RESEARCH REPORT
Composite Materials

Composite Materials Research

This report by MIT's Industrial Liaison Program identifies selected MIT research and faculty with expertise in the area of the composite materials. This survey by MIT’s Industrial Liaison Program captures information dated between mid- to late-2008 and September 2010.

For more information, please contact MIT’s Industrial Liaison Program at +1-617-253-2691.

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COMPOSITE MATERIALS IN GENERAL

TECHNOLOGY LABORATORY FOR ADVANCED MATERIALS AND STRUCTURES (TELAMS)
Other Investigators: Prof. John Dugundji, Prof. Brian L Wardle
Date: 05/05/10
http://web.mit.edu/telams/
http://web.mit.edu/telams/pages/publications_00.html

The Technology Laboratory for Advanced Materials and Structures (TELAMS), known since its establishment as TELAC (The Technology Laboratory for Advanced Composites), has been dedicated to providing leadership in the advancement of the knowledge and capabilities of the composites and structures community through education of students, original research, and interaction with the community at large. This leadership continues today at TELAMS, with an emphasis on composite materials, as the research topics span a wide spectrum, from basic understanding of composite materials to their behavior in specific structural configurations, with the ultimate objective of gaining a sufficient understanding of the properties of a composite laminate's basic building block, and how these properties interact to determine properties of laminates and structures made of composite materials.

Recently, the focus of the laboratory has broadened into other areas, and thus its renaming. These areas include multi-scale modeling and simulation of the mechanics of advanced materials used in the aerospace industry with emphasis on understanding the influence of micro-structural features of deformation and failure in their effective engineering response, computational modeling in solid mechanics, and design, fabrication, and testing of micro-electromechanical systems (MEMS), along with their associated materials and processes...
http://web.mit.edu/telams/

CHEMICAL PRODUCTION OF FUNCTIONALIZED GRAPHENE FOR ENHANCED COMPOSITE MATERIALS
Fall 2009 MIT Deshpande Center for Technological Innovation Ignition Grant
Prof. Timothy Swager, John D MacArthur Professor of Chemistry,
http://web.mit.edu/chemistry/www/faculty/swager.html

Graphene, a sheet of carbon one atom thick, is the thinnest and strongest known material. There are many commercial applications where graphene could be used as part of a composite material such as in electronic packaging for organic electronics, gas-transport barrier agents, materials for the semiconductor industry, and food and beverage packaging. The challenge is to produce graphene economically in large quantities. This project will develop a chemical process to produce graphene at a very reasonable cost which would allow the manufacture of a new class and exciting materials and products.
AEROSPACE & AUTOMOTIVE APPLICATIONS

NANO-ENGINEERED COMPOSITE AEROSPACE STRUCTURES (NECST) CONSORTIUM
Director: Prof. Brian L. Wardle, Associate Professor of Aeronautics and Astronautics,
http://necst.mit.edu/

NECST formally launched in May 2007 during the first Members-only meeting on the MIT campus. The NECST Consortium’s technology focus is to improve the performance of advanced aerospace materials/structures through strategic use of carbon nanotubes (CNTs) combined with traditional advanced composites to form hybrid architectures. Two primary 3D nano-engineered architectures are being explored and developed, both polymer-matrix based. The fabrication strategy involves novel synthesis of high-quality, long (several millimeters), aligned CNTs placed strategically in existing advanced composite systems. Early results have demonstrated that high-quality CNT/traditional hybrid composite laminates can be architected and fabricated at rates and scales that can be used in full-scale aerospace structures; this made the formation of the NECST industry Consortium imperative...

The research of the Consortium spans topics from fundamental science (e.g., catalyst characteristics for CNT growth) to more applied research such as laminate level manufacturing and characterization, to such topics as environmental health and safety of nanostructured materials... More at http://necst.mit.edu/

MIT News Office: “Researchers make carbon nanotubes without metal catalyst”

Oxides, as well as metals, seem to be able to sprout carbon nanotubes, study finds
Kate Greene, MIT News Office correspondent, August 10, 2009

Carbon nanotubes - tiny, rolled-up tubes of graphite - promise to add speed to electronic circuits and strength to materials like carbon composites, used in airplanes and racecars. A major problem, however, is that the metals used to grow nanotubes react unfavorably with materials found in circuits and composites. But now, researchers at MIT have for the first time shown that nanotubes can grow without a metal catalyst. The researchers demonstrate that zirconium oxide, the same compound found in cubic zirconia "fake diamonds," can also grow nanotubes, but without the unwanted side effects of metal.

The implications of ditching metals in the production of carbon nanotubes are great. Historically, nanotubes have been grown with elements such as iron, gold and cobalt. But these can be toxic and cause problems in clean room environments. Moreover, the use of metals in nanotube synthesis makes it difficult to view the formation process using infrared spectroscopy, a challenge that has kept researchers in the dark about some of the aspects of nanotube growth.

"I think this fundamentally changes the discussion about how we understand carbon nanotubes synthesis," says Brian Wardle, professor of aeronautics and astronautics who led the study, published Aug. 10 in the online version of the Journal of the American Chemical Society...

The researchers found that if they just used zirconium oxide nanoparticles on the substrate, they could coax carbon into nanotubes as well. Importantly, the mechanism for growth seems to be completely different from that of metal nanoparticle-grown tubes. Instead of dissolving into the
nanoparticle and precipitating out, zirconia-grown nanotubes appear to assemble directly on the surface.

One of the most exciting implications of the finding is that it means that carbon fiber and composites, used to make different types of crafts, could be strengthened by nanotubes. "Composites are durable, but fail under certain loading conditions, like when plywood flakes and splinters apart," says Stephen Steiner, an MIT graduate student and the study's first author. "But what if you could reinforce composites at the microlevel with nanotubes the way that rebar reinforces concrete in a building or a bridge? That's what we're trying to do to improve the mechanical properties and resistance to fracturing of carbon composites."... http://web.mit.edu/newsoffice/2009/nanotubes-0810.html

METHODOLOGY TO EXTEND LIFE AND PREVENT FAILURE OF CRITICAL AIRPLANE ENGINE COMPONENTS VIA AN IMPROVED NON-DESTRUCTIVE EVALUATION (NDE) PROCESS
Principal Investigator: Prof. Thomas W Eagar
Date: 05/07/09
Center for Materials Research in Archaeology and Ethnology

This project deals with critical engine life-limited parts (LLPs) in airplane engines to detect defects smaller than 0.030 x 0.015 inches in length reliably using both surface and bulk NDE techniques. The FAA has defined engine LLPs as rotor and major static structural parts whose primary failure is likely to result in a hazardous engine effect. As the fleet of commercial aircraft ages, the possibility of a hazardous engine effect due to fatigue crack propagation increases. Advanced NDE techniques being evaluated in this research have the capability of detecting flaws before critical failure occurs.

