

***Materials Science and
Engineering at Michigan: Current
State, Accomplishments, Challenges and
Opportunities***

September 2012

Peter F. Green

Chair, Department of Materials Science and Engineering

*Director, DOE Center for Solar and Thermal Energy
Conversion (CSTEC)*

Road Map

- MSE: Mission, Identity and Objectives
- Noteworthy achievements 2011-2012: education, research
- Comparative trends: students, faculty, research expenditures
- Collaborative educational outreach efforts with local and global reach
- Challenges and Opportunities

Selected Examples of Achievements

- MSE undergraduates were finalists in Michigan Clean Energy Venture Challenge
- Scientific/Technical Accomplishments
 - (i) Distinguished Dissertation award Chris Nelson: atomic scale structure and dynamics of domains during electrical switching in ferroelectric thin films
 - (ii) New materials based on computational design for efficient energy conversion (Kim, Kieffer, Green)
 - (iii) Cheap flexible solar cells based on nanostructures (Boukai)
 - (iv) new sensor for nerve agents (Kim)
 - (v) Design of hydrophobic and oleophobic surfaces (Tuteja)
- DOE Software Innovation Center for Integrated Multi-Scale Modeling of Structural Metals... John Allison

MSE Faculty hired during the last 3 years



The Newest Faces of the Second Decade in Materials Science & Engineering



Alan Taub

Retired: GM VP for
Global Research

New Startups by MSE Faculty

- **HECAMCO LLC**, founded in 2011 to commercialize carbon building materials and hydrogen fuels from coal pyrolysis. (Halloran)
- **DDM System Corp** (2012)... 3D-printing technologies. (Halloran, *Suman Das*)
- **Silicium Energy** 2011- (Boukai)
- **Arborlight, LLC** 2011 (Shtein, *P-C Ku*)

MSE faculty (23 faculty)-21 FTE

- **5 Assistant Professors**
 1. Emmanouil Kiopakis (*Theory-energy light emitting diodes, photovoltaics*)-US Berkeley Ph.D-Physics
 2. Pierre Ferdinand Poudeu (*Solid State Chemistry-functional oxides*)-German Univ. Ph.D-Chemistry
 3. Emmanuelle Marquis (*Metallurgy, atom probe*)-Northwestern Univ. PhD-Materials
 4. Boukai (*functional inorganic materials: Thermoelectrics, photovoltaics*)- Caltech Ph.D-Chemistry
 5. Tuteja (*Soft Materials, surfaces*)-Michigan State PhD (AFOSR Young Investigator)-Chemical Engineering
- **4 Associate Professors (all are CAREER or PCASE Awardees):**
 - Thornton (*Computational Materials Science*)-Ph.D Theoretical Astro Physics (Chicago)
 - Shtein (*Organic Electronics*)-Ph.D Princeton (Chemical Engineering)
 - Kim (*Functional Organic Materials*)- Ph.D Materials (MIT)
 - van der Ven (*Computational Materials Science*)-Ph.D. Materials (MIT)
- **15 Professors (most have joint appointments with other departments)**
- **14 Courtesy appointments in MSE of faculty from other departments**

Mission Statement

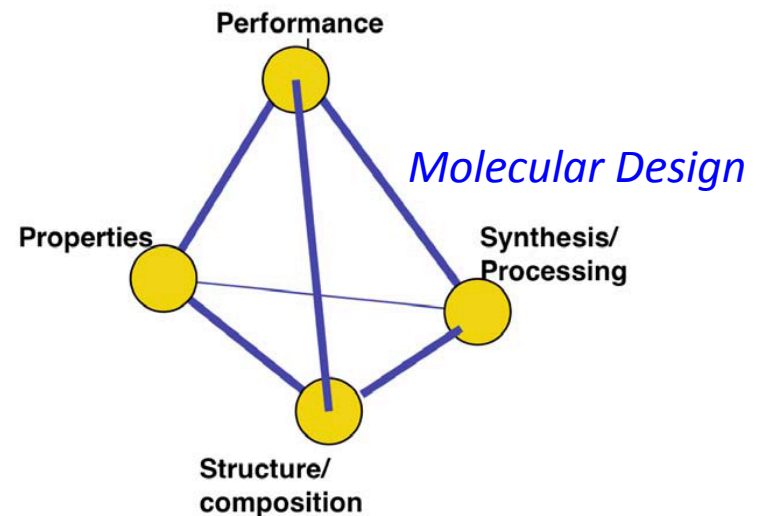
- Our *Mission* is:
 - to educate creative and productive scientists and engineers, in the fundamental principles of the science and engineering of materials, who will provide future leadership in industry, academia and government laboratories;
 - to produce new advances in the science and technology of materials;
 - to serve as a bridge between various materials research efforts throughout the University via various scientific and technical centers;
 - to collaborate with industrial and government researchers on problems of technological significance.

MSE: What do we do?

- Natural bridge between areas of engineering, medicine and the sciences.

- **Exploit IDEAS from:** Thermodynamics, kinetics/transport properties, Quantum mechanics, statistical mechanics
- **Measure, calculate, or compute**, the structure and properties of materials of varying compositions and structures.
- **Develop** rules and methods/strategies for the synthesis/processing of materials with specific properties “tailored” for specific applications

Nanoscience and nanotechnology are cross-cutting areas of emphasis



The Materials Science Tetrahedron

MSE: strategies for problem solving

Material
Systems

Metals

Ceramics

“Hard”
Semiconductors

Soft Matter

Design -
processing/
synthesis -
measurement

Quantum, Stat. Mech., Thermo, Kinetics

Measurement of properties:
Macroscopic, nanoscale

Computational Materials Science

- I. Atomic/Molecular design and synthesis;
- II. “Tailoring” of morphology: structure from macro- to nano-scale

Material
Functionality

Thermoelectrics

Structural materials

Piezoelectric/Ferroelectric

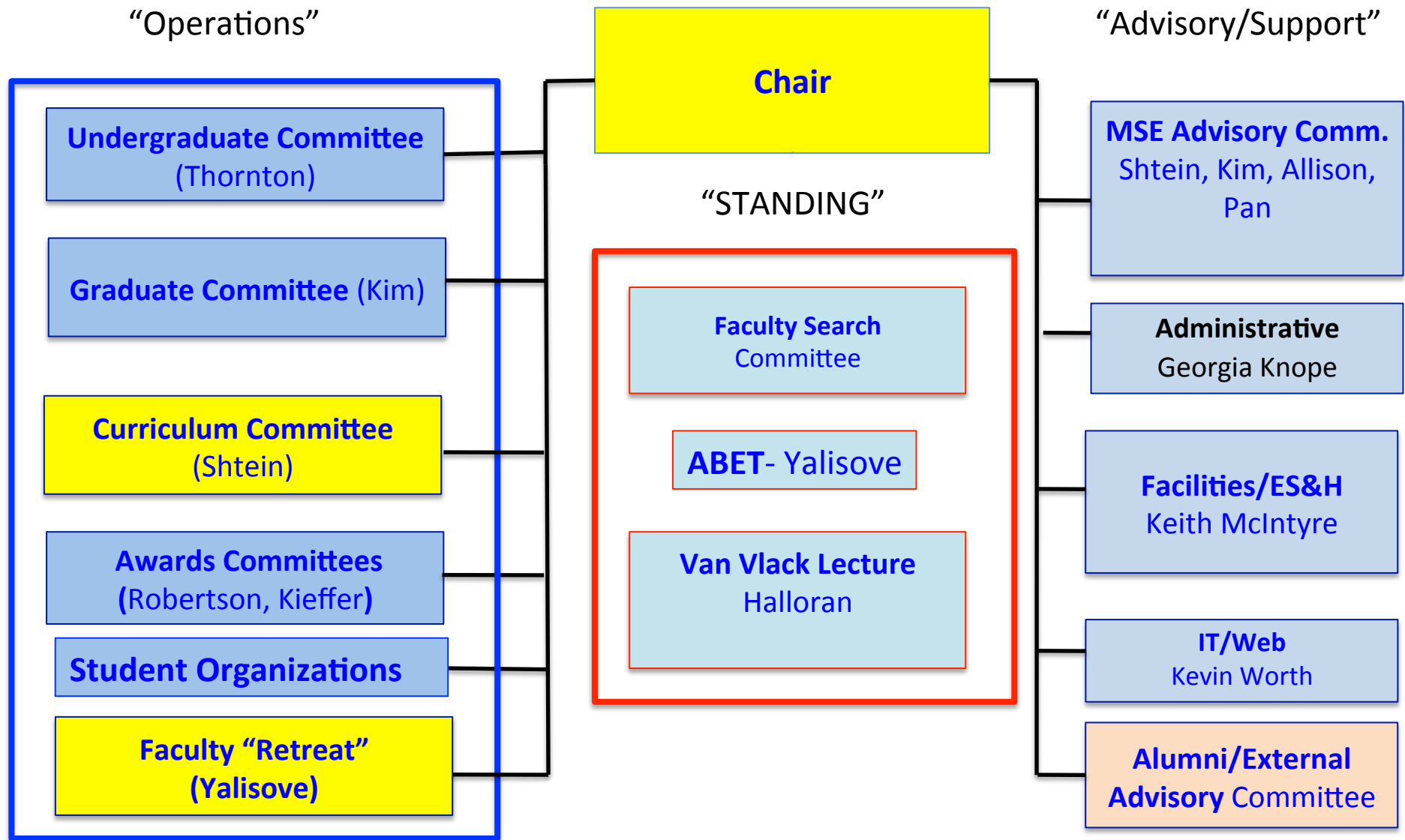
Sensors

Superconductors

Electronic materials

Solar Cells

A “Snapshot” of the MSE Organization:
Operations, Standing and Support/Advisory functions



