SYMPOSIUM K

Biological and Bio-Inspired Materials and Devices

March 29 - April 1, 2005

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* Invited paper
Biomimicry, and the Structures and Functions of Diatom Silaffins.

These serine hydrolases, which show significant all-or-nothing behavior in vitro. These results clearly support the hypothesis that the formation of the cell wall, suggesting that there are at least two distinct steps in this process. Using a proteomic approach, we identified proteins associated with an enriched cell wall fraction, and monitored expression of genes encoding these proteins during cell wall synthesis. From these results, we focused on two aspects of cellular metabolism related to silicification: polyamine metabolism and vesicle trafficking. Using known inhibitors of polyamine synthesis, we have been able to modify the resulting silica structure, in a manner consistent with the two-step process seen by electron microscopy. These approaches are facilitating our understanding of the process of silica structure formation in diatoms, and constitute the first steps in manipulation of structure.

Diatoms are a large group of unicellular microalgae encased by silica cell walls that exhibit species-specific, mostly porous micro-and nanometric patterns. Recently, unique proteins (silaffins) and unusually long polyamine chains (LCPA) have been identified and implicated in silica morphogenesis. Based on the data obtained from work on the diatom Cylindrotheca fusiformis it has been suggested that diatom biosilica morphogenesis may generally require at least two components: LCPA, which accelerate acidic polycondensation and regulate silica nanoparticles, but also regulates the activity of LCPA. However, the structure of C. fusiformis biosilica is rather unusual being mainly composed of long non-porous bands. Therefore, it has been unclear whether general conclusions about the mechanism of biosilica morphogenesis can be drawn from studies on C. fusiformis. Furthermore, elucidation of the role of silaffins in biosilica morphogenesis has been hampered by the lack of structural and functional data of silaffins from other diatom species. Recently, we have characterized the silaffins from the diatom Thalassiosira pseudonana, a species exhibiting porous biosilica nanoparticles. It is demonstrated that this organism contains LCPA as well as regulatory silaffins, which drastically influenced silica formation in vitro. These results clearly support the hypothesis that silaffins play a major role in diatom silica nanofabrication. Chemical characterization of T. pseudonana silaffins and isolation of the corresponding genes enabled unprecedented insight into the regulation of silica structure.

Control of Nanoparticle Assembly using DNA-Modified Diatom Templates. Nathaniel Long Rego, Emma Kate Payne, Shad Thaxton and Chad A. Mirkin; Chemistry, Northwestern University, Evanston, Illinois.

Microorganisms have proven to be versatile templates for the organization of nanostructured materials into larger scale functional architectures. An ideal biological template would be one that could be chemically modified in a versatile manner using conventional bench-top methods so that the interaction between the template and the nanostructured materials could be understood and easily controlled. To this end, we have investigated using diatoms as templates for the assembly of pre-fabricated nanoparticles. Specifically, we show that diatom cell walls can be covalently functionalized with DNA and then used as templates for the sequence-specific assembly of DNA-functionalized nanoparticles. We further demonstrate that the template can program the assembly of multiple layers of nanoparticles onto the template. This is a potentially powerful method for producing intrinsically ordered, hierarchically assembled macroscopic structures whose properties can be tuned at the nanoscale.

Blue Luminescent Biogenic Silicon-Germanium Oxide Nanocomposites. Shuhong Liu1, Clayton Jeffrey1, Gregory L. Rorrer1, Chih-hung Chang1, Jun Jiao2 and James A. Hedberg2; 1Chemical Engineering Department, Oregon State University, Corvallis, Oregon; 2Physics, Portland State University, Portland, Oregon.

Marine diatoms are a class of microalgae that possess cell walls composed of silica nanoparticles. These organisms actively assimilate silicon dioxide (SiO₂) from seawater and polymerize it into silica nanoparticles by a protein-mediated precipitation process, and then assemble the silica nanoparticles into intricate patterns that constitute the cell wall microarchitecture (consists of around 30nm of SiO₂ nanoparticles) of the diatom frustule. The biomineralization capacity of marine diatoms, Nitzschia, has been harnessed to biologically manufacture silicon oxide / germanium oxide nanocomposite materials. Germanium was incorporated into living diatom cell mass by a two-stage cultivation process. The micro- and nanostructures of these biogenic oxide nanocomposites before and after post processing were characterized by electron diffraction, HR-TEM with EDX, and XRD. Photoluminescence (PL) measurements were performed on these biogenic nanocomposites with the potential of using the organics. Strong blue photoluminescence was observed from samples treated with H₂O₂ and oxygen plasma. A clear blueshift was observed from the biogenic oxides with the addition of germanium. It is believed that self-trapped excitation affected by quantum confinement effect is responsible for the PL from these biogenic oxide nanocomposites. This research is supported by National Science Foundation Bioengineering and Environmental Systems program under grant number BES-0900648.

The Role of Electrostatic Interactions, Hydrogen Bonding and the Hydrophobic Effect in the Regulation of Amorphous Silica Structures. Carole Celia Perry, Siddharth V. Patwardhan, David Belton and Graham Tilbury; Biomedical and Natural Sciences, Nottingham Trent University, Nottingham, United Kingdom.

In nature, several classes of biosilifying organisms process soluble silicon to generate hierarchically organised and biogenic silica structures under mild conditions of pH and temperature. Precise control in shaping biosilica in contrast, current synthetic procedures typically employ relatively harsh conditions for the preparation of silicas and exhibit relatively poor morphological control. In order to gain insights into biosilicification, several studies have been carried out on biosilifying organisms wherein organic-biomolecules have been isolated and identified. These bioextracts control in vitro silicification via catalysis, aggregation and/or templating. This contribution looks at the effect of different strength bonding interactions between silicon (in a variety of forms from the simple molecule through to particles and aggregates) and biomolecules on all stages of silica formation in vitro. The behaviour of amino acids and other small nitrogen containing molecules, proteins (including biosilica extracts such as silicatein, collagen and recombinant proteins of specific secondary structure), monosaccharides, polysaccharides and other functionalised polymers will all be discussed. The effect of these interactions on the formation of the silica and hence its properties (either as a biomaterial) or as a commercially relevant product will be discussed.

Self-Assembly of Proteins that Direct Biological Silicification. Meredith Murz1, Hiro Tsuruta1 and Daniel E. Morse1, 2; 1Department of Molecular, Cellular, and Developmental Biology, University of California at Santa Barbara, Santa Barbara, California; 2Institute for Collaborative Biotechnologies, University of California at Santa Barbara, Santa Barbara, California; 3Stanford Synchrotron Radiation Laboratory, Menlo Park, California.

Siliceous marine sponges have developed unique biomolecular machinery for the precisely controlled supramolecular assembly of silicon-based biomaterials. In particular, the needle-like glass structures, or spicules, of the marine sponge Petrosia cristata are composed of a central (axial) protein filament that directs the formation of the surrounding silica. The filament is 2 nm long and 1 μm in width, and is composed of three related proteins known as silicin α, β, and γ. These serine hydrolases, which show significant homology to a family of calicysins proteases, catalyze the
condensation of silicon alkoxide precursors into silica glass (SiO₂) and spatially direct deposition of the silica around the axial filament. Fiber diffraction patterns indicate that the silica film possesses long-range order, with component proteins arranged in a helical assembly. However, it is unclear how silicatein proteins organize into a filament or how the filament structure might influence inorganic product formation. Recent studies demonstrate that silicatein subunits self-assemble in vitro into filamentous structures, thereby recapitulating the biological process. In vitro assembly is influenced by temperature, pH and ionic strength, and has been investigated using structural and spectroscopic techniques in addition to electron microscopy to characterize assembly intermediates and kinetics. These experiments suggest a mechanism in which silicatein subunits assemble into 15 nm spheres that align in a linear arrangement to form protofilaments; these further assemble into higher order filamentous structures. Sequence differences between the silicateins for formation, yields high-resolution inorganic replicas of the creation of concentrated polyelectrolyte inks that flow through the cross-section of the replicated structure. By coupling tailoring ink composition, we have patterned polyaniline-rich scaffolds throughout the micro- and nanoscale features of the original bio-scaffolds, endows these with fine features of the silica scaffold into a chemically-compatible substrate, and then aspen assembly. However, it is unclear how silicatein proteins organize into a filament or how the filament structure might influence inorganic product formation. Recent studies demonstrate that silicatein subunits self-assemble in vitro into filamentous structures, thereby recapitulating the biological process. In vitro assembly is influenced by temperature, pH and ionic strength, and has been investigated using structural and spectroscopic techniques in addition to electron microscopy to characterize assembly intermediates and kinetics. These experiments suggest a mechanism in which silicatein subunits assemble into 15 nm spheres that align in a linear arrangement to form protofilaments; these further assemble into higher order filamentous structures. Sequence differences between the silicateins for formation, yields high-resolution inorganic replicas of the creation of concentrated polyelectrolyte inks that flow through the cross-section of the replicated structure. By coupling tailoring ink composition, we have patterned polyaniline-rich scaffolds throughout the cross-section of the replicated structure. By coupling DWA with biomimetic silicification, we have demonstrated the formation of artificial diatom-like structures. In ongoing efforts, we are exploring the mineralization of hydrogel-and other polyelectrolyte-based scaffolds patterned by DWA.

11:15 AM K1.7
Biomimetic Sulfidation of 3-D Polyelectrolyte Scaffolds Assembled by Direct Writing. Mingju Xu1, Eric Duose2 and Jennifer A. Lewis1,2,1,1. Chemical & Biomolecular Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois; 2Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois.

We have developed a novel approach to patterning 3D polyelectrolyte scaffolds by direct-write assembly (DWA). Central to our approach is the creation of electroinks that flow through fine deposition nozzles and then "set" almost instantaneously to facilitate shape retention as they span gaps in underlying layers. By tailoring ink composition, we have patterned polyaniline-rich scaffolds that, when introduced to silica acid, will undergo silicification under ambient conditions. This mineralization process, which mimics diatom formation, yields high-resolution inorganic replicas of the polyelectrolyte scaffolds. Si and O element mapping by STEM and Auger revealed that these species are uniformly distributed throughout the cross-section of the replicated structure. By coupling DWA with biomimetic silicification, we have demonstrated the formation of artificial diatom-like structures. In ongoing efforts, we are exploring the mineralization of hydrogel-and other polyelectrolyte-based scaffolds patterned by DWA.

11:30 AM K1.8

Intensive global activity to produce advanced micro-to-nanoscale devices has led to significant interest in biologically self-assembled nanoparticle structures. Certain micro-organisms are adept at assembling three-dimensional (3-D) biomineralized (biologic) micro-structures with precise shapes and fine (nanoscale) features. An exceptional variety of intricate 3-D structures are generated by aquatic micro-algae known as diatoms. Diatoms are single-celled organisms that assemble microshells (frustules) comprised of silica. Potential applications for such diatom-like materials will be discussed.

11:45 AM K1.9
Small-angle X-ray Scattering, FTIR and SEM Characterization of Nanostructured PVA/TEOS Hybrids by Chemical Crosslinking. Herman Sander Mansur and Alexandra Piscitelli Mansur; Metallurgical and Materials Engineering, Federal University of Minas Gerais, Belo Horizonte, MG, Brazil.

In the present work, novel hybrid nanostructured composite materials were produced to be used in many potential applications such as biomedical, drug delivery systems, tridimensional scaffolds for biomaterials and tissue engineering, biomembranes and optical devices among others. Hybrids were synthesized by reacting poly (vinyl alcohol) (PVA) in aqueous solution with silicon alkoxide tetraethoxysilane (TEOS). PVA/TEOS hybrids were also modified in the nanometer-scale by using bionatinetic silicification, glutaeraldehyde (GA) during the synthesis involving hydrolysis and policondensation of PVA/TEOS. The characterization of hybrids was carried out by using Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and Small Angle X-ray Scattering (SAXS) techniques. FTIR spectra showed major vibration bands associated with organic-inorganic chemical groups of PVA/TEOS. Also, typical absorption bands related to glutaraldehyde alkyd chain have indicated the crosslinking reaction of the hybrid network with glutaraldehyde (PVA/TEOS/GA). Small-angle X-ray scattering results have indicated different nano-ordered dispersive phases for PVA, PVA/TEOS hybrid and PVA/TEOS/GA chemically crosslinked hybrid. SEM photomicrographs have clearly indicated different morphologies from chemically crosslinked polymer network compared to PVA hybrid samples without glutaraldehyde reaction. The SAXS and FTIR spectroscopy characterizations have confirmed that hybrid materials were successfully obtained based on the combination of PVA and TEOS with glutaraldehyde crosslinked nanometer-scale network.

SESSION K2/L2: Joint Session: Functional Biomaterials and Biomimetics
Chairs: Trevor Douglas and William J. Landis
Tuesday Afternoon, March 29, 2005
Room 3002 (Moscone West)

1:30 PM K2.1/L2.1
Lamellar Bone: Old and New Insights into Structure and Function. Steve Weimer1, Eugenia Klein1, Meir Barak2, Paul Zaslansky1 and Ron Shahn2; 1Department of Structural Biology, Weizmann Institute, Rehovot, Israel; 2Faculty of Agriculture, Hebrew University, Rehovot, Israel.

The lamellar bone structure of bone is widespread, especially among the mammals. It was first identified by van Leeuwenhoek in 1691 and is still not fully understood. The basic motif resembles that of plywood, with parallel arrays of mineralized collagen fibrils arranged in layers with different orientations in a two-dimensional plane. Within the collagen fibril, are layers of very small plate-shaped crystals of carbonate apatite. Adjacent fibrils tend to have their layers aligned, but there is a progressive rotation of the fibrils from one surface plane of an individual lamella to the next. Here we confirm and amplify aspects of this structure using a Schottky FEG SEM with in-lens SE detector, and also show that there is a third structural element with mineralized collagen fibrils aligning the canaliculi, and hence being aligned perpendicular to the main lamellar plane. These fibrils originate from the main lamellar structure, but describe a 90 degree rotation to align themselves orthogonally to the lamellar plane. They may well fulfill a "pinning" function, by firmly bonding adjacent lamellae. Lamellae are often intimately deposited in parallel arrays, but as a result of remodeling, reform as cylindrical secondary osteons. The elastic properties of lamellar bone are for the most part due to the lamellar structure, whereas the fracture properties are profoundly influenced by the cylindrical osteonal structure. To reveal new insights into the structure-mechanical properties of lamellar bone, supported by grant DE009544 from the NIDCR to SW.

2:00 PM K2.2/L2.2
Mechanisms Governing the Inelastic Deformation of Bone. Anthony Evans, Materials, UCSB, Santa Barbara, California.

To understand the inelastic response of cortical and trabecular bone, a three-part investigation has been conducted. In the first, a flexural test protocol has been designed and implemented that monitors the axial and transverse strains on both the tensile and compressive surfaces of cortical bone. The results are used to assess the relative contributions of dilatation and shear to the inelastic deformation. Unload/reload tests have characterized the hysteresis and provided
suggestion that collagen fibrils and mineral plates are not the only components of bone with a mechanical role. There appears to be "glue" that binds mineralized collagen fibrils to other mineralized collagen fibrils. Order of magnitude calculations show that less than 1% by weight of this "glue" can have profound effects on the fracture resistance of bone, because it involves a remarkable natural toughening and strengthening system: sacrificial bonds and hidden length. The sacrificial bond-hidden length system can dissipate large amounts of work against entropic forces while stretching out the hidden length that is exposed when sacrificial bonds break. This appears to occur when mineralized collagen fibrils are torn apart and slid relative to each other during bone fracture. In bone, this system depends on the presence of multivalent positive ions such as calcium ions. This dependence allows us to follow the involvement of the sacrificial bond-hidden length system right up to macroscopic fracture testing. Many bone matrix proteoglycans and glycoproteins have negatively charged groups at physiological pHs that could be bound together into sacrificial bonds by multivalent positive ions, and are thus natural candidates for this "glue." We cannot, however, rule out a possible involvement of nonfibrillar collagen. Further research will be necessary to determine precisely which candidate or candidates are involved.

2:45 PM K2.4/L2.4
Contact-induced Deformation and Failure of Dental Multilayers: Effects of Loading Rate. Xinni Niu, Min Huang, Jikou Zhou and Winston O. Soboyejo; Mechanical and Aerospace Engineering, Princeton University, Princeton, New Jersey.

This paper presents the results of a combined experimental, analytical and computational study of contact deformation and cracking in dental multi-layers. Dental structures are idealized as layered composites (real teeth and dental restorations). The mechanisms of contact-induced deformation and cracking are then studied at different loading rates. A combination of viscous deformation and fracture mechanics models is used to predict the effects of loading rate on the failure conditions in the dental multilayers deformed under monotonic and cyclic loading. These employ rate dependent constitutive relations and visco-elastic material properties that are obtained from joint and foundation materials subjected to compressive loading in air and in water. Analytical and finite element predictions of loading rate effects are shown to be in good agreement with experimental measurements, when the combined effects of viscous deformation and sub-critical cracking are modeled within a mechanically-based framework.

3:30 PM *K2.5/L2.5
High-Efficiency Fiber-Optical Network in a Glass Sponge. Joanna Aizenberg1, Andrew D. Yablon2, V. C. Sundar1, James C. Weaver1 and Micin Ilan1; 1Bell Labs/Lucent, Murray Hill, New Jersey; 2OFS Laboratories, Murray Hill, New Jersey; UCSB, Santa Barbara, California; Tel-Aviv University, Tel-Aviv, Israel.

Even the most advanced optical designs made by humans are often primitive relative to the optical systems that have evolved in Nature. I will describe natural media, including sand, provided by a deep-sea sponge Euplectella, whose hierarchical architecture and hybrid character offer outstanding optical and mechanical properties. We demonstrate that the sponge forms glass fibers that are remarkably similar to commercial silica optical fibers. We show the sponge has a characteristic design that encompasses a high refractive index core composed of Na-doped silica, with the refractive index higher than that of vitreous silica; and a low refractive index cladding composed of organically glued, multiple layers of hydrated silica. The presence of the lens-like structures at the end of these biofibers that improves the light-collecting efficiency, high fracture toughness arising from their composite structure, the presence of index-raising dopants and the abundance of these fibers suggest that they may be used as building blocks in the bottom-up fabrication of inorganic structures. I will cover our efforts using biomolecules for growing inorganic structures and to exploit self-assembling structures for material synthesis by engineering desired functionalities into the self-assembling biomolecules for bottom-up fabrication.

4:00 PM *K2.6/L2.6

The interface between biology, chemistry, and materials science has motivated biomimetic approaches to the formation of inorganic nanomaterials. Biomolecules (proteins, peptides) and biomolecular architectures are being used as templates for the synthesis of inorganic nanomaterials. Our research efforts have been directed at not only understanding how biological organisms control and grow of inorganic materials, but also how this activity can be controlled in vitro. Biomolecules or biomolecular architectures can be used as building blocks in the bottom-up fabrication of inorganic structures. I will cover our efforts using biomolecules for growing inorganic structures and to exploit self-assembling structures for material synthesis by engineering desired functionalities into the self-assembling biomolecules for bottom-up fabrication.

4:30 PM K2.7/L2.7
Chemically-Tailored Nanofibers Derived from Self-Assembled Natural Templates. Samuel Shian1, Dori Landry2, Ye Cai3, Brian Pilenki4, Mark Hildebrand5 and Ken H. Sandhage6; 1Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia; 2Scripps Institute of Oceanography, University of California, San Diego, La Jolla, California.

Spectacular feats of nanoparticle self-assembly can be found in nature. Intricate three-dimensional (3-D) microspheres (frustules) comprised of amorphous silica nanoparticles are constructed by diatoms (aquatic micro-algae). Each of the tens of thousands of extant diatom species assembles a frustule with a unique shape and pattern of sub-micron features. The diatom CorethronCristatulum forms a frustule with a high aspect ratio (a few hundred in diameter, tens of microns in length). These natural "nano"fibers would be attractive for a variety of applications, if the silica-based chemistry could be altered to expand the range of properties without loss of the fiber shape. In this work, we demonstrate how the silica-based frustules of the CorethronCristatulum diatom can be converted into titanium dioxide nanofibers using a multistep gas/silica displacement reaction. The chemical conversion process was performed in two steps: i) a displacement reaction of TiF4(g) with SiO2(s) to yield TiO2(s) and then ii) conversion of the TiO2(s) into TiO2(s) upon exposure to oxygen. The influence of processing parameters on the extent of reaction and on the resulting morphology will be discussed. With judicious choice of processing conditions, the CorethronCristatulum spines were successfully converted into nanocrystalline titania (titanate) nanofibers.

