Combustion Synthesis provides an attractive alternative to conventional manufacturing routes for the production of advanced materials. The Center for Commercial Applications of Combustion in Space (CCACS) at the Colorado School of Mines (CSM) has utilized this method to fabricate innovative porous materials for prospective orthopedic, orthodontic and maxillo-facial applications. In this study, an SHS-produced NiTi-TiC intermetallic-ceramic composite of varying chemistry and porosity has been subjected to a biomimetic process to verify its medical potential. The immersion in a simulated body fluid (SBF) has resulted in the formation of a thin bone-like apatitic layer on its surface. Analysis of the coating by TF-XRD and ESEM has shown that the apatitic layer grown in this manner closely resembles that of bone and that the mechanism of apatite formation is similar to that seen on other Ti-based alloys. The preliminary investigation thus indicates SHS-produced NiTi-TiC composites of differing porosities as potential 3D bioactive scaffolds for bone tissue engineering applications.

SESSION Z9/AA8: Joint Session: Nano Structured Surfaces and Materials in Biology and Medicine
Chairs: Joel Collier and Craig Halberstadt
Thursday Morning, December 2, 2004
Room 304 (Hynes)

8:30 AM *Z9.1/AA8.1

Self-Assembling Nanomaterials for Regenerative Medicine.
Samuel I. Stupp, Materials Science, Chemistry, and Medicine, Northwestern University, Evanston, Illinois.

The molecular and nanoscale design of synthetic environments that emulate extracellular matrices is critical for the future of regenerative medicine. These matrices need to manage cells into regenerative events that recapitulate development. Ideally, they should also hone in to the right tissues by self-assembly and be programmed to disappear into nutrients after completing their tasks. Chemistry's role lies in the supramolecular crafting of synthetic matrices that will allow cells to survive, control their proliferation, guide them in space or recruit them into the space of the matrix, and, most importantly, control their differentiation into a desired lineage. This lecture describes the design of peptide amphiphiles that form solid, cylindrical nanofibers designed to present artificially high densities of epitopes to cells with interesting biological consequences. This will be illustrated with experiments using neural progenitor cells that demonstrate how chemically designed matrices could help promote the regeneration of the central nervous system. Other systems are able to guide the differentiation of human stem cells and trigger events important in angiogenesis. Finally, systems of supramolecular nanofibers can be used to template the formation of inorganic crystals like those found in bone, leading to biomineralization in vivo under conditions that would not normally promote bone regeneration.

9:00 AM Z9.2/AA8.2

Self Assembled Monolayers: A Versatile Tool for Investigating Immune Cell Signaling on the Submicron Scale.
Wageesha Senaratne[1,2,3], Prabuddha Sengupta[2], Vladimir Jakubek[1], David Holowka[2,3], Barbara Baird[2,3] and Christopher K. Ober[1,3]; [1]Materials Science and Engineering, Cornell University, Ithaca, New York; [2]Chemistry and Chemical Biology, Cornell University, Ithaca, New York; [3]Nanobiotechnology Center, Cornell University, Ithaca, New York.

We utilize self-assembled monolayers (SAMs) as molecular templates to engage and cluster IgE-receptors on RBL mast cells with sub-micron scale spatial resolution. Bioactive templates were fabricated using electron beam lithography, and these consisted of gold arrays on silicon with patterns from 1 μm down to 200 nm. These gold arrays served as molecular tethering sites, enabling covalent binding of functionalized self-assembled monolayers of alkanethiols. The free ends of the monolayers were functionalized with 2,4-dinitrophenyl(DNP)-caproate-based ligands which interact specifically with anti-DNP IgE bound to its high affinity cell surface receptor, FcεRI on RBL mast cells. Present results indicate that these patterned SAM arrays can function as a powerful tool for visualization and systematic characterization of submicron scale co-redistribution of membrane and cytosolic components in IgE receptor mediated immune cell signaling.