BIOLOGICAL & NATURAL MATERIALS

BIOMOLECULAR MATERIALS GROUP
Prof. Angela Belcher, Gersheshausen Professor of Materials Science and Engineering and Biological Engineering, and MacArthur Fellow,
http://dmse.mit.edu/faculty/faculty/belcher/index.html

...In the Biomolecular Materials Group, we are evolving simple organisms using directed evolution to work with the elements in the rest of the periodic table. We encourage these organisms to grow and assemble technologically important materials and devices for energy, the environment, and medicine. These hybrid organic-inorganic electronic and magnetic materials have been used in applications as varied as solar cells, batteries, medical diagnostics and basic single molecule interactions related to disease. In doing so, we have capitalized on many of the wonderful properties of biology–using only non-toxic materials, employing self-repair mechanisms, self-assembling precisely and over longer ranges, and adapting and evolving to become better over time. http://belcher10.mit.edu/research/

http://pubs.acs.org/doi/abs/10.1021/nl1005993

We report the synthesis and electrochemical activity of gold and silver noble metals and their alloy nanowires using multiple virus clones as anode materials for lithium ion batteries. Using two clones, one for specificity (p8#9 virus) and one versatility (E4 virus), noble metal nanowires of high-aspect ratio with diameters below 50 nm were successfully synthesized with control over particle sizes, morphologies, and compositions. The biologically derived noble metal alloy nanowires showed electrochemical activities toward lithium even when the electrodes were prepared from bulk powder forms. The improvement in capacity retention was accomplished by alloy formation and surface stabilization. Although the cost of noble metals renders them a less ideal choice for lithium ion batteries, these noble metal/alloy nanowires serve as great model systems to study electrochemically induced transformation at the nanoscale. Given the demonstration of the electrochemical activity of noble metal alloy nanowires with various compositions, the M13 biological toolkit extended its utility for the study on the basic electrochemical property of materials.

CELLULAR SOLIDS GROUP
Prof. Lorna Gibson, Matoula S Salapapas Professor of Materials Science and Engineering, and Professor of Civil and Environmental Engineering and Mechanical Engineering,
http://dmse.mit.edu/faculty/faculty/ljgibson/

Many materials have a cellular structure, with either a two-dimensional array of prismatic cells, as in a honeycomb, or a three-dimensional array of polyhedral cells, as in a foam. Engineering honeycombs and foams can now be made from nearly any material: polymers, metals, ceramics, glasses and composites, with pore sizes ranging from nanometers to millimeters... Cellular materials are increasingly used in biomedical applications. Open-cell titanium foams are used to replace trabecular bone. Porous scaffolds for regeneration of damaged or diseased tissues often resemble an open-cell foam. Cellular materials are also widespread in nature in plant and animal tissues: examples include wood, cork, plant parenchyma, trabecular bone and lung alveoli.

Our group has contributed to the understanding of the mechanics of cellular solids, as well as to their use in many of the above applications. Recent and current projects include: the mechanics of fluid flow through open-cell foams for helmets and blast protection; the design and characterization of osteochondral scaffolds for the regeneration of cartilage as well as the underlying bone; and the mechanical interaction between biological cells, such as fibroblasts, and tissue engineering scaffolds (e.g., cell migration, contraction).
http://web.mit.edu/dmse/csg/Research.html

Cellular Solids in Nature
Date: 06/19/09

Natural cellular materials such as (a) cork (b) balsa wood (c) sponge (d) trabecular bone (e) coral (f) cuttlefish bone (g) iris leaf and (h) stalk of a plant are observed.
**Scaffolds for Tissue Regeneration**

Date: 06/19/09

Collagen-GAG scaffolds -- These collagen-GAG scaffolds were made using a freeze-drying technique developed in Prof. Yannas’ lab and modified in collaboration with our group. Scaffolds like this are used for regenerating skin in burn patients. Our group has worked in collaboration with Prof. Yannas’ group, as well as Prof. Bonfield’s group at Cambridge University, on modifying the scaffolds for use in regenerating cartilage.

Mineralized collagen-GAG scaffolds -- The mineralized collagen-GAG scaffolds shown above were made using a freeze-drying technique developed in collaboration with Prof. Yannas’ group, as well as Prof. Bonfield’s group at Cambridge University. These scaffolds are designed for bone regeneration.

Osteochondral Scaffold -- A micro-computed tomography image of an osteochondral scaffold, showing the upper collagen-GAG compartment as well as the lower collagen-GAG-calcium phosphate compartment. The scaffold is designed to regenerate cartilage as well as the underlying bone. This work was done in collaboration with Prof. Yannas’ group, as well as Prof. Bonfield’s group at Cambridge University. [http://web.mit.edu/dmse/csg/Tissue_Regeneration.html](http://web.mit.edu/dmse/csg/Tissue_Regeneration.html)

**MECHANICAL PROPERTY AMPLIFICATION IN NATURAL MATERIALS**

Principal Investigator: Prof. Christine Ortiz, Dean for Graduate Education and Professor of Materials Science and Engineering. [http://dmse.mit.edu/faculty/faculty/cortiz/](http://dmse.mit.edu/faculty/faculty/cortiz/)

Other Investigators: Prof. Mary C Boyce, Prof. Raul A Radovitzky

Date: 06/24/08

Institute for Soldier Nanotechnologies—Ballistic and Blast Protection

[http://web.mit.edu/isn/research/sra03/project03_01_03.html](http://web.mit.edu/isn/research/sra03/project03_01_03.html)

Researchers, lead by Ortiz and involves investigating natural occurring nanostructured materials to establish design laws to guide the fabrication of man-made nanocomposites that will exhibit high strength and toughness. This project is motivated from the perspective of mechanical property amplification of structural materials. The elucidation of mechanical design principles and energy absorption mechanisms which go beyond a simple composite rule of mixtures is of interest for many nonballistic/nonblast materials applications. The team will investigate the exact types of threats a range of hard nanostructured biocomposites experience in their environment; i.e. load magnitudes, rates, type, penetration vs. blunt impact, etc. Ortiz will supervise the structural and mechanical study of the chosen systems using state-of-the-art nanoscale mechanical testing instruments and microscopy. In particular there will be a sustained effort to develop methodologies that are able to quantitatively assess the mechanical properties of small volume samples and measure local property gradients/heterogeneity, which are extremely important to the development of improved nanoscale materials systems for Army applications. The project also involves Boyce and Radovitzky for theoretical modeling, in the field of finite element analysis (FEA) as well as multilayered structures. In addition, a collaboration with several Army research labs will aim to bridge the modeling of the studied systems from atomistic scale to macroscale, so as to enable prediction of larger scale mechanical behaviors from nanoscale properties.
NANOMECHANICS OF COLLAGEN FIBRILS
Principal Investigator: Prof. Markus J Buehler, Esther and Harold E Edgerton Career Development Associate Professor of Civil and Environmental Engineering, http://cee.mit.edu/buehler
Date: 11/25/08

Atomistic-based hierarchical multiscale modeling of a complex biological composite material. Our hierarchical multi-scale simulation scheme enables us to develop a fundamental, atomistic based description of collagen. Our molecular model of collagen is used to investigate several aspects related to collagen based tissues, including source of elasticity, fracture behavior, molecular origin of diseases, synthesis of synthetic collagen and the mechanics of mineralized tissue such as bone.