4:45 PM K2.8/L2.8
A H langue: Br and I in the Jaws of Nereis, a Marine Worm. Henrik Birkedal1, Rashida Khan2, Nelle Shao3, Frank W. Zei2, Gabe D. Stucky2 and Herbert Waite3; 1Department of Chemistry, University of Aarhus, Aarhus, Denmark; 2Department of Chemistry and Biochemistry, University of California, Santa Barbara, Santa Barbara, California; 3Materials Department, University of California, Santa Barbara, Santa Barbara, California; Department of Molecular, Cellular, and Developmental Biology, University of California, Santa Barbara, Santa Barbara, California; Department of Materials Science and Engineering, Vienna University of Technology, Vienna, Austria.

The marine worm Nereis has a pair of pincer-like jaws that it uses to collect food. They consist of a proteinaceous matrix reinforced by Zn, the concentration of which increases towards the tip of the jaw [1]. The jaws also contain three of the halogens: Cl, Br and I [1] while the heavier halogens are not. Here we show that they are rather concentrated towards the jaw outer surface and that they are bound to the amino acids of the protein matrix by post translational modifications. Several of these modified amino acids have not previously been observed in Nature. We suggest that the exterior of the jaw is analogous to the selenized protein of invertebrate and speculate on the possible roles of this outer coating.

K3.1 Synthesis and Structural Characterization of Silica Gels Prepared with Amines and Polyamine Catalysts. Katya Delak1 and Nita Sahai2;1 Chemistry, University of Wisconsin, Madison, Wisconsin; 2Geology and Geophysics, University of Wisconsin, Madison, Wisconsin.

Diatom and sponge proteins implicated in biogenic silica formation contain amine and polyamine moieties that have been shown to be necessary for protein catalytic activity. Previously, we have shown that simple amines and polyamines, chosen for their similarity to the moieties found in silica-precipitating proteins, can catalyze organosilicate hydrolysis and condensation at near-neutral pH. In this study, we examine the influence of these same catalysts on the formation of silica gels from tetraethoxysilicate. We characterize the influence of amine type and pH on gelation time. In addition, we use light scattering techniques coupled with electron microscopy to determine how the choice of catalyst and pH condition can be used to tailor the resulting gel and precipitate morphology.

K3.2 Development of a Biocompatible Ink for Thermal Inket Printing. Harry E. Suga1,2, Lawrence L. Bratton2 and Rajesh R. Naik2;1 Department of Chemistry, University of Dayton, Dayton, Ohio; 2Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio.

The increasing demand for patterned biomolecules requires a new method for such patterning which is less harsh than the current methods involving the utilization of photolithography, and UV processing. One possible alternative involves the use of ink jet printing technology, a field with potential for both research and increasing application. The development of a water-based, biocompatible ink formulation for use with thermal ink jet printing will be discussed. The deposited ink adheres to diverse substrates while retaining the biological activity of the biomolecules. Additionally, a silica precipitating peptide dissolved in an aqueous solution can be patterned utilizing this technique, allowing for the formation of patterned silica nanoparticles on a flexible substrate.

K3.3 Polychaete Worm is an Expert Sand Mason. Huan Zhao, Chengjin Sun and Herbert Waite; Dept. of Mol Cellu and Dev Biology, Marine Science Institute, Santa Barbara, California.

The marine polychaete Phragmatopoma californica cements together building materials in its habitat such as sand and shell to construct its dwelling tubes in a manner closely resembling stone masonry. The cement is intriguing, first because so little is used, and second, because it solidifies rapidly from a liquid emulsion reminiscent of a complex coacervate. Several lines of current research strongly suggest that phosphoserine-rich proteins are the dominant proteins in this cement. In this paper, we present two serine-rich precursor protein cDNA sequences which were isolated from the cDNA library constructed from the cement gland in the thorax of P. californica. Both cDNA encoded sequences consist of repeated motif (S)nY, where n=3-12. Based on the deduced sequence, the amino acid composition of the two proteins is up to 60 mol% and 90 mol% serine, with almost 10 mol% tyrosine also present in both. These are the highest serine-containing proteins found so far in nature and, following phosphorylation, account for the high level of bound Mg and Ca in the cement.

K3.4 Elasticity and Piezoelectricity in Biological Systems on the Nanoscale: From Bones to Butterflies. Brian J. Rodriguez1, Alexei Gruverman2 and Sergey V. Kalinin3;1 Physics, North Carolina State University, Raleigh, North Carolina; 2Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina; 3Condensed Matter Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Functional properties of biological systems are determined by an intricate set of mechanical and electromechanical interactions on the length scales that span several orders of magnitude: from macro to nano. Electromechanical coupling is a universal property of biological systems that was first discovered when Lyle Gardner observed the effect of "animal electricity" in a frog egg. Understanding the inherently intertwined mechanical and electromechanical properties, such as elasticity and piezoelectricity, in living systems can provide an insight into the functionality of biomaterials and understand the biological relevance of these properties. Here, we present a scanning probe microscopy based approach for elastic and electromechanical imaging and spectroscopy of biological systems - from imaging the elasticity map in butterfly wings to differentiation of elastic and piezoelectric properties in enamel and dentine layers of human tooth to measuring the electromechanical response of a collagen molecule bundle. This allows us to repeat Galvani's experiment on the nanoscale - more than two centuries later and with a million times higher resolution. Research performed as a Eugene P. Wigner Fellow (SVK). AG acknowledges financial support of the National Science Foundation (Grant No. DMR02-55632).

K3.5 Comparison of Piezoresistive and Optical Read-Out Methods for Microcantilever-Based Biosensor Fabricated by Surface Micromachining Technique. Kwang-Ho Na1, Kyung Do Kim2, Kyung Ah Yoo3, C. J. Kang4 and Yong-Sang Kim5; 1Electrical Engineering, Myongji University, Yongin, South Korea; 2Physics, Myongji University, Yongin, South Korea.

The widespread availability of inexpensive microfabricated cantilever in renewed interest in biosensor-based. Molecular recognition on the cantilever surface results in a mechanical response, that produces a microcantilever bending of few nm and a shift of the resonant frequency. The most common method is measuring the deflection of a cantilever because it is not sensitive to the damping in the liquid environment, in which only a single side is coated with receptor molecules. The surface stress change of the sensitized cantilever with respect to the other side gives a cantilever bending owing to the expansion/contraction of a cantilever side with respect to the receptor side. Commonly the most wide spread detection technique, used in most commercial AFMs, in the optical leverage method that had advantage of high resolution. However it has many disadvantages in biosensors. It is difficult to make it portable because external optical devices such as laser diode and photodiode are needed and measurements in opaque liquids is impossible. If the piezoresistive readout in biosensor is used to measure the deflection of the microcantilevers, the drawbacks will eliminate because of the direct measurement without optical devices. We investigated the characteristics of piezoresistive and optical read-out methods after measuring the bending of microcantilever-based biosensor at the same time. The microcantilever-based biosensor was fabricated by surface micromachining technique. The polysilicon piezoresistor was used for piezoresistive read-out and deposited by low pressure chemical vapor deposition (LPCVD) with a thickness of 300nm. The microcantilever is bending from the difference of the surface stress caused by the formation of a glutaraldehyde/cystamine dithyldichloride bilayer on the gold-coated microcantilever. The fluid cell for liquid flow was fabricated using PDMS and glass. The liquid flow was driven by gravity and the flow rate of 12-14µl/min was kept constant during the whole measurement. In order to evaluate the characteristics of the microcantilever, the cystamine terminated with thiol was covalently immobilized on the gold-coated side of the cantilever and glutaraldehyde that would be bonded with amine groups in the cystamine was injected subsequently. This process was characterized by measuring the deflection of the cantilever in real time monitoring. The deflection of the cantilever was measured both by piezoresistive method and by optical read-out method at the same time for the analysis of the sensitivity and the resolution.

K3.6 Influence of the Crosslinked Chitosan Sphere and Films on the Calcium Carbonate Crystallization. Aniceto David Neira-Carrillo1,2,3, Francisco Martinez2, Jaime Retuerre1, Maria Soledad Fernandez1,2 and Jose Luis Arias1,2; 1Biological Veterinary and Animal Science, University of Chile, Santiago, Province, Chile; 2Center for Advanced Interdisciplinary Research in Materials, CINMat, Santiago, Chile; 3Faculty of Physics and Mathematics, University of Chile, Santiago, Chile.

Biomineralization is the process by which living forms induce the precipitation of mineral materials and leads to the formation of precisely controlled inorganic–organic composites, in which the minute organic component exerts substantial control on the mineralization process, which results in the formation of particles of uniform size, novel crystal morphology, specific crystallographic orientation and interesting properties (1,2). Crystal growth is typically heterogeneous crystallization and occurs in association with surfaces and occurs in a constrained volume. In nature, the living forms produce a geometrically well defined microenvironment, controlling not only the addition of the functionalized organic macromolecules but also variables such as localization and velocity of ions flux which itself is constrained volume. In order to investigate the influence of the crosslinked chitosan sphere and films on the CaCO3 crystallization in vitro in a constrained volume, we have prepared sphere of chitosan in NaOH solution and compared with films. The crystallization method
was based on the Sitting-drop method by Dominguez-Vera (3). We suspecting that crosslinked grade of chitosan sphere and films alter the diffusion of the glucose concentration during the reaction between aqueous glucose and GOD immobilized on the film surface was confirmed for the W-PS and A-PS film coloration. The amount of GOD on W-PS was approximately 2 times higher than that on A-PS, which indicates that W-PS is better than A-PS for GOD immobilization. The glucose concentration over A-PS was lower than that over W-PS. Thus, the concentrations over W-PS and A-PS reduced from 28mM to 25mM and 23mM, respectively. The activity of GOD on A-PS was higher than that on W-PS and a portion of GOD activity on A-PS was found to be significantly higher than on W-PS for making functional surface with GOD immobilized on it. The activity of GOD was found to depend on treating medium (water or aqueous ammonia solution) and the relation between the enzyme activity and treatment media. Immobilization of GOD on PS films was carried out by the following method: PS films were placed in water or aqueous ammonia solution and aerated using ozone gas with irradiation of UV light. The films treated in water (W-PS) and in aqueous ammonia solution (A-PS) were immersed in an aqueous GOD solution (10 mg/ml) at room temperature for 24 hr. The total amount of GOD immobilized on the films was determined by the dye-binding method. The activity of GOD on the film was evaluated by decrease in the glucose concentration during the reaction between aqueous glucose solution and GOD-immobilized film. The present work was performed on the film surface was confirmed for the W-PS and A-PS film coloration. The amount of GOD on W-PS was approximately 2 times higher than that on A-PS, which indicates that W-PS is better than A-PS for GOD immobilization. The glucose concentration over A-PS was lower than that over W-PS. Thus, the concentrations over W-PS and A-PS reduced from 28mM to 25mM and 23mM, respectively. The activity of GOD on A-PS was higher than that on W-PS and a portion of GOD activity on A-PS was found to be significantly higher than on W-PS for making functional surface with GOD immobilized on it. The activity of GOD was found to depend on treating medium (water or aqueous ammonia solution) in O2/UVE treatment.


X-ray Absorption Spectroscopy (XAS) has been used to characterize the structural evolution of bio-inspired crystallization systems. We present an XAS investigation of calcite growth on carboxyl terminated alkanethiol self-assembled monolayers (SAMs) prepared on Au(111) substrates. In the natural world, bio-organisms utilize surface matrices of organic molecules to control the mode of mineral crystallization from solution. Elaborate, hierarchical inorganic assemblies are often generated, which can exhibit architecture at the sub-micron scale. Such precise engineering of of crystal structures, therefore, may have direct application in the fabrication of inorganic components for optical and electronic devices. Hence, an understanding of the underlying physical processes is required to aid development of new material growth technologies. Self-assembled monolayers of w-substituted alkanethiols serve as templates for patterned crystallization and, as such, mimic the natural processes of biomineralization. In addition, these systems offer a relative simplicity of structure. As a consequence, they represent suitable models from which to characterize the interaction between organic and inorganic phases during crystal nucleation and growth. This interaction resides at the heart of biomineralization processes. XAS provides ideal capabilities for the investigation of structural development at the organic/inorganic interface during crystallization. Due to the chemical specificity of the technique, atoms at the buried interface can be probed directly. Furthermore, the X-ray Absorption Near Edge Structure (XANES), the first component of XAS, provides assignment of the local environment about a specific element and can yield the structure of the crystalline mineral. This work was supported by the Division of Chemical Sciences, Office of Basic Energy Science, and performed under the auspices of the U.S. DOE by LBNL under contract No. W-7405-ENG-48

K8.8 Biomineralization of CaCO3 Crystals. Kaustavy Sinha1, Debabrata Rautray2, Murali Sastry2 and Absar Ahmad2; 1Department of Materials & Metallurgical Engineering, University of Nevada, Reno, Nevada, 2Department of Materials Chemistry and Biochemical Sciences, National Chemical Laboratory, Pune, Maharashtra, India.

The biogenic CaCO3 crystals are grown by simple exposure of aqueous Ca2+ ions to Fusarium sp. Rhodococcus sp. The reaction of Ca2+ ions with the Fusarium sp. produces crystal-form shaped calcium particles while, the highly unstable vaterite polymorph in a disklike morphology in contact with Rhodococcus sp. The morphology and crystallography of CaCO3 crystals in solution are modulated by proteins/biomolecules not normally associated with calcareous microorganisms. Many fungi and actinomycetes are known to produce reasonable amount of CaCO3 during growth. The CO2 released from such microorganisms is used to react with Ca ions and synthesize truly biogenic CaCO3 crystals.

K8.9 Surface Treatment of Polyethylene with Ozone / UV in Water and Aqueous Ammonia Solution and Enzymatic Activity of Surface-Immobilized Glucose Oxidase. Ken Yamagisawa1, Takuro N. Murakami1, Yoshitaka Hirano2, Yoshikazu Tokuoka3, Mitsuaki Takashima2 and Norimichi Kawashima1; 1Biomedical Engineering, Toin University of Yokohama, Yokohama, Kanagawa, Japan; 2Chemical Science and Engineering, Tokyo National College of Technology, Hachioji, Tokyo, Japan.

In recent years, the controlling of adsorption and adhesion of biomolecules, medicines, or cells on the polymer surface has attracted considerable attention in biosensor science to defined crystals morphology. Furthermore, a functionalized sulfate polystyrene polymer as a additive into the CaCO3 crystallization was used. This polymer was incorporated in situe of the chitosan sphere formation and mechanically, too. The crosslinking agents: Formaldehyde, Glutaraldehyde, Ethylendioxy, Poly(propylene glycol)diglycidyl ether were used. The swelling(%) of the crosslinked sphere and films chitosan in buffer TRIS at pH 8 were determined. Chitosan samples of high (Aldrich, 85% deacetylation) and low (Fluka, 75% deacetylation) molecular weight were used. The intra-chitosan crystals shows different morphologies and were related to the crosslinked grade of the chitosan sphere and films. The obtained crystallography was deposited in a Tesla BS 343 A scanning electron microscope (SEM).

K8.10 Enhanced Biocompatibility of GPC by MeV Ion Bombardment. Robert Zimmermann1, 1 Materials & Metallurgical, University of Nevada, Reno, Nevada; 2University of Nevada, Reno, Nevada; 3Department of Materials Chemistry and Biochemical Sciences, National Chemical Laboratory, Pune, Maharashtra, India.

Glasy Polymeric Carbon (GPC) is completely biocompatible and is widely used as a material for artificial heart valves and in other biomedical applications. Although it is ideally suited for fluid flow in the blood stream, collagenous tissue that normally forms around the metallic parts of a GPC heart valve loses adhesion and embolism downstream. We have shown that moderate fluence of MeV ions, especially oxygen ions, increases the surface roughness of GPC on a scale appropriate for enhancing tissue adhesion. Ion bombardment also increases the surface hardness of GPC, already an extremely hard material. In vitro biomechanical tests have been carried out with model cell lines to demonstrate that MeV ion bombardment can favorably influence the surface of GPC for biomedical applications.


Hydroxyapatite (HAP) coating has been studied to improve biocompatibility of Ti or Ti-alloy implants. Micro-arc process (MAP) is an electrochemical route applicable for the HAP coating and through it porous HAP films strongly bound to Ti implants can be achieved. Also, it allows precision and easy coating on complicate implant parts. In this study amorphous calcium phosphate films with ~20 mm thickness were coated on Ti using MAP. The coated films were immersed into a buffer solution containing Ca2+ and HPO42- ions. The temperature and time period of the solution treatments were controlled for the crystallization kinetics study. X-ray diffraction (XRD) analyses on the films showed crystallinity of ~ 92 % after the solution treatment at 30°C for 12 h. The volume fraction values of...


K3.14 Metal-peptide Nanoassemblies: Combining the Principles of Supramolecular Coordination Chemistry with De Novo Protein Design. Michael Y. Ogawa, Mihail Tsurkan and Fei Xie; Department of Chemistry and Center for Photochemical Sciences, Bowling Green State University, Bowling Green, Ohio. 

Our group is developing methods to exploit the directional bonding properties of coordination compounds to orient synthetic α-helical coiled-coil protein domains in ways that can create new nanostructured materials. The current approach utilizes both non-covalent and disulfide crosslinked coiled-coils as bridging ligands to join together Pt(en) coordination complexes in geometries that are dictated by the steric demands of the metal center, where en = ethylene diamine. The peptide sequences employed in this study were based on the metal complex NPs synthesis in the apoferritin cavity. We also succeeded to synthesize the three metal NPs in the apoferritin cavity, for example, Co, Ni, Cr NPs (2). Besides these NPs, semiconductor NPs synthesis in the apoferritin cavity have been desired. However, there was only one report describing semiconductor CdS (3) and CdSe NPs synthesis (4) in the apoferritin cavity. To make compound semiconductor and ZnSe NPs in the apoferritin cavity, we designed a new chemical synthesis strategy which makes the chemical reaction of compound semiconductor element ions dramatically slow, so that the semiconductor NPs can be synthesized inside the cavity of apoferritin. By optimizing reaction parameters, the ZnSe NPs are efficiently produced. These NPs were characterized by the high resolution TEM, XRD, EDX and EELS analysis and they are proved to be ZnSe NPs. Furthermore, we employed some mutant apoferritins to study the difference of the core formation ratio (CFR) and to understand the mechanism of ZnSe NPs synthesis in the apoferritin cavity. From these results, three factors are proved to be important. (i) 3-fold channel; selective introduction of Zn ion into apoferritin cavity, (ii) apoferritin internal potential; Zn ion accumulation in the apoferritin cavity and (iii) the ferroxidase center; Zn ion binding and then making the ZnSe nuclei at internal apoferritin cavity. The application of these obtained NPs as the key components of advanced applications. References (1) Yamashita, I., Thin Solid Films, 393, 12 (2001). (2) Okuda, M., Iwahori, K., Yamashita, I., Yosilnura, H., Biotech. Bioeng., 74(2),188 (2003) (3) Wongs, K. W., Mann, S. Adv. Mater. 8, 928 (1996) (4) Yamashita, I.; Hayashi, J.; Hara, M. Chem. Lett., 33, 1158 (2004) 

K3.13 Fabrication of Indium Oxide Semiconductor Nano-particles using Ferritin. Mitsuhiro Okudab,1, Ichiro Yamashitab,2, Kenji Iwahorc, and Hideyuki Yoshishita2, ATRL, Matsushita Electric Industry Co., Ltd., Kyoto, Japan; 2Meiji University, Kanagawa, Japan; 3CREST, Japan Science and Technology Agency, Nara, Japan. 