9:15 AM Z9.3/AA8.3

Topographically-controlled Orientation of Tobacco Mosaic Virus on Nanopatterned Substrates.
Matthew J. D'Amato[1], Nicholas L. Abbott[2,1], Barbara A. Israel[3], Mark A. Eriksson[4,1] and Robert W. Carpick[5,1]; [1]Materials Science Program, University of Wisconsin, Madison, Wisconsin; [2]Chemical and Biological Engineering, University of Wisconsin, Madison, Wisconsin; [3]Pathobiological Sciences, University of Wisconsin, Madison, Wisconsin; [4]Physics, University of Wisconsin, Madison, Wisconsin; [5]Engineering Physics, University of Wisconsin, Madison, Wisconsin.

Understanding the interaction of virus particles with surfaces containing engineered nanoscale topography is important for answering fundamental questions in biology as well as many applications in nanobiotechnology. The latter includes sensors for rapid and sensitive detection of viruses. We use intermittent-contact mode atomic force microscopy (IC AFM) to characterize the orientation and distribution of tobacco mosaic virus (TMV), an anisotropically-shaped rigid virus. TMV is adsorbed to nanopatterned polyurethane substrates with corrugated line patterning of various widths (30-2000 nm) and depths (5, 40, and >200 nm). On 40 nm deep, 200 nm wide patterns, we observe an unexpected bimodal distribution of orthogonal alignment angles that correlates with whether the TMV particle resides on a ridge or in a trench. While TMV particles in the trenches are preferentially aligned parallel to the long axis of the lines, particles on the ridges are aligned, surprisingly, transverse to them. A normal distribution of ridge particles exhibits a standard deviation of 38 degrees whereas the control surface (particles on flat polyurethane) has a 52 degree standard deviation – a much flatter distribution, as expected. IC AFM images of samples in air and liquid (aqueous buffer), and of samples with tailored surface chemistry (an amine-terminated self-assembled monolayer, with an appropriate isoelectric point to adsorb the charged virus particles from solution) are used to understand the effects of sample preparation and nanoscale patterning on orientation. We will discuss the mechanisms that lead to this alignment, including capillary- and flow-driven alignment and particle motion kinetics, and how this new effect can be exploited for virus sensing and assembly applications.

9:30 AM Z9.4/AA8.4

Antimicrobial Thin Films Produced via Polyelectrolyte Self-Assembly.
Jaime Grunlan[1,2], John Choi[3] and Albert Lin[3]; [1]Mechanical Engineering, Texas A&M University, College Station, Texas; [2]Avery Research Center, Avery Dennison Corporation, Pasadena, California; [3]Biological Science, Biola University, La Mirada, California.

Antimicrobial wound dressing technologies currently used in the marketplace suffer from a variety of drawbacks that include slow activation, instability of ingredients, opacity, and staining of skin. In an effort to improve upon these shortcomings, highly effective antimicrobial thin films were prepared using a technique known as layer-by-layer (LBL) or electrostatic self-assembly (ESA). The LBL process is a thin film deposition technique involving the buildup of oppositely charged bilayers (i.e., anionic-cationic pairs) that are 1-100 nm thick, depending on a variety of factors. This technique has been used to successfully produce electrochromic, photovoltaic, and biocompatible thin films beginning with water-based starting materials. The ability to control coating thickness at the nanometer-level, easily insert variable components without altering the process, and deposit under ambient conditions are some of the key advantages of this technique. In most cases, these multilayer thin films are more transparent, higher performance, and easier to manufacture than current competitive techniques. In the present case, films were produced using polyethylenimine (PEI) as the polycation and poly(acrylic acid) (PAA) as the polyanion. Two antimicrobial agents, silver and cetrimide, were added to separate PEI solutions prior to deposition onto poly(ethylene terephthalate) (PET) film. Thin films containing 16-bilayers (anionic-cationic pairs) were tested for antimicrobial activity using the Kirby-Bauer method. PET with no antimicrobial coating showed no zone of inhibition (ZOI) against S. aureus or E. coli, which indicates that PET has no intrinsic antiseptic properties. With the addition of 20mM silver nitrate to the PEI solution, the resulting 16-bilayer film showed a 1 mm ZOI against S. aureus and a 2 mm ZOI against E. coli. This result was very comparable to that observed for commercial wound dressings that use silver as their active ingredient and the LBL films have %T > 96% across the visible spectrum. By producing the same 16-bilayer film with cetrimide instead of silver, the ZOI grew to 11 mm against S. aureus and 3 mm against E. coli. Cetrimide is a quaternary ammonium molecule with a small hydrocarbon tail and is believed to be much more mobile than silver in a moist environment. In shake flask testing, however, the silver-based film lasts three days in contrast to the cetrimide film that is no longer active after one 24-hour test period. This indicates that silver is a better agent for sustained release. The ESA technique is particularly advantageous because multiple ingredients can be easily deposited into one thin film to create hybrid functionality (e.g., silver combined with cetrimide for strong initial kill along with sustained antimicrobial release). The versatility in antimicrobial performance demonstrated here has the potential to extend into drug delivery and other biomedical applications requiring hybrid functionality.