Examples of Noteworthy Achievements

1. MSE undergraduates were finalists in Michigan Clean Energy Venture Challenge
2. Scientific/Technical Accomplishments
 - (i) Distinguished Dissertation award Chris Nelson: atomic scale structure and dynamics of domains during electrical switching in ferroelectric thin films
 - (ii) New materials based on computational design for efficient energy conversion (Kim, Kieffer, Green; Kim Kieffer)
 - (iii) New environmentally friendly process for organic solar cells
 - (iv) Cheap flexible solar cells based on nanostructures (Boukai)
 - (v) new sensor for nerve agents (Kim)
 - (vi) Design of hydrophobic and oleophobic surfaces (Tuteja)
4. Large computational based collaborative grant (Allison)
5. MSE ABET self study used as a model for universities

Michigan Clean Energy Venture Challenge: MSE Students from F'2011 MSE 489 projects

The University of Michigan Team M-Wrap

Accepting a \$5,000 award at the Michigan Clean Energy Venture Challenge. They are standing with DTE Energy vice president Knut Simonsen (left) and Bob Lutz, retired vice chairman of GM. Friday, Feb 17, 2012 at Blau Auditorium at U-M The Ross School of Business.

Photo by Marcin Szczepanski/University of Michigan, COE Multimedia Producer



The members of the team from left to right are: Weidong Chen, Shwetha Maddur, Rachel Rademacher, Heather Wilsher, Grace Hsia, and Devon Triplett.

Team Warmilu, LLC

<http://www.warmilu.org>

Grace Hsia (MSE)

Weidong Chen (MSE)

Shwetha Maddur (MSE)

Rachel Rademacher (MSE)

Heather Wilsher (MSE)

joined forces with...

Vivek Pejaver (BME)

Austin Ruby (Ross)

Infant warming blankets

“Components will feature heat retention, light weight, comfort, and low cost.”

The University of Michigan Arbor Solar Technologies Team



The members of the team from left to right are: Alessandra McGinnis, John Strader, Tyler Austin, James Detlefs, Ashwin Betrabet, and Eric Jones.

Receiving a \$5,000 award at the Michigan Clean Energy Venture Challenge. They are standing with DTE Energy vice president Knut Simonsen (left) and Bob Lutz, retired vice chairman of GM. Friday, Feb 17, 2012 at Blau Auditorium at U-M The Ross School of Business.

Photo by Marcin Szczepanski/University of Michigan, COE Multimedia Producer

Team Arbor Solar Technologies

James Detlefs (MSE)

Allessandra McGinnis (MSE)

Ashwin Betrabet (MSE)

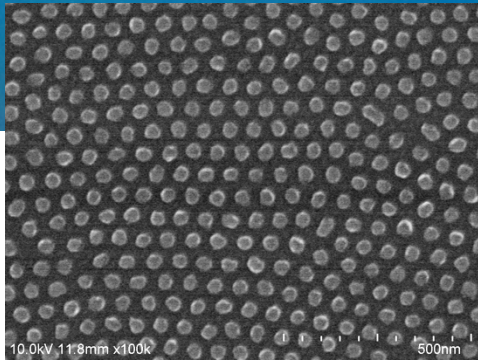
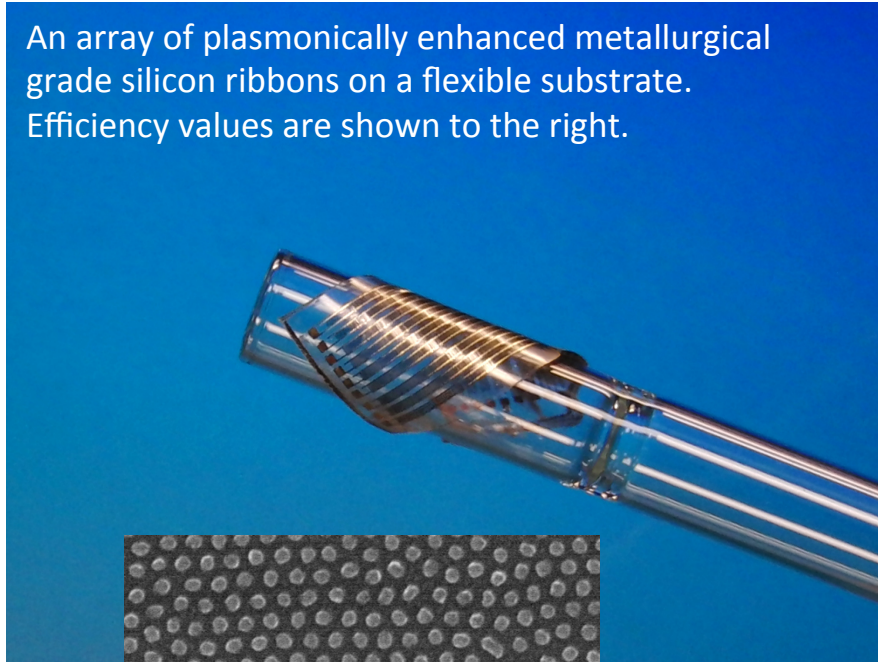
“energy-efficient lighting scheme”

External Recognition

- *Sharon Glotzer* - Member, American Academy of Arts and Sciences
- - Simons Investigator, named July 2012 to inaugural class
-
- *Rachel Goldman* - Fellow of the American Vacuum Society
- *Peter Green* - Fellow, Royal Society of Chemistry
- Designated by the Editors of Physical Review/Physical Review Letters-outstanding referee-
- *Nicholas Kotov* - 2012 Stine Award for Materials Research (AIChE)
- *Joerg Lahann* - 2011 Fellow of the American Institute, Medical & Biological Engineering
- *Richard Laine* - Elected Fellow of the Polymer Division of the American Chemical Society
- *Emmanuelle Marquis* - 2012 K.F.J. Heinrich Award from Microanalysis Society
- *Jyoti Mazumder* - Elected to the National Academy of Engineering
- *Xiaoqing Pan* - Elected Fellow of American Ceramic Society
-
- *Michael Thouless* - Elected Fellow of the Institute of Materials, Minerals & Mining (UK)

Inexpensive **low grade silicon** used to make efficient solar cells (Akram Boukai)

An array of plasmonically enhanced metallurgical grade silicon ribbons on a flexible substrate. Efficiency values are shown to the right.

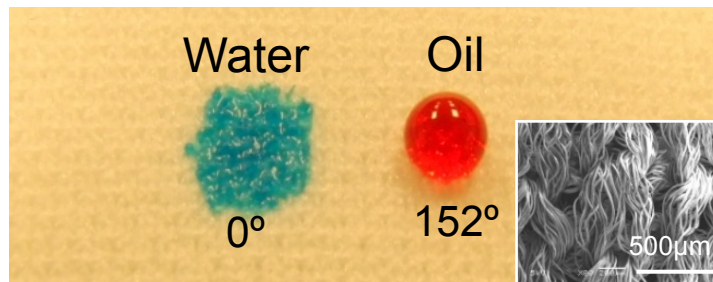
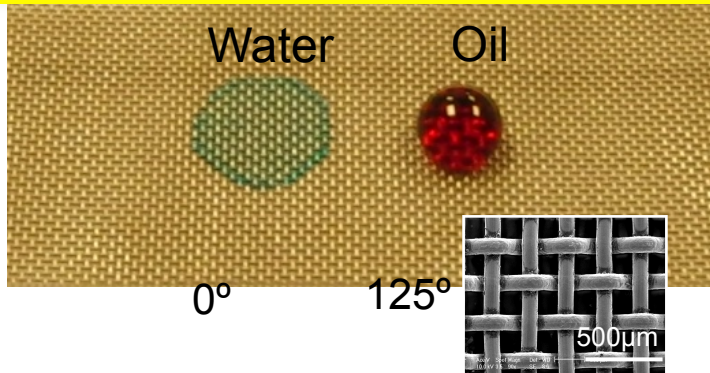


An array of 20 nm diameter Ag nanoparticles on top of a metallurgical grade silicon ribbon

Price is 0.2 of the cost of purified silicon
Used in solar cells

Published in:
Nanoletters, September 2012
C&EN News

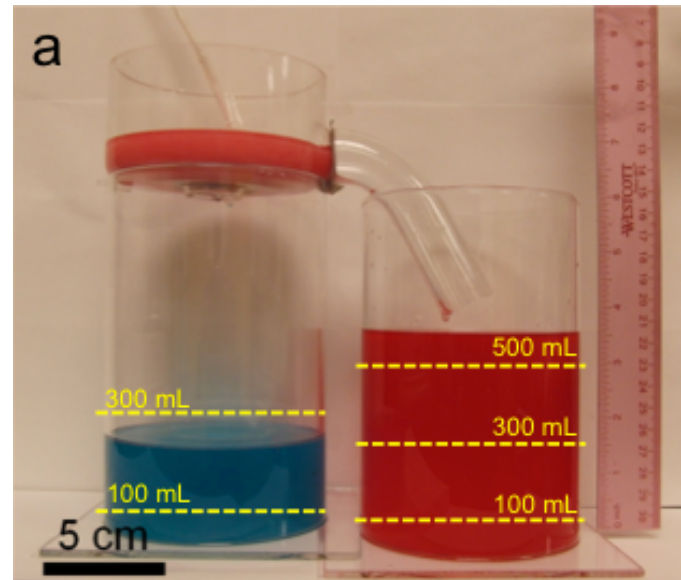
Membranes for oil-water separation (Tuteja Group)



Developed one of the first coatings that counter-intuitively are hydrophilic and oleophobic.