Inorganic materials of nanometer order attract attention from application point of view. Many methods for fabrication of nano-inorganic materials were developed including physical and chemical methods. New method is also required for nano-inorganic materials to be ordered as two-dimensional crystal as a first step for making nanometric functional structures. We propose biological method to synthesize nano-inorganic materials and make two- or three-dimensional crystal of them. Ferritin is a spherical protein with a diameter of 12 nm. It has a cavity, 7 nm in diameter, surrounded by 24 polypeptide subunits. It is known that there are hydrophilic channels which penetrate the protein shell and are considered to be the pathway of Fe(II) ions. Therefore, two natural apoferritins were also required for inorganic materials to be ordered as two-dimensional crystal. Ferritin and its cavity have been reported to be a useful synthezs in the apoferritin cavity. When Pt(en)(NO3)2 was treated with excess MALDI-MS shows the existence of a progression of metal-peptide corner units. The results show that formation of the lower molecular weight Pt-corner units was favored, in contrast to the behavior observed for the Pt-en anticorner units. The concentration of each material were 0.1mg/ml recombinant L-apoferritin, 40mM HCl, 200 mM monobasic sodium phosphate, 16 mM ammonium and 1mM indium sulfate. The final indium sulfate was the final step to start the core formation reaction. The samples were negatively stained by uraithoglucose and observed by TEM. Uraithoglucose does not stain the cavity because steric hindrance prevents it from going through the cavity. Almost all incubated recombinant L-apoferritin formed indium oxide cores. The elements of obtained cores were determined by energy dispersive X-ray analysis (EDX). The EELS spectrum shows high resolution TEM image showed the clear lattices which correspond Inum oxide crystal. These results indicate that recombinant L-apoferritin formed indium oxide core in the cavity. References (1) Hikono, T., Uraga, Y., Fuyuki, T., Yamashita, I., Jpn. J. Appl. Phys., 42, 308 - 309. (2003) (2) Okuda, M., Iwahori, K. Yamashita, I., Yoshishita H., Biotech. Bioeng., 74(2), 188-194 (2003) 

K3.15 Selective Deposition of DNA-functionalized Gold Nanoparticles into Surface Nanopores. Angela C. Niemz1, Krisann Baudypadhyay1,2, Eric Tsa,1 Liz Hs1, Annie Tsa2 and Shenda M. Baker1; 1Keeck Graduate Institute, Claremont, California. 

We report the optimization of a novel approach for depositing individual DNA-functionalized gold nanoparticles into hexagonal arrays of surface nanopores generated from diblock copolymer thin films. These self-assembled DNA nanopores arrays can be used as scaffold to direct the ordered and selective secondary assembly of other.
DNA-functionalized nanoscopic entities, and are applicable in the development of novel biosensor surfaces. Deposition of individual DNA nanospheres is achieved through self-assembly processes matching between the two entities. We have obtained arrays of surface nanoparticles from hexagonally ordered thin poly(styrene)-b-poly(methylmethacrylate) (PS-PMA) diblock copolymer films in a variety of substrates, including silicon, quartz and glass. Nanoporous templates with pore diameters of 17±3 nm, 31±5 nm and 40±5 nm were fabricated through use of diblock copolymers of different molecular weights. Similarly, we have synthesized modified gold electrodes in total hydrated size from 17±3 nm to 37±4 nm, starting from 5 to 15 nm diameter colloidal gold. We will discuss how the relative sizes of these two nanoporous units affect the self-assembly process. To examine the deposition of negatively charged DNA nanospheres into the surface nanoparticles, we have functionalized these nanoporous templates with a variety of positively charged amine-containing silanes. We employed solid-phase DNA synthesis to introduce selective functionalization of the nanopore's silicon oxide surface while maintaining metallic DNA interactions with the nanopore walls. We further utilized electric fields to obtain more effective surface deposition of DNA nanospheres. These DNA nanosphere arrays have been characterized using atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS). We will also present preliminary studies on the use of these DNA nanosphere arrays for the controlled secondary self-assembly of other DNA-functionalized nanoscopic entities, on the integration of this system with a novel nucleic acid amplification technology, and on the detection of the immobilized DNA nanospheres using AFM as well as electronic methods.

K3.18: Nanostructure of β-Sheet Fibrils Constructed by Peptide Self-Assembly. Matthew S. Lum1, Karthikan Rajagopala2, Joel P. Schneider3 and Darrin J. Pochan1; 1Materials Science and Engineering, University of Delaware, Newark, Delaware; 2Chemistry and Biochemistry, University of Delaware, Newark, Delaware.

A 20-residue peptide consisting of alternating valine and lysine residues flanking a tetra-peptide turn sequence has been shown to self-assemble via differing pathways into dramatically different materials. The primary structure of the turn sequence is critical in defining the different self-assembled pathways. Under appropriate solution conditions (pH, high salt, high ionic strength), peptides with turn sequences designed to adopt a type II' turn intramolecularly fold into β-hairpin conformations leading to the reversible assembly of β-sheet rich hydrogels. Alternatively, almost identical peptides differing in only the chirality of one turn sequence amino acid (L vs. D proline) do not fold into a β-hairpin but instead adopt an extended β-sheet conformation and irreversibly assemble into fibrillar structures. These fibrillar structures are similar to classic β-anoylaid or prion fibrils. Fibrils are formed by lateral association of individual β-sheet filaments providing an untwisted, un-branched fibril morphology with dimensions of 5 to 100 nm in width and up to a few micrometers 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. Solution conditions can be altered to control the kinetics of assembly and, thus, the hierarchical, laminated structure of the mature fibrils. The structure and assembly have been investigated with electron and atomic force microscopies, x-ray diffraction, and circular dichroism and FT-IR spectroscopies. Comparison with control peptides that lack a central turn sequence will be discussed to investigate the role of turn sequence in the self-assembly process and nanostructure of the fibrils.

K3.17: Novel Concept for Antifouling Paints with Zero Endocrine Disrupting Chemicals (EDCs) Elution by Interpenetrating Polymer Networks (IPNs). Masahiko Naito, Takashi Nishi, Kenji Maru, Takahiko Kamei, Takashi Iwashita, Iminohi and Michiyo Fujiki; Graduate School of Materials Science, Nara Institute of Science and Technology, Ikoma, Nara, Japan.

Marine fouling organisms, such as barnacles and blue mussels, have caused serious economic losses by attaching onto the hulls of ships, and the pipes in power plants. For the prevention of that adhesion, self-polishing type antifouling paints, in which the organotin compounds, tributyltin oxide (TBT) or cuprous oxide are hydrolyzed, and elute to the seawater to kill the marine fouling organisms, have been used as highly effective antifouling agents. Over a few decades, it has been reported that the eluted organotin compounds cause a variety of sub-lethal actions on the immune system cell activity, and develops male characteristics to female organisms. Thus, TBT is confirmed to be the endocrine disrupting chemicals (EDCs). The use of TBT-containing antifouling paints, therefore, will be replaced worldwide for non-toxic paints. Recently, we have developed non-EDCs-containing marine paints using organic-inorganic nanocomposite materials. To screen, isolate and evaluate the highly efficient repellent active compounds, an easy bioassay on blue mussels edulis gallopervicialis, which utilizes the escape behavior of the blue mussels from the repellent-active materials, was employed. From the initial screening, 4-octylthiophene was isolated as a highly efficient repellent-active compound equivalent to TPTO. A one-step coupling reaction between 4-octylthiophene and methacryloyl chloride under cooling conditions led to polymerizable N-(4-octylthiophenyl) methacrylamide (NOMA) at high yield (>70%). Subsequently, NOMA was copolymerized with methyl methacrylate (MMA) initiated by 5wt% of AIBN at 80°C with varying composition rate. The obtained copolymers were cast on Webron New FMO 1.5 and evaluated by the aforementioned biological assay with the blue mussels. The repellent activity of these olefin copolymers was relatively high, up to approximately 80% of TPTO at the specific ratio between NOMA and MMA. In addition to the bio-chemical repellent activity of the NOMA-bearing olefin copolymers against the marine organisms, the interpenetrating polymer network (IPNs) were prepared with silicone resins and NOMA-bearing olefin copolymers, because of the physical repellent activity of silicone resins, such as surface tension. 35% of NOMA, MMA, silicone resin and the poly(vinylsilane) were mixed in a flask. Into the solution were added AIBN and acetic acid as a radical initiator and a condensation agent, respectively. The solution was heated at 80°C overnight. After evaporating the solvent, this IPN did not dissolve in any solvents and elute to the seawater, determined by a quartz crystal microbalance at the nanogram order.

The repellent activity of the obtained IPNs improved, and was equal to the repellent activity of TPTO, probably due to the cooperative effect between the bio-chemical and physical activities. The presentation will include more detail such as mechanism, characterization, and long-term use.


We present a theoretical analysis of the dynamics of energy transfer in dendrimers. In one example, energy transfer occurs between donor groups on the periphery of the molecule and an acceptor group in the core. Detailed structural studies show that comparatively rare events, in which the peripheral groups wrap to the core, dominate the energy transfer. In the other example, energy transfer proceeds via a series of independent steps down an energy gradient. We find that a venerable Förster model, which describes the Coulombic interaction in terms of point dipoles, is inadequate to determine the transfer rates. We employ an alternative method based on transition density cubes to analyze the effects of dynamics and temperature. The implications of our results for on-going ultrafast pump-probe experiments are discussed.

K3.18: Synthesis and Characterization of Multivalent Artificial Glycoconjugates. Ying Wang1,2 and Kristi L. Kiel1,2; 1Department of Materials Science and Engineering, University of Delaware, Newark, Delaware; 2Delaware Biotechnology Institute, Newark, Delaware.

A family of alanine- and glutamine-rich artificial proteins, which contain glutamic acid residues at specific distances targeted to match the receptor spacing of certain toxins and lectins, have been synthesized via expression in E. coli. Previous work has demonstrated that the purified proteins form highly helical structures in aqueous solution, and the degree of helicity can be modified via alterations in solution conditions. Subsequent modification of these proteins with saccharides has been conducted via coupling of amine-functionalized saccharides with the glutamic acid functional groups of the protein polymer. Specifically, 1-amino-deoxy-D-galactose has been coupled to the polymer chains of the amine-terminated dendrimers (AAAQAQQQAQQAAQAAAQQQAQQQAQQ, via amide bond formation in the presence of the coupling reagent HBTU). The position of the glutamic acid residues in this sequence, coupled with their modification with galactose, was chosen in order to optimize binding of the artificial glycoprotein to cholera toxin. The successful modification of the protein polymer with galactose was established via mass spectrometry, NMR spectroscopy, SDS-PAGE, and photometric methods. Measurement of the modified protein polymer via circular dichroism spectroscopy show that the glycosylated protein maintains a highly helical structure. Enzyme-linked immunosorbent assays suggest the avid binding of these glycopeptides to cholera toxin.

K3.20: Fabrication of Magnetic Hollow Silica Nanospheres for Bio-Applications. Weiwei Zhao1,2, Lei Shuai1,2, Danial Wainright1,2, Jianfeng Chen1,2 and Charles J. O'Connor1,2; 1Advanced Materials
In this presentation, we report a successful synthesis of magnetic hollow silica nanostructures (MHSNS). The MHSNS were fabricated with one step coating of Fe3O4 magnetic nanoparticles (NPs) and silica on nanosized spherical and tubular calcium carbonate (CaCO3) surface under alkaline conditions, in which the nanosized CaCO3 were used as silica and tetraethoxysilane and magnetic NPs as precursors. The as-synthesized nanostructures were immersed in an acidic solution to remove CaCO3 NPs, forming MHSNS. The MHSNS were characterized by SEM, TEM, and SQUID. SEM and TEM results showed that a thin layer of silica (10 nm) embedded with the magnetic NPs was successfully formed and nanocasted calcium carbonate nano-templates were completely removed. SQUID results demonstrated that magnetization of MHSNS was dependent of temperature, exhibiting superparamagnetic. In addition, the bio-applications of such MHSNS are also discussed.

K3.23 Immobilization Of Thylakoid Membranes Via Self-Assembled Monolayers. Kien Bang Lanel,2, Elizabeth F. Irwin3, Kevin E. Heathcliff3, and Liwei Lin1.1Department of Mechanical and Aerospace Engineering, University of California at Berkeley, Berkeley, California; 2Berkeley Sensor and Actuator Center, University of California at Berkeley, Berkeley, California; 3Department of Bioengineering, University of California at Berkeley, Berkeley, California; 4Department of Materials Science and Engineering, University of California at Berkeley, Berkeley, California.

Photosynthetic thylakoid membranes were immobilized onto a gold substrate functionalized by self-assembled monolayers (SAMs) of cystamine and pyrroloquinoline quinone (PQQ) as part of our efforts to fabricate MEMS photosynthetic solar cells (PSC) and biosensors [1]. Thylakoid membranes are sub-cellular plant structures with embedded photosynthetic photosystems that capture the energy of incident photons to oxidize water and transfer the resulting electrons into the electron transport chain. A quartz crystal microbalance with dissipation (QCM-D) was used to verify the deposition kinetics of the SAMs and thylakoids. The Sauerbrey equation—which relates the change in resonant frequency of the crystal with the change in mass attached to the crystal surface, including bound water—was employed to calculate the surface densities of the added layers [2]. Finally, a monolayer of cystamine was chemisorbed to a clean Au surface and rinsed with water to remove physisorbed material. Most of the cystamine adsorbed within the first minute of being introduced to the Au surface, resulting in a surface density of 7 x 10¹⁰ mol/cm². The PQQ surface densities measured using QCM-D were comparable to but more accurate than values previously reported using cyclic voltammetry [3]. Finally, thylakoid membranes were isolated from baby spinach using a standard fractionation procedure and covalently bound to the PQQ monolayer, also using carbodiimide chemistries. The resulting thylakoid monolayer had a surface density of 370 ng/cm² and was also stable during rinsing. This thylakoid-PQQ-cystamine-Au monolayer stack allows the transfer of electrons generated by photosynthetic activity from the thylakoids directly to the underlying gold and provides a platform suitable for various MEMS applications. In PSCs, the immobilized thylakoids could be used to harness light to generate electrical current. For sensor applications, the thylakoids could be used to detect biochemical agents such that interrupt flow of electrons in the transport chain. [1] K. B. Lam, E. Johnson, and L. Lin, "A Bio-Solar Cell Powered By Sub-Cellular Plant Photosystem", in Proc IEEE Conf on Sensor Electron. Mech. Syst.(MEMS 2004), Maastricht, The Netherlands, Jan. 25-29, 2004, pp.220-223. [2] M. Rodahl and B. Kasemo, "A simple setup to simultaneously measure the resonant frequency and absolute dielectric factor of a quartz crystal microbalance," Rev. of Scientific Instruments, vol. 67, no. 9, pp.3238-3241, 1996. [3] A. Bardea, E. Katz, A. F. Buckmann, and I. Willner, "NAD+-dependent enzyme electrodes: electrical contact of cofactor-dependent enzymes and electrodes," J. Am. Chem. Soc., vol. 119, pp.9114-9119, 1997.
novel materials and structures for a wide range of applications, including nanoelectronic and nanomechanical systems. Hierarchical structures that are assembled in steps and have dimensions that are independently controlled at each step are highly desirable since they offer flexibility in their design and versatility for applications. In this work, we describe the self-assembly of such hierarchical structures using Waterston-Crick hybridization. The process begins with the construction of a 2D scaffolding from a set of 21 synthetic oligonucleotides that are designed to hybridize to oligonucleotides bound to nanoparticles, resulting in rows of closely spaced hybridization sites. The extended features used in this study is a 5'-d(A)15 sequence. After its formation in solution, the DNA scaffolding is attached to a mica surface, thereby providing a template for later nanoparticle assembly. The prototype nanoparticles used in this study are composed ofDX molecules and have a single-stranded hairpin structure. The extended feature used in this study is a 5'-d(A)15 sequence. The extended feature used in this study is a 5'-d(A)15 sequence.

The characterization of the arrays by atomic force microscopy and transmission electron microscopy shows that high yield 2D arrays are formed for N in the range of 7 to 15. Array formation does not form for N less than 7, possibly because of aggregation of the components under the hybridization conditions. The spacing between components within the rows scales with N from the range of 7 to 15, with a corresponding gap between the Au particle cores of 2 to 3 nm. These results demonstrate that the self-assembly of nanoparticle arrays in which the inter-row spacing is controlled by the DNA scaffolding design and the spacing between components is controlled by the number of bases in the nanoparticle's DNA shell.

8:15 AM K4.2


There has been an intriguing suggestion that Staphylococcus aureus α-hemolysin (α-HL), a stable heptameric transmembrane protein pore, may be used to perform rapid, single-molecule DNA sequencing process. This unnatural utilization of the protein has been the focus of intense work in the past few years. One fundamental requirement that had not been fully assessed is the possibility of achieving nucleobase sensitivity within a single-molecule DNA sequencing process. This unnatural utilization of the protein has the potential to be used for high-resolution analysis of DNA molecules.

The discovery of the α-HL pore demonstrated that the α-HL pore can recognize ss-DNA with an apparent single nucleobase resolution. DNA threading protein, transmembrane proteins and DNA-rolling circles holding potentials, formation of an α-HL-DNA pseudorotaxane is identified by the reduction in ion channel conductance caused by the presence of the ss-DNA inside the pore. Streptavidin binding to the biotin-terminated ss-DNA at the trans side complete Rotoraxane formation. Homopurine based rotaxanes and pseudorotaxanes are shown to possess significantly smaller current than homopyrimidine based structures. Series of adenine (a purine based nucleotide) and cytosine (a pyrimidine based nucleotide) DNA block copolymers and cytosine homopolymeric strands with position-specific single-nucleotide adenosine substitutions are used to discover and locate a specific nucleotide position responsible for the measured current, twofold nucleotides away from the pore. The pore location at which detection occurs is found to be near the trans entrance. The discovery of the α-HL can recognize ss-DNA with an apparent single nucleobase resolution strengthens the case for its utility in rapid single-molecule DNA sequencing.

8:30 AM K4.5

Electroactive Luminescent Nanowires of Self-Assembled Oligoelectrolyte-Ampholytid Fibers. Anna Herland, Peter Nilsson 1, Johan Olsson 2, Peter Konradsson 2, Per Hammarström 1 and Olle Inganäs 1. 1Applied Physics, IFM, Linköping, Sweden; 2Chemistry, IFM, Linköping, Sweden.

The development of self-assembled nanoscopic materials for controlled bottom-up fabrication of biomolecular devices is of current interest. In this work, the self-assembly and the three-dimensionally ordered structures of biomolecules could be used as excellent construction tools for the assembly of electronic devices. The wires are ubiquitous. These wires can be carrying current to devices, or can be formed into integrated devices. Amorphous fibers have been used to create templates for metal nanowires, where metals were nanotransferred to the amorphous fiber structures post-self-assembly of the amorphous fibers. We have taken a different route and generated self-assembling electroactive bio-organic nanowires with 10 nm (width) and lengths up to 10 μm. The nanowires are based on protein amorphous fiber conjugated with conjugated oligoanalogous with a thiophene backbone. The nanowires are formed in acidic environment (pH 1.6) and at moderately elevated temperature (65°C). The luminescent oligomers were integrated into the fiber, which was evident from the intensity and spectral distribution of the photoluminescence from the morphology of supramolecular structures in the form of bundled nanowires. The electro-optical properties of the wires are demonstrated with reversible electrochemical doping induced fluorescence quenching, thus demonstrating both electrochemical transport and electroactivity. We suggest that this self-assembled method can be used for several types of electroactive organic materials.

The possibility to synthesize and design ampholytic forming peptides and proteins can be used in the formation of wires or devices. The peptides can further be designed with address functions for anchoring of the wire to electrodes or other wires. Furthermore, changes in optical properties of the conjugated oligoelectrolytes can be used to probe amorphous fibril formation. As stated above the oligoelectrolyte chains can be present during amorphous fibril formation or be added to pre-formed fibrils, which results in a different spectral distribution. The conformation changes of the protein result in alterations in the geometry and the electronic structure of the oligoelectrolyte chains, which have been monitored with absorption and emission spectroscopy. This principle has lately been shown when conjugated polymers (CPs) were used as optical probes to monitor conformation changes in [2] and calcium-induced conformation changes in calmodulin.[3]

References: (1) Nilsson, K. P.; Rydberg, J.;

10:15 AM K4.6
Fabrication of Hierarchical Structures using Protein Cages as Building Blocks. Michael T. Klen1,3,4, Eric Gillizette1,3,4, Peter Socol2,3, Mark Allen1,3,4, Mark Young2,3,4 and Trevor Douglas1,3,4; 1Chemistry & Biochemistry, Montana State University, Bozeman, Montana; 2Center for BioInspired Nanomaterials, Montana State University, Bozeman, Montana; 3Center for the BioInspired Materials, Montana State University, Bozeman, Montana; 4Thermal Biology Institute, Montana State University, Bozeman, Montana.