PLASTICITY AND FRACTURE MECHANICS OF BONE
Principal Investigator: Prof. Markus J Buehler, Esther and Harold E Edgerton Career Development Associate Professor of Civil and Environmental Engineering, http://cee.mit.edu/buehler

Molecular modeling is used to study the elementary deformation mechanisms of fracture of bone materials. This provides insight into the origin of bone's great toughness, high strength and light weight... http://web.mit.edu/mbuehler/www/index.html#research

Paper: “Merger of structure and material in nacre and bone – Perspectives on de novo biomimetic materials”

In contrast to synthetic materials, evolutionary developments in biology have resulted in materials with remarkable structural properties, made out of relatively weak constituents, arranged in complex hierarchical patterns. For instance, nacre from seashells is primarily made of a fragile ceramic, yet it exhibits superior levels of strength and toughness. Structural features leading to this performance consist of a microstructure organized in a hierarchical fashion, and the addition of a small volume fraction of biopolymers. A key to this mechanical performance is the cohesion and sliding of wavy ceramic tablets. Another example is bone, a structural biological material made of a collagen protein phase and nanoscopic mineral platelets, reaching high levels of toughness and strength per weight. The design and fabrication of de novo synthetic materials that aim to utilize the deformation and hardening mechanism of biological materials such as bone or nacre is an active area of research in mechanics of materials. In this review, our current knowledge on microstructure and mechanics of nacre and bone are described, and a review of the fabrication of nacre-inspired artificial and related materials is presented...
BUILDING & INFRASTRUCTURE TECHNOLOGIES

CONCRETE SUSTAINABILITY HUB (CSH)
Executive Director: Prof. Hamlin M. Jennings, Adjunct Professor of Civil and Environmental Engineering, http://cee.mit.edu/jennings

Concrete Materials Science Platform
One of the most critical issues for a sustainable development of concrete as the backbone material for infrastructure and housing is to address the CO2 footprint of concrete materials. We propose a new way to address this issue, one that is based on a shift of paradigm that will transform the way cement based materials are designed and characterized by industry for “green” concrete applications. The basis of our paradigm-shifting R & D is the first atomistic-scale computational model of this complex material from which we will predict new structures and improved properties that will revolutionize how cement is designed, slash CO2 emissions, and enable US leadership in future energy-related cement technologies. To drive this idea from discovery to technology, MIT scientists and engineers will leverage collaborations and industrial partnerships of the Concrete Sustainability Hub with Federal Laboratory experts and computational resources. http://web.mit.edu/cshub/research/index.html

Thrust II – Precipitation of the C-S-H gel
The large number of coupled chemical reactions during the formation of the C-S-H gel and its heterogeneity make difficult a proper characterization of its nucleation and growth mechanism. Our team goal is to study how the C-S-H gel is formed from the electrolyte pore solution, using reactive Molecular Dynamics and Monte Carlo approaches. We will obtain the growth kinetics of the C-S-H gel. http://web.mit.edu/cshub/research/projects.html

Thrust III – Micro-texture Development
The key process at the microscale is the percolation of the colloidal C-S-H gel nanoparticles. Using a variety of atomistic simulation methods combined with advanced statistical physics (meta-dynamics approaches), we aim to explore these forces, which will lead to understanding the complex processes that take place in the cement paste, i.e. setting, creep, and shrinkage. http://web.mit.edu/cshub/research/projects.html

INFRASTRUCTURE SCIENCE & TECHNOLOGY (IST) GROUP
Professor Oral Buyukozturk, Professor of Civil and Environmental Engineering, http://cee.mit.edu/buyukozturk

The general goal of the IST Group is to contribute to the science and engineering knowledge base for the advancement of understanding, assessment, and effective renewal of civil infrastructure systems. The IST Group aims at the development of new scientific and engineering knowledge in the following key areas:

- Deterioration science examines conditions and processes by which materials and structures breakdown overtime. Our understanding needs to be improved as a basis for designing, building, and maintaining structures that are durable, safe, and environmentally sound.
• Assessment technologies allow us to assess the existing mechanical condition of materials and structures. Research in this area is needed to develop effective nondestructive evaluation techniques and improved sensor technologies.

• Renewal engineering aims at the extension of the life of physical infrastructure systems and components, and at the enhancement of load capacities of these systems to meet the increased demands imposed on them. We focus our research in this aspect on developing and implementing effective repair and strengthening methods using high performance advanced composite materials. See: http://web.mit.edu/istgroup/ist/index.html

Projects:

**Debonding of Bi-layer Material Systems under Moisture Effects: A Multi-scale Fracture Approach**
Date: 8/05/10

To develop a methodology to apply molecular dynamics (MD) simulation to the study of interface fracture in bi-layer material systems with and without moisture effect. To extend the applicability of MD to meso-scale structure, a multi-scale analysis technique that combines MD and FEM will be developed. More: http://web.mit.edu/istgroup/ist/research/molecular_dynamics.html

**Energy Dissipation Properties of Infilled RC Frames Retrofitted with CFRP**
Date: 8/05/10

Retrofitting and strengthening of existing reinforced concrete (RC) structures against earthquake effects has become a subject of focus during the last decade...

The main objective of this study is to determine the best energy dissipative retrofitting technique for an effective strengthening of the infilled RC frames by the use of Carbon Fiber Reinforced Polymers sheets. Infill walls in RC frames are essential stiffness, strength and damping sources and they increase the energy dissipation capacities of the overall structure.

For this study, CFRP strips where applied to the infilled frames to convert the frame structure into a load resisting composite system with increased stiffness and strength capacities, and especially improved damping and energy dissipation properties. Alternative retrofitting schemes, namely diamond cross braced and cross braced configurations, have been evaluated in order to preserve the weak beam column joint region while keeping the integrity of the system... More at http://web.mit.edu/istgroup/ist/documents/earthquake_summary.pdf

**Moisture Affected Debonding in FRP Retrofitted Systems - An Interface Fracture Approach**
Date: 08/05/10

The objective of this research is to develop an in-depth mechanistic understanding of the behavior of interfacial fracture through proper quantification of moisture affected debonding in FRP retrofitted concrete systems in order to form a basis for future design guideline development... http://web.mit.edu/istgroup/ist/research/moistureDebonding.htm and http://web.mit.edu/istgroup/ist/documents/NSF_Project_Summary_revised.pdf
Remote Detection of Damages in FRP-retrofitted Concrete Structures using Acoustic-Laser Vibrometry

Date: 08/05/10

Damage in FRP-concrete Systems Fiber-reinforced polymer (FRP) composites are being used to retrofit or strengthen existing concrete structural members. Nonetheless, subsequent damage to the repaired systems can occur in form of interface debonding and concrete cracking underneath FRP layer. These invisible damages are caused by environmental exposure, recurring seismic event, or insufficient workmanship during repair process. It has been recently identified that a FRP-retrofitted concrete beams and columns could appear safe without showing any sign of substantial damage, yet containing a severely deteriorated concrete and debonded FRP composites. Therefore, an efficient NDT technique is required for timely damage detection.