Membranes based on these coatings can allow, for the first time, for the gravity based separation of all kinds of oil-water mixtures.

Applications include clean up of oil-spills, waste-water treatment, emulsion break-up, and oil-extraction.



This is the first-ever setup developed for the continuous separation of oil-water emulsions which utilizes only gravity. The membrane separation efficiency exceeds 99.99%.

UM Patent filed. U.S. Non-Provisional Application No. 13/159,950, PCT International Application No. PCT/US2011/040353

Nature Communications,

Oil spill cleanup: Smart filter can strain oil out of water

Published on Aug 28, 2012
Contact Nicole Casal Moore



ANN ARBOR, Mich.—A smart filter with a shape-shifting surface can separate oil and water using gravity alone, an advancement that could be useful in cleaning up environmental oil spills, among other applications, say its University of Michigan developers.

The system could provide a more efficient way to remove crude oil from watersheds without using additional chemical detergents, or even after detergents have been added, said Anish Tuteja, an assistant professor of materials science and engineering. Tuteja is the corresponding author of a paper on the research published in the Aug. 28 issue of *Nature Communications*.

The researchers created a filter coating that repels oil but attracts water, bucking conventional materials' properties. Most natural substances soak up oil, and the few that repel it also repel water because water has a higher surface tension.



Researchers have developed a special filter coating that essentially can strain oil out of water. It works by repelling oil, but attracting water, which are unconventional properties for a material to have. On an untreated piece of window screen, water (dyed blue) beads up, but oil (dyed pink) soaks through. On the treated surface, the pink oil beads up, but water would soak through. The coating could help advance oil spill clean-up and make it more efficient. Photo by Laura Rudich

Home > Volume 90 Issue 36 > Membrane Separates Oil And Water With Ease



Volume 90 Issue 36 | p. 9 | News of The Week
Issue Date: September 3, 2012 | Web Date: August 31, 2012

Membrane Separates Oil And Water With Ease

Materials: Hydrophilic-oleophobic combo could clean up oil spills
By Stephen K. Ritter

Department: Science & Technology
News Channels: Environmental Science, Materials SCENE, Nano Science
Keywords: hydrophilic, hydrophobic, membrane, POSS, oil spill, emulsion, separations

Oil and water usually don't mix, but when the two end up together, say in an oil spill or in an emulsion, they can be nearly impossible to completely separate. But by combining a water-loving polymer with an oil-repelling silicon-based material, researchers have created a new breed of membrane that can separate bulk amounts of any type of oil-water mixture by simply gravity filtration.

The scientific team that created the hydro-responsive membrane, as it is called, believes it will become an energy-efficient, cost-effective means of cleaning up oil spills.

Traditional membrane-based filtration systems are energy-intensive because the targeted mixture typically must be pumped through the membrane for efficient separation. These membranes are subject to fouling by viscous materials such as oil. Using their effectiveness over time, and typically aren't versatile enough to separate all types of oil-water mixtures, which range from oil and water layers to surfactant-laden emulsions.



SUPERMEMBRANE SEPARATES OIL AND WATER WITH EASE
Even though oil and water don't mix, when they do come together, as in oil spills, they're difficult to separate. Researchers at the University of Michigan and the Air Force Lab have now developed a membrane that separates the substances with ease, via gravity filtration. In this clip, watch the membrane in action and learn about the material's make from.

Credit: University of Michigan/C&EN/YouTube

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Oil spill cleanup: Smart filter can strain oil out of water

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Tuesday, August 28, 2012

Click to enlarge
Researchers have developed a special filter coating that essentially can strain oil out of water.

Researchers have developed a special filter coating that essentially can strain oil out of water.

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Unmixing oil and water

A new filter that separates the two substances only using gravity could help clean oil spills

By Rachel Ehrenberg
Web edition : Tuesday, August 28th, 2012

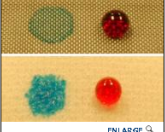
A-A Text Size

Oil and water's disdain for each other is legendary, but once forced to coningle they're nearly impossible to separate. Now scientists have developed a specialized filter that cleanly separates the two, allowing water to pass through and leaving oil behind.

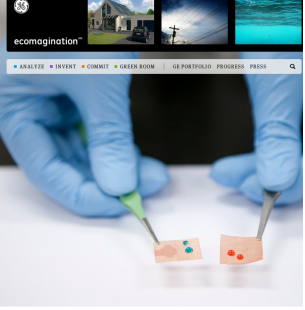
Such filters could prove useful for cleaning up oil spills or cleaning water at treatment plants.

A simple setup using the new filter successfully removed more than 99.99 percent of oil from an oil-water mix, researchers report online August 28 in *Nature Communications*.

Oil and water both stick to their own, playing on opposite sides of the room at a molecular cocktail party. But add a chemical called a surfactant — molecules that are partly attracted to water and partly attracted to oil — and you've got a social lubricant that forces water and oil to mingle. Once this socializing happens, it's difficult to undo.



ENLARGE
A blend of compounds coating stainless steel mesh (top) or polyester fabric (bottom) allows water (blue) to wet the surface while oil (red) is repelled and beads up. Such filters could help clean up oil spills.
A. Kote et al./Nature Communications 2012



Smart Filter Uses Gravity to Clean Up Oil Spills

Yusuf Yalaz | Tue Sep 11 2012

At the University of Michigan, materials scientists have developed a smart filter that can remove 99.9 percent of oil from water using gravity. The researchers reported their findings in the August 28 edition of *Nature Communications*.

- Research highlights

Top ten highlights

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Chemistry: A solution for oil-water separation

Nature Communications
August 29, 2012

A gravity-driven process that can separate oil and water mixtures with 99.9% efficiency is described in *Nature Communications* this week. Specially designed reconfigurable membranes are shown to separate a variety of oil-water mixtures using only gravity, making it an energy efficient, cost-effective approach. The method could find use in the clean up of oil spills, wastewater treatment, fuel purification and the separation of commercially relevant emulsions.

Traditional membrane-based oil-water separation technologies are energy-intensive and can be limited by fouling (which slows down the process) or the inability of a single membrane to separate all types of oil-water mixtures. The membranes designed by Anish Tuteja and colleagues overcome these issues by having reconfigurable surface chemistry and using capillary forces to completely separate a range of oil-water mixtures, including emulsions. They demonstrate continuous separation of emulsions for over 100 hours without a decrease in flow.

Recent events, such as the Deepwater Horizon oil-spill in the Gulf of Mexico, have highlighted the difficulty of effective oil-water separation. The authors anticipate that their process could be used to in clean up operations, among other applications.



Holy Kaw! All the topics that interest us

Chemical-free filter splits oil from water [video]

Posted Sep 7th, 2012 at 11:26 AM and seen 1042 times

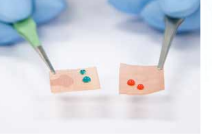


ET PERSPECTIVES

By Bob Pez, August 30, 2012

Researchers at the University of Michigan have developed a new filter coating that can separate oil and water using gravity alone, potentially providing an efficient means of cleaning oil spills from watersheds without the use of detergents.

Most natural substances soak up oil, and the few that repel it also repel water.



Smart Filter Could Help Clean Oil Spills Without Detergents

By Bob Pez, August 30, 2012

Researchers at the University of Michigan have developed a new filter coating that can separate oil and water using gravity alone, an advancement that could be useful in cleaning up environmental oil spills, among other applications, say its University of Michigan developers.

The system could provide a more efficient way to remove crude oil from watersheds without using additional chemical detergents, or even after detergents have been added, said Anish Tuteja, an assistant professor of materials science and engineering. Tuteja is the author of a paper that appears in *Nature Communications*.