Biomimetic approaches to materials chemistry have provided a new avenue for the synthesis and assembly of nanomaterials. There is growing interest in materials chemistry to take advantage of the physical and chemical properties of biological systems for development of the next generation of nanomaterials. Protein cages exist in a variety of sizes and shapes and the protein surfaces can be used as synthetic platforms for chemical modification. The ability of some protein cages to form self-assembled arrays on a variety of substrates is of significant interest as possible precursors to interesting nanomaterials such as magnetic semiconductors. This work makes use of chemical and genetically modified spherical protein cages like the Copper Chlorotic Mottle Virus (CCMV) that self assemble into hierarchical structures by design on length scales approaching microns in 2 or 3 dimensions. A solid phase synthetic approach was adopted to generate protein cages with an asymmetric presentation of selected functional groups. Control of protein cages with different presentations of functional groups allow for the formation of larger structures through a "lock and key" mechanism. The incorporation of magnetic nanoparticles was also performed generating 2- and 3-dimensional nanostructures of varying size and shape. Due to the asymmetry of the particle cages, assembly of synthetic functional groups in a spatially controlled manner, thereby breaking the symmetry of the particle. Finally, protein cages with asymmetric functional groups can impart the ability to form hierarchical structures in 2- or 3-dimensions.

10:30 AM K4.7
Self-Assembled Material Nanostructure Defined By The Secondary Structure Of Amphiphilic Diblock Copolypeptides. Lisa M. Palacios1, Darrin J. Pochan1, Timothy Denning1, Eric Holowka2 and Andrew Nowak3; 1Materials Science and Engineering, University of Delaware, Newark, Delaware; 2Bioengineering, University of California, Los Angeles, Los Angeles, California.

Diblock copolypeptides consisting of a hydrophilic lysine (K) block and a hydrophobic leucine (L) block were designed to self-assemble due to their amphiphilic nature and the defined secondary structure of the hydrophobic block. In aqueous solution, these copolypeptides assemble into spherical hydrogels at low volume fractions of polymer (vol. fraction polymer ≥0.5 wt%). The micro- and nanoscale morphology of the hydrogels has been well 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. Altering the molecular design, such as hydrophobic to hydrophilic block ratios and overall polypeptide chain length, affected the overall hydrogel rigidity, determined rheologically, with very weak hydrogels being formed from chains with <10 mol% hydrophobic content and with degrees of polymerization above 300 and below 126. Decreasing the polypeptide chain length to below a degree of polymerization ~100 resulted in vesicle formation on the microscale without additional external force. Both the nanoscale morphology and the formation of hydrogels to the assembly pathway resulted in the formation of twisted fibrils or hexagonal single crystals. In all assemblies, regardless of the resulting structure, the secondary structure of the hydrophobic block remains an a-helix, as determined by circular dichroism (CD). These results indicate that the nanoscale assembly of these polypeptides into membranes is intrinsic to this class of molecules whereas any hierarchical, macroscopic assembly can be controlled through the assembly environment and molecular design.

10:45 AM K4.8

This work describes the development of a novel methodology for the fabrication and stabilization of multilayer peptide nanofilms. The specific approach involves the exceptionally versatile technique of nanomanufacturing known as electrostatic self-assembly (ESA) of oppositely-charged polyelectrolytes. The polyelectrolytes of greatest interest here are designed peptide chains. The amino acid cysteine is introduced, as it permits reversible disulfide bond formation (chemical cross-linking) between peptide chains. The role of solution pH, ionic strength, and adsorption of designed disulfide peptide has been investigated in detail using a combination of physical techniques. Moreover, we have studied the role and importance of disulfide bond formations in stabilizing ESA multilayer nanofilms. Our results show that the ESA process can be exquisitely controlled, and substantial increased stability of ESA films is achieved by disulfide cross-linking. Unlike other cross-linking methods (e.g. glutaraldehyde treatment), disulfide bridge formation is “peptide-based formation” and results in a new avenue for the fabrication of biological multilayer thin films with desired properties and superior stability. This is expected to lead to broader applications of ESA nano-assembly in biotechnology and biomimetics.

11:00 AM K4.9
Bio-inspired Design of Modular Multi-domain Polymers for Advanced Biomaterials. Zhibin Guan, Jason T. Roland, Dora Guzman and Jane Z. Bai; Chemistry, University of California, Irvine, California.

Native load-bearing proteins, such as the muscle protein titin, exhibit a remarkable degree of combined toughness, strength, and elasticity which have yet to be matched by synthetic materials. Single molecule nanomechanical studies on titin and other modular proteins suggest these properties derive in part from specific effects due to a modular mechanism. The sequential unfolding allows modular polymers to sustain a large force over the whole extension of the chain, which makes the polymer strong, along with a large area under the force-extension curve, making it tough as well. In addition, when the external force is removed, the unfolded domains of modular proteins will refold automatically, making them elastic. Inspired by nature, one research effort in my group is aimed at designing synthetic biomolecules that form high order structures by programming non-covalent interactions into polymer chain. The goal is to achieve synthetic biomaterials with combined strength, toughness and elasticity. Three classes of well-defined modular polymers have been synthesized in our laboratory: (1) using quadrupole hydrogen-bonding motif 2-ureidon-4-pyrimidone (Upy) to direct the formation loops along a polymer chain (J. Am. Chem. Soc. 2004, 126, 2058); (2) using a peptidomimetic beta-sheet based double-clossed loop (DCL) as module (J. Am. Chem. Soc. ASAP); and (3) an engineered protein G domain III as module. Single molecule force-extension experiments revealed the sequential unfolding of the loops or domains as these modular polymers are stretched, resulting in sawtooth-patterned curves similar to those seen in titin and other biopolymers. In this talk, we will discuss our designs, syntheses and single-molecule studies of polymers having modular domain structures.

11:15 AM K4.10
Synthesis of Transient Amorphous Calcium Carbonate, and Its Transformation to Oriented Calcite Crystals. Yong-Jun Han1 and Joanna Aizenberg1; 1Materials Research Department, Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey; 2Lawrence Livermore National Laboratory, Livermore, California.

The ability of biological systems to exert precise control over the shape, size, orientation and hierarchical ordering of inorganic materials is of great interest to chemists and materials scientists, who are beginning to recognize its potential in the development of new synthetic pathways and in the improvement of existing materials. Amorphous calcium carbonate (ACC), one of many polymorphs of calcium carbonate but highly metastable, is often observed in biology, with somewhat enigmatic function, ranging from the structural support to the storage of calcium and carbonate ions for future use. The ability to obtain ACC as a slowly growing material has been very challenging. In this presentation, we report our experimental results on materials synthesis using the latter biological strategy. We form transient ACC film on a specially designed self-assembled monolayer (SAM) and use it as ion storage. The recrystallization of ACC into oriented calcite crystals is then induced by introducing the nucleation site into the system without additional calcium or carbonate ions. The mechanism of phase stabilization and recrystallization as well as its implication in biomimetic will be discussed.

11:30 AM K4.11
The Characterization of a Novel DNA Immobilization on DNAchips by Carboxylate-Functionalized Peptides. Junghoon Yang1,2, Kwang-Soo Lee1,2, Guo-Jun Zhang2, Hitoshi
since diamond has excellent electrical and chemical properties such as wide potential window, chemical-physical stability, biocompatibility and so on, diamond is expected as a suitable material for electrochemical and biological applications. In case, H-terminated diamond surface are directly aminated for controlling the density of probe DNA. Then, partially aminated diamond surface was modified by carboxyl aromatic compound(CAC), telephatic and trimesic acid, as linker. In addition, amine-terminated DNA oligonucleotides were immobilized on the micro-structurally patterned diamond surfaces. The novel immobilization method by the surface functionalization by CAC is more effective on diamond surface than on other materials. First, the space between the binding sites of probe DNA has to be considered for hybridization efficiency because the excess density of probe DNA decreases the probability of hybridization. The partially aminated diamond surface is not necessary to space due to control density of amino function, directly. In addition, amide bindings between aminated-diamond surface and CAC or probe DNA and CAC or CAC are more stable than van der waals binding because carbonylic group have been included unshared electron more than aldehyde group. Therefore, direct immobilization method can overcome this disadvantage, weak interaction between probe DNA and surface functional group. For the surface functionalized by DNA, aminated diamond surface was formed in ammonia gas on H-terminated diamond surface by UV. H-terminated aminated-diamond surface except for the masked micropatterns by gold has been formed in order to improve the signal-to-background ratio. The immobilization specificity was evaluated by using of 5 amino-modified oligonucleotides labeled with Cy-5 at its 3 end attached onto microstructured patterns treated different CAC. The EDAC for activation of carboxyl group. We confirm that probe DNA oligonucleotides were immobilized on diamond substrate and hybridized with target DNA. Also, Fluorescence intensity increased when target DNA was hybridized on carboxylated diamond surface with both trimesic acid and terephthalated diamond surface because the different density of carboxyl function. The fluorescence intensity increased by a factor of 1.7, which reflectted that the carboxylated binding-site of terephthalated acid is two as high as that of trimesic acid. The 0.3 difference is due to steric effect between immobilized probe DNA.


Barbara Aichner1,2, Michael Mertig4, Alexander Kirchner3, Oskar Paris4, Ingoagner Jager1, and Peter Fratzl4; 1Department of Materials Science, Austrian Academy of Sciences, Leoben, Austria; 2Department of Biotechnology, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany; 3Max-Bergmann-Center of Biomedicine, University of Technology, Dresden, Germany.

Pd and Pt nanoparticles were produced using isolated S-layer proteins (crystalline bacterial surface layers) which form regular two-dimensional arrays as templates. After adsorption of the precursor metal K2PtCl4 or K2PdCl4, either a chemical reducing agent or exposure to synchrotron radiation led to the formation of monodisperse metallic nanoparticles with radii from 1.5 to 8 nm depending on the reaction conditions. In order to study the metalization process and the interplay between the metal loading and the protein template, we characterized the S-layers as well as the size and arrangement of the metal particles by means of small angle x-ray and neutron scattering. In-situ investigations of the synchrotron radiation induced formation of Pd particles on the S-layers of Sporosarcina ureae showed that the protein templates were indeed capable of stabilizing particles with radii of 1.2-1.5 nm. We did not observe any coarsening during our investigations. The small angle scattering studies were complemented by UV/Vis spectroscopy and transmission electron microscopy investigations which showed that the metal particles were preferentially formed into the pores of the periodic protein structure. From our results we conclude that S-layer proteins are suitable templates to produce stable arrays of metallic Pd and Pt nanoparticles. We acknowledge the financial support of the EU project BIO-CAT (European Union grant number GRD1-2001-04024).


Ichiro Yamashita, ATR, Mitsubishi Electric Industy Co., Ltd., Kyoto, Japan; 2CREST, Japan Science and Technology Agency, Kyoto, Japan; 3NAIST, Nara, Japan.

Biologic and semiconductor technology have progressed independently. The distance between them has been large and a substantial interdisciplinair research area has been left untouched. Now, bio- and semiconductor technology have come and met in the nanometer size range. In such context, the fusion of biology and semiconductor technology is about to start and a new interdisciplinary research area is emerging. There are two manners to fuse bio- and semiconductor technology.


2:00 PM K5.3 Positioning of DNA Nanowires Decorated with Luminous Conjugated Polyelectrolyte. Per Bjork, Anna Herland, Peter Asberg, Peter Nilsson and Olle Inganas; Applied Physics, IFM, Linköping, Sweden.

The ability to control the preparation of ordered nanometer scale structures at certain predefined positions is a major challenge in the field of nanotechnology. In this regard, biological systems offer interesting possibilities for device fabrication (bionanomaterials), where the assembly of electronic polymers is controlled by the interactions with macromolecular assemblies, in this case λ-DNA. A complex of the conjugated polyelectrolyte, with a polystyrene backbone, and the λ-DNA is formed in solution and then stretched into aligned photoluminescent arrays by molecular combing techniques on energy patterned surfaces. Interaction studies of polyelectrolyte layers/solutions and DNA has been done using SPR and optical methods [1, 2]. Furthermore, targeting positions on the

2:15 PM K5.3

Zinc oxide represents a promising material for functional applications, e.g. as a phosphor or a transparent and conductive oxide due to its electronic and optical properties. Due to these advantages, the self-assembly and re-structuring of zinc oxide-based materials and devices is a challenging research field. For that purpose, the deposition from aqueous media basically provides an effective means. However, in the case of zinc oxide the deposition behavior is strongly controlled by the tendency to form elongated micron-sized crystals that make the formation of smooth homogeneous nanostructures impossible. Recently, the preparation of zinc oxide-based nanostructured films was reported [1]. This method involves macromolecular organic additives like graft copolymers or homopolymers, which are added to the aqueous deposition medium. Owing to the interaction of these polymers with zinc oxide in solution the growth of well-defined crystals is impeded and organic/inorganic hybrid nanoparticles are formed. The subsequent assembly of these particles can be controlled by organically modified surfaces and yields nanostructured films with luminescent properties. Living nature also applies a variety of organic molecules that interact with metal ions. One example is the zinc finger, which is made of amino acid units. These units built up a configuration of a DNA-binding protein that resembles a finger and contains usually histidine and cysteine, binding a zinc ion. Within this paper the suitability of amino acids and oligopeptides as structure-directing agents is discussed. According to this bioinspired approach these biomolecules were investigated in a combinatorial way with respect to the evolution of nano-scale architectures. Whereas the head-mentioned macromolecular organic additives mainly support film formation these small molecules are able to trigger the morphology in general, dependent on the kind and sequence of the amino acid units. It will be shown that this approach opens up pathways for nanomanufacturing as well as for the deposition of a variety of morphologies ranging from grain-like via two to three dimensional features. Besides morphological aspects the structural characterization of these solids by means of X-ray diffraction, electron and atomic force microscopy as well as photoelectron and infrared spectroscopy will be discussed in order to extract the function of the biomolecules with regard to the formation of the inorganic phases. In addition, functional properties like the wetting or biological behavior of treated [1] see e. g. R. C. Hoffmann, S. Jia, J. Bill, M. R. De Guire, P. Aldinger, ”Influences of Additives on the Formation of ZnO Thin Films by Forced Hydrolysis”, J. Ceram. Soc. Jpn, Supplement 112 (2005).

2:30 PM K5.4
Biogenic Synthesis of Metal Oxides using Protein Cages as Reactors. Vincenzo Velcich, Mark Allen 2,4, Debbie Willits 2,4, Keith Gilmore 3,4, Mark Young 4,5 and Trevor Douglas 1,4. 1Chemistry and Biochemistry, Montana State University, Bozeman, Montana; 2Plant Sciences, Montana State University, Bozeman, Montana; 3Physics, Montana State University, Bozeman, Montana; 4Center for BioInspired Nanomaterials, Montana State University, Bozeman, Montana.

Supramolecular proteins that assemble into cage like architectures have been used for nanomaterials synthesis. Specifically ferritin and ferritin like proteins can be used as size constrained reaction vessels that encapsulate materials that have sizes that are determined by the internal dimensions of the protein cage. These range from 5 nm for the ferritin like protein from Listeria innocua to 24 nm for the interior of an engineered plant virus (Cowpea chlorotic mottle virus). Inorganic materials synthesized within these constrained reaction volumes are microdispersed in size. The crystallinity and phase of material prepared is determined by the reaction conditions, which are mild compared to other preparative methods. This presentation will focus on the synthesis and characterization of inorganic materials prepared inside a variety of protein cages that range in exterior diameters from 9 to 30 nm and interior diameters of 5 to 25 nm. Particularly, the size dependent magnetic behavior of these nanoparticles will be discussed. When 5 nm ferrimagnetic spiral ferries (FCF) were isolated inside of Listeria innocua, the resulting behavior is superparamagnetic at room temperature. However, when the same material is prepared inside Cowpea chlorotic mottle virus, the resulting magnetic behavior is that of ferrimagnetic temperature as determined by AC magnetic susceptibility measurements and vibrating sample magnetometry. This illustrates the utility of using protein cage architectures for materials synthesis where size dependent magnetic properties can be tuned by choice of the protein cage.

2:45 PM K5.5
Biocompatible-Based Nanostructuring and Metallization. Moto Kato 1, Sinan Balci 2, Anan Kadri 1, Fabian Boes 3, Alexander M. Bittner 1, Christina Wege 3, Holger Jeske 3 and Klaus Kern 1; Exp. II, Max-Planck-Institut MSP, Halle, Sachsen-Anhalt, Germany; 2Nano-scale science, Max-Planck-Institut FK, Stuttgart, Germany; 3Molekularbiologie und Virusforschung, der Pflanzen, University of Stuttgart, Stuttgart, Germany.

Ordered structures in the nanometer scale become more and more important in research and future applications. One of the most promising approaches is the use of large supramolecular assemblies with intrinsic order, e.g. biomolecules. We present a biochemical approach to surface structuring and metallization on the nanoscale. The templates we use are Tobacco mosaic virus (TMV) and Potato virus X (PVX), nanotubular plant viruses that consist of self-assembled RNA strands and proteins. The immobilization of the viruses is attained on well-defined inorganic surfaces. We work with bare and chemically modified substrates or with self-assembled monolayers. In this way we achieve a fine tuning of the chemical properties of the surface in order to address the chemical groups on the viral surface. For the approach to ordered structures of TMV on surfaces we use the method of micro contact printing, while imaging is carried out with scanning probe microscopy, especially non-contact AFM. For the metallization we employ the technique of electronless deposition of metals. By making use of the metal-cation-binding properties of certain amino acid oligopeptides we are able to trigger the formation of small clusters of gold, nickel, cobalt and copper either on the outer surface or inside the nanoscale virus channel. With this method nanowires of nickel and cobalt with 3 nm diameter and up to 600 nm lengths can be achieved. The metallization is investigated with a transmission electron microscope.

2:30 PM K5.6
Molecular Chaperones for Stimuli-Responsive Nanomachines. Takugo Aida and Kazushi Kinbara; Department of Chemistry and Biotechnology, The University of Tokyo, Tokyo, Japan.

Chaperonin proteins GroEL and T.th cpn assist folding of newly formed or denatured proteins by the action of ATP. These chaperonins have a nanoscopic cylindrical cavity, where denatured proteins are captured. The included proteins, after folding, are released by the action of ATP as the result of an induced conformational change of the cavity [Roseman, A.M.; Chen, S.; White, H.; Braig, K.; Sabol, H.R. Cell 1996, 87, 241]. We succeeded in the fabrication of a new nanoscale ATP-responsive molecular machine by combining the unique biological mechanism involving chaperonin proteins into the chemistry of semiconductor nanoparticles [Jabbi, D.; Kinbara, K.; Ishida Y.; Ishii, N.; Ozechi, M.; Yohda, M.; Aida, T. Nature 2003, 420, 928]. CdS nanoparticles (2-4 nm) were prepared according to a method reported by Murakoshi and coworkers. For the complexation with chaperonins, a DMF solution of CdS nanoparticles was added to a Tris/HCl buffer solution of GroEL or T.th cpn. Complexes of T.th cpn and GroEL with CdS nanoparticles were isolated by size-exclusion chromatography (SEC). For T.th cpn, an complexed SEC trace of this solution with an UV/fluorescence dual detector showed single, sharp elution peaks, which were superimposable with one another at nearly the same elution volume as intact T.th cpn. Since intact T.th cpn is hardly fluorescent, the above results strongly indicate that CdS nanoparticle is colocalized with T.th cpn to form an inclusion complex [T.th cpn/CdS nanoparticle]. A TEM picture of [T.th cpn/CdS nanoparticle] showed that the inner cavity of T.th cpn is considerably dark, due to the presence of CdS nanoparticle within the protein cavity. [T.th cpn/CdS nanoparticle] is thermally stable and maintains its characteristic photoluminescence activity up to 80 C, while [GroEL/CdS nanoparticle] is stable only up to 60 C. When a Tris/HCl buffer solution of ATP containing magnesium chloride was added to a buffer solution of [T.th cpn/CdS nanoparticle] containing KC1, the mixture turned slightly cloudy within seconds to the colloidal substances, where the supramolecular solution after centrifugation was no longer fluorescent. The release of CdS nanoparticles from [T.th cpn/CdS nanoparticle] by the action of ATP was clearly demonstrated by analytical SEC with an UV/fluorescence dual detector. After the addition of ATP, the UV response of the SEC trace of [T.th cpn/CdS nanoparticle] showed a sharp elution peak assignable to T.th cpn and an additional broad peak in the lower molecular weight region due to ATP and its hydrolyzed products, which were observed for these two peaks. The fraction corresponding to T.th cpn, isolated
Our goal is to combine polymers and proteins to form a hierarchically structured multifunctional material that has both the highly ordered structure of the polymer and the order and biological function of the protein. By chemically linking or embedding self-assembling biological molecules in structuring-forming block copolymers, this self-organization of the biomolecules can affect the evolution of the block copolymers, and similarly, the structural evolution of the copolymers can affect self-assembly of the proteins. The materials utilized were an amphoteric diblock copolymer of poly(styrene) (PS) and poly(ethylene oxide) (PEO) denoted P(S-b-EO) and horse spleen ferritin (HSF). Solvent casting has been shown to be a viable and rapid route by which arrays of nanoscopic PEO domains oriented normal to the surface can be produced in a glassy PS matrix in films with thickness several times the period of the copolymer. HSF in modified (genetic or chemical) or unmodified forms has shown effects on the self-assembly and microphase separation of the P(S-b-EO) block copolymer and has been a target to promote outcomes for the fabrication of hybrid inorganic-organic materials. Ferritins are storage protein cages belonging to Class II ferrox-carboxylic proteins composed of 24 subunits arranged in octahedral symmetry, which are self-assembled to form a 12 nm diameter cage with a 7.5-8.0 nm diameter cavity. About 4000 iron atoms can be stored in the central core of ferritin as iron (III) oxycitride, mainly ferrihydrite (5Fe₂O₇·9H₂O). Most ferritins are very stable particles, and can withstand 65°C and tolerate a pH range between 4 and 9. Many studies have demonstrated that ferritins can be used as nanoreactors successfully localize imaging ligands or drugs in disease sites. In this for the formulation of inorganic nanocrystals. Combined with their magnetic modulation particle systems and the order of polymers and the specificity of proteins are expected to form the functional component of devices where both organization and specific biological function are required, e.g., sensors, adaptable materials, biocompatible devices.