9:45 AM Z9.5/AA8.5

Effect of Nano- to Micro-Scale Surface Topography on the Orientation of Endothelial Cells.
Pimpon Uttayarat[1], Peter I. Lelkes[2] and Russell J. Composto[1]; [1]Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania; [2]School of Biomedical Engineering, Science and Health Systems, Drexel University, Philadelphia, Pennsylvania.

A model vascular graft of cross-linked polydimethylsiloxane (PDMS) has been modified with protein and varied topographically to promote endothelial cell attachment as well as to guide cell-substrate interactions. PDMS with a smooth surface (RMS roughness 0.5 nm) and grating-textured surfaces, having channel depths of 100 nm, 500 nm, 1 μm and 5 μm, and lateral width of 4 μm, are fabricated. While the pre-adsorbed fibronectin promotes cell adhesion, the underlying topographic features provide a contact guidance that influences cell morphology and cell orientation. Using phase contrast microscopy after seeding cells for 1, 4, 24 and 48 h, cell elongation and alignment parallel to the grating direction increases monotonically with increasing channel depth, reaches maximum orientation at 1 μm, and

then slightly decreases at 5 μm. By fluorescence staining of F-actin and vinculin, cytoskeleton and focal contacts are observed to preferentially orient parallel to the grating direction on textured surfaces having depths of 1 and 5 μm. Confocal and scanning electron microscopies show that cell protrusions extend into channels and also along the side walls of the channels. Cell proliferation is found to be independent of surface topography. At confluence, cell orientation is retained on textured PDMS surfaces. Using surface topography to create contact guidance provides an alternative pathway to obtain endothelial cell alignment, similar to flow in the natural blood vessel.

10:30 AM Z9.6/AA8.6

Competitive Adsorption of Plasma Proteins on Dextran-Modified Silicon Surfaces. Michela Ombelli[1], Samuel Bernard[1], Lauren Costello[2], Qing Cheng Meng[1], Russell J. Composto[2,3] and David M. Eckmann[1,4]; [1]Department of Anesthesia, University of Pennsylvania, Philadelphia, Pennsylvania; [2]Department of Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania; [3]Center for Bioactive Materials and Tissue Engineering, University of Pennsylvania, Philadelphia, Pennsylvania; [4]The Institute for Medicine and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.