RUSSIA NEWS

HAPPENING IN RUSSIA RIGHT NOW

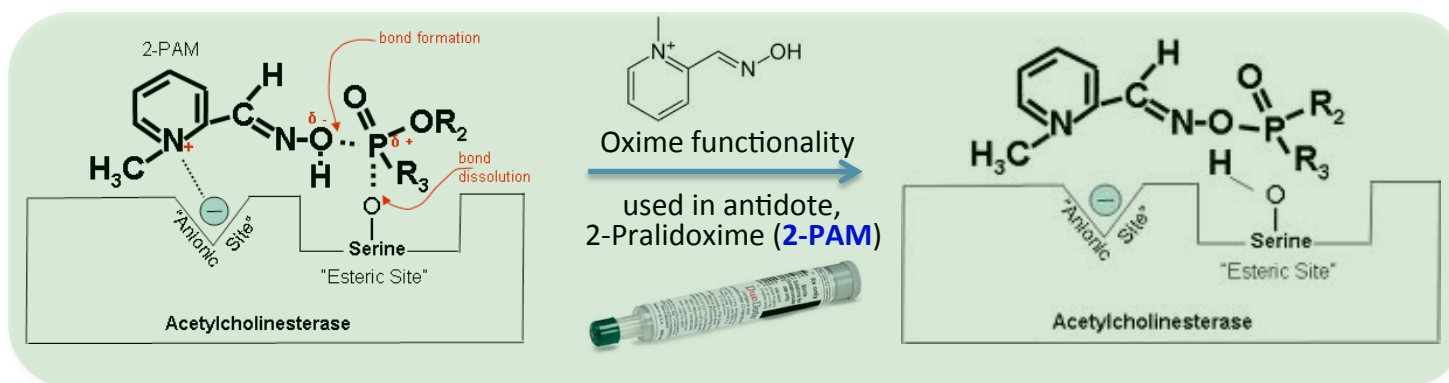
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HOME • LATEST • PHYSICISTS HAVE LEARNED TO SEPARATE THE OIL FROM THE WATER BY GRAVITY

Physicists have learned to separate the oil from the water by gravity

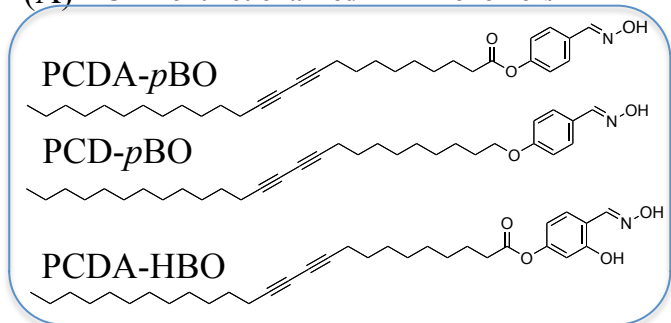
Colorimetric Nerve Agents Sensors



The Rock: VX agent

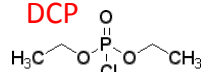


(A) Oxime functionalized PDA monomers

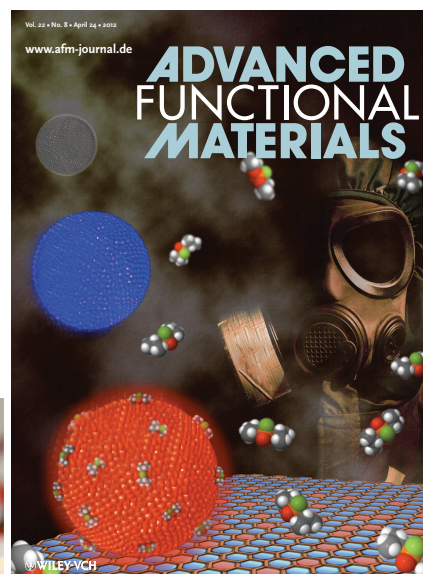
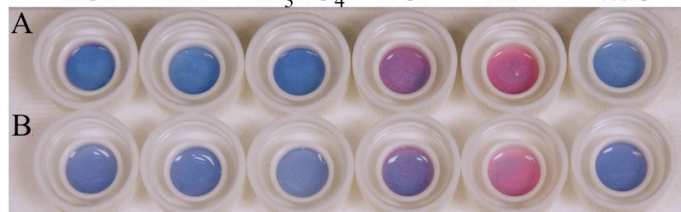
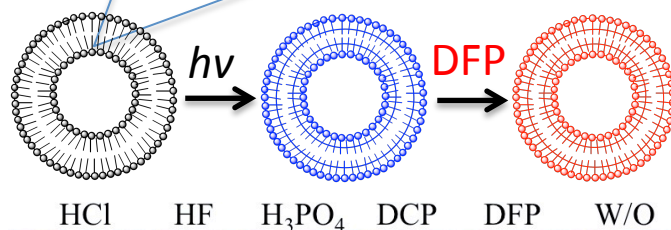
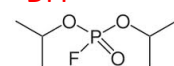


Nerve Agent Simulants

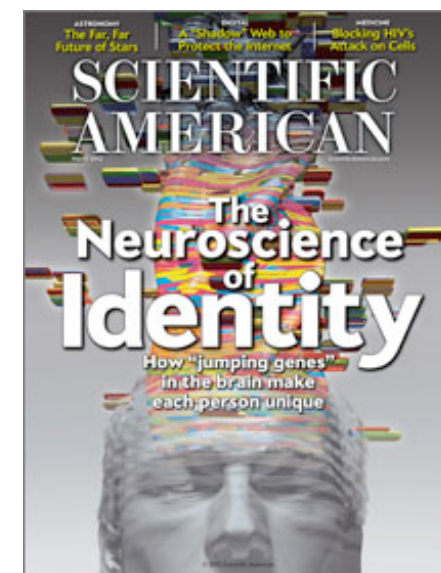
DCP



DFP



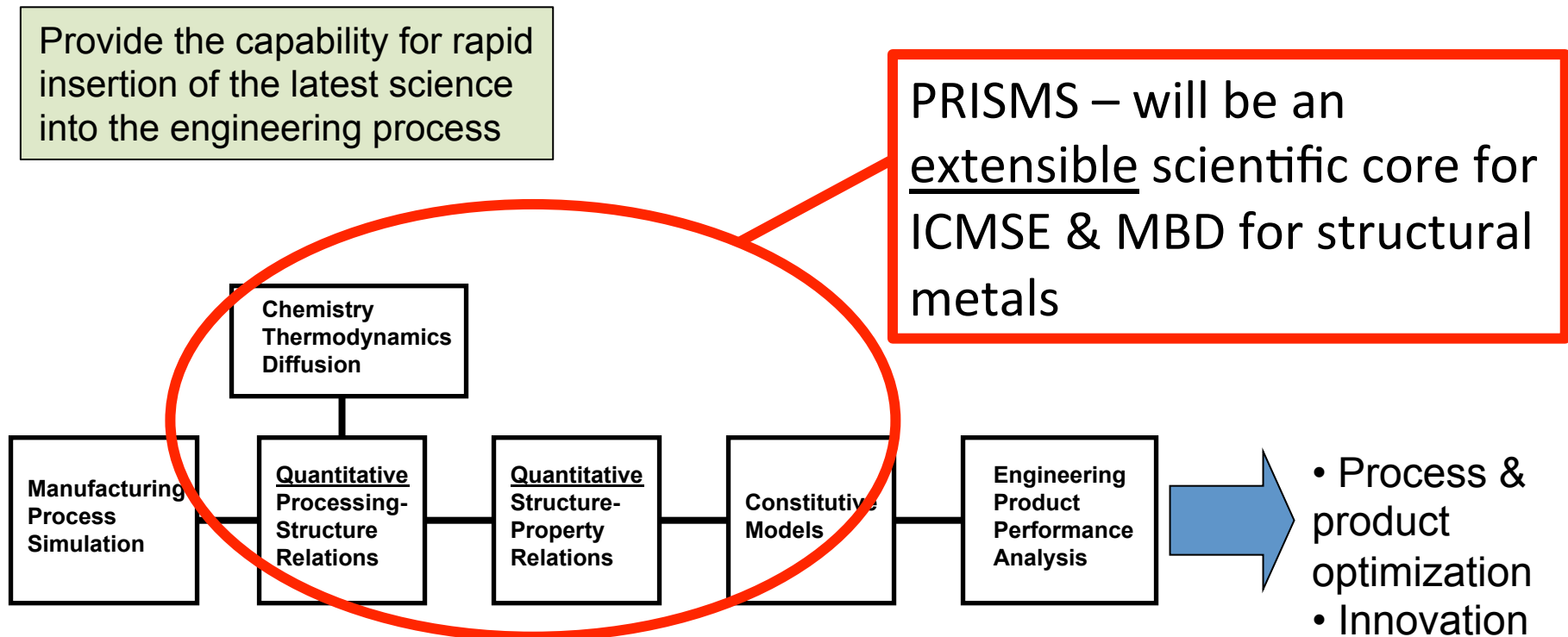
Jiseok Lee, Sungbaek Seo,
Jinsang Kim,
Adv. Funct. Mater
2012, 22, 1632.



