# Materials Science and Engineering at Michigan: Current and Future

October 26, 2012

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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

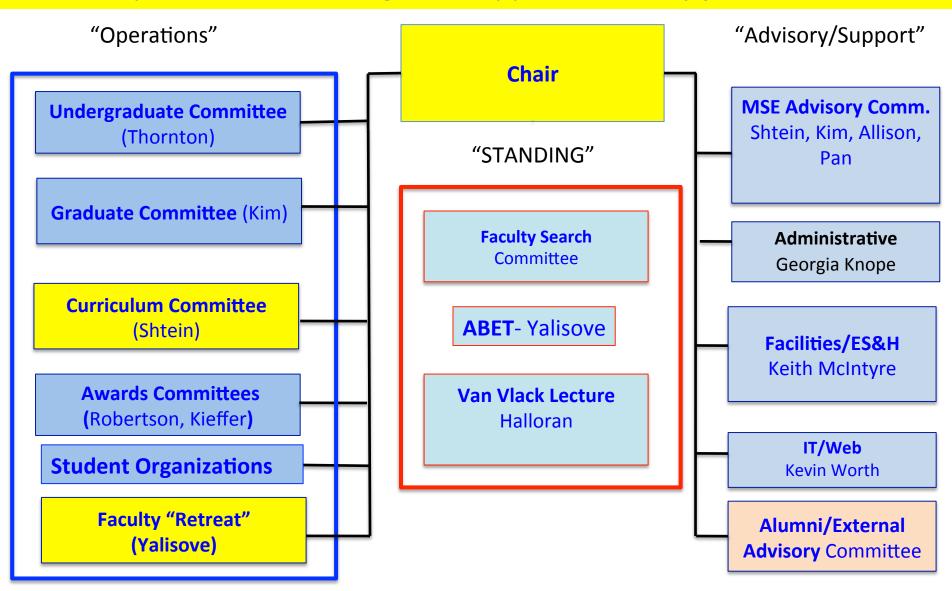
## **Mission Statement**

#### • 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.

### A "Snapshot" of the MSE Organization:

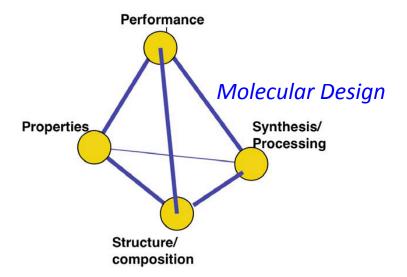
Operations, Standing and Support/Advisory functions



#### 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
- Nanoscience and nanotechnology are crosscutting areas of emphasis

- 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



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** 

- 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

## 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 Marqius (*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

# 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

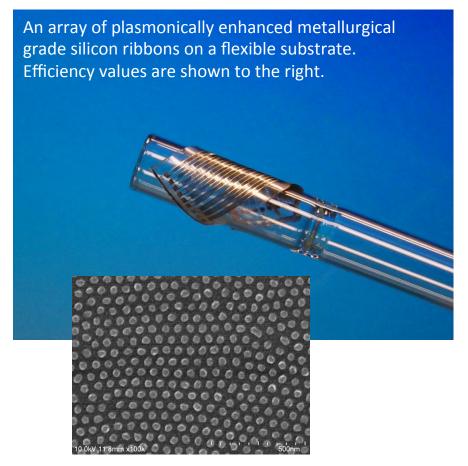
## External Recognition

- 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
  - Inaugural Editor-in-Chief Materials Communications (MRS/Cambridge Univ. Press)
- Nicholas Kotov 2012 Stine Award for Materials Research (AICHE)
- <u>Joerg Lahann</u> 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)

## Examples of Noteworthy Achievements (2011-12)

- 1. MSE undergraduates were finalists in Michigan Clean Energy Venture Challenge
- 2. Scientific/Technical Accomplishments
  - (i) Distinguished Dissertation award <u>Chris Nelson</u>: atomic scale structure and dynamics of domains during electrical switching in ferroelectric thin films
  - (ii) New materials and processes based on computational design for efficient energy conversion
  - (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)