The initial response of blood exposed to an artificial surface is the adsorption of blood proteins which triggers a number of biological reactions such as inflammation and blood coagulation and competitive protein adsorption plays a key role in the hemocompatibility of the surface. The synthesis of nonfouling surfaces is therefore one of the major prerequisites for devices for biomedical applications. Dextran, a highly hydrophilic, neutral polysaccharide, is one of the main components of the endothelial cell glycocalyx and has the ability of reducing nonspecific protein adsorption and cell adhesion and, therefore, is generally coupled with a wide variety of surfaces to improve their biocompatibility. We have developed a procedure for covalently binding dextran on silicon wafers pre-activated by amine terminated APTES and we have been able to reach a high level of control on the thickness, wettability and roughness of the coatings by varying the molecular weight, polydispersity and the degree of chemical oxidation of the dextrans. We have also demonstrated that monodisperse, high molecular weight dextran coatings applied on microcapillary glass tubes show bubble adhesion properties almost identical to the values found for *invivo* and *exvivo* experiments of microvascular gas embolism. In the present research effort we focus on a detailed investigation of competitive plasma protein adsorption on dextran-modified silicon surfaces so that we can use our ability of tuning the physical and morphological properties of the coatings to optimize their long-term ability to control biofouling. Adsorbed mixtures of bovine serum albumin and bovine fibrinogen are eluted from the surfaces by exposure to acetonitrile and/or sodium dodecyl sulfate solutions. The freeze-dried desorbed protein fractions are then separated and quantified by high-performance liquid chromatography. Competitive adsorption of proteins from more complex mixtures and eventually from dilute bovine plasma on the dextran-grafted silicon surfaces has been evaluated using the same methodology. Supported by NIH Grants R01 HL60230 and R01 HL67986

10:45 AM Z9.7/AA8.7

Surface-Patterned PEO Nanohydrogels to Control Cell-Substrate Interactions. Peter Krsko[1], Ye Hong[1], Keri Vartanian[2], Herbert M. Geller[2] and Matthew R. Libera[1]; [1]Chemical, Biomedical and Materials Engineering Department, Stevens Institute of Technology, Hoboken, New Jersey; [2]National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, Maryland.

Signal transduction to cells by extracellular matrix occurs at the molecular level, and there is mounting evidence that the nanoscale spatial distribution of ECM signaling proteins can significantly affect cytoskeletal organization, gene expression, and process development. Our goal is to use surfaces whose affinity for proteins and cells is modulated at nano and micro length scales to control cell-substrate interactions at the subcellular level. In contrast to monolayer surface-patterning technologies such as soft lithography and dip-pen nanolithography, we are patterning hydrogel films and using these to control the presentation and spatial distribution of adhesion-promoting ECM proteins such as laminin and fibronectin. We are creating nanohydrogels and microhydrogels using low-energy focused electron beams to locally crosslink PEO films and have made thin-film gels on silicon substrates with gel diameters as small as 100 nm and as large as 1 cm. By varying the incident electron dose, we control the nano/micro gel swelling, and we can control the one-dimensional swelling anywhere from unity to as much as fifteen times. Consistent with the large body of literature on PEG and PEGylated surfaces, we find that fibronectin and laminin do not adsorb onto lightly crosslinked, high swelling PEO microhydrogels. Neurons, macrophages, and fibroblasts are also repelled by these surfaces. However, Fn and Ln both adsorb significantly onto heavily crosslinked gels, and, in turn, these proteins signal for cell adhesion. We have also demonstrated the alternate approach of covalently binding Fn and Ln to high-swelling patterned functionalized PEG. By exploiting the ability to modulate these surfaces at micron and sub micron lengths scales together with the flexible patterning capabilities of modern electron-optical systems, we have been able to create surfaces which control whether, where, and what shape neurons, macrophages, and fibroblasts adhere.

11:00 AM Z9.8/AA8.8

Multicomponent protein patterning with photogenerated polyelectrolyte bilayers. Junsang Doh[1] and Darrell J. Irvine[2,3]; [1]Department of Chemical Engineering, MIT, Cambridge, Massachusetts; [2]Department of Material Science and Engineering, MIT, Cambridge, Massachusetts; [3]Biological Engineering Division, MIT, Cambridge, Massachusetts.