Highlighted in
Scientific American:
Extreme Tech
March 2012

DOE Software Innovation Center for Integrated Multi-Scale Modeling of Structural Metals

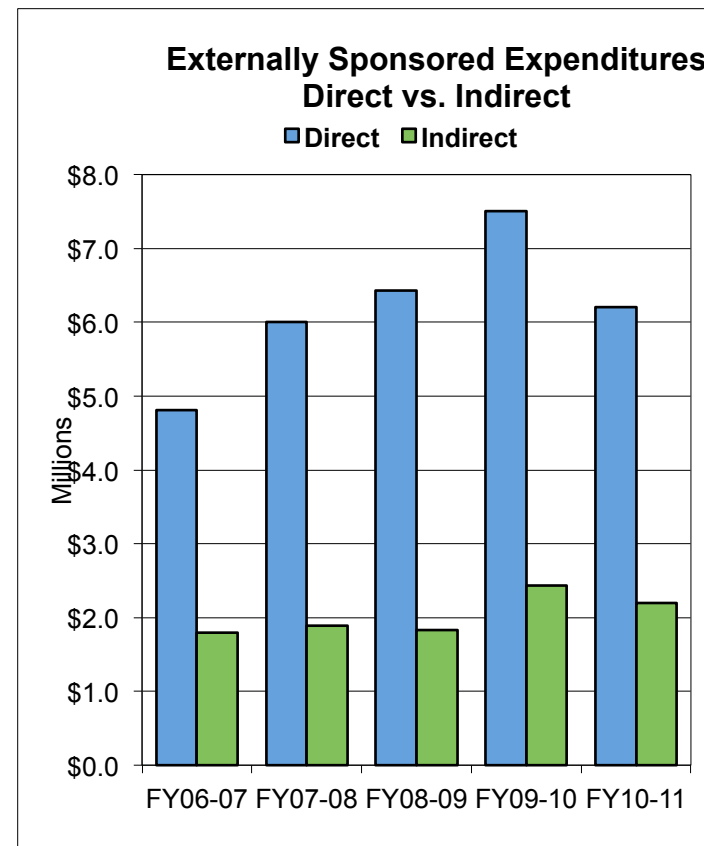
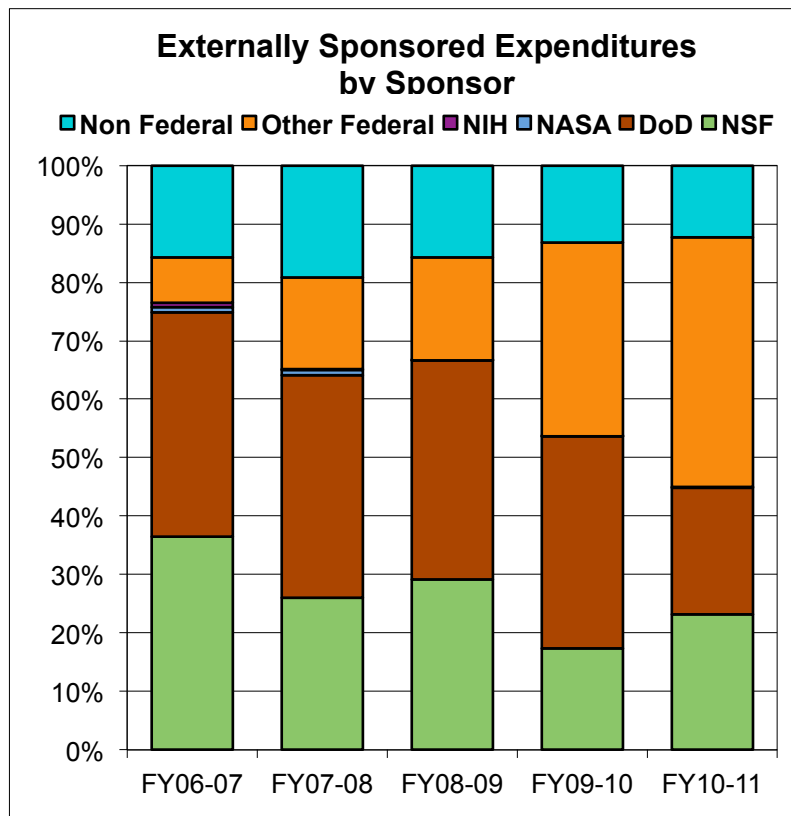
- John Allison -



1. *Develop Advanced Open Source Computational Methods*
2. *Tightly Couple Experiments and Models*

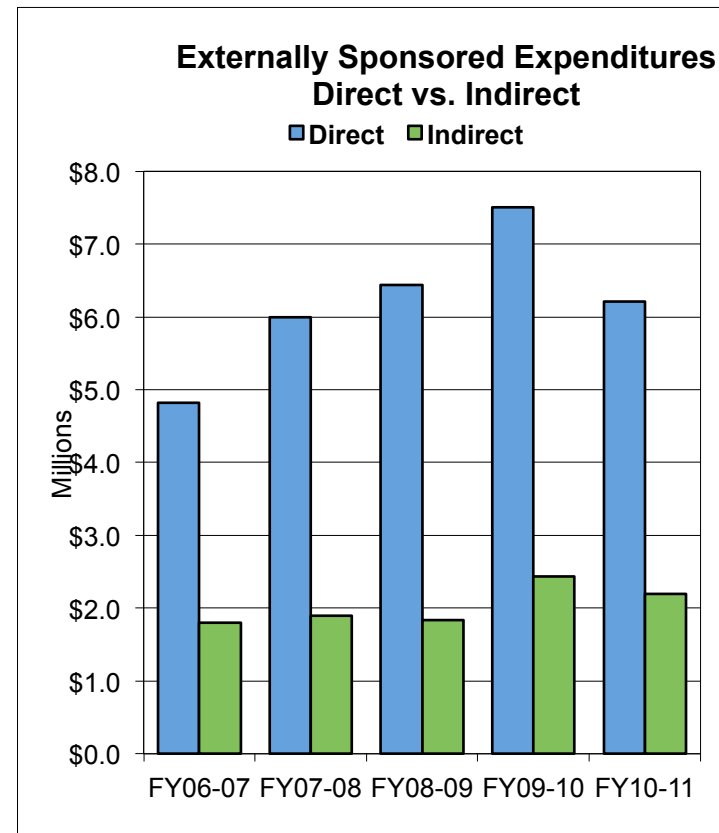
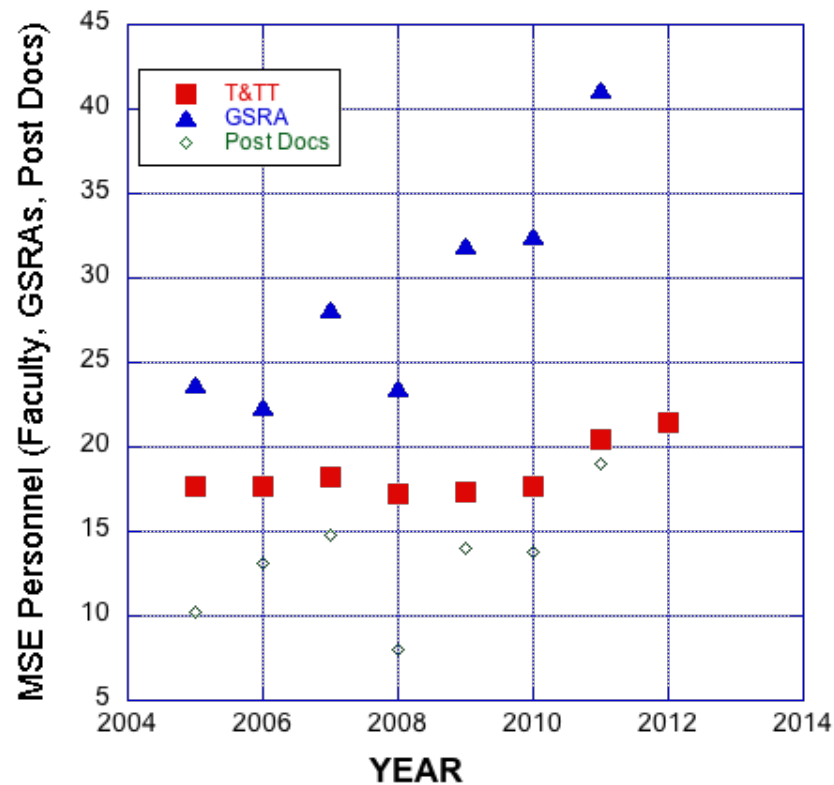
Trends: students, faculty and
research expenditures