The objective is to develop a technique to image flaws and damage in FRP-retrofitted concrete members, using an experimental opto-acoustic system, that employs difference in vibration signal of acoustically excited externally bonded FRP plates or wrapped FRP sheets. More at http://web.mit.edu/istgroup/ist/research/acoustic_ndt.html

ELECTRONICS, PHOTONICS - RELATED

ORGANIC & NANOSTRUCTURED ELECTRONICS (ONE LAB)
Principal Investigator: Prof. Vladimir Bulović, VanBuren N Hansford (1937) Professor of Electrical Engineering; Director, Organic and Nanostructured Electronics Laboratory (ONE Lab); and Co-Director, Solar Frontiers Center and Solar Revolutions Project, http://www.rle.mit.edu/organic/people.htm

We study physical properties of organic thin films, structures, and devices. Our fundamental findings are applied to the development of practical optoelectronic, electronic, and photonic organic devices of nano-scale thickness, including visible LEDs, lasers, solar cells, photodetectors, transistors, chemical sensors, and memory cells. In addition to working on small-molecular-weight van der Waals bonded organic thin films, we are also examining hybrid organic/inorganic structures, polymer solids, and self-assembled materials. Integral to this research is development of new methods for materials growth and techniques for directed nano-scale patterning over large areas. More at http://www.rle.mit.edu/organic/research.htm

Heterojunction Photodetector Consisting of Metal-Oxide and Colloidal Quantum Dot Thin Films
Principal Investigator: Prof. Vladimir Bulović, VanBuren N Hansford (1937) Professor of Electrical Engineering; Director, Organic and Nanostructured Electronics Laboratory (ONE Lab); and Co-Director, Solar Frontiers Center and Solar Revolutions Project, http://www.rle.mit.edu/rleonline/People/VladimirBulovic.html
Other Investigator(s): Prof. Moungi G Bawendi, Lester Wolfe Professor of Chemistry http://web.mit.edu/chemistry/www/faculty/bawendi.html
We demonstrate a heterojunction photodetector consisting of a metal-oxide charge transport layer and a colloidal quantum-dot (QD) charge-generation layer. To make the device, a metal-oxide semiconductor, SnO2, is sputter-deposited over an array of interdigitated gold electrodes. A thin film of PbS QDs is then spin-coated over the structure. The optical and electrical characteristics of the device can be optimized independently through the modification of these two layers.

The metal-oxide and QD layers form a type-II hetero-interface suitable for dissociating photogenerated excitons. Exciton dissociation at the interface results in the generation of holes in the QD layer and electrons in the metal-oxide layer. A bias corresponding to a field of ~104 V/cm is applied across the electrodes to facilitate carrier collection. The increased electron density increases the metal-oxide film conductivity, which in turn manifests an increase in lateral current through the device. A plot of the spectrally resolved external quantum efficiency is shown, with high efficiency response matching the spectral response of quantum-dot absorption...


**Inkjet-printed Quantum Dot and Polymer Composites for Electroluminescent Devices**

Principal Investigator: Prof. Vladimir Bulović, VanBuren N Hansford (1937) Professor of Electrical Engineering; Director, Organic and Nanostructured Electronics Laboratory (ONE Lab); and Co-Director, Solar Frontiers Center and Solar Revolutions Project,

http://www.rle.mit.edu/rleonline/People/VladimirBulovic.html

Other Investigator(s): Prof. Moungi G Bawendi, Lester Wolfe Professor of Chemistry

http://web.mit.edu/chemistry/www/faculty/bawendi.html

Date: 11/13/08

We introduce a technique for the reliable deposition of intricate, multicolored patterns using a quantum dot (QD) and polymer composite and demonstrate its application for robust AC-driven displays with high brightness and saturated colors. The AC electroluminescent (AC EL) devices are a well-established technology. Their relatively simple fabrication and long operating lifetimes make them desirable for large-area displays; however, a major challenge with AC EL remains finding efficient and stable red phosphors for multicolored displays. Colloidally synthesized QDs are robust, solution-processable lumophores offering tunable and narrowband photoluminescence across the visible spectrum. By integrating QDs into an AC EL device, we demonstrate patterning of saturated red, green, and blue pixels that operate at video brightness...


**Solution-Processed Organic Solar Concentrators**

Principal Investigator: Prof. Marc A Baldo, Associate Professor of Electrical Engineering, and Associate Director, Research Laboratory of Electronics (RLE),

http://www.rle.mit.edu/rleonline/People/MarcA.Baldo.html

Date: 11/13/08

Solar energy is a clean and abundant energy source that promises to provide sustainable and economical sources of renewable power. Solar power generation is growing; however, it is still more expensive than fossil-fuel-based electricity sources. To address the cost of solar power, we are developing organic solar concentrators (OSCs) as an alternative to conventional solar...
concentrators. These OSCs do not require tracking of the sun or cooling of the solar cells and they require a smaller area of photovoltaic (PV) cells for the same power output.

An OSC is composed of organic chromophores to absorb sunlight and re-emit photons into a planar waveguide with PV cells attached to the edges. The performance of an OSC is largely limited by self-absorption of the emitted photons by organic chromophores due to an overlap between their absorption and emission. We have investigated the used of novel chromophores and their compositions to reduce the overlap between emission and absorption. We coat glass flat-plate collectors using solution-processing, resulting in low-cost, thin-film solar collectors. This enables us to use recent advances in organic optoelectronics and apply near-field energy transfer to reduce the required concentration and hence the self-absorption of the emissive dye.

The ratio of the area of the concentrator to the area of the PV cell is the geometric gain, G. We show the external quantum efficiency (EQE) as a function of geometric gain for different systems measured at lambda = 489 nm for the composite perylene-based fluorescent system compared to the conventional 4-(dicyanomethylene)-2-t-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran(16) (DCJTB)-based fluorescent system, measured at lambda = 532 nm. The DCJTB-based OSC shows the strong self-absorption. The self-absorption is lower in the composite perylene-based OSC, consistent with the spectroscopic data.

UNIAXIAL STRAINED-SI GATE-ALL-AROUND NANOWIRE FETS
Principal Investigator: Prof. Judy L Hoyt, Professor of Electrical Engineering
Associate Director of Fabrication and Safety Officer, Microsystems Technology Laboratories (MTL), http://www-mlt.mit.edu/~jlhoyt/
Date: 10/16/09
Depts/Labs/Centers: Microsystems Technology Laboratories

In this work, GAA strained-Si NW n-MOSFETs were fabricated using a top-down approach and their intrinsic and extrinsic performance was measured. We show a sample cross-section transmission electron microscopy image of a GAA strained-Si n-MOSFET, looking down the axis of the nanowires in the device channel, showing parallel nanowires with diameter ~ 8 nm, and LTO gate dielectric. Mobility of the GAA nanowires was extracted by measuring the intrinsic gate-channel capacitance using the split-CV method, after subtracting the parasitic capacitance measured on neighboring structures without NWs. The channel intrinsic conductance was corrected for series resistance. We also show the electron effective mobility vs. average inversion charge density for ~49 nm-wide strained-Si GAA NWs, measured by both the 2-FET method and split CV, demonstrating excellent agreement between the two mobility extraction techniques. Universal (100) mobility and the mobility of planar SOI and SSDOI (t=8.7nm, close to the average thickness of strained-Si NW) and unstrained-Si NWs (WNW=44nm) are also shown for comparison. The strained-Si nanowire shows mobility enhancement over universal, thin-body planar SOI and SOI NW devices (with the slightly smaller width of ~44nm).

MIT News Story: “Straining forward: Nanowires made of ‘strained silicon’ — silicon whose atoms have been pried slightly apart — show how to keep increases in computer power coming”
Larry Hardesty, MIT News Office, January 6, 2010
Computers keep getting more powerful because silicon transistors keep getting smaller. But that miniaturization can’t continue much further without a change to the transistors’ design, which has remained more or less the same for 40 years. One potential successor to today’s silicon transistors is silicon nanowires, tiny filaments of silicon suspended like the strings of a guitar between electrically conducting pads...

Electrical-engineering professor Judy Hoyt and her graduate students Pouya Hashemi and Leonardo Gomez improved the performance of silicon-nanowire transistors by, basically, prying the atoms of the silicon slightly farther apart than they would be naturally, which allows electrons to flow through the wires more freely. Such “strained silicon” has been a standard way to improve the performance of conventional transistors since 2003. But Hoyt was one of the early researchers in the field...

