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Northwestern University

Materials Research Science and  
Engineering Center

Overview by  
Center Director Monica Olvera de la Cruz

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Excellence in materials research & education is an important mission of Northwestern University (NU).

Faculty members from various departments and schools are involved in materials research at NU.

## Materials Research Science and Engineering Center (MRSEC): Multifunctional Nanoscale Material Structures

### Director's Overview:

Research Organization

Emerging Research Seeds

Facilities

Industrial Outreach and International Collaborations



# NU-MRSEC Mission

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