Research Expenditures in MSE



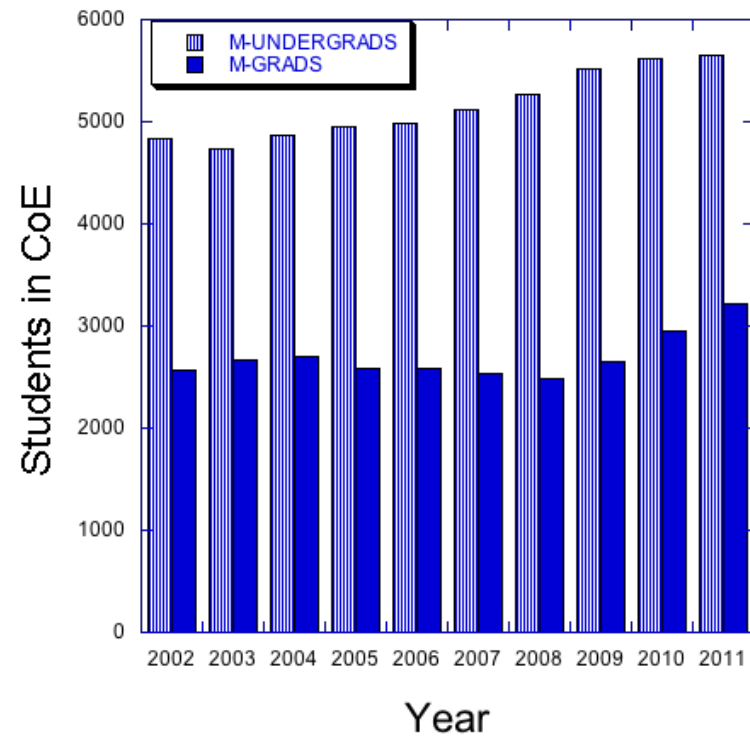
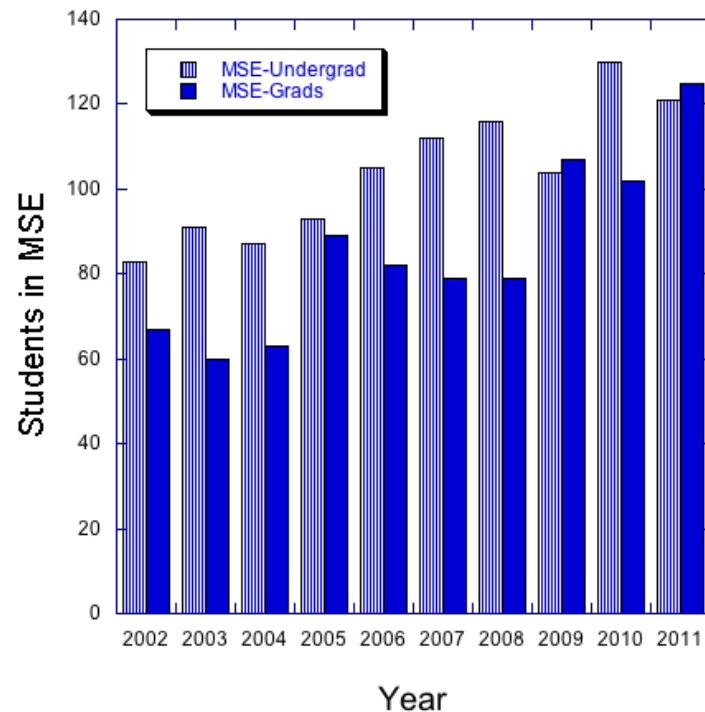
Through effective teaming with people of different skill sets we have changed research directions to compete for new sources
Much of our success is based on the large investment in computational researchers.... Increased DOE funding

Personnel/Expenditure Trends



With comparable number of faculty GSRA's increased ~factor of and research expenditures ~50%

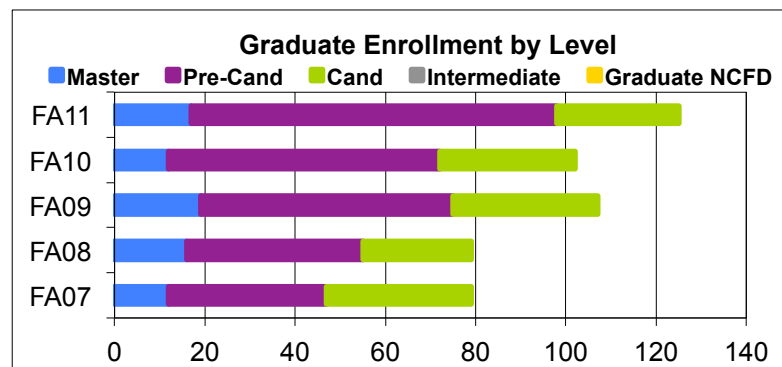
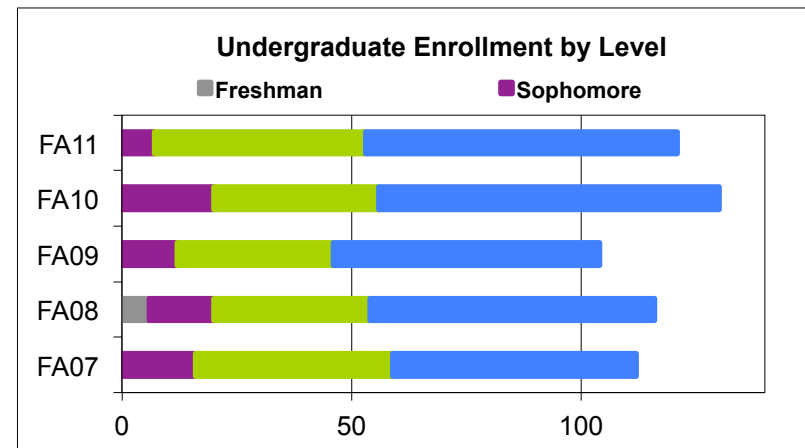
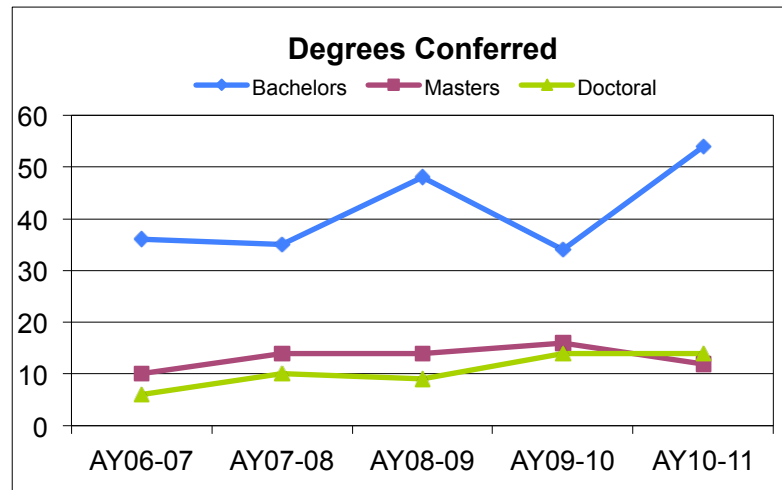
Enrollment Trends in MSE and the CoE



Current Enrollments

- 145 Graduate students (~30 additional students who are supervised by MSE faculty)
- ~144 declared undergraduate majors

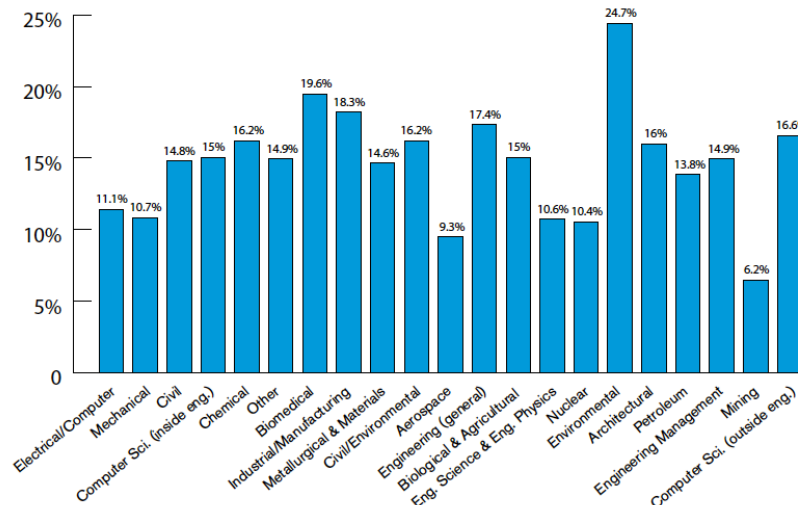
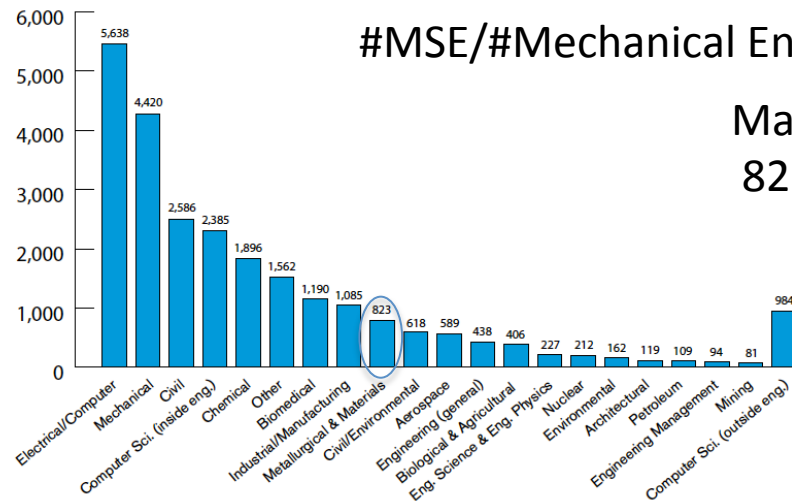
Degree and Enrollment Trends in MSE