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



Used in solar cells

**Published in:** 

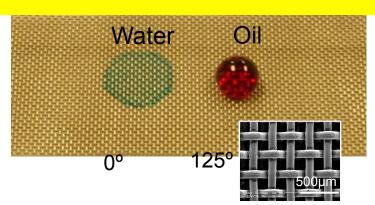
Nanoletters, September 2012 C&EN News

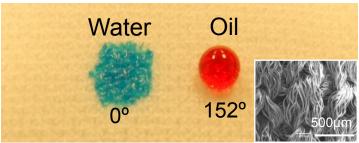
Price is 0.2 of the cost of purified silicon

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



#### Membranes for oil-water separation (Tuteja Group)

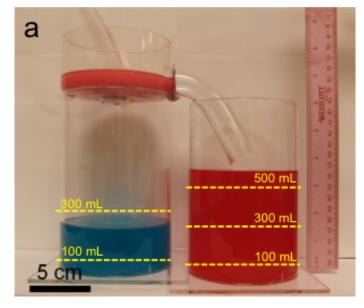




Developed one of the first coatings that counter-intuitively are hydrophilic and oleophobic.

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.

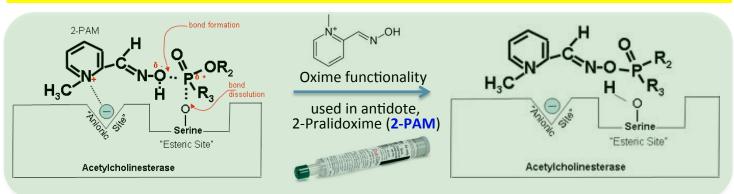


This is the first-ever setup developed for the continuous separation of oil-water emulsions which utilizes only gravity. The membrane separation efficiency exceeds 99.99%.

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

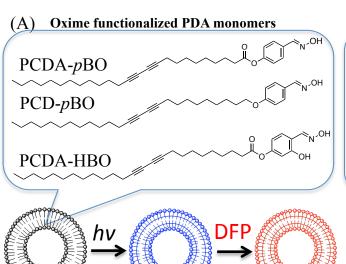
Nature Communications,

### Colorimetric Nerve Agents Sensors



The Rock: VX agent



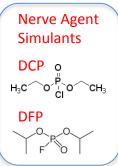


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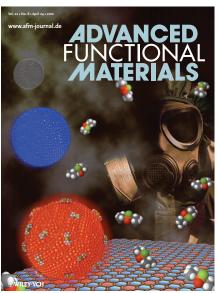
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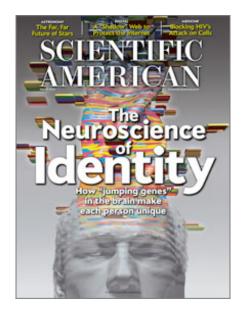
W/O







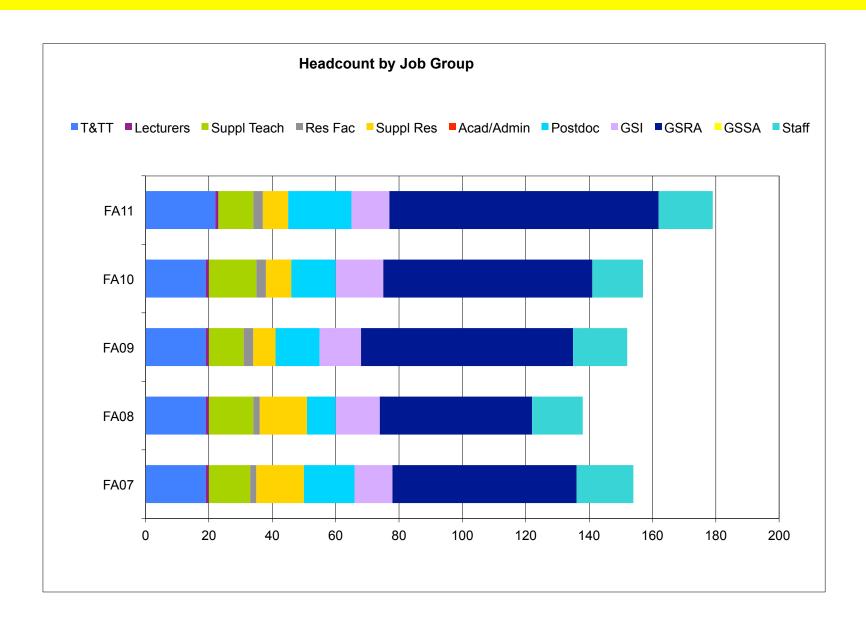
Jiseok Lee, Sungbaek Seo, Jinsang Kim, **Adv. Funct. Mater** 2012, 22, 1632.