To build their stacked nanowire transistors, the MIT researchers begin with a normal silicon wafer, on which they deposit a silicon-germanium composite. Because germanium atoms are bigger than silicon atoms, the distances between atoms in the silicon-germanium layer are greater than they would be in a layer of pure silicon. When the researchers deposit another layer of silicon on top of the composite, the silicon atoms try to align themselves with the atoms beneath them, so they, too, end up spaced slightly farther apart...


ENERGY, ENVIRONMENT, SUSTAINABILITY APPLICATIONS

MATERIALS SYSTEMS LABORATORY (MSL)
Faculty Director: Professor Joel Clark, http://dmse.mit.edu/faculty/faculty/jpclark/
Research Director: Dr. Frank Field III, http://esd.mit.edu/Faculty_Pages/field/field.htm

The Materials Systems Laboratory (MSL) studies the strategic implications of materials and materials processing choices. MSL research seeks to understand the competitive position of materials in specific applications, such as assessment of different candidate materials, assessment of process technologies, and evaluation of both the economic and non-economic consequences of each alternative. We also evaluate the promise and limits of materials, processes and designs; identify specific areas of improvement for each alternative that will improve its competitiveness; and determine the "best case" scenario for each option... http://msl.mit.edu/msl_about.html

Project Examples:

Materials Scarcity
This work examines how recycling provides benefit as a risk-mitigating strategy against scarcity because recycling can diversify the risks of primary supply instabilities and reduce the impact of price fluctuations upon firms. The experimental platform for this examination is a System Dynamics simulation model that strives to capture the dynamics of a particular material’s market supply, demand and price, focused initially on platinum.
**Aluminum Recycling Strategy**

This work has investigated increasing recycled aluminum usage in production by developing models that explicitly capture uncertainties in aluminum demand and scrap aluminum supply (price, composition, and availability). We have also developed models to evaluate upgrading strategies, such as sorting and segregation, as well as materials flow analysis of end-of-life aluminum. This work has been developed with the support of several industrial partners including Hydro Aluminum Metal Products, Aleris International, and Alcoa.

More at… [http://msl.mit.edu/msl_about.html](http://msl.mit.edu/msl_about.html) and [http://msl.mit.edu/msl_projects.html](http://msl.mit.edu/msl_projects.html)

**NANOFIBER MEMBRANES**


Date: 03/17/09

Electrospun fiber membranes possess high specific surface area, high porosity, small fiber size and low weight. Each of these remarkable properties suggest a broad range of applications. In our research, we take advantage of these properties to develop functional membranes through the inclusion of reactive or responsive compounds or nanoparticles upon and within the fibers. Such membranes have applications in chemical and biological protection, filtration and detoxification of toxic industrial gas or liquid streams, sensing and other areas. In one example, we have developed photocatalytically active nanofiber membranes combining both electrospinning and electrolyte nanoassembly techniques for protective clothing system, electrochemical power, sensor, and electrode applications. Highly reactive TiO2 nanoparticles were assembled on various electrospun polymeric nanofibers to achieve functional fiber membranes for photocatalytic degradation of toxic industrial chemicals...

...We have focused on the fabrication of electrospun magnetic composite membranes with polymers such as PVA, PEO, PCL and PAN, which can be used in water treatment, and in chemical and biological processing.


**CARBON-BASED NANOMATERIALS FOR ENVIRONMENTAL APPLICATIONS**

Principal Investigator: Prof. Paula T Hammond, Bayer Professor of Chemical Engineering, [http://web.mit.edu/hammond/lab/nasim.htm](http://web.mit.edu/hammond/lab/nasim.htm)

Date: 06/10/10

The unique and tunable properties of carbon-based nanomaterials such as carbon nanotubes and grapheine and their composites (with polymer) can be optimized for high-flux membranes for desalination and renewable energy technologies such as electrode materials for dye-sensitized solar cell and ultracapacitor energy storage devices. For the fabrication of such devices, the method of layer-by-layer self-assembly of oppositely charged nanoparticles, nanotubes (functionalized) and polymers will be employed. This method allows fabricating nanoporous films with controlled thicknesses in the range of a few hundred nanometers to several micrometers suitable for the applications. The film structures and their properties will be analyzed along with
the performances of the devices, so that conclusions with respect to the relevant structure-property relationships could be drawn.

**LAYER-BY-LAYER ASSEMBLED MEMBRANES FOR SOLAR-POWERED WATER ELECTROLYSIS APPLICATIONS**
Principal Investigator:  Prof. Paula T Hammond, Bayer Professor of Chemical Engineering,  
http://web.mit.edu/cheme/people/profile.html?id=14  
Date:  06/10/10  
http://web.mit.edu/hammond/lab/davis.htm

This project is part of the National Science Foundation (NSF) Center for Chemical Innovation Solar Project, focusing on solar powered electrolysis of water for fuel production. The research team will be designing functional membranes for photoelectrochemical cells that are both protonically and electronically conducting. These membranes will be assembled via an electrostatic layer-by-layer deposition process, which has been shown to generate nanoscale integrated thin film composites capable of creating a continuous conducting network.

**PRUSSIAN BLUE-BASED ELECTROCHEMICALLY RESPONSIVE FILMS**
Principal Investigator:  Prof. Paula T Hammond, Bayer Professor of Chemical Engineering,  
http://web.mit.edu/cheme/people/profile.html?id=14  
Date:  03/17/09  
http://web.mit.edu/hammond/lab/cebeci.htm

Work is currently on the electrochemically mechano-mutable nanocomposite polyelectrolyte multilayer (PEM) films that incorporate Prussian Blue (PB) nanoparticles, which are inorganic iron hexacyanoferrate orthorhombic polycrystals. The chemical formula of crystalline structure is Fe7(CN)18(H2O)x where 14 * x * 16 and polycrystalline nanoparticles are typically 5-7 nm in size, which undergo multiple reversible oxidation states upon an electrochemical potential application.

As the Hammond Group has previously demonstrated1-2, PB nanoparticles and various strong and weak positively charged polyelectrolytes will be assembled in a layer-by-layer method to produce insoluble, thin films held together by ionic crosslinks. By tuning the polymer/iron ratio, PB particle size in the PEM films will be changed and surface of the PB nanoparticle will be modified. By using different polycations, such as poly(allylaminehydrochloride) (PAH), linear polyethyleneimine (LPEI), branched polyethyleneimine (BPEI), poly(diallyldimethyl-ammonium chloride) (PDAC), and some other commercial polycations, the charge density in the films be varied. When the PB in these LbL films is switched to the neutral Prussian Brown state (when the iron atoms in the nanoparticles are completely oxidized), the films are no longer electroneutral; hence, deconstruct due to the electrostatic repulsion of positively charged polymer chains.