Magnetic-PLGA Microparticles As Potential Oral Delivery Vehicles of "Hot" and "Cold" Drugs. Daniel Ho1, Chris Yin1, Omid C. Farokhzad2,3 and Robert S. Langer1; 1Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Department of Anesthesiology, Brigham and Women's Hospital, Harvard Medical School, Cambridge, Massachusetts, and 3Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Oral delivery of peptides and protein therapeutics has been extensively studied in the past several decades. This route of administration is preferred because it increases patient compliance and comfort over parenteral route, which accounts for the administration of more than ninety percent of FDA approved protein drugs. Clinically effective oral delivery systems for protein therapeutics have not been established. Proteins administered orally withstand 65°C and tolerate a pH range between 4 and 9. Many studies have demonstrated that ferritins can be used as nanoreactors successfully localize imaging ligands or drugs in disease sites. In this for the formulation of inorganic nanocrystals. Combined with their magnetic modulation particle systems and the order of polymers and the specificity of proteins are expected to form the functional component of devices where both organization and specific biological function are required, e.g., sensors, adaptable materials, biocompatible devices.

Surface plasmon resonance biosensor based on phase measurement. Kotaro Kajikawa1,2 and Ryo Naraoka3; 1Information Processing, Tokyo Institute of Technology, Yokohama, Japan; 2PRESTO, JST Japan Science and Technology Agency, Saitama, Japan.

Surface plasmon is a surface electromagnetic wave, which is originated from the association of charge-density oscillation of free electrons at a metal surface and a light wave. Since the surface plasmon resonance (SPR) provides a highly sensitive and label-free detection method, it is widely used in these days in the fields of biochemistry and genetic engineering. Recently the phase measurement of reflected light in the attenuated total reflection (ATR) upon the SPR condition is paid attention because the phase measurement allows us considerably high sensitivity. The shift of the phase is affected by the existence of the dielectric layer on the metal surface, so that we can detect the affinity of the biological molecules by monitoring the phase shift of the
reflected light. There are a few experimental reports on the phase detection. In most of the studies, the phase detection is based on the heterodyne detection because it provides real-time measurement that is important for biological affinity kinetic measurements. The Rotating analyzer method is another way for phase detection. Although it does not provide the rapid detection, the advantages of the rotating analyzer method are comparable with the heterodyne technique, are (1) the optical geometry is simple (2) it can be applied to spectroscopic measurements (3) it is applicable not only to sensor applications such as affinity biosensors but also highly sensitive spectroscopy. However there are many experimental reports that adopted the rotating analyzer method for phase detection and little is known about the details in the analysis. In this paper we demonstrate the highly sensitive sensing of molecular adsorption on metal surface using the rotating analyzer method under the SPR condition. We found that the method yields the RI resolution of the ambient medium 10^-7, which is almost compatible with that of the heterodyne method and is two orders of magnitude better than that of the conventional SPR method based on the angle detection. Real-time measurement using this method is also demonstrated.

8:15 AM K6.2

Chemically functionalized apertures with large aspect ratios constitute a platform of choice for bio-organism sensing. We fabricated apertures on pre-patterned silicon platforms with aspect ratios >20:1 with iron-based ion beam milling, and are very skilled at using visual cues to position themselves very close to the shore where food is abundant. The visual behaviours and the animal does not possess any other central processing units. The consequence is that the behaviour of the jellyfish is controlled by the nervous system only, which is the basis for high-resolution visual tasks. In other eyes, the information to a single nervous system, in which photonic structures are designed much more for crysis and not only produce strong polarisation effects but also can produce colour stimulus synthesis using a doubly periodic multilayered photonic structure. Optical systems also exist that employ remarkable 3D photonic crystals of cuticle to produce partial photonic band gaps, with the effect that bright light is reflected over a broad angle range. From the perspective of modern optical technology, this indicates an evolutionary step further along the photonic road, since in principle, 3D periodicity potentially manipulates the flow of light in all directions. In current butterflies the common 3D structure, referred to as the "eyespots" consists halved by a honeycomb of cuticle. The physical structure of this inverse-opal photonic crystal, while varying somewhat between examined species, appears consistently as a minor variation of tetrahedral. Interestingly, band gap calculations indicate that a perfect tetrahedral configuration offers the highest reflectivity over the broadest angle range for a given refractive index contrast between component media. Given constraints associated with cuticular morphology and the ecological and taxonomic selection pressures that exists, the physical design of this photonic structure has converged towards one of the most efficient configurations. Numerous studies, many of them very recent, have sought to discover and characterise the photonic structure of cuticle, but this has been notoriously challenging. One of them has revealed system designs that have evolved and existed naturally for millennia and that were, until their discovery in nature, thought to have been the product of technological innovation. Principally, this talk will advances made in the characterisation of Lepidoptera photonic systems, believed by many to be among the most diverse in the natural world.

9:30 AM K6.5

We are interested in learning from natural optical systems, whose hierarchical architecture and hybrid character offer outstanding optical properties and enable multi-faced roles. It was found that in light-sensitive brittlestars, uniform microlens arrays with integrated pores are formed, which enable diffused chromatophore cells through the pores. Such biolens exhibit transmission tunability, diaphragm action, numerical aperture tunability, wavelength selectivity, minimization of the "cross-talk" between the lenses, and improved angular selectivity. For the unique lens structure and functionality, we have created porous hexagonal microlens arrays that are analogous to the biological structures. Using the porous network as a microfluidic system, we have used optical properties and can study the possibility of actuating different liquids (e.g. with selective refractive index and/or including dyes that absorb certain wavelength) in and out of pores, to achieve a wide range of tunability of the lens optical properties.

9:45 AM K6.6
Conjugated Polyelectrolytes: Conformation Sensitivity Optical Probes for the Recording of Biological Processes. Peter Nilsson1, Anna Herland1, Johan Olsson1, Johan Rydberg2, Lars Balter3, Peter Konradsson1, Per Hammarström2 and Olle Inganas2; 1IFM, Biomolecular and Organic Electronics, Linköping, Sweden; 2IFM, Organic Chemistry, Linköping, Sweden; 3IFM, Chemistry, Linköping, Sweden.

Conjugated polyelectrolytes with ionic side chains have been used for the detection of single nucleotide polymorphism (SNP) in DNA [1], conformational alterations of synthetic peptides [2, 3], conformational alterations of Calmodulin and binding of Ca2+-activated Calmodulin (CaM) to Calcineurin (a part of the intra-cellular signal pathway) [4], and amyloid fibril formation of amyloidogenic proteins. The conformational flexibility of polymers, also found in conjugated polyelectrolytes, allows direct connection between the geometry of chains and the resulting electronic structure and processes. If conformational changes of biomolecules could be detected, direct conformational changes of the polyelectrolyte backbone, an alteration of the absorption and emission properties from the polyelectrolyte would be observed. The detection method is based on non-covalent assembly of the conjugated polyelectrolyte and the receptor of interest. Upon
The development of small particles of microporous Si as components of an autonomous system that can sense, perform rudimentary signal processing, communicate, and move about will be described. Each particle contains in its nanostructure the necessary components to allow self-assembly, spectroscopic identification, chemical sensing, and motion. The particles are generated by electrically chemically etching discrete porous one-dimensional dielectric stack (rugate) mirrors into silicon. The complex multilayered structure produces a distinctive reflectivity spectrum that serves as a robust code, allowing positive identification and discrimination of many different types of particles. The intensity and wavelength of reflected light is determined in part by the refractive index of the porous nanostructure, which is modified by adsorption of vapors or by specific chemical reactions within the chemically modified porous Si matrix. Sensing is accomplished when liquid or vapor infuses into the porous mirrors, inducing predictable shifts in the optical spectra. Chemically asymmetric particles are also described, which can spontaneously align at an organic liquid/water interface. Finally, the synthesis of photonic crystals with superparamagnetic nanoparticles of Fe3O4 incorporated into the porous nanostructure will be described. The addition of magnetic fields allows the materials to chaperone micrometer-scale liquid droplets by application of an external magnetic field. 


Methods of synthesizing monodispersed, strongly magnetic ferrite nanoparticles have been well documented. However, encapsulation of these particles within an overlay of biologically active molecules and their subsequent stabilization in a physiological medium has not yet been reported. Such particles could be used to bind and transport proteins. Following introduction into a living organism, they could also provide a means of monitoring and influencing cellular processes. Perhaps most importantly, these bio-functionalized magnetic NPs would provide a crucial component in the ultra-sensitive magnetic detection of both proteins and nucleic acids. We report the successful bio-functionalization of 12 nm manganese ferrite (MnFe2O4) NPs. We demonstrate the site-specific binding of biotin and DNA functionalized NPs onto protein and complementary streptavidin microarrays, respectively. Imaging these substrates with scanning squid microscopy, we show that these particles retain their magnetic properties. Finally, we demonstrate a novel method of detecting the hybridization of these magnetic NPs to DNA within live cell systems using a nanoparticle-based system comprised of a protein patterned magnetic tunnel junction situated in orthogonal magnetic fields.

11:15 AM K6.9 Electropermabilization of Mammalian Cells Visualized with Fluorescent Semiconductor Nanocrystals (Quantum Dots). Yinghua Sun1, P. Thomas Vennes2, Jingling Wang3, Andras Kuth1; 1Department of Materials Science, University of Southern California, Los Angeles, California; 2Department of Electrical Engineering-Electrophysics, University of Southern California, Los Angeles, California; 3MOSIS, Information Sciences Institute, University of Southern California, Los Angeles, California; 4Cedars-Sinai Medical Center, University of Southern California, Los Angeles, California; 5Department of Biomedical Engineering, University of Southern California, Los Angeles, California.

As a bright and stable inorganic fluorescence probe quantum dots have great advantages for the long-term cell observation and in vivo tracking. Electropermabilization or electropenetration has intensively studied recently as an effective technology for gene transfection and drug delivery. Pulsed electric fields can induce reversible membrane breakdown and result in dynamic pores in the cell membrane. This makes the cell permeable to specific molecules in short time but these pores can spontaneously reseal without lethal consequences for the cell. It is found the transfer of small molecules with electroporation is very rapid and efficiency but the big challenge is the transfer of macromolecules, such as plasmids. According to the experiment and simulation results nanocavities could not enter cells by diffusion like small molecules or ions. An electropermabilization model has been proposed and discussed by Zimney and Teissee that electric field can trap these particles on the cell membrane and then cells take them inside by some unknown kinetics in a relative long time. In this work the behavior and processes of electroporation were tracked in 48 hours with quantum dots depended on their special properties. First it is the fluorescence of nanometer-scale particles with the similar size as DNA molecules. Second quantum dots can keep photostability and chemical stability inside cells for over days or even weeks without strong decay in fluorescence and obvious effects on the cell viability. In addition, their high brightness is very helpful to track the motion of small amount of particles in a dynamic live system. The long-term observations revealed that nanometer particles were trapped on the cell membrane after pulsing and the trapping time depended on many cellular factors and particle sizes. Most quantum dots taken by cells aggregated in lysosomes in the cytoplasm without entering nuclei. And the motion of quantum dots inside cells and the behavior of myeloma and ovolara cells were tracked in 48 hours after electroporation.

11:30 AM K6.10 Biologically-Compatible Gd6(Carbon Nanostructures) as Advance Contrast Agents for Magnetic Resonance Imaging. Baijai Shiharan1,2,3, Keith Hartman1,2,3, Kyle Kissel1,2,3, Lena Ann Tran1,2,3, Lon J. Wilson1,2,3, Irene Russolova1, Robert D. Bol'skar1, Sabrina Laus1, Eva Toth1, Alain Borel1, Gabriel Gonzalez1, Lothar Helm2 and Andre E. Merbach1; 1Chemistry Dept, Rice University, Houston, Texas; 2Center for Nanoscience and Technology, Rice University, Houston, Texas; 3Center for Biological and Environmental Nanotechnology, Rice University, Houston, Texas; 4Texas Center for Superconductivity, University of Houston, Houston, Texas; 5TTI Research Inc., West Ridge, Colorado; 6Institut de Chimie Moleculaire et Biologique, Ecole Polytechnique Federal de Lausanne, Lausanne, Vaud, Switzerland; 7Departament de Quimica Inorganica, Universitat de Barcelona, Barcelona, Barcelona, Spain.

Paramagnetic gadolinium-containing carbon nanostructures are currently being pursued as a new paradigm in magnetic resonance imaging (MRI) contrast agent (CA) design.1 These compounds offer fundamental advantages over commercially-available Gd-based chelated compounds, the most important being the complete lack of metal ion dissociation under physiological conditions. Additionally, these systems exhibit unusually large proton relaxivities (efficiency), and offer the potential for intracellular imaging. Our recent work with derivatized Gd@C60-based nanomaterials, Gd@C60(COOH)2Gd4 and Gd@C60(OH)4, have shown them to exhibit exceptionally large proton relaxivities approaching 100 μM−1 s−1 approximately twenty times larger than currently clinically-used MRI agents. Water-proton relaxivities have been measured in aqueous solution at variable temperature (278-335 K) and, for the first time, as a function of magnetic field (5T-10 T), and proton relaxivities display a remarkable pH-dependency, increasing dramatically with decreasing pH (pH: 3-12). Water-soluble fullerene materials (such as the neuroprotective fullerene drug, C3) readily cross cell membranes, suggesting the potential uses of these CA as the first intracellular, as well as pH-responsive, MRI CAs.2,3 In addition to these gadofullerene-based CAs, we have also recently prepared the first carbon nanotube-based MRI CAs. These CAs are derived from ultra-short (20-50 nm) carbon nanotubes (UB-tubes).
which have been internally loaded with aqueous Gd3+ ions to yield Gdn3+-decorated SWNTs used in the development of novel MRI contrast agents. These contrast agents provide an alternative to current iron oxide nanoparticles for MRI imaging. This work was supported by the Robert A. Welch Foundation (C-0627). 2) Sitharaman, B.; Merbach, A. E.; Nash, C. J.; Alford, J. M.; T. Am. Chem. Soc., 2004, (in press). 3) Sitharaman, B.; Wilson, L. J.; Nano Letters; 2004; (in press). This research is sponsored by the Robert A. Welch Foundation (C-0627) and the NIH (Grant 1-R01-EB000703).

SESSION K7: Bio-inspired Devices

Chair: Michael Sailor
Thursday Afternoon, March 31, 2005
Room 3002 (Moscone West)

1:30 PM *K7.1
Active Biological Transport Systems as Functional Components of Nanoscale Materials and Devices.
George D. Bachand, Susan B. Rivera, Andrew K. Boal, Marlene Bachand, Jun Liu and Bruce C. Bunker; Bionanoelectronic Materials and Interfaces, Sandia National Laboratories, Albuquerque, New Mexico.

Energy-consuming transport systems play a key role in a wide array of biological processes such as diffusion, cellular signaling, and muscle contraction. The exploitation of such non-equilibrium processes in nanomaterial architectures may enable the development of new devices and materials in which the assembly, disassembly, and organization may be programmed or self-regulated. Our work has specifically focused on a biological active transport system consisting of kinesin molecular motors and microtubule filaments as a means for organizing and transporting nanocomposite materials at synthetic interfaces. For this work, surface-tethered kinesin motor proteins are used in the gliding motility geometry to propel functionalized microtubule "shuttles" across a surface. A number of critical technical issues have been addressed to date and include: (1) engineering robust biological components, (2) developing interfacial chemistries for attachment of synthetic nanoparticles, and (3) characterizing factors affecting nanoparticle transport. The prerequisite and enabling technologies necessary to utilize kinesin and microtubules to develop integrated nanomaterials and devices will be discussed. In addition, several key demonstrations will be presented to illustrate the application of this transport technology in hybrid systems. *Sandia is a multiprogram Laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

2:00 PM *K7.2
Nanomachines Made from DNA. Andrew Tuerkerfield, Department of Physics, Univ of Oxford, Oxford, United Kingdom.

DNA is a wonderful material for nanoscale construction. It is a structural material whose assembly can be programmed by making use of its information-carrying capability; its hybridization can also be used as an energy source for molecular devices. I shall describe our research on three-dimensional nanofabrication, DNA protein crystals and molecular machinery. I shall review research on nanomachines made from DNA and describe our own progress towards the construction of a free-running synthetic molecular motor.

2:30 PM K7.3

Biology has had millennia to perfect the mechanisms it uses to move fluids over surfaces. One of the most ubiquitous of these mechanisms is through the use of cilia, hairlike projections on cellular surfaces that actively beat in fluid to impart momentum. Cilia are present at all stages of development, in vastly different species, suggesting the motif is useful and efficient for the purpose of fluid transport in living systems. These systems are complex and important, both from a fundamental science perspective and from a clinical aspect.

Understanding how cilia work and how they fail has implications for Cystic Fibrosis treatment, for instance. In our group, we are studying living systems, while at the same time fabricating artificial cilia systems for modeling and applications. We have approached the problem of actuation of nano- and micro-scale systems using magnetic actuation, and shown success in emulating some of the behaviors of biological cilia. We have prepared magnetic nanorod-based surfaces and shown exciting actuation and fluid flow in biologically relevant systems. Flexible magneeto-elastic cilia structures have also been developed using templating techniques, and show promise for applications in microfluidics.

2:45 PM K7.4
Carbon Nanotube Bio-Complexes for Bio-Molecular Recognition. Xiao-Wu Tang, Sarunya Bangaratupit, Nadine Wang Shi Kam, Naimi Nakayama, Qian Wang, Erhan Yenilmez and Hongjie Dai; Chemistry, Stanford University, Stanford, California.