140 current declared Majors

Currently: 144 Grad students: 25% female 5% URM

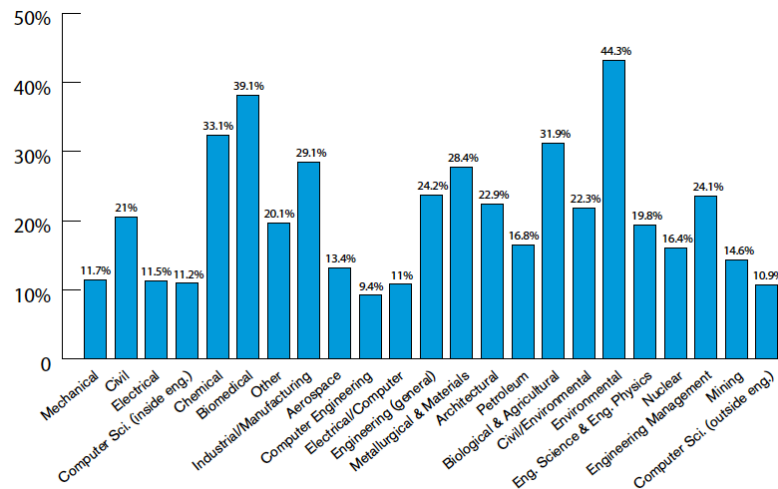
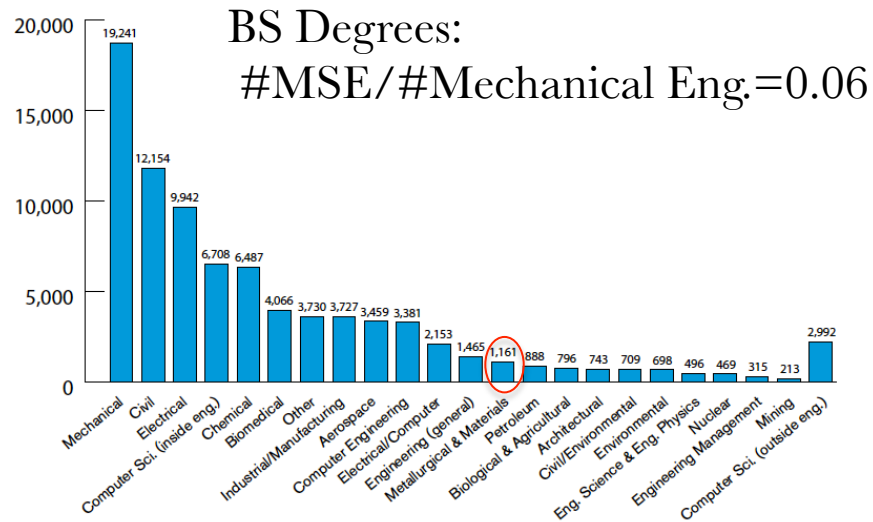
Tenured Faculty in Engineering



Black Faculty 2.5%
Hispanic Faculty 3.6%
Women (2010) 13.2%

Bachelors and Doctoral Degrees Awarded in MSE

2010-2011: Michigan vs. National Average



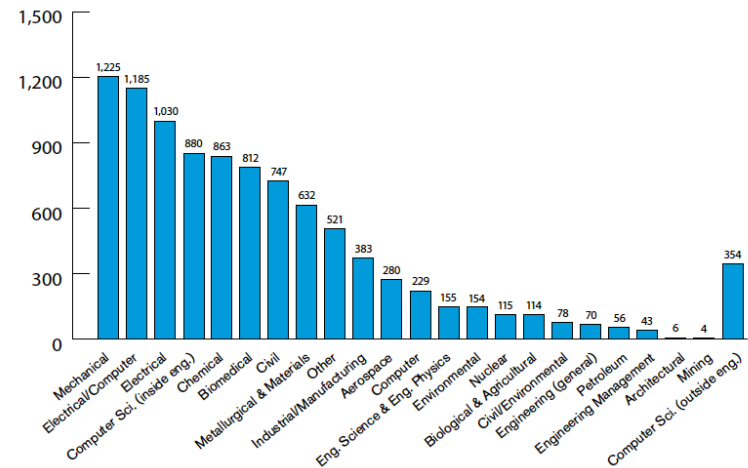
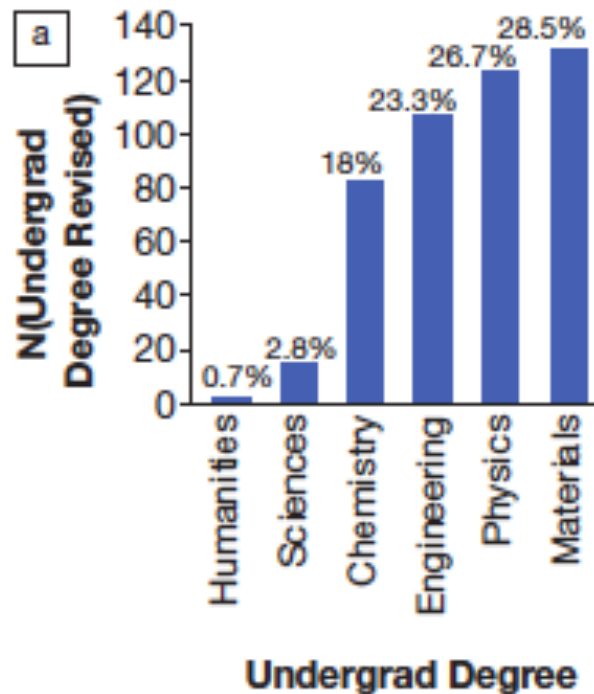
Bachelors Degrees awarded to Women

Michigan MSE: 35%

National Average: 24%

Our Graduate Students

Where do they come from?



PhD Degrees:

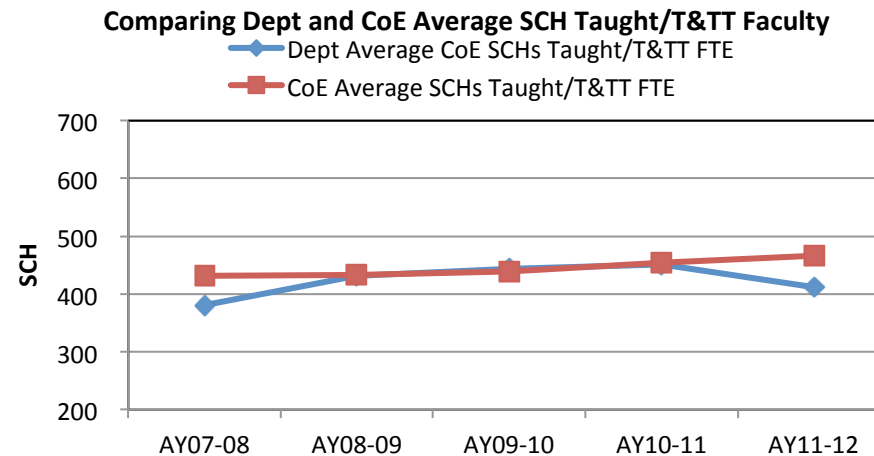
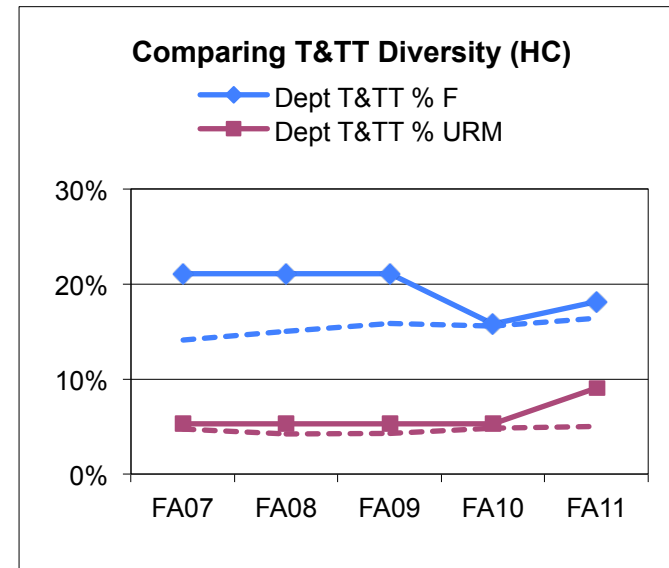
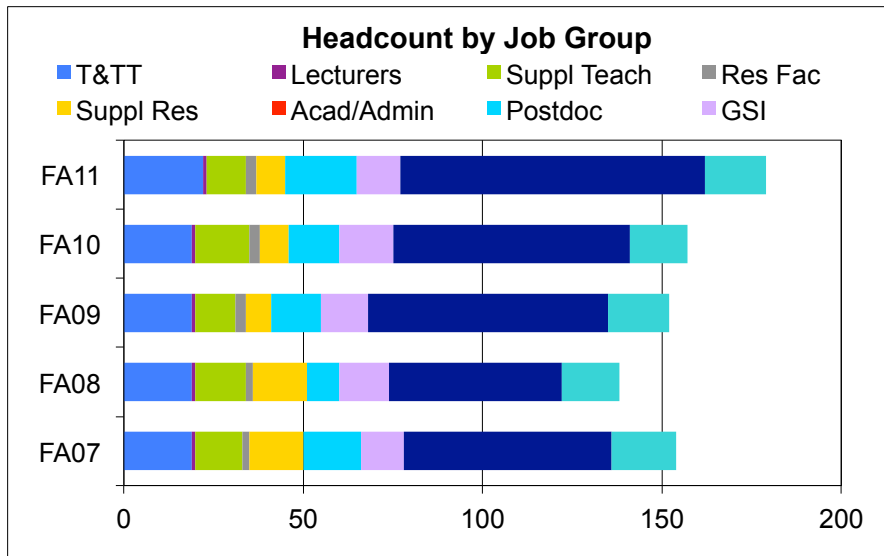
$$\#MSE/\#Mechanical\ Eng.=0.56$$

Doctorates awarded to Women:

National: 27%

Michigan MSE: 36%

Personnel/Teaching Productivity



Collaborative Educational Efforts in MSE

OUTREACH ACTIVITIES

Materials World Network on III-V Bismide Materials for IR and Mid IR Semiconductors