**WIND AND GEOTHERMAL: USE OF CORK COMPOSITE IN WIND TURBINE BLADE CONSTRUCTION**
Student:  Sarah Reed, MIT CadLab,  http://cadlab.mit.edu/  
2009 MIT Energy Night

Cork, a renewable material that can be harvested from the Cork Oak every 9-10 years for 200 years, is lightweight, thermally and acoustically insulating, and resistant to rot. These properties are similar to those of Balsa Wood, a material commonly used in wind turbine blades. For these
reasons, an exploration into the use of cork composite in wind turbine blades has been conducted. Research began with materials testing on cork/epoxy composite samples. Following promising results from the materials testing, work began in June 2009 on prototype construction. See: http://energynight.mit.edu/presenters-1/wind-use-of-cork-composite-in-wind-turbine-blade-construction and http://cadlab.mit.edu/

INSTITUTE FOR SOLDIER NANOTECHNOLOGIES (ISN)

BALLISTIC AND BLAST PROTECTION
Strategic Research Area (SRA) 3 will concentrate research from 14 faculty on the critically important strategic Soldier capabilities of blast protection and ballistic protection. Recognizing the importance of blast related Soldier injuries in current operations, we are increasing the ISN’s efforts in blast protection. This will complement and indeed enrich our ballistic protection research. In particular, SRA-3 will direct considerable assets towards understanding blast interactions with materials including human (brain) tissue as well as various anthropogenic energy absorbing structures including microframe structures that contain nano-trusses.

Theme 3.1: Lightweight Nano-architectures for Ultra-Strong Energy Absorbing Materials
The unifying thrust of this theme is careful study of a range of different materials that are of interest for providing lightweight and very high mechanicals strength. These materials include stiff chain polymers based on iptycene and related monomers that incorporate pendant groups at strategic sites along the polymer axis. These polymers provide different mechanisms for absorbing mechanical energy while accommodating appreciable deformation without structural failure...

Project 3.1.2: Ultra Light Weight Micro-trusses and Photopatterned Nanocomposites
Prof. Mary C. Boyce, Department of Mechanical Engineering
Prof. Edwin L. (Ned) Thomas, Department of Materials Science and Engineering

Project 3.1.2 by Thomas and Boyce will investigate well-defined submicron scale microframe structures with 100nm feature sizes as low density materials for blast and ballistic protection. Geometry can be controlled by interference lithography and selection of a variety of soft and hard materials - photopolymers and via templating-infiltrating, other materials (e.g. other polymers and polymer nanocomposites, ceramics, metals) to create a materials system with desired properties. The ability to access length scales below a critical length scale for the mechanical behavior of the (polymer) material has been demonstrated. The proposed work will enable other materials to be made into geometrically regular networks and these materials will be deformed under a variety of conditions, including split Hopkinson bar testing to further explore their high rate behavior. http://web.mit.edu/isn/research/sra03/project03_01_02.html

Project 3.1.3: Mechanical Property Amplification in Natural Materials
Prof. Mary C. Boyce, Department of Mechanical Engineering
Prof. Christine Ortiz, Department of Materials Science and Engineering
Prof. Raul Radovitzky, Department of Aeronautics and Astronautics
Project 3.1.3 is led by Ortiz and involves investigating natural occurring nanostructured materials to establish design laws to guide the fabrication of man-made nanocomposites that will exhibit high strength and toughness. This project is motivated from the perspective of mechanical property amplification of structural materials. The elucidation of mechanical design principles and energy absorption mechanisms which go beyond a simple composite rule of mixtures is of interest for many nonballistic/nonblast materials applications. The team will investigate the exact types of threats a range of hard nanostructured biocomposites experience in their environment; i.e. load magnitudes, rates, type, penetration vs. blunt impact, etc. Ortiz will supervise the structural and mechanical study of the chosen systems using state-of-the-art nanoscale mechanical testing instruments and microscopy. In particular there will be a sustained effort to develop methodologies that are able to quantitatively assess the mechanical properties of small volume samples and measure local property gradients/heterogeneity, which are extremely important to the development of improved nanoscale materials systems for Army applications. The project also involves Boyce and Radovitzky for theoretical modeling, in the field of finite element analysis (FEA) as well as multilayered structures. In addition, a collaboration with several Army research labs will aim to bridge the modeling of the studied systems from atomistic scale to macroscale, so as to enable prediction of larger scale mechanical behaviors from nanoscale properties. http://web.mit.edu/isn/research/sra03/project03_01_03.html

**Project 3.2.1: Materials and Structures for Blast Damage and Injury Mitigation**

Prof. Mary C. Boyce, Department of Mechanical Engineering  
Prof. Keith A. Nelson, Department of Chemistry  
Prof. Raul Radovitzky, Department of Aeronautics and Astronautics  
Prof. Gregory C. Rutledge, Department of Materials Science and Engineering  
Prof. Simona Socrate, Department of Mechanical Engineering  
Prof. Edwin L. (Ned) Thomas, Department of Materials Science and Engineering

Project 3.2.1 broadly considers the development of new armor materials and structures that address pressure wave effects from blast, in addition to improving ballistic protection. The work concerns the development of new protective materials, the design of material systems, for example cellular solids, with potential for high blast energy absorption, and understanding how blast itself as well as protective materials under blast loading, interact with the human body. The project encompasses experiments and computational modeling, fabrication and characterization of novel materials and structures, including nanocomposites and the analysis of blast-sandwich structure and blast-human interactions, with emphasis on major causes of injury to the Soldier. http://web.mit.edu/isn/research/sra03/project03_02_01.html

**Project 3.3.1: Lightweight Nanocrystalline Alloy Fibers for Impact and Blast Protection**

Prof. Gerbrand Ceder, Department of Materials Science and Engineering  
Prof. Nicola Marzari, Department of Materials Science and Engineering  
Prof. Christopher A. Schuh, Department of Materials Science and Engineering

Project 3.2.1 broadly considers the development of new armor materials and structures that address pressure wave effects from blast, in addition to improving ballistic protection. The work concerns the development of new protective materials, the design of material systems, for example cellular solids, with potential for high blast energy absorption, and understanding how blast itself as well as protective materials under blast loading, interact with the human body. The project encompasses experiments and computational modeling, fabrication and characterization
of novel materials and structures, including nanocomposites and the analysis of blast-sandwich structure and blast-human interactions, with emphasis on major causes of injury to the Soldier.
http://web.mit.edu/isn/research/sra03/project03_03_01.html

NUCLEAR

A FUNCTIONALLY GRADED COMPOSITE FOR RESISTING CORROSION IN LEAD-BISMUTH COOLED NUCLEAR REACTORS AT TEMPERATURES UP TO 700 °C

Prof. Ron Ballinger, http://dmse.mit.edu/faculty/faculty/hvymet/
Laboratory Staff: Pete Stahle
Graduate Student: Mike Short
H. H. Uhlig Corrosion Lab

The goal of this project is to develop a Functionally Graded Composite (FGC) to resist liquid Pb-Bi corrosion in Lead Fast Reactors. Currently Lead Fast Reactors are limited at about 600 °C by material performance - liquid Pb-Bi corrodes the steel coolant piping and fuel cladding at a very high rate. Steels high in chromium and silicon have been shown to resist Pb-Bi corrosion very well, but they do not retain the tensile strength needed to stay serviceable at high (~700 °C) temperatures. In addition, silicon alloys become very brittle upon exposure to radiation. In this project we will demonstrate the commercial feasibility of making pipe and tube with a structurally sound wall and a corrosion resistant layer to stop Pb-Bi corrosion. A ferritic/martensitic steel (T91) and an ODS steel (MA957) will be compared in terms of cost and performance.
http://uhliglab.scripts.mit.edu/projects.php

“Diffusional stability of ferritic martensitic steel composite for service in advanced lead bismuth cooled nuclear reactors.”