Fabrication of surfaces patterned with multiple proteins organized on more than one length scale can be useful for mimicking cell surfaces or the extracellular environment. Such surfaces can be used to address fundamental biological questions related to cell-cell interactions or cell-extracellular matrix interactions, since protein ligands can be presented to cells in a controlled manner. To achieve this goal, we synthesized a novel photoresist polymer that can be processed under mild aqueous conditions, and developed a new patterning strategy based on the unique properties of this photoresist. A random terpolymer composed of o-nitrobenzyl methacrylate (o-NBMA), methyl methacrylate (MMA) and poly (ethylene glycol) methacrylate (PEGMA) was synthesized by free radical polymerization, and biotin was covalently attached to the hydroxyl end groups of the PEGMA repeat units. Upon UV exposure (250nm) of films of the resist, the o-nitrobenzyl group of the resist was cleaved and carboxylic acid was generated. Polyacids generated by UV irradiation showed pH dependent solubility in water; exposed material was insoluble in water at low pH, but dissolved above pH 6.6. In addition to its pH-dependent development, the resist could be used to create photogenerated polyelectrolyte bilayers: When the photoresist (PR) was spincoated over a poly(allylamine)-coated substrate, exposed to UV, and developed with PBS (pH 7.4, 10mM sodium phosphate and 140mM NaCl), the bulk of the PR film was dissolved, but a polyelectrolyte bilayer formed in situ at the PR/polycation interface remained bound to the substrate. Using these novel characteristics, we developed a photolithographic process using a lift-off approach to pattern two proteins into two different micron scale domains without exposing either biomolecule to conditions outside the narrow range of physiological pH, ionic strength, and temperature where their stability is greatest. This protein patterning technique was extended to patterning protein-conjugated particles (from nanometer size quantum dots to submicron size polymeric particles) to implement multiple length scale ligand presentation. Currently, we are applying this patterning methodology to create surfaces presenting T cell-stimulating protein ligands, in order to study the effect of ligand density and spatial distribution on T cell function.

11:15 AM Z9.9/AA8.9

Specific Antibody-Antigen Interaction on a Functional Lipid-Membrane Vesicles Modified Surface. Hea-Yeon Lee, Ho-Sup Jung and Tomoji Kawai; ISIR-SANKEN, Osaka Univ., Osaka, Japan.

Recently, the possibility of analyzing high-throughput proteomics using microarrays has attracted great interest. Especially, a specific array of capture antibody that maintains its bio-reactivity is a critical milestone for applications of future immunosensors because immobilization is based on very specific interaction between the immobilized ligand and its counterpart We will present a strong specific antibody-antigen interaction on a functional lipid-membrane vesicle (liposome, FLVs) modified gold surface using streptavidin-biotin interaction. Real-time quartz crystal microbalance (QCM) response and surface plasmon resonance (SPR) after reaction of a target antigen HSA was observed only for a specific immobilized anti-HSA antibody. Electrochemical immunoassay by specific antibody-antigen (Ag-Ab) interactions showed variation of redox peak current only on a specific-array electrode. This specific protein array system using FLVs may be useful for immune disease therapy. Acknowledgements: Financial support from the New Energy and Industrial Technology Development Organization (NEDO) is gratefully acknowledged.

11:30 AM *Z9.10/AA8.10

Nanofeaturing biomaterials for specific cell responses. Adam Sebastian Curtis, Centre for Cell Engineering, University of Glasgow, Glasgow, United Kingdom.

A range of fabrication methods including electron beam lithography or polymer demixing have ben used to create masters from which nanotopography can be embossed or molded onto a range of polymer surfaces. Related methods can be used to print nanochemistry onto

such surfaces. These materials have been used to examine the behaviour of a variety of mammalian (including human) cell types to nanofeatures. Effects on cell adhesion,cell movement, cytoskeletal organizarion amd gene expression will be reported and reviewed. Effects on adhesion are related to the dimensions and spacing of nanofeatures. The same applies to the organization of the cytoskeleton. Extensive changes in gene expression can be detected with some types of nanofeature resulting in partial phenotype shifts. These phenotype changes are reversible. Random arrangements of nanofeatures are little different in their effects on these cells from those seen on ultraflat surfaces. The mechanisms that may produce these responses will be discussed and the possible uses of such surfaces in medical devices will be outlined.