Joanna Mirecki Millunchick (*University of Michigan*), **DMR-0908745**

International Team:

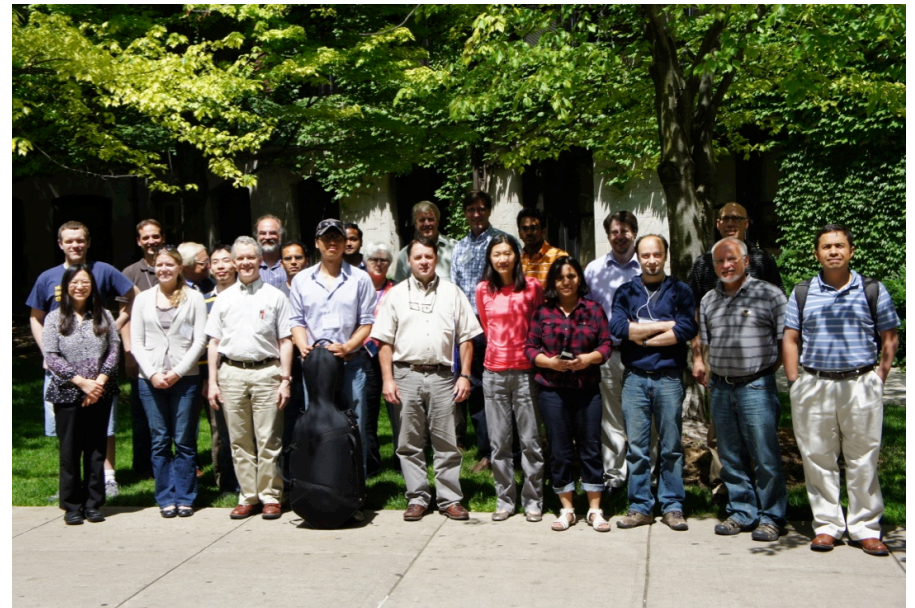
- Shane Johnson, Arizona State University, Tempe, AZ
- Stephan Koch, Philipps-Universität, Marburg, Germany
- Joanna M. Millunchick, University of Michigan, Ann Arbor, MI
- Patricia Mooney, Simon Fraser University, Burnaby, Canada
- Stephen Sweeney, University of Surrey, Guildford, UK
- Tom Tiedje, University of Victoria, Victoria, Canada

Three international workshops have been organized by the Network, which have established a vibrant new scientific community. As proof of this, next year's workshop will be organized by individuals outside of the original collaboration.

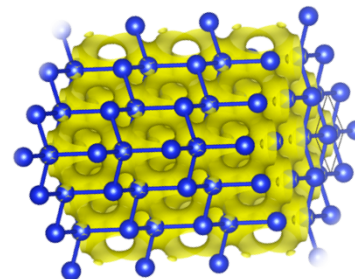


NSF Summer School for Integrated Computational Materials Education PI: Katsuyo Thornton, MSE

To address the challenges in integrating computational techniques into the undergraduate MSE curricula, the 2nd Summer School for Integrated Computational Materials Education was held at the University of Michigan in Ann Arbor from June 11 to 22, 2012. The two-week summer school included a “crash course” on computational materials science and engineering and focus sessions on educational modules that can be adopted into existing core courses. Twenty one participants including professors, postdocs and graduate students attended the Summer School. All who responded plan to implement at least one module into an undergraduate course at their home institutions. CoE contributed to this event through a cost-share. Anton Van der Ven and John Allison from MSE each contributed a lecture.



Participants joined from Cambridge University, Case Western Reserve University, Carnegie Mellon, Cornell, Johns Hopkins, Michigan Tech, Northwestern University, Ohio State, Texas A&M, University of Michigan, Timken (industry).



The new module provides students with experience with density functional theory.

NSF Joint US-Africa Materials Research School

Addis Ababa, Ethiopia, December 8-21, 2012

Theme: *Materials research for sustainable energy*

Organizers: Haile (Caltech), Billings (Columbia), Green (Michigan)

- The *goal* is to develop materials research programs, facilitated in part, through collaborations between United States and African researchers.
- Intended for students and postdoctoral researchers from both continents, and taught by world class Materials researchers.
- Approximately 50 doctoral and early career materials researchers will spend two weeks in historic Addis Ababa, Ethiopia.
- The program will include plenary scientific and tutorial lectures, hands on problem solving, as well as social and cultural events. Topics include: photocatalysis, photovoltaics, thermoelectrics, fuel cells and batteries.

NSF-DMR 1069120

Research Experience in Paris

Ecole Polytechnique

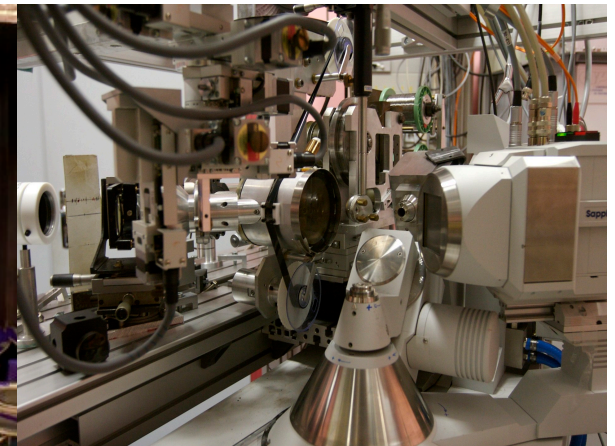
Ecole Nationale de Techniques Avancées (ENSTA)

The Louvre l'Institut d' Optique Graduate School

(Yalisove) CoE/CUOS/MSE



Students stay at Cite Universitaire in downtown Paris



Outreach Programs in MSE: Cass Technical High School in downtown Detroit (Akram Boukai)

Cass Tech (2142) students: 95% are African-American and 2% are Hispanic.

- hands-on battery demonstrations.
- Students built a batteries using vinegar and several different metals.
- powered a handheld calculator with the battery.

Detroit Are Pre-College Engineering Program: **5 week Saturday series** of materials science demonstrations



Pictures from the various outreach activities at Cass Tech and DAPCEP organized by Professor Akram Boukai. Left and center pictures are from Boukai's visit to Cass Tech High School. Right picture is from Boukai's participation in DAPCEP.

ASM Materials Camp, 2006-

Materials Science and Engineering,
class room and hands-on training, for
high school teachers

-Approximately 30 high school teachers
from around the country spend one
week in the department for training



Challenges and Opportunities

Opportunities for Materials Research

- Advanced Manufacturing
- Nanoscience/nanotechnology...on going
- Energy Storage/Energy conversion
- Innovation/Commercialization
- STEM Education

Opportunities: Advanced Manufacturing

- Advanced Manufacturing Partnership (AMP), “a national effort bringing together industry, universities, and the federal government to invest in the emerging technologies that will create high quality manufacturing jobs and enhance our global competitiveness,”
- Materials Genome Initiative (MGI). The MGI “will support the development of computational tools, software, new methods for material characterization, and the development of open standards and databases that will make the process of discovery and development of advanced materials faster, less expensive, and more predictable.”

Curricula Development *responding* to trends in the environment including research directions

- Integrated Computational Materials Engineering (ICME). “ICME integrates knowledge, developed from basic scientific methodology, into the development of computer simulation tools/models, with manufacturing insights and information into produce design.” MSE faculty are actively involved in curriculum development in this arena.
 - New course introduced
 - New computational modules integrated into the primary MSE undergraduate laboratories (MSE 360 and MSE365)
- [Entrepreneurial Activities](#)...integrated into MSE489 (Materials Processing Design) ...new course taught by Shtein/Tuteja
- New MSE 480 (Materials and Engineering Design) - taught by Shtein/Taub
- New [nanoscience](#) course: theory (van der Ven/Kioupakakis)
- New Courses on [functional organic materials](#) (Kim, Laine)

Startups by MSE Faculty

- Adaptive Materials (Halloran), Inc in 2000...acquisition by Ultra Electronics-PLC, it is now call Ultra-AMI. still located in Ann Arbor <http://www.ultra-ami.com>
- HECAMCO LLC, founded in 2011 to commercialized carbon building materials and hydrogen fuels from coal pyrolysis. (Halloran)
- DDM System Corp... 3D-printing technologies. (Halloran)
- Nanocerox 1996-(Laine)
- Mayaterials 2003- (Laine)
- Silicium Energy 2011- (Boukai)
- Arborlight, LLC 2011 (Shtein)

Challenges:

Amount of space and the quality of space!

The department was designed and build for a smaller faculty performing less sophisticated experiments

- The field has evolved rapidly involving considerably more activities that require wet chemistry
- Low vibration space required for nanoscale measurements
- Clean space requirements...air handling...etc.

Materials Science and Engineering: Diverse and highly interdisciplinary

- Use fundamental ideas from the fields of science and mathematics to **develop** rules and methods/strategies for the design and synthesis/processing of materials with properties **“tailored” for applications**
- Our research relies on computational tools, diagnostic tools to measure structure and properties at the nanoscale and atomic scale, and we rely on innovative chemical synthesis
- Through effective teaming with researchers of different skill sets we have the flexibility to change research directions to compete for new sources
 - Research expenditures, enrollments in our field has increased significantly during the last 5 years.
 - Faculty productivity has increased significantly
 - Student quality has increased significantly during the last 5 years.