Novel nanomaterials for bioassay applications represent a rapidly progressing field of nanotechnology and nanobiotechnology. Here, we report advances in developing 1) magnetic biosensors based on single-walled carbon nanotube (SWNT) field effect transistors (FET) and 2) a generic approach for patterning bio-molecules on SiO2 or quartz surface using SWNT thin film as the anchor. A SWNT is a quasi-one dimensional wire with only surface atoms. The electronic properties of a SWNT are extremely sensitive to its surrounding chemical and electrostatic environment, thus allows direct electrical detection of biological events on tube surface. In addition, SWNT-FET sensors (nm to 10nm in size) can be integrated into massive arrays in lab-on-chip fashions for analyzing and detecting [2,3] large numbers of bio-molecules with high throughput. Carbon nanotube synthesis by catalyzed Chemical Vapor Deposition (CVD) combined with microfabrication is our basic approach to fabricate nanotube-based sensors for sensing applications. Real-time monitoring of 15mer and 30mer DNA hybridization at ~nM concentration in phosphate buffered saline (PBS) has been demonstrated. Single-particle detection is anticipated with short channel (~10nm) SWNT-FET with a single semiconductor tube across the source and drain electrodes. SWNT-FETs passivated with hydroxylated molecules exhibit excellent sensitivity to pH and are proven to be stable in a wide pH range. pH-sensitive SWNT-FETs will serve as a platform for building Enzyme-Modified FETs (EnFET) where hydrogen ions are produced or consumed by the enzymatic reaction. Recent progress has been made in the synthesis and purification of high density SWNT thin film on both SiO2 and quartz surfaces, which are easily patterned by photolithography techniques. Bio-molecules such as protein and nucleic acid oligomers can then be labeled to the patterned SWNT-FET film and the bioactivity of these enzymes can be investigated by optical fluorescence measurements. Polymer chains irreversibly adsorb onto nanotubes to form a monolayer via van der Waals and hydrophobic interactions in aqueous solutions. Synthesis of SWNT-FET film and the nanotube chemistry can be investigated by optical fluorescence measurements. This work provides an alternative to current immobilization chemistries in DNA micro-array and proteomics. Confocal images of fluorescence labeled DNA oligos and biotin immobilized on patterned nanotube arrays will be presented. References: 1. R. Chen, H. Choi, S. Bangsaruntip, E. Yenilmez, X. Tang, Q. Wang, Y. Chang, and H. Dai, JACS 126, p. 1563. 2. R. Chen, S. Bangaratupit, K. A. Drouvalakis, N. Wang Shi Kam, M. Shim, Y. Li, W. Kim, F. J. Utz, and H. Dai, PNAS 100 (2003) p. 4984. 3. G. Dovbeshko, O. Repninka, E. Obratzsova, V. Shogum, Chem. Phys. Lett. 372, p. 432. 4. M. O’Connell, P. Boul, L. Erikson, C. Huffman, Y. Wang, E. Harens, C. Kuper, J. Tour, K. Ausman, R. Smalley, Chem. Phys. Lett., 342, p. 265.
Controlling the behavior of viable, multipotent stem cells is a major challenge in regenerative medicine. By tuning specific properties of a biomaterial, we have made significant progress towards precise in vitro control of stem cells. Such stem cells have very recently been shown to grow and develop into neurons and other types of cells, making them attractive for Parkinson's and Alzheimer's therapy. Our materials design has focused on creating synthetic equivalents of endogenous molecules by developing biomimetic polymer surfaces. In this work, we proliferated and differentiated rat hippocampal stem cells seeded on peptide-modified hydrogel surfaces, consisting of a biocompatible, non-fouling interpenetrating polymer network (IPN) of poly(acrylamide-co-ethylene glycol acrylic acid) ([P(AAm-co-EG/AAc)]). The bioactive component of the hydrogel was a 15 amino acid oligopeptide containing the Arg-Gly-Asp (RGD) sequence, which mimics the ligands of adhesion proteins found within extracellular matrices (e.g., laminin in the brain) and binds to integrin receptors. Both proliferation and differentiation of neural stem cells were supported and influenced by the biomaterial.

In proliferating culture conditions, the RGD-containing peptides stimulated cells to proliferate and fostered adoption of cell monolayer morphologies consistent with increased proliferation. Proliferation on RGD-negative control surfaces was severely reduced, and different cell morphologies including large spherical cell aggregates were observed on surfaces without the bioactive peptide. The number of spherical cell aggregates increased as the surface bioactive peptide concentration decreased. Similar spherical aggregates have been seen in suspension for multipotent neural stem cells, and have influencing the proliferative potential of such cells before differentiation into mature neuronal, oligodendrocytic, and astrocytic phenotypes. In differentiating culture conditions, the high RGD density support led to the generation of uniform cell aggregates at high cell densities for 1-2 weeks. However, immunostaining revealed that these cells contained altered levels of mature cell markers as compared to cells on natural laminin matrices. Our results suggest that synthetic polymeric surfaces containing only the RGD-integrin binding domain can promote in vitro expansion of specific phenotypes. This is a major step in engineering a purely synthetic environment, completely free of animal-derived products, to precisely control the signals presented to stem cells. Further work with this biomaterial can be used to investigate various material property effects, including that of mechanical stiffness, on stem cell behavior.

Chitosan-alginate Hybrid Scaffolds for Bone Tissue Engineering. Zhengsheng Li1,2, Miqin Zhang1, Kip D. Hauch1, Denim Xiao3 and Hasma Ramay1; 1 Material Sciences and Engineering, University of Washington, Seattle, Washington; 2Department of Orthopedics, Shenzhen People's Hospital, Shenzhen, China.

Here we report on the development of a biodegradable porous scaffold made from naturally derived chitosan and alginate polymers with significantly improved mechanical and biological properties as compared to its chitosan counterpart, and it is structurally stable due to the strong ionic bonding between the aniline groups of chitosan and the carboxyl groups of alginate. The chitosan-alginate scaffold with porosity of ~22% attained compressive modulus of 8.10 MPa and yield strength of 0.46 MPa, respectively, which are about three times of the values for the pure chitosan scaffold. The cell-material interaction study indicated that osteoblast cells seeded on the chitosan-alginate scaffold cultured in vitro without osteogenic medium appeared to attach and proliferate well and promoted the deposition of minerals in a very short time. Unlike chitosan scaffolds which can only be fabricated from acidic solutions, the chitosan-alginate scaffold developed in this study can be fabricated in either acidic, basic or neutral solution. This unique attribute provides a favorable environment for incorporating proteins with less risk of denaturation for sustained release in vivo. The in vivo study showed that the chitosan-alginate scaffold was promoted bone mineralization and deposited connective tissue and calcified matrix within the entire scaffold structure. These encouraging results support the potential applications of the chitosan-alginate scaffolds as an improved alternative to traditional polymer scaffolds for tissue engineering applications. This work was supported by the grant NIH-NHLBI (HL64387-03) and University of Washington Engineered Biomaterials Research Center (NSF-EEC 0529161).
Molecular imprinting of synthetic polymers is a cost-effective and versatile method to synthesize robust man-made receptors. Here, we describe the first attempt to imprint polymers with mammalian cells. Polyurethane thin films were surface imprinted with whole erythrocytes and erythrocyte ghosts using a rational imprint-lithography technique. AB0 blood group determination was achieved with plasmonic devices coated with the bioprinted polyurethanes. The imprinted polymers show a high selectivity for the adsorption of intact red blood cells rather than for mechanically ruptured cells. Red blood cells are selectively adhered on pits imprinted with the same templating erythrocytes. The selectivity pattern of AB0 polymers reflects the antigen composition of the erythrocyte membrane. Furthermore, blood group typing was performed in whole blood samples. The implications of these results for biotechnological applications will be discussed.

Active and Adaptable Photochromic and Thermochromic Electrospun Fibers, Fabrics and Membranes for Bionanomaterials and Tissue Engineering

Electrospun micro and nanofibers, fabrics and membranes with photo- and thermo-switchable color have been produced. A mixture of polymers and commercially dyed with photochromic and/or thermochromic properties was electrospun from a common solvent at room temperature. The resulting fibers exhibit a uniform distribution of dye molecules as shown by laser scanning confocal fluorescence measurements. After electrospraining the photochromic and thermochromic properties are preserved in the fibers, fabrics and membranes. The very high surface-to-volume ratio of the fibers and non-woven fabrics increases the efficiency of the color switching process. The change of the colors by changing the environmental conditions can be used for detection of angiogenesis and the sensing degradation of tissue engineered constructs will be discussed.

SESSION K9: Poster Session: Biological and Bio-inspired Materials and Devices I

K9.1 Novel Nanoscale Biosensor for Lactate Analysis in Sweat

Arun Kunji1, Jessica Otto1, Ashok Kumar1,2 and Shekhar Bhanasi1,2; 1Nanonatural and Nanomaterial Research Center, University of Miami, Coral Gables, Florida; 2Department of Mechanical Engineering, University of South Florida, Tampa, Florida; 3Department of Electrical Engineering, University of South Florida, Tampa, Florida.

The sweat glands are coiled, tubelike structures located in the dermis and subcutaneous layer of the skin. Each tube extends to the skin surface and opens at a pore. These glands function to regulate body temperature, transport electrolytes and waste products from the body surface. Sweat consists of water and a small amount of electrolytes, minerals, and other wastes. Lactate and potassium were the only components found to correlate significantly with the state of hydration, stiffness, and pH of the stratum corneum (SC). Moreover, sweat lactate is a product of the sweat gland itself, a decrease in oxygen supply induces a decrease in sweat lactate concentration and a decrease in sweat gland activity. The increase in pressure to soft tissue will cause a rise in sweat lactate concentration with respect to the rest of the body's sweat lactate concentration. The development of pressure sores, or bedsores, is significant on the health of a bedridden individual as well as requirements for health care professionals. A novel nanoscale sweat lactate biosensor that could continuously monitor a patients sweat lactate level would allow the health care professionals to know when to turn a bedridden individual and thus relieve pressure sores. In the present study, attempts have been made to develop an ion selective electrode at nanoscale which is capable of detecting sweat lactate concentration in very low amounts (micro liter) with high specificity and selectivity. The nanoscale ion selective electrode is prepared by modifying nanoparticles with a biological recognition layer containing lactate oxidase and ferricyanide as an electron mediator. The nanoscale electrode is capable of selectively detecting lactate in the skin sweat using cyclic voltammetry. The values monitored were sweat lactate concentration simultaneously with the electrical potential difference at the duct orifice. Modified nanoparticles are characterized with SEM, FTIR, and UV visible. This research is supported from NSF IGERT grant.
be modified to bind to their ligand (the analyte) and provide a direct fluorescence signal proportional to ligand concentration. Corresponding biosensors are often referred to as “reagentless” as they do not use competitive binding partners or other additional reagents.

A change in fluorescence of the fluorescent label occurs due to protein conformational change upon binding of the protein to the corresponding ligand. Binding proteins must be immobilized within a biosensor matrix in a manner that allows analyte-induced conformational change of the binding molecules. Here, we describe methods of chemically immobilizing dye (IABD) labeled maltose binding proteins (MBP) to a poly(methylene glycol) (PEG) hydrogel. The results showed that upon adding free maltose solution, the fluorescence intensity of immobilized MBP increased ~2 fold over that of free-MBP, a fluorescence change close to that of MBP in solution. Determination of the immobilized protein’s equilibrium dissociation constant was performed by titrating immobilized MBP with different maltose concentrations; the dissociation constant (Kd) obtained was 2.8 mg/maltose. We also demonstrated that the hydrogel-maltose interactions are sensitive to maltose concentration. These findings suggest that immobilized engineered binding proteins in PEG hydrogels could enable development of implantable, continuous-reaching biosensor.

K9.5

Bioinspired Sensors. Nikolas Chalkias1 and Emmanuel Giannelis2;
1Chemical and Biomolecular Engineering, Cornell University, Ithaca, New York; 2Materials Science and Engineering, Cornell University, Ithaca, New York.

Nanohybrid artificial membranes made by intercalation of amphiphilic molecules into the galleries of a layered host exhibit characteristics similar to biological membranes and they can be used as sensors. Specifically the nanohybrid membranes can be used as sensors for different analytes including saccharin. Different responses have been observed even from the small changes that have occurred in the saccharin and its sodium salt suggesting that the nanohybrid might be useful in developing an electronic nose. The dynamic range of the saccharin sensor is 20 - 500μM. In this paper we will present our results on sensor fabrication and testing and discuss possible sensing mechanisms.

K9.6

Physically Tunable Amphiphilic Diblock Copoly peptide Vesicles. Eric Peter Holokea1, Lisa Palestis1, Darrin Pochan2 and Timothy J. Deming3; 1Materials Engineering, University of California Santa Barbara, Goleta, California; 2Materials Engineering, University of Delaware, Wilmington, Delaware; 3Bioengineering, University of California Los Angeles, Los Angeles, California.

Recently, the transition metal mediated living polymerization of block copolymerpolyeletrolytes from α-amino-N-carboxyanhydrides (NCA) has allowed the synthesis of copolymerproducts having a high degree of chain length control as well as the ability to incorporate a wide range of functional groups. An attractive benefit of this system is that it is able to form well defined interactions with amino acids and peptide analogues. An attractive benefit of this system is the ability to tailor polymer structures with amino acids that form known secondary structures, which can then be used to drive self-assembly of complex supramolecular structures. Spontaneous copolymerpolyelectrolyte vesicles, which are stable upon formulation, have recently shown to have features that include a hydrophilic core and its sodium salt suggesting that the nanohybrid might be useful in developing a new type of electronic nose. The dynamic range of the saccharin sensor is 20 - 500μM. In this paper we will present our results on sensor fabrication and testing and discuss possible sensing mechanisms.

K9.7


Hydroxyapatite/collagen (HAp/Col) composites have been studied as bone filling materials that will substitute for autogenous bone implants. We have developed a novel HAp/Col nanocomposite with similar nanostructure to native bone tissues through a self-organization mechanism. The consolidated HAp/Col nanocomposite showed excellent biocompatibility and biomechanical activity for the bone tissues. The control of pore structure in the composite will improve cell migration and mechanical strength, and regenerate neo-vascularization. The pore structures in this study, porosity of 30% and porosity of 80% (80% weight ratio), were synthesized by a co-precipitation method using Ca(OH)2, H3PO4, and Col as starting substances. The temperature and pH were kept at 40°C and 8.0, where Col fibril formation and HAp/Coll crosslinking are similimer similar to biological membranes and they can be used as sensors. Specifically the nanohybrid membranes can be used as sensors for different analytes including saccharin. Different responses have been observed even from the small changes that have occurred in the saccharin and its sodium salt suggesting that the nanohybrid might be useful in developing an electronic nose. The dynamic range of the saccharin sensor is 20 - 500μM. In this paper we will present our results on sensor fabrication and testing and discuss possible sensing mechanisms.

K9.8


Conjugated polyelectrolytes (CPs), conjugated polymers with ionic functionalities, can be utilized to study many kinds of biomolecular events, thus enabling different biosensor devices. CPs offer possibilities for very sensitive measurements of biomolecular interactions, DNA hybridization [1] or confornmational changes in proteins [2]. The development of biosensor devices capable of selectively detecting these types of biomolecular interactions is highly topical, for parallel and high throughput detection. One condition to be able to use CPs for detection of molecules in biological samples is biological compatibility with a aqueous environment. We have shown that CPWs is active and capable of changing its conformation on a solid support using SPR [3] and QCM-D [Asberg, manuscript in preparation]. Therefore, CPW has good characteristics to follow biomolecular events in a biochip format. In this work we have focused on how to make bioschips capable to distinguish between correctly folded and misfolded proteins. Detection of misfolded proteins or peptides is of special interest with the rising problem of prion diseases, and large scale production of protein pharmaceuticals. The present method is based on the modification of a surface using soft lithographic methods, microcontact printing (μCP) with PDMS stamps. Patterned PADs are used to create a hydrophobic pattern through the substrate [4]. Surface modification using μCP on selected areas is a process that minimizes the waste material. Sensitive molecules, such as biomolecules, should preferably be applied to the chip surface in their optimal solution. Depending on the wetting of the solution on the patterned substrate, the solute/surface interactions adsorbed molecules appear in a negative or positive pattern on the hydrophobic/hydrophilic pattern. This may depend on the degree and presence of hydrophobic/hydrophilic exposure, the charge and charge density distribution on the biomolecule or conformation of the biomolecule.
Polymer (PPy) is a conducting polymer with growing applications in the biomedical field. Various dopants have been incorporated into PPy to improve properties ranging from conductivity to biocompatibility. Recently groups have modified the pyrrole monomer by the addition of a biotin molecule to create immune conjugates for medical applications. Biotin is a small molecule that is bound tightly by the protein, streptavidin. The biotin/streptavidin complex has been utilized to create sensors and anchor biotinylated molecules to various surfaces. The ability to incorporate biotin into the electrodeposition step would eliminate the need for the complicated process of chemically altering the pyrrole monomer. We have used biotin in combination with sodium dodecylbenzenesulfonate (NaDBS) as dopants for the electrodeposition of PPy. NaDBS provides the desired conductive and structural properties while the biotin creates the interactive polymer surface. Because the biotin-doped PPy is formed in one electrodeposition process, the production complexity and times are greatly reduced from currently available methods. Drug delivery applications are also possible because the biotin is not part of the polymer backbone. The incorporation and functionality of the biotin in the PPy has been demonstrated through the addition of a fluorescently labeled streptavidin after polymer deposition.

Fluorescent intensity was measured to determine the biotin/streptavidin binding levels. The stability of the biotin in the polymer is important for future biomedical applications. This stability of the biotin was evaluated in a serum matrix by fluorescent intensity measurements over a three week period. The ability to incorporate biotin into PPy through the electrodeposition process provides a unique platform for future sensor and drug delivery applications.

Tissue engineering to replace diseased or damaged tissue is a potentially effective method for treating medical conditions that currently have poor prognosis. This investigation focuses on the development of synthetic constructs for such treatment of ischemic cardiac injury as a result of myocardial infarction. To address this issue, we focus on matrix-assisted myocardium regeneration (MAMR), or the use of engineered materials to foster the restoration of functional tissue growth within damaged myocardium. Our lab has created artificial extracellular matrices (ECMs) that are environmentally responsive and orthogonally tunable with respect to mechanical properties (e.g. G*), biological ligands, tissue adhesion, and protease degradation. We have characterized the physical properties of semi-interpenetrating polymer networks (SiPnP) consisting of linear polycrylic acid (pAAc) chains within a thermo-responsive N-isopropylacrylamide-co-acrylic acid network [p(NIPAam-co-AAc)]. To impart bioactivity into the hydrogels, the pAAc linear chains have been functionalized with peptides containing the cellular binding domain RGD and a potent angiogenic growth factor. These modified p(NIPAam-co-AAc) serve as useful tools for forming in one electrodeposition process, the production complexity and functionality of the biotin in the PPy has been demonstrated through the addition of a fluorescently labeled streptavidin after polymer deposition.

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as a platform for the protein chip will be introduced. Typical values based on fluorescence intensity counts for specific and non-specific binding are 90,000 and 100, respectively.


Tissue engineering has become a great interest in materials science research in the past decade. Porous biomaterials play a crucial role by creating a scaffold structure for tissue regeneration. Structural integrity is a key attribute during the course of tissue formation. Scaffolds supply the necessary foundation for cell attachment, proliferation, and differentiation. A number of factors important for cell scaffolding success are the addition of growth factors and other protein coatings. Our lab has chosen a synthetic biodegradable polymer that can create an interconnected foam structure. We have fabricated porous polycaprolactone (PCL) 3-D scaffolds and later seeded them with mouse embryonic stem cells (ES cells). In vitro degradation studies were conducted at 37°C while submerged in a phosphate buffered solution. The scaffolds were analyzed for mass loss, morphology, and molecular weight. Our PCL scaffolds lost less than 4% of their mass during the 9 week degradation study. It was also found that this tough and elastic material remains in its originally designed morphology much longer than other biodegradable polymers (polypeptides or polyesters). ES cells were seeded onto the scaffold after various protein coatings were applied. We explored various coating techniques to modify cellular results using these scaffolds. When PCL foams were coated with antibody activity and selectivity, the retention of antibody-antigen selectivity in a variety of biologically relevant analyte environments, and the application of a novel photopolymerization method, which allows patterning and fabrication of polymeric micromachined scaffolds based on antibody-antigen detection. These milestones have been demonstrated with a variety of antigens with varying molecular weight, biological stability and function. Also, current work is being investigated to facilitate the detection of microbial antigens.

**K9.15 Viscoelastic Properties of Ultrathin Films of Hyaluronic Acid as Measured using a Quartz Crystal Microbalance with Dissipation.** James Eric Ho and Kevin E. Realy; Department of Biomechanical Engineering, UC Berkeley, Berkeley, California.