To combat liquid metal corrosion from lead–bismuth eutectic coolant in the fuel cladding and coolant piping of generation IV fast fission reactors, a composite that employs a Fe–Cr–Si steel layer weld clad on a structural layer of alloy T91 (Fe–9Cr–1Mo) is being developed. Diffusion of Si away from the cladding during service can compromise corrosion resistance, whereas carbon redistribution will affect mechanical properties and phase stability. Diffusion of silicon and carbon in a manufactured sample of the composite has been investigated both experimentally and by modeling... http://web.mit.edu/hereiam/Public/2010-IHT130.pdf

NUCLEAR SCIENCE & ENGINEERING (NSE) DOCTORAL RESEARCH EXPO, MARCH 2010

Thirty-nine students presented posters on a broad array of topics ranging from combating noise in quantum operations to the conceptual design of an annular-fueled water reactor. The presentations made for lively discussion among presenters and visitors from within the Department and from around the Institute. Three judges, Professors Jacopo Buongiorno, Paola Cappellero, and Dennis Whyte, selected the best poster in the Expo. Michael Short’s poster, A
Best Poster Prize: A Functionally Graded Composite for Corrosion Resistance in High Temperature Lead and Lead-Bismuth Cooled Systems
By Michael Short http://www.mike-short.com/, 
See: http://web.mit.edu/nse/events/poster/poster-expo-m-short.html

SENSORS

NANOWIRE- AND MICROSPHERE-TEMPLATED GAS SENSORS
Principal Investigator: Prof. Harry L Tuller, Professor of Ceramics and Electronic Materials, and Director, Crystal Physics and Electroceramics Laboratory (CPEL), http://dmse.mit.edu/faculty/faculty/hltuller/
Date: 04/22/10

Novel materials synthesis techniques were used to fabricate nanostructured and macroporous semiconducting metal oxide (SMO) films exhibiting exceptionally high sensitivity to reducing and oxidizing gases, as compared to conventionally prepared specimens. Increased sensitivity resulted from an elevated surface area and reduced specimen cross section. Several processing routes were pursued including electrospinning of semiconducting metal oxide (SMO) nanowires into a highly porous mat structure and microsphere templating followed by pulsed laser deposition (PLD) of macroporous SMO material onto the microsphere templates.

The TiO2/poly(vinyl acetate) composite nanofiber mats were electrospun onto interdigitated Pt electrode arrays, producing a mesh of 200-500 nm sheaths filled with ~10 nm thick single-crystal anatase fibrils. Testing in the presence of NO2 gas at 300°C demonstrated a minimum detection limit (MDL) of below 1 ppb1. Chemical and physical synthesis routes were combined to prepare macroporous CaCu3Ti4O12 and TiO2 thin films by PLD onto PMMA microsphere-templated substrates. Stable quasi-ordered hollow hemispheres with diameter and wall thicknesses of 800 nm and 100 nm, respectively, were obtained. Current-voltage and impedance spectroscopy measurements point to the crucial role played by grain boundary barriers in controlling the electrical properties of these films. The macroporous CaCu- 3Ti4O12 films exhibited a much superior H2 gas sensitivity (55ppm MDL) to non-templated films2, while macroporous TiO2 films exhibit excellent NOx sensitivity. Studies are continuing to more carefully correlate sensor response with SMO microstructure, morphology, and chemistry.

TACTILE SENSORS AND ACTUATORS FOR SMART SURFACE APPLICATIONS
Date: 10/06/09

Novel tactile sensor and actuator devices using zinc oxide nanowires have been developed to enhance the interaction between people and their environment for smart surface applications. Both the sensor and actuator device use the piezoelectric effect of zinc oxide (ZnO) nanowires.
The devices are based on a cross-bar network comprising a top and bottom array of electrodes around a composite of vertically grown nanowires and an insulating polymer. This cross-bar network allows for individually addressable locations for both sensing and actuation. The results for the tactile pressure sensor show a clear spike in current when an insulating tip is placed on and removed from the surface. This result is compared to controls including a touch on the adjacent cross electrodes and testing another device without wires. Both tests show at least an order of magnitude difference in current between the control and the pressure sensor. The actuator device utilizes a thin membrane of thermally grown silicon dioxide that is oscillated at resonance to induce tactile sensation. The oxide membrane is fabricated by using a deep backside etch of a silicon wafer and utilizing the thermally grown oxide as an etch stop. The rest of the device is very similar to the pressure sensor with an electrode cross bar network and a zinc oxide nanowire polymer composite. The nanowires are grown in a furnace by chemical vapour deposition or by a low temperature hydrothermal method, producing wires of length of 1–12?m.

The system is actuated by applying an alternating current through the top and bottom electrodes. The piezoelectric nanowires expand and contract according to the AC signal. The results show a first resonance peak at 139kHz, followed by a slightly lower peak at 191kHz. The amplitude of oscillation is still not known precisely, but it is estimated to be approximately 15nm at 33V. Currently, haptic feedback for portable electronic devices such as mobile phones is limited to vibration over a large area or the whole phone. This project addresses these issues by making the tactile actuators and sensors smaller than the pixel size that the finger can sense. This small pixel size leads to virtual buttons and textured surfaces that are software-controlled and infinitely variable. The long term goal of the project is to have a transparent and flexible device so that it can be incorporated into a variety of different displays and surfaces.

ANALYSIS, SIMULATION, MODELING

MECHANICAL PROPERTIES OF ULTRATHIN POLYMER FILMS
Prof. Robert Cohen, St. Laurent Professor of Chemical Engineering, and Director, Program in Polymer Science & Technology http://web.mit.edu/cohengroup/rec.html

We have developed a modified version of a strain-induced buckling instability technique that relies on the analysis of a two-beam composite film deposited on an elastomeric poly(dimethylsiloxane) (PDMS) substrate. This method broadens the applicability of previous techniques to a wider array of thin film materials without significantly affecting the convenience and ease of use that gives the buckling instability technique many advantages in the field of thin film mechanical characterization. We have previously shown that the “strain-induced elastic buckling instability for mechanical measurements” (SIEBIMM) technique is suitable for testing polyelectrolyte multilayers (PEMs) that are amenable to deposition directly on the testing substrate. Here we demonstrate how PEMs that would not normally be amenable to deposition on PDMS can be assembled onto a thin layer of polystyrene (PS) that has been transferred to the PDMS surface and treated to promote adhesion. Multilayers assembled onto the PS-coated PDMS substrates yielded thin two-beam PS-PEM composite films on the surface of the PDMS substrates. We demonstrate how these two-beam composite films buckled similarly to their homogeneous counterparts, and how by proper analysis of the mechanics it was possible to deconvolute the contribution of the PS to arrive at a Young’s modulus value for the PEM part of the two-beam film. Accuracy of the new method was confirmed by comparing results from two systems evaluated with both conventional SIEBIMM and the two-beam technique. Following this,
we demonstrate modulus measurements on two PEM assemblies of poly(allylamine hydrochloride) (PAH) and poly(acrylic acid) (PAA), one deposited at pH 3.5 and one at pH 4.0. Both of these systems could not be measured by the conventional SIEBIMM approach. Thus, measurements were possible only by employing a two-beam analysis.

http://web.mit.edu/cohengroup/research.html

MODELING OF NANOFIBERS AND NONWOVEN MATERIALS
Principal Investigator: Prof. Gregory C Rutledge, Lamont du Pont Professor of Chemical Engineering, http://web.mit.edu/cheme/people/profile.html?id=25
Date: 03/17/09

Electrospinning of polymeric nanofibers is a promising approach for development and commercialization of 1-D nanomaterials. Their combined characteristics of small fiber diameter (50-500 nm) and large surface area (10-100 m2/g) make polymeric nanofibers an exciting new class of materials that can be used in many applications such as filters, composites, fuel cells, nanowires, catalyst supports, drug delivery devices and tissue scaffolds. Of fundamental necessity for many of these applications is an understanding of the properties of individual nanofibers and their effects on the nonwoven material behavior.