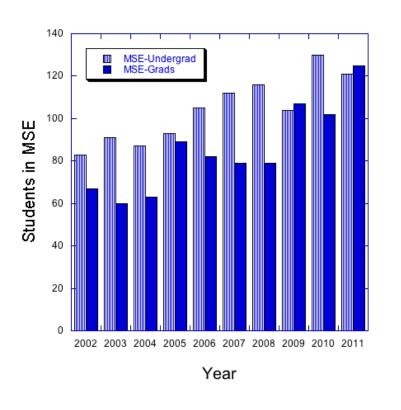
Highlighted in Scientific American: Extreme Tech March 2012

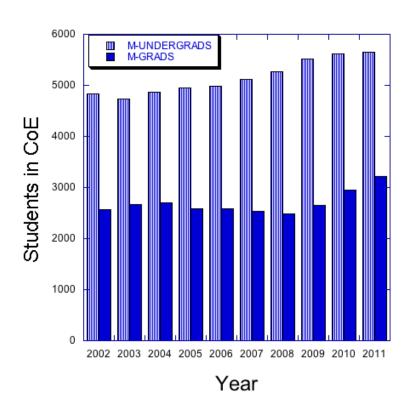
# Trends: students, faculty and research directions

## Personnel/Teaching Productivity



#### **Enrollment Trends in MSE and the CoE**

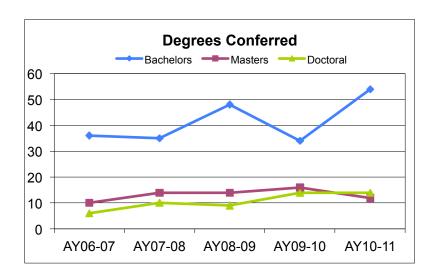




#### **Current Enrollments**

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

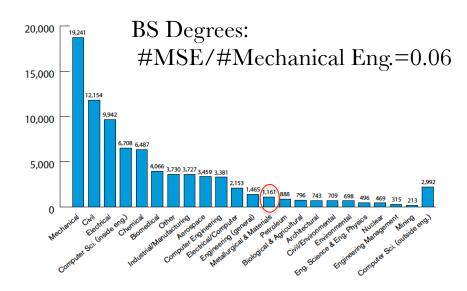
## Degree Trends in MSE

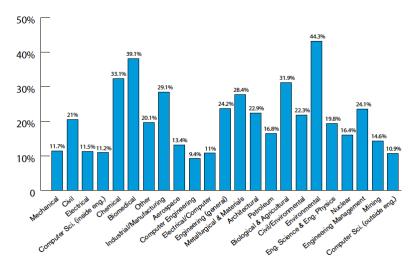


145 current declared Majors

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

# Bachelors and Doctoral Degrees Awarded in MSE 2010-2011: Michigan vs. National Average





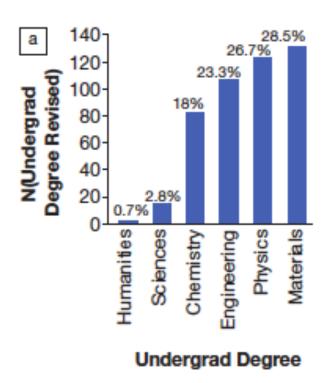
#### **Bachelors Degrees awarded to Women**

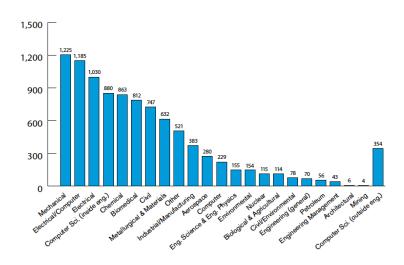
Michigan MSE: 35% National Average: 24%

ASEE "engineering by numbers" 2012

## Graduate Students in MSE: Nationwide

Where do they come from?