Hyaluronic acid (HA) has been proposed as an implant coating due to its nonaggregating and nonfouling nature. Its performance may relate to its viscoelastic properties, which have been shown to modulate cell response in other systems. 1 To elucidate these properties, the shear modulus, shear viscosity and thickness of HA thin films on quartz substrates were determined using a surface-sensitive technique termed quartz crystal microbalance with dissipation monitoring (QCM-D). The technique is an expanded variant of the linearized Sauerbrey approach for rigid thin films, which allows for incorporation of lossy effects that are frequency dependent. Squeezed quartz crystals (Qsense) were grafted with HA (1.3MDa, Genzyme) using a standard carbodiimide chemistry protocol. 2 The surface chemistry was characterized with XPS and contact angle goniometry, where the values were consistent with literature. 3 The shear modules were measured under N2 gas in a quartz D300 to characterize the dried HA film thickness using the Sauerbrey equation. Modeling software by Qsense was used to delineate the viscoelastic properties of HA when swelled in PBS (Gibco) by using a Kelvin-Voigt (KV) approach. Humidity and buffer swelling experiments were performed to highlight the propensity of HA to adsorb large amounts of water. Ex situ measurements showed a dried HA layer thickness of 4 nm (according to Sauerbrey) and a PDS-swelled thickness of 29 nm (according to KV modeling), giving a swelling ratio over 7. The maximum shear modulus in buffer was 41 kPa, while the shear viscosity in buffer ranged from 0.3 - 2.5 cp. Fibrillization (Fgn) adsorption and hysteresis of the adsorbed activity was tested with QCM-D, while short-term osteoblast cell adhesion was measured in order to compare to the known nonfouling nature of HA. Fgn adsorption was performed at 10% serum concentration in PBS, while HAs adsorption was done at 1% serum in PBS. Fgn adsorption to HA was inhibited by 80% compared to control, similar to radiolabeled experiments. 4 MC3T3-E1 cells were seeded at 155 cells/well (12 well TC plate) onto quartz crystals grafted with identical chemistry protocol and pretreatment with 1% FBS, 24 hours, control, and HA-treated surfaces were rinsed and cell numbers were counted. The HA chemistry resisted cell adhesion, even though measurable serum protein adhesion to HA-grafted surfaces was observed. HAs appeared to have lower efficiency of HA to potentiate short-term cell adhesion, but QCM-D, XPS and contact angle studies demonstrated detectable HAs activity towards the grafted HA film, contrary to previous research. 5 References: 1. Wang H-B, Denko M, et al. (2000) Am J Physiol 279: C1345 - C1354 2. Siler HA, Barber TA, et al. (2002) J Biomed Mater Res 61: 391-398 3. Deffie KM, Hagen KM, et al. (1999) J Biomater Sci Polymer Edn 10: 1063 -1074 4. Lowry KM, Beavers EM. (1994) J Biomed Mater Res 28: 861 - 864 Acknowledgments: Funded by NIH Grant number: AR63187.

**K9.16 A Rapid Antigen Detection Assay using Photographed Whole Antibodies.** Robert Sagle 1, Kristyn Masters 2, Christopher Bowman 1 and Kristi Anseth 2, 1Chemical and Biological Engineering, University of Colorado-Boulder, Boulder, Colorado; 2Howard Hughes Medical Institute, Chevy Chase, Maryland; 3University of Colorado Health Sciences Center, Biomaterials Research Center, Denver, Colorado.

Antibody surface immobilization techniques have had a significant impact on the detection of both specific antigens for clinical diagnostics. To date, most antigen detection assays (e.g., standard enzyme-linked immunosorbent assays) rely on monolayer formation or physiosorption methods to immobilize antibodies to surfaces. However, that approach exemplifies drawbacks associated with coating procedures, including non-specific protein interactions, and non-specific protein interactions that lead to limited sensitivity (nM), and time-consuming assay procedures (1-10 hours). Further, these issues lead to an inability to detect antigens such as those that have a short half-life in biologically complex fluids. Thus, recent research has focused on methods to bind antibodies covalently to surfaces through conventional protein functional sites, such as amine and carboxy terminal groups, as well as antibody-specific thiol groups. While these approaches reduce the possibility of antibody desorption, surface-bound antibodies and biomolecules often lose their activity and/or selectivity due to conformational and mobility restrictions or mass transfer limitations. Furthermore, antibody activity is often lost due to reduction of antigen binding, which results from the coupling process. In this work, acrylated whole antibodies, termed antimers, were synthesized with the goal of establishing a controlled polymerization method to immobilize antibody activity in a manner that bears both sensitivity (nM) and high mobility. Further, this approach enables covalent binding of the antibodies to grafted PEG-containing tethers to help prevent non-specific protein interactions while providing independent control over tether density, composition, and location. When integrated, these contributions greatly improve detection sensitivity (< pM) and response time (~ 15 min). In this research we demonstrate three significant milestones: the ability to polymerize whole antibodies as polymer grafted tethers, which is integral in maintaining antibody activity and selectivity, the retention of antigen-antibody selectivity in a variety of biologically relevant analyte environments, and the application of a novel photopolymerization method, which allows patterning and fabrication of polymeric micromachined scaffolds based on antibody-antigen detection. These milestones have been demonstrated with a variety of antigens with varying molecular weight, biological stability and function. Also, current work is being investigated to facilitate the detection of microbial antigens.

**K9.17 Mossbauer and Raman Spectroscopy of the Iron (II) -Porphyrin Biomaterial for Potential Application as a Spin-Based Electronic Device.** Aboubaker Chedikh Boye 1,4, Soose Nchaya 1, Bassirou Lo 1, Oumar Sakho 1,2, Papa Doua Doua Tall 1,4, N. Pearson 2, G. M. Erasmus 3, Vittoria Pichiedda 3, Giorgio Hearn 3 and Wolfe W. Wakeham 3 1Physics, University of the Witwatersrand, Johannesburg, Gauteng, South Africa; 2School of Physics, University of the Witwatersrand, Johannesburg, Gauteng, South Africa; 3University Internal Institute, Princeton University, Princeton, New Jersey.

Resonant Raman and 57Fe Mossbauer Spectroscopy (MS) under hydrostatic pressure in a diamond-anvil cell are used to investigate the spin-structure response of the 3d manifold of Fe in the ferric haem-porphyrin [Fe(TPP)(NCS)] compound. Extreme pressure conditions using a modified Mossbauer system have enabled the magnetic investigations of samples in a volume of pico-litres in the sample cavity of a Diamond Anvil Cell. The study of the pressure response of such organo-metallic systems is fundamentally important because iron porphyrins are found in biology as haem proteins whose activity is sensitively dependent on the structural configuration which may in turn be influenced by the iron spin-state configuration. The results of 57Fe Mossbauer Spectroscopy (MS) under hydrostatic pressure show a pressure-induced spin-switching from the high-moment (nominal atomic spin S = 5/2) to the lowest moment (nominal S = 1/2) electronic state in [Fe(TPP)(NCS)] compound. Such a spin-switching is shown to occur at moderate pressure conditions of 5-10 GPa at room temperature. Raman spectra of both states is compared and associated with different structural configurations of the molecule. Resonant Raman Spectroscopy are used to get additional informations on the vibrational modes. The change of the magnetic moment of such paramagnetic compound from ca. 5.8 BM at low
pressure to ca. 1.8 BM at high pressure is discussed in view of potential applications in molecular electronics.

K9.18 Immobilization of Proteins on the Surface of Silanized Hydroxyapatite. Akira Matsumoto, Toshiyuki Hashi, Syunjiru Yonuki, Yutii Kimigata and Junji Tannoaki; Biomaterials Center, National Institute for Materials Science, Tsukuba.

Hydroxyapatite (HAp) is widely used as bioceramics for bone and dental tissue reconstructions due to its excellent biocompatibility with hard tissues and high osteoconductivity. HAp has an interesting property as an adsorbent for biopolymers such as protein. The absorption ability of HAp is useful for the preparation of HAp/protein composites. However, the proteins were easily removed from the HAp surface in vitro and in vivo studies, which depend on the ionic strengths and pH values in aqueous systems. To overcome these problems, it is important to bond protein onto HAp surface only by using a binding material. Silane coupling agent is one of the binding materials with the ability to bond inorganic materials such as glass, mineral fillers, metals and metallic oxides to organic resins. Furthermore, previous studies showed that the silane coupling agent is useful material for coating on the HAp surface. This study focused on the coupling agent as a binding material between HAp and four different proteins such as acidic proteins of fibrinogen, fibronectin and vimentin, and basic proteins of collagen. These proteins were important factors for the cell attachment onto the materials surfaces in cell culture. We immobilized these proteins onto the surface of HAp sintered body with 20nm in diameter and 2nm in thickness by introducing covalent bonding via aminopropyltriethoxysilane (APS). The existence of APS on the HAp surface was confirmed by zeta-potential measurements. The proteins immobilized on the pure HAp and APS/HAp were observed by atomic force microscopy (AFM). Simadzu: SPM, zeta-potential measurements and the stability of protein/APS/HAp and protein composites was evaluated after soaking in PBS and NaCl solutions with various concentrations. AFM analyses and zeta-potential measurements revealed that proteins are firmly bonded on the APS/HAp surface in the solutions. However, the Col/HAp composite is unstable in the high NaCl concentrations. The fibrinogen, fibronectin and vimentin are unstable and removed from the pure HAp surface in the PBS solutions whereas the APS/HAp was firmly bonded to these proteins in the PBS solution. We concluded that proteins immobilized on the APS/HAp are more stable than those immobilized on the normal HAp in high ionic strength solutions (PBS and NaCl).

K9.19 Transferred to K10.1

K9.20 Hydroxyapatite Coatings Deposited by KrF-Laser Ablation and its Adhesion to Metallic and Ceramic Implants. Won-Jun Lee 1, Sang-WooK Lee 1, Hyeely Kim 1, Dae-Joon Kim 1 and Jung-Sung Hahn 1; 1Department of Advanced Materials Engineering and Bioengineering Research Center, Sejong University, Seoul, South Korea; 2Department of Prosthodontics and Dental Research Center, College of Dentistry, Seoul National University, Seoul, South Korea.

Hydroxyapatite (HA), Ca10(PO4)6(OH)2, is currently used as a biomaterial for many applications in both dentistry and orthopedics, because it is the main chemical component of bone. Nevertheless, due to the poor mechanical properties of bulk HA, it cannot be used as implant device materials for load-bearing applications. The solution is to apply HA as a coating on Ti or Ti-based alloy implants. In this way, the mechanical properties of the implants are supported by the metallic structure, while the osteointegration is promoted by the bioactive surface of HA. Plasma-spray (PS) was the first method used for coating implants with HA, and the PS coatings exhibited better bone healing than uncoated implants; however, there were some issues affecting the long-term stability of the implants. The main problems of PS coatings are related with the presence of other calcium phosphate phases, the porosity and the poor coating-substrate adhesion. In this study, the HA coatings with a high degree of crystalline phase were prepared by pulsed laser deposition (PLD) method using a KrF excimer laser (at 248 nm). Crystalline HA films could be obtained at elevated temperatures under oxidizing conditions. To overcame these stability of protein/APS/HAp and protein/HAp composites was sintered body with 20nm in diameter and 2nm in thickness by using a binding material. Silane coupling agent is one of the binding materials with the ability to bond inorganic materials such as glass, mineral fillers, metals and metallic oxides to organic resins. Furthermore, previous studies showed that the silane coupling agent is useful material for coating on the HAp surface. This study focused on the coupling agent as a binding material between HAp and four different proteins such as acidic proteins of fibrinogen, fibronectin and vimentin, and basic proteins of collagen. These proteins were important factors for the cell attachment onto the materials surfaces in cell culture. We immobilized these proteins onto the surface of HAp sintered body with 20nm in diameter and 2nm in thickness by introducing covalent bonding via aminopropyltriethoxysilane (APS). The existence of APS on the HAp surface was confirmed by zeta-potential measurements. The proteins immobilized on the pure HAp and APS/HAp were observed by atomic force microscopy (AFM). Simadzu: SPM, zeta-potential measurements and the stability of protein/APS/HAp and protein composites was evaluated after soaking in PBS and NaCl solutions with various concentrations. AFM analyses and zeta-potential measurements revealed that proteins are firmly bonded on the APS/HAp surface in the solutions. However, the Col/HAp composite is unstable in the high NaCl concentrations. The fibrinogen, fibronectin and vimentin are unstable and removed from the pure HAp surface in the PBS solutions whereas the APS/HAp was firmly bonded to these proteins in the PBS solution. We concluded that proteins immobilized on the APS/HAp are more stable than those immobilized on the normal HAp in high ionic strength solutions (PBS and NaCl).

K9.21 Fabrication and Characterization of Active Matrix Array for Cell Probing and Screening. Seung-Ik Jun 1, Timothy E. McKnight 2, Anatoli V. Melechko 3, Michael L. Simpson 1, 2 and Philip D. Rack 1; 1Materials Science and Engineering, The University of Tennessee, Knoxville, Tennessee; 2Molecular Scale Engineering and Nanoscience Research Group, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

In order to achieve multiple cell stimulation and recording with high electrode density and low manufacturing cost, we have fabricated and characterized an active matrix array for cell probing and screening that provides great potential to execute direct cell sensing/probing and recording with high resolution. Each unit pixel in the array is individually addressed by a thin film transistor (TFT) and the vertically aligned carbon nanofibers (CNF) for probing cells are fabricated on the drain electrode of TFT. The CNF is grown by direct current plasma enhanced chemical vapor deposition (DC-CVD) using a nickel catalyst. The impedance difference between cell probing site and reference electrode is recorded by semiconductor analyzer connected with output terminals. Also, the impedance change with cell probing can be measured by applying sine-wave input and recording the signal stored in storage capacitors after frame scanning in the TFTs. Consequently, actively addressed nanofiber arrays enable bidirectional interfacing with tissue matrices in a format that allows for intercellular probing of cell-to-cell communication as well as the potential for intracellular residence of probes within individual cells. In our research, we exploit these non-planar electrode systems for efficient coupling with excitable cell matrices as well as for interfacing with biochemical manipulation of single cells. In our presentation, we will discuss the fabrication sequence of the invented metal-oxide-semiconductor (MOS) TFT, and will elaborate the materials issues related to integrating the carbon nanofibers with the TFT.

K9.22 SPM and Charge Transport Measurements Through DNA. Molecules of Complex Sequence. Hezy Cohen 1, Claude Nogues 2, Ron Naaman 3 and Danny Porth 1; 1Physical Chemistry, The Hebrew University of Jerusalem, Jerusalem, Israel; 2Department of Chemical Physics, The Weizmann Institute, Rehovot, Israel.

The ability of DNA to transport charge carriers and the possible mechanisms for this transport were debated over the past few years. Part of the debate originated from the variety of measurement approaches, samples preparation, experimental set-ups and environmental conditions. The main factor for charge transport in measurements previously reported were the attachment to the surface along the molecule and the non-chemical bonding of the molecules to the contact electrodes. Indeed, current was measured in single molecules and blocked in long molecules attached to the surface. Inspired by Cui et al. 4, we have adopted an experimental approach that enables to overcome these difficulties by measuring current through DNA molecules chemically connected on both sides to a metal substrate and a gold pad, 5 which is connected with output terminals. Also, the impedance change with cell probing can be measured by applying sine-wave input and recording the signal stored in storage capacitors after frame scanning in the TFTs. Consequently, actively addressed nanofiber arrays enable bidirectional interfacing with tissue matrices in a format that allows for intercellular probing of cell-to-cell communication as well as the potential for intracellular residence of probes within individual cells. In our research, we exploit these non-planar electrode systems for efficient coupling with excitable cell matrices as well as for interfacing with biochemical manipulation of single cells. In our presentation, we will discuss the fabrication sequence of the invented metal-oxide-semiconductor (MOS) TFT, and will elaborate the materials issues related to integrating the carbon nanofibers with the TFT.

To combat the deleterious effects of radiation and other stresses on long-term human space exploration, it is critical to better understand the mechanisms of these effects. The complex interactions of multiple cellular and subcellular processes and the dynamic performance of muscle cells will provide us with complete dynamic data to develop effective countermeasures to combat these adverse effects. Unlike the conventional measurements techniques, we have created a novel method capable of in situ characterization of the mechanical properties of muscle at both tissue and single-cell levels using a self-assembling system. This system has shown the capability of spatially and selectively directed growth and differentiation of myocytes into single bundle in situ, attachment of these functional bundles to MEMS structures, and the controlled release of the resultant hybrid devices without any manual assistance. The mechanical properties of the frontosternal myocytes 1-3-day-old Sprague-Dawley rats (NRKMs), such as substrate-induced stress and Young’s modulus, have been measured using this force transducer and were found to be 2-2.5 kPa and 40 kPa respectively. Using this force transducer to expand the system to dynamically monitor the cellular activities in response to the external applied stresses. It has been noted that intracellular calcium concentrations of cardiac myocytes fluctuate between 10-5M - 10-7M upon contraction and relaxation respectively. Using an intracellular fluorescent calcium indicator we can correlate fluorescence density with cellular function. By monitoring the fluorescent signal, we can visualize calcium fluxes and in turn determine what state a particular cell is in. In addition to detecting cellular activity, the effect of UV radiation and mechanical stresses on the cells are also under investigation. Further study of genetically engineered cells will enable us to in situ monitor the molecular and genetic information and simultaneously investigate the correlation between cellular activities with the mechanical properties. The self-assembly system established is not only suitable for studying dynamic mechanics of muscle cells, including the correlation of intracellular activities with external factors, but also applied to the studies of other cells.

SESSION K10: Biomaterials: Theory and Experiment
Chair: Elaine DiMasi
Friday Morning, April 1, 2005
Room 2007 (Moscone West)

8:30 AM K10.1
Simulations and Design of a New Green Fluorescence Protein Mutant. Murat Cetinkaya1, Ahmet Zeytin2, Andrew Bradbury2 and Melik C. Denizli1 1Engineering Science and Mechanics, The Pennsylvania State University, University Park, Pennsylvania; 2Biogenic Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

A set of new green fluorescence protein (GFP) mutants are experimentally created by modifying four loop regions of GFP. The excitation / emission spectra of a number of different GFP mutants were determined and some GFPs showed a reduction in both the absorption and emission at each wavelength. We have performed molecular dynamics simulations of these mutants using the AMBER force field. We especially concentrated on loop3 (residues 171-175) modifications since new residue insertions to this region cause drastic changes in fluorescence intensity properties. A possible explanation is the quenching of the chromophore located at the center of the structure due to local unfolding. A 10 ns molecular dynamics simulation showed that insertion in the loop3 region creates local unfolding of the "beta-can" structure of GFP, confirming our hypothesis for the change in fluorescence intensity of the protein. We have also performed simulations regarding other loop regions and compared with the corresponding experimental data.

8:45 AM K10.2
Nano-Phononics in Biological Systems. Alexander A. Balandin and Vladimir A. Fonoberov; Nano-Device Laboratory, Department of Electrical Engineering, University of California, Riverside, California.

Viruses have recently attracted attention as biological templates for assembly of nanostructures and nanoelectronic circuits [1]. They can be coated with metals, silica or semiconductor materials and form end-to-end and/or looped assemblies. Such viruses as tobacco mosaic virus (TMV) and M13 bacteriophage have appropriate cylindrical shape and particularly suitable dimensions: M13 is 860 nm long and 6.5 nm in diameter, while TMV is 300 nm long, 18 nm in diameter and with a 4 nm in diameter anhelix of the protein, i.e. vibrational modes of these viruses is important for material and structural characterization of the virus-based nano-templates, for in-situ monitoring of the nanostructure self-assembly, and for understanding of interactions of the biological-typical interfaces. In this paper we review our recent theoretical and experimental results on phonon spectra of TMV and M13 bacteriophage immersed in air and water. The low-frequency phonon dispersion has been rigorously calculated using the complex-frequency approach. The radial breathing modes of TMV and M13 viruses in air are found to be 1.85 cm^-1 and 6.42 cm^-1, respectively. If the viruses are in water, the above frequencies become 2.10 cm^-1 and 6.12 cm^-1, respectively [2]. The quality factor Re(w)/Im(w) for radial vibrations of TMV in water is about 3.8 for the radial breathing mode and about 10 for the second radial mode. Strongly interacting modes of these viruses have been identified in a wide spectral range and the vibrational spectrum have been studied experimentally by means of the non-resonant micro-Raman spectroscopy. We analysed the damping in vibrations in water and discussed the application of the micro-Raman spectroscopy for monitoring virus-based nanostructures [3]. The authors acknowledge the financial and program support of the Microelectronics Advanced Research Corporation (MARCO) and its Focus Center on Functional Engineered Nano Architectonics (FENA).

8:00 AM K10.3
Guanine Quartet Networks Stabilized by Cooperative Hydrogen Bonds. Roberto Otero Martin, Maya Schoeck, Luis M. Molina, Erik Laegsgaard, Ivan Stensgaard, Bjork Hammer and Flemming Besenbacher; Department of Physics and Astronomy, University of Aarhus, Aarhus, Denmark.

Hydrogen bonding between DNA or RNA bases is one of the main interactions that determine the conformation and backbone stability of nucleic acid molecules. Apart from the Watson-Crick model for base pairing, NA bases can form other hydrogen-bonded aggregates that lead to different DNA structures, like quadruplexes or i-motifs. In spite of the increasing evidence for the in vivo existence and function of these structures, the exact physico-chemical nature of the hydrogen bonds and the importance of charge transfer contribution to the stabilization energy associated to hydrogen bonding in these structures is still under debate. Here we show, by high-resolution, variable-temperature Scanning Tunnelling Microscopy (STM), that the NA base guanine (G), deposited under ultra-clean conditions onto the inert Ag(111) substrate, self-assembles into a hydrogen-bonded network of G-quartets with the same structure as that found in quadruplex telomeric DNA. Comparison with our Density Functional Theory (DFT) calculations shows that the strong preference of G molecules to form quartets arises from a cooperative effect that strengthens the hydrogen bonds within the G-quartet network relative to those in isolated G dimers.