In this area, our aim is to develop new models with which to investigate the size-dependent properties of polymeric nanofibers and to relate fabric properties to fiber properties by using multiscale modeling techniques. These structure-property models complement on-going efforts to model the electrospinning process. They are also essential to fill a gap between fabric measurements and fiber property characterization. The models themselves provide new insights into the relationships between fiber structure and electrospun fabric performance. In addition, the models serve as tools for future design of new materials and set goals for the production of fibers and fabrics with particular performance characteristics.

We are using molecular dynamics (MD) simulations to identify and evaluate the size dependent properties of polymeric nanofibers...


MECHANICAL PROPERTIES OF METALLIC GLASS MATRIX COMPOSITES
Principal Investigator: Prof. Christopher A Schuh, Danae and Vasilios Salapatas Associate Professor of Metallurgy, http://dmse.mit.edu/faculty/faculty/schuh/
Date: 06/22/09

Bulk metallic glass matrix composites (BMGMCs) are a new class of composite material, designed to take advantage of the impressive strength and high elastic limit of metallic glasses, while improving toughness and suppressing localized failure through the introduction of microstructure. Depending upon the system thermodynamics and processing kinetics, the reinforcement phase in BMGMCs may itself be inherently ductile or brittle, and the second phase volume fraction is also often quite tailorble... Our group studies the microstructure-property connections in BMGMCs, with special emphasis on mechanical properties. At high temperatures, we investigate the flow rheology of composites for its implications in shape forming. At low temperatures we study strength, plasticity, toughness, and interaction of shear bands with
inclusion phases. We also employ computer simulations to study the mechanics of this new class of composites.

More at … http://schuh.mit.edu/research/amorph_composite.html

**MICROSTRUCTURE-PROPERTY CORRELATIONS**

Principal Investigator: Prof. Christopher A Schuh, Danae and Vasilios Salapatas Associate Professor of Metallurgy, [http://dmse.mit.edu/faculty/faculty/schuh/](http://dmse.mit.edu/faculty/faculty/schuh/)

Date: 06/22/09

Heterogeneity is present in materials at various length scales and in different forms. For example, polycrystalline materials are heterogeneous in that they are composed of crystals of different orientations and that they contain defects of various dimensions, e.g., dislocations and grain boundaries. Another type of heterogeneity is the variation in compositions, such as in composites and porous media. These structural heterogeneities result in a distribution of local materials properties. From this known distribution we can evaluate the apparent or effective properties of heterogeneous materials. The goal is to quantitatively correlate the effective properties with the connectivity among various microstructural elements, which is the object of percolation theory. Combining homogenization schemes with percolation concepts offers a robust approach to understanding microstructure-property relationships. We study discrete network problems and also more common continuum problems using both theoretical modeling and computer simulations. For example, we show the effective diffusivity of a ternary grain boundary network calculated from the model (color surface plot) and from a simulation (gray dots). We also experimentally seek to improve the mechanical properties of metallic materials by manipulating the connectivity of the heterogeneous interfacial networks.

More at … [http://schuh.mit.edu/research/microstructure_properties.html](http://schuh.mit.edu/research/microstructure_properties.html)

**SHAPE MEMORY MATERIALS—MULTIFUNCTIONAL COMPOSITES**

Principal Investigator: Prof. Christopher A Schuh, Danae and Vasilios Salapatas Associate Professor of Metallurgy, [http://dmse.mit.edu/faculty/faculty/schuh/](http://dmse.mit.edu/faculty/faculty/schuh/)

Date: 06/22/09

Shape memory materials exhibit pseudo-elastic behaviors and shape memory properties. They can be deformed 'elastically' up to 7-8% or even higher strain which will completely recover upon unloading. If deformed at a low temperature, they will also recover their original shapes when heated to above a certain critical temperature. A lot of energy is dissipated in one pseudo-elastic loading/unloading cycle, making shape memory materials excellent candidates for mechanical damping applications. What is more, the coupling between thermal and mechanical fields enables these materials to be used as actuators or components in multifunctional composites and devices. The group is investigating the pseudo-elastic and shape memory properties of Cu-Al-Ni shape memory alloys. Cu-based alloys are relatively inexpensive compared to other alloys, and have good thermal and electrical conductance. We are making fine structures of these alloys and studying the size effects of the damping capabilities and shape memory properties.

SELF-ASSEMBLY OF PROTEIN/POLYMER NANOSTRUCTURES
Principal Investigator: Prof. Bradley D Olsen, Raymond A (1921) and Helen E St. Laurent Career Development Assistant Professor of Chemical Engineering, 
http://web.mit.edu/cheme/people/profile.html?id=45
Date: 01/26/10

Polymeric materials provide integral structures in advanced technologies such as fuel cells, organic photovoltaics, nanopatterned hard drives, and biomedical devices. Nature also uses polymers to produce ultra-strong spider silk fibers, tough organic/inorganic composites, and some of the most efficient catalysts (enzymes). The unique physical properties of these materials arise from the large size of the polymer molecules and its effect on molecular structure and dynamics. Our research in polymer physics attempts to understand the statistical mechanics, thermodynamics, and transport properties of these large molecules and to apply this understanding to the intelligent design of polymeric materials with new and interesting properties for applications in biotechnology, energy, and sustainability. 
http://web.mit.edu/bdolsen/www/research.html

THE ARMSTRONG GROUP: POLYMER MOLECULAR THEORY AND FLUID MECHANICS, MULTISCALE PROCESS MODELING
Principal Investigator: Prof. Robert C Armstrong, Chevron Professor of Chemical Engineering, 
http://web.mit.edu/cheme/people/profile.html?id=1
Date: 01/14/09

... In our group we use theoretical, computational, and experimental methods to elucidate the rheology and fluid mechanics of non-Newtonian fluids. A wide variety of fluids are being studied including dilute polymer solutions, concentrated polymer solutions and melts, liquid crystalline polymers, biological polymers, concentrated suspensions, biodegradable polymers, and composites of rigid fillers and polymers. For many of these systems we are developing structural and molecular models which are of great importance for interrelating the microstructure with processing conditions, and in understanding the physics of these flows at interfaces.

We are also developing numerical methods for solving viscoelastic flow problems. These are among the most challenging numerical simulations facing scientists today. The finite element method is currently being used to solve confined and free surface flow problems for differential and integral viscoelastic fluid models, and for molecular and structural models for polymer solutions, liquid crystals, and suspensions. A particular area of interest is developing efficient methods for coupling the solution of molecular conformation evolution with the macroscopic flow problem. We are also interested in general methods for moving between fine-grain and coarse-grain descriptions of the molecules in a simulation. Efforts are also aimed at matching computational results with experimental results obtained by applying laser Doppler velocimetry, video imaging, birefringence, NMR, and standard rheometry to investigate model flows of these materials...

More at … http://web.mit.edu/armstronggroup/