PhD Degrees: #MSE/#Mechanical Eng.=0.56

#### **Doctorates awarded to Women:**

National: 27%

Michigan MSE: 36%

## **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

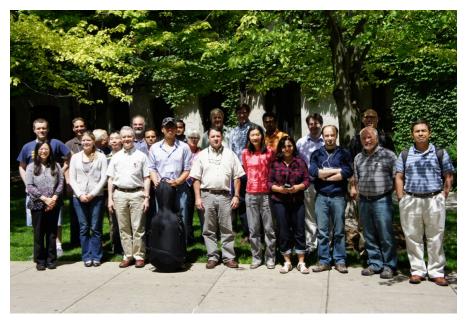
Three international workshops have been organized by the Network, which have established a vibrant new scientific community. As proof of this, next year's workshop will be organized by individuals outside of the original collaboration.



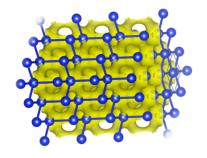


# NSF Summer School for Integrated Computational Materials Education PI: Katsuyo Thornton, MSE

To address the challenges in integrating computational techniques into the undergraduate MSE curricula, the 2<sup>nd</sup> 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

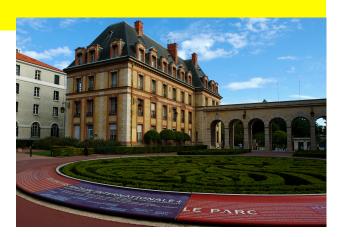
#### **Research Experience in Paris**

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**

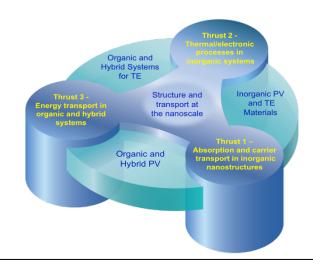
- Advanced Manufacturing
- Nanoscience/nanotechnology...on going
- Energy Storage/Energy conversion
- Innovation/Commercialization
- STEM Education

# Opportunities: Advanced Manufacturing (2011-OSTP)

- 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."

### CENTER FOR SOLAR AND THERMAL ENERGY CONVERSION Peter F. Green (University of Michigan)

Design and synthesize new materials for high efficiency photovoltaic (PV) and thermoelectric (TE) devices, predicated on new fundamental insights into equilibrium and non-equilibrium processes, including quantum phenomena, that occur in materials over various spatial and temporal scales.

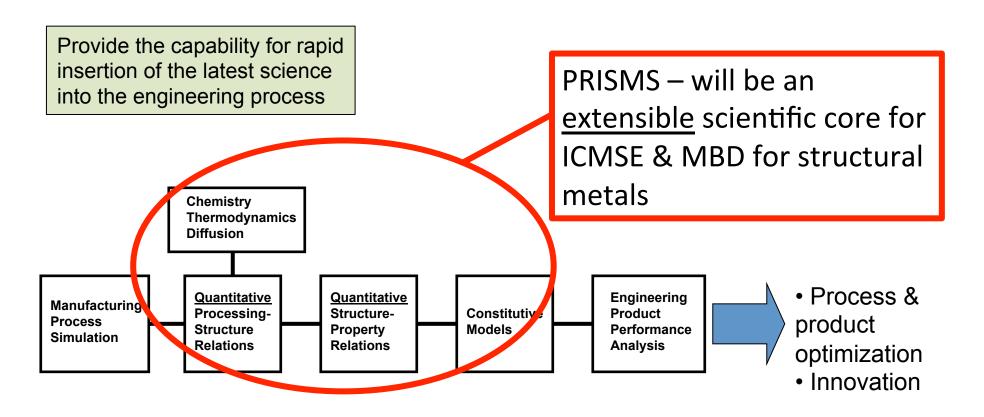


#### RESEARCH OBJECTIVES AND DIRECTIONS

Research in CSTEC falls in three synergistic and collaborative thrusts, under a unifying concept: *structure and transport at the nanoscale*.

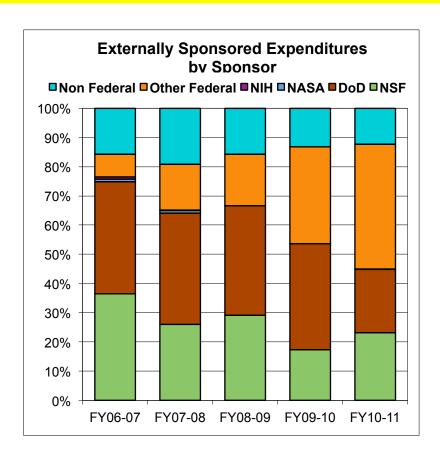
<u>Thrust 1</u>: exploit unique quantum effects at the nanoscale to achieve high efficiency solar energy conversion. <u>Thrust 2</u>: to understand and to exploit fundamental mechanisms and processes to achieve high figures of merit in thermoelectric (inorganic, hybrid or molecular) materials. <u>Thrust 3</u>: investigate the molecular and structural origins of energy conversion phenomena in organic and hybrid material systems.

# 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

## 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

## 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 <a href="http://www.ultra-ami.com">http://www.ultra-ami.com</a>
- HECAMCO LLC, founded in 2011 to commercialized carbon building materials and hydrogen fuels from coal pyrolysis. (Halloran)
- DDM System Corp... 3D-printing technologies. (Halloran/Das)
- Nanocerox 1996-(Laine)
- Mayaterials 2003- (Laine)
- Silicium Energy 2011- (Boukai)
- Arborlight, LLC 2011 (Shtein/Ku))

# 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
- New Courses on functional organic materials (Kim, Laine)

# 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



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

The Ross School of Business.

Receiving a \$5,000 award at the

Michigan Clean Energy Venture

Challenge. They are standing with

DTE Energy vice president Knut Si-

monsen (left) and Bob Lutz, retired vice chairman of GM. Friday, Feb

17, 2012 at Blau Auditorium at U-M

The members of the team from left to right are:
Allessandra McGinnis John Strader Tyler Austin James Detlefs, Ashwin Retrahet, and Fric Jones

#### **Team Arbor Solar Technologies**

James Detlefs (MSE) Allessandra McGinnis (MSE) Ashwin Betrabet (MSE)

"energy-efficient lighting scheme"

### **Challenges:**

## Amount of space and the quality of space!

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

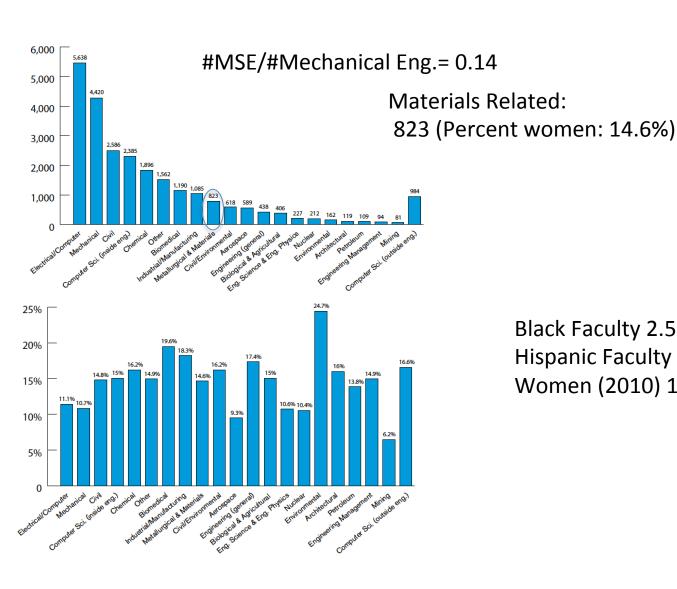
- The field has evolved rapidly involving considerably more activities that require wet chemistry
- Low vibration space required for nanoscale measurements
- Clean space requirements...air handling...etc.

## 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.

# THANK YOU

## Tenured Faculty in Engineering: National



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

# Selected Examples of Achievements

- MSE undergraduates were finalists in Michigan Clean Energy Venture Challenge
- Scientific/Technical Accomplishments
  - (i) Distinguished Dissertation award <u>Chris Nelson</u>: atomic scale structure and dynamics of domains during electricalswitching in ferroelectric thin films
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- DOE Software Innovation Center for <u>Integrated Multi-Scale</u> Modeling of Structural Metals...John Allison