9:15 AM K10.4
Molecular Recognition in 2D Binary Mixtures of DNA Bases Studied by STM. Maya Schoeck, Eva Rauls, Roberto Otero Martin, Wei Xu, 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. These processes have found an application in the field of Nanotechnology, and strands of complementary DNA sequences have been used to directly self-assemble of nanostructures. In principle, the complementarity in hydrogen-donors and acceptors groups in single DNA bases might as well be used as molecular recognition processes, that could be used to control 2D molecular assemblies as well. However, the existence of "wobble" or "deviant" base pairs, and a possible disturbing effect of the substrate on the hydrogen bonds made this possibility more difficult to explore. 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) by means of a combination of STM experiments and DFT calculations. 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 structures that contain G-C bonds, possibly with the arrangement that resembles a Watson-Crick pair in DNA molecule. The stronger bond between G and C molecules with respect to G-G or C-C pairs explain the enhanced thermal stability of the combined G-C mixture. This result shows that the hydrogen-bonding interaction alone can steer the processes necessary for molecular recognition to take place in 2D networks, thereby opening new avenues to design molecular self-assemblies with desired geometries.
Quantum Chemistry Approach to Modeling of Molecular Adsorption at Crystal Interfaces. Andrzej Wierzbicki, Edward A. Salter, Selim Elhadj and Patricia M. Dove; Department of Chemistry, University of South Alabama, Mobile, Alabama; Department of Geosciences, Virginia Tech, Blacksburg, Virginia.

Recent rapid progress in the development of quantum chemistry software and the better understanding of computer performance have made it possible to start implementing more realistic models of molecular adsorption at crystal interfaces. It is widely believed that interfacial adsorption models based on the molecular mechanics approach, which uses a continuum dielectric model to represent solvent, could provide an inadequate description of adsorption, especially in those cases where solvent molecules many significantly impact the adsorption process. We will address the complex issue of surface-specific adsorption at crystal interfaces in the presence of explicit water molecules. We will use the semicircular and ab initio methods of quantum mechanics to address the role of the solvent for the binding energy of adsorption and the conformation of adsorbed polypeptides at crystal interfaces.

Aspartate Chain Length Controls Calcite Step Morphology by Differential Step Recognition. Selim Elhadj, Edward Salter, Andrzej Wierzbicki, Patricia Dove, Nizhou Han and James De Yoreo; Geosciences, Virginia Tech, Blacksburg, Virginia; Chemistry, University of South Alabama, Mobile, Alabama; Chemistry and Material Sciences, Lawrence Livermore National Labs, Livermore, California.

Most controlled crystallization is believed to be achieved under the direction of macromolecular protein-based templates with specific affinities for assembling and assembling the desired growth units. This reliance upon cellular proteins with specific sequences and structures suggests that the chemistry and stereochemistry of the amino acids forming the proteins are essential in conferring targeted activity in controlled biosynthesis. Calcium carbonate is a key biogenic mineral and model system to study the molecular mechanisms by which amino acids and peptides interact with individual steps. Investigations of molecularly resolved crystal-peptide interactions can reveal how biomolecules achieve regulated growth during biomineralization. Our previous studies have focused on the role of specific single and dipeptide species known to constitute a significant fraction of the proteins involved in biomineralization processes, in particular, acidic amino acids and aspartate. In this study, we extend our investigation to the role of aspartate chain length because they represent integral part of the active site of these biomolecules. In particular, the effect of aspartylpeptides (Asp-n, n=1,2,4,5,6) on the kinetics and thermodynamics of calcite growth were investigated and compared with models of calcite-Amp interactions. Using in situ Atomic Force Microscopy and precisely characterized solutions, our experimental measurements of growth kinetics and observations of the calcite hillock morphology at the nanoscale show that step directions with acute and obtuse geometries are affected differently for all aspartate derivatives. Short chain aspartates (n=<2) roughen acute steps more strongly than obtuse steps. This situation is exactly reversed for longer chain aspartates (n>3). Further, the Asp concentration required to replicate the steps decreases with increasing length of the Asp peptide. Circular Dichroism measurements were performed to confirm the aspartate conformations assumed in the modeling. We examine the molecular origin for these experimental findings using molecular modeling. Not unexpectedly, due to cooperative binding, the concentration required to affect step edge morphology is predicted to decrease exponentially with increasing aspartate chain length. This trend correlates with the measured inhibition of step motion and can be explained by relating chain length to calcite step binding and dehydration energy. Our findings suggest that there is a qualitative change in the nature of aspartate-calcite step interactions with increasing aspartate chain length. This change is accompanied by an exponential increase in the degree of aspartate binding. This chain length dependent differential binding to opposing calcite steps may be an additional mechanism by which biomineralizing proteins can achieve regulation of calcite growth.
Recent studies have established that the mace layer of mollusks possess a number of proteins that assist in the formation and stabilization of the aragonite polymorph during shell development. However, very little is known regarding the mechanism of protein manipulation of calcium carbonate biomineral formation. In particular, the relationship between the secondary structure recognition of mineral surface features is not clearly understood.

Previously, we identified 30 AA N-terminal mineral binding domains that originate from three different nacre-specific proteins (AP7, AP24, n10). These binding domains termed AP7-N, AP24-N, and n10-N, induce morphological changes in calcium carbonates in vitro and are similar in amino acid composition, but differ significantly from each other with regard to their primary sequences. Using a flow cell-equipped AFM instrument, we investigated the sites of adsorption of each mineral-binding domain onto calcite dislocation hilllocks. We find that AP7-N and AP24-N both preferentially interact with the acute step edges of dislocation hilllocks, leading to bunching of these step edges. Moreover, AP7-N and AP24-N both induce formation of deposits on terrace surfaces. Comparatively, AP24-N exhibited higher mineral modification activity over AP7-N with regard to step edge inhibition and deposit formation. In contrast, n10-N exhibits an increased preference for terrace surfaces, which leads to plugging growth morphology that block the advance of acute and obtuse step edges and the emergence of new non-parallel steps. Random scrambling of the n10-N and AP7-N sequences resulted in substantially reduced mineral modification activities, indicating the necessity of the primary sequence of each polypeptide is crucial for recognition of surface features.

Titanium implants have been used for decades with success in various applications. The characteristic of titanium that allows acceptance in the body is not well defined. It is hypothesized that the interaction of titanium implants with inorganic components of bodily fluids is key to stabilization of the aragonite polymorph during shell development. In particular, the relationship between the secondary structure recognition of mineral surface features is not clearly understood. It is known that osteopontin is an important protein involved with bone formation and is known to affect the growth of both hydroxyapatite and dicalcium phosphate. However, very little is known regarding the mechanism of protein manipulation of calcium carbonate biomineral formation. In particular, the relationship between the secondary structure recognition of mineral surface features is not clearly understood.

Previously, we identified 30 AA N-terminal mineral binding domains that originate from three different nacre-specific proteins (AP7, AP24, n10). These binding domains termed AP7-N, AP24-N, and n10-N, induce morphological changes in calcium carbonates in vitro and are similar in amino acid composition, but differ significantly from each other with regard to their primary sequences. Using a flow cell-equipped AFM instrument, we investigated the sites of adsorption of each mineral-binding domain onto calcite dislocation hilllocks. We find that AP7-N and AP24-N both preferentially interact with the acute step edges of dislocation hilllocks, leading to bunching of these step edges. Moreover, AP7-N and AP24-N both induce formation of deposits on terrace surfaces. Comparatively, AP24-N exhibited higher mineral modification activity over AP7-N with regard to step edge inhibition and deposit formation. In contrast, n10-N exhibits an increased preference for terrace surfaces, which leads to plugging growth morphology that block the advance of acute and obtuse step edges and the emergence of new non-parallel steps. Random scrambling of the n10-N and AP7-N sequences resulted in substantially reduced mineral modification activities, indicating the necessity of the primary sequence of each polypeptide is crucial for recognition of surface features.

Titanium implants have been used for decades with success in various applications. The characteristic of titanium that allows acceptance in the body is not well defined. It is hypothesized that the interaction of titanium implants with inorganic components of bodily fluids is key to stabilization of the aragonite polymorph during shell development. In particular, the relationship between the secondary structure recognition of mineral surface features is not clearly understood. It is known that osteopontin is an important protein involved with bone formation and is known to affect the growth of both hydroxyapatite and dicalcium phosphate. However, very little is known regarding the mechanism of protein manipulation of calcium carbonate biomineral formation. In particular, the relationship between the secondary structure recognition of mineral surface features is not clearly understood.

Previously, we identified 30 AA N-terminal mineral binding domains that originate from three different nacre-specific proteins (AP7, AP24, n10). These binding domains termed AP7-N, AP24-N, and n10-N, induce morphological changes in calcium carbonates in vitro and are similar in amino acid composition, but differ significantly from each other with regard to their primary sequences. Using a flow cell-equipped AFM instrument, we investigated the sites of adsorption of each mineral-binding domain onto calcite dislocation hilllocks. We find that AP7-N and AP24-N both preferentially interact with the acute step edges of dislocation hilllocks, leading to bunching of these step edges. Moreover, AP7-N and AP24-N both induce formation of deposits on terrace surfaces. Comparatively, AP24-N exhibited higher mineral modification activity over AP7-N with regard to step edge inhibition and deposit formation. In contrast, n10-N exhibits an increased preference for terrace surfaces, which leads to plugging growth morphology that block the advance of acute and obtuse step edges and the emergence of new non-parallel steps. Random scrambling of the n10-N and AP7-N sequences resulted in substantially reduced mineral modification activities, indicating the necessity of the primary sequence of each polypeptide is crucial for recognition of surface features.
Bimolecular interactions lead to the formation of inorganic crystals with unique, ordered, refined shapes that are regulated by specific macromolecules. Bioceramics are composite materials composed of an intimately associated network of organic macromolecules and inorganic crystals organized on a scale from angstroms to millimeters, where the minute amount of organic material not only increases the mechanical properties of the bioceramic, but also contributes to the nucleation, growth, shape and final organization of the inorganic phase. In order to know how the organic phase regulates the formation of hard tissues, we evaluated the effect of soluble matrices extracted from different bioceramics on crystal morphology. Soluble matrices obtained after decalcification of the bioceramics were biochemically characterized by electrophoresis and dot blot using monoclonal antibodies against some proteoglycans, and the effect on crystal morphology using in vitro crystallization assays was analyzed by SEM.

Crystal morphology modifications are closely related with the structure and charging of the organic macromolecules involved.

Lipidated Peptides as Templates for CaCO3 Mineralization. Kren Alexander1, Silvia Cavalli1, Daniela C. Poppescu2, Emily E. Tellers1, Mark Overhand1 and Nico A. J. M. Sommerdijk2; 1Leiden Institute of Chemistry, Leiden University, Leiden, Netherlands; 2Laboratory of Macromolecular and Organic Chemistry, Eindhoven University of Technology, Eindhoven, Netherlands.

The formation of crystals in nature is a very sophisticated process. In order to gain a deeper understanding of this fascinating event, biominetics are chosen as templates. In particular, well-defined Langmuir monolayers can be employed as molecular blueprints for the oriented nucleation of inorganic materials. In our study a series of amphiphilic peptides were designed incorporating a peptide head group of variable length: two, three and four repeated units of alternating hydrophilic and hydrophobic amino acid residues. This alternation plays a primary role in the generation of beta-sheet secondary structure at the air/water interface. Furthermore a phospholipid tail was introduced to stabilize the monolayer. This approach should provide a network of carboxylic acid groups positioned at specific distances in order to direct CaCO3 calcite crystal growth. In the work described here self-organizing beta-sheet monolayers acted as template in the crystallization of CaCO3, resulting in habit-modified calcite crystals with two main kinds of morphologies.

Investigating Protein-Mineral Interactions in a Marine Invertebrate System. Géraldine Plik, Sunesh Vallyattelil1, Brigitte Wopenka1, Siping Roger Qu2, James J. De Yoreo1 and Daniel E. Morse1; 1Biomolecular Science and Engineering Graduate Program, University of California, Santa Barbara, Santa Barbara, California; 2Department of Chemistry, National University of Singapore, Singapore, Singapore; 3Department of Earth and Planetary Sciences, Washington University, St. Louis, Missouri; 4Department of Chemistry and Materials Science, Lawrence Livermore National Laboratory, Livermore, California.

The predominance of acidic proteins and polysaccharides detected in biomineralized CaCO3 structures suggests that mineralization is controlled through interactions between charged macromolecules and mineral ions and surfaces. In this study, the most acidic proteins were selectively isolated from abalone shell mucus. These proteins are two variants of 8.7 and 7.8 kDa designated AP8 (for arginine proteins of approximately 8 kDa) and AP9, respectively. The AP8 composition was dominated by Asx (~35 mol%) and Gly (~40 mol%) residues, indicating that their structures have high Ca2+ binding capacity and backbone flexibility. In vitro mineralization of CaCO3 in the presence of the purified AP8 proteins resulted in elongated calcite crystals, demonstrating that the AP8 proteins are more effective crystal-modulators than other proteins from the same biomineralized material. AFM analyses reveal that stereochemical recognition by the AP8 proteins occurs at the step edges of calcite hillocks to modify both the kinetics and morphology of crystal growth. By combining molecular with conventional macroscopic crystal analyses, we provide direct evidence to support the hypothesis that protein-mineral interactions at the step edges of crystal surfaces can be responsible for the corresponding morphologies of macroscopic crystals. These observations thus help resolve the competing theories of face- versus step-specific interactions between proteins and crystal surfaces proposed for related biomineralization systems. This insight into the complex interactions that take place between newly forming biogenic minerals and the macromolecules that control their crystallization.

Well Dispersed Nanophase Titania in Poly-lactic-co-glycolic Acid (PLGA) Scaffolds for Bone Tissue Engineering Applications. Hsinin Liu1, Elliott B. Shansovich1 and Thomas J. Webster2; 1Materials Engineering, Purdue University, West Lafayette, Indiana; 2Biomedical Engineering, Purdue University, West Lafayette, Indiana.

Bone substitutes are often required to replace damaged tissue due to injuries, diseases and genetic malformations. Traditional bone substitutes, such as autografts, allografts, xenografts and metallic implants, are far from ideal and each have their own specific problems and limitations. Bone tissue engineering offers a promising opportunity for bone regeneration in a natural way. However, currently the scientific challenges of bone tissue engineering lie in the development of suitable scaffold materials that can improve cell adhesion, proliferation and differentiation. The design of nanophase titania/PLGA composites offers an exciting approach to combine the advantages of a degradable polymer with nano-size ceramic grains to optimize physical and biological properties for bone regeneration. Importantly, nanophase titania mimics the size scale of constituent components of bone since bone itself is a nanostructured composite composed of organic and inorganic phases. studying materials that can improve bone regeneration.

Mineralization of bones and teeth occur by the nucleation of hydroxyapatite crystals in an extracellular matrix consisting of predominantly type 1 collagen and a variety of noncollagenous proteins. Among the noncollagenous proteins, dentin matrix protein 1 (DMP1) an acidic protein found in the mineralised matrix of bones and teeth has been postulated to play an important role in interacting with calcium ions and mineral surfaces. To investigate on the mineral initiating role of DMP1 we have devised a methodology to study its properties in a semi solid medium mimicking the extracellular environment in mineralized tissues. In this procedure the crystals were grown by controlled chemical reaction between calcium and phosphate ions at physiological pH and temperature with and without recombinant DMP1 (rDMP1). After 45 days of growth the calcium phosphate deposits were observed using electron microscopy (SEM). Results demonstrate the presence of spherical and platy crystals in the absence of rDMP1, whereas only spherulitic crystals were seen in the presence of DMP1. These crystals were
further characterized by powder x-ray diffraction analysis (XRD), Raman spectroscopic analysis, Scanning electron microscopic analysis and energy dispersive spectroscopic (EDX) analysis. Results from these analysis showed that the spherulitic and platy crystals grown in the absence of r-DMPI were predominantly monetite and brushite respectively. Crystals grown in the presence of r-DMPI were identified as hydroxyapatite. Further, the calcium and phosphorous content were confirmed by EDX analysis and the Ca/P ratio of the crystals grown in the presence of r-DMPI was found to be between 1.64-1.67. Thus, DMPI can control the calcium phosphate crystal morphology during crystal nucleation and growth. This research was supported by NIH grant 16538.

**4:00 PM K13.3**

Probing In Vitro Interactions of Immortalized Human Bone Marrow Stromal Cells with Novel Bioactive Glass Coatings. 

Jie Song1,2, Eduardo Saiz3, Vicent Eng2, Carolyn R. Bertozzi1,2, and Antonio P. Tomas2,1; 1Materials Sciences Division, Lawrence Berkeley National Lab, Berkeley, California; 2Molecular Foundry, Lawrence Berkeley National Lab, Berkeley, California; 3Departments of Chemistry and Molecular and Cell Biology, University of California, Berkeley, California.

Metals have been widely used for fracture fixation, joint replacement and dental applications. To improve the ability of bioinert metallic implants to bond to osseous and dental tissues, bioactive surface coatings such as hydroxyapatite (HA) are often applied via plasma spray. Although these bioactive ceramics have been shown to facilitate the implant-tissue integration and lead to faster healing, in vivo studies have demonstrated that the unreliable metal-ceramic adhesion contributes to the long-term failure of these implants. A novel glass family in the Si-Na-K-Mg-Ca-P-O system has been developed to prepare graded glass-HA coatings on metallic implants using a simple enameling technique. The coatings consist of a high silica layer in contact with the alloy and a surface layer that is a mixture of a low silica glass and HA particles. The coatings form apatite in simulated body fluid while maintaining excellent adhesion with the alloy. To probe the physiological relevance of these novel coatings for potential implant applications, the proliferation and expression of osteoblastic marker proteins of normal human osteoblastic cells on these glasses should be examined. Normal human osteoblasts (NIHOst) and bone marrow stromal cells (BMC) have limited proliferative life span in culture and gradually lose their osteogenic potential in culture, making the use of these cell lines for screening biocompatible implant coatings inconvenient. Immortalized human bone marrow stromal cells (hTERT-BMCs), established via ectopic expression of human telomerase in normal human BMCs, have extended life span in culture and do not exhibit growth deregulation. They were seeded onto a number of novel glasses, alloy substrates with graded coatings, and Ti6Al4V and tissue culture polystyrene controls for in vitro cell culture studies. These cells were cultured in the presence of 1,25-dihydroxyvitamin D3, which is known to induce differentiation of BMCs into osteoblasts lineage. Cell lysates were collected at various time points, and cell proliferation was examined using a dsDNA quantification assay. The expression of osteogenic marker proteins including osteocalcin and osteopontin, as well as important extracellular matrix proteins such as collagen I and cytoskeletal protein -tubulin, was examined by Western blotting and microtiter plate immunoassays. The expression of alkaline phosphatase activity and the extent of mineralization in culture were also quantified.

**4:15 PM K13.4**

Hydroxyapatite Thin Films Produced by Radio Frequency Magnetron Sputtering from Two Facing Targets. 

Donald E. Ellis1,2, Z. Hong1, L. Luan1, Alexandre Rossi1, Alexandre Mello1, J. G. Eon1, John Keterson2 and Joice Terra3; 1Physics and Astronomy, Northwestern University, Evanston, Illinois; 2Chemistry, Northwestern University, Evanston, Illinois; 3Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, RJ, Brazil; 4Instituto de Quimica, Fed. University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil.

We have produced hydroxyapatite (HA) thin films on fused silica using R.F. magnetron sputtering from two facing targets in a right angle geometry. This design greatly reduces negative-ion re-sputtering effects caused by oxynions, and thus preserves the stoichiometry of the targets. We studied both as-sputtered and annealed films (800°C in Ar) Water vapor was introduced during either the deposition or annealing process. Films were characterized by AFM, stylus profilometry, XRD, XPS, FTIR and Raman spectroscopy. Our XPS measurements showed that the as-sputtered films retain the same Ca/P ratio as that of the targets over a wide range of Ar pressures. Our XRD results show that the films are highly-textured along the HA(x00) direction. A comparison was also made for growth on several different substrates (SiO2, Si(100), Si(110), Si(111) and Ti. Structural and bonding characteristics of the films are discussed in the light of atomistic simulations and Density Functional electronic structure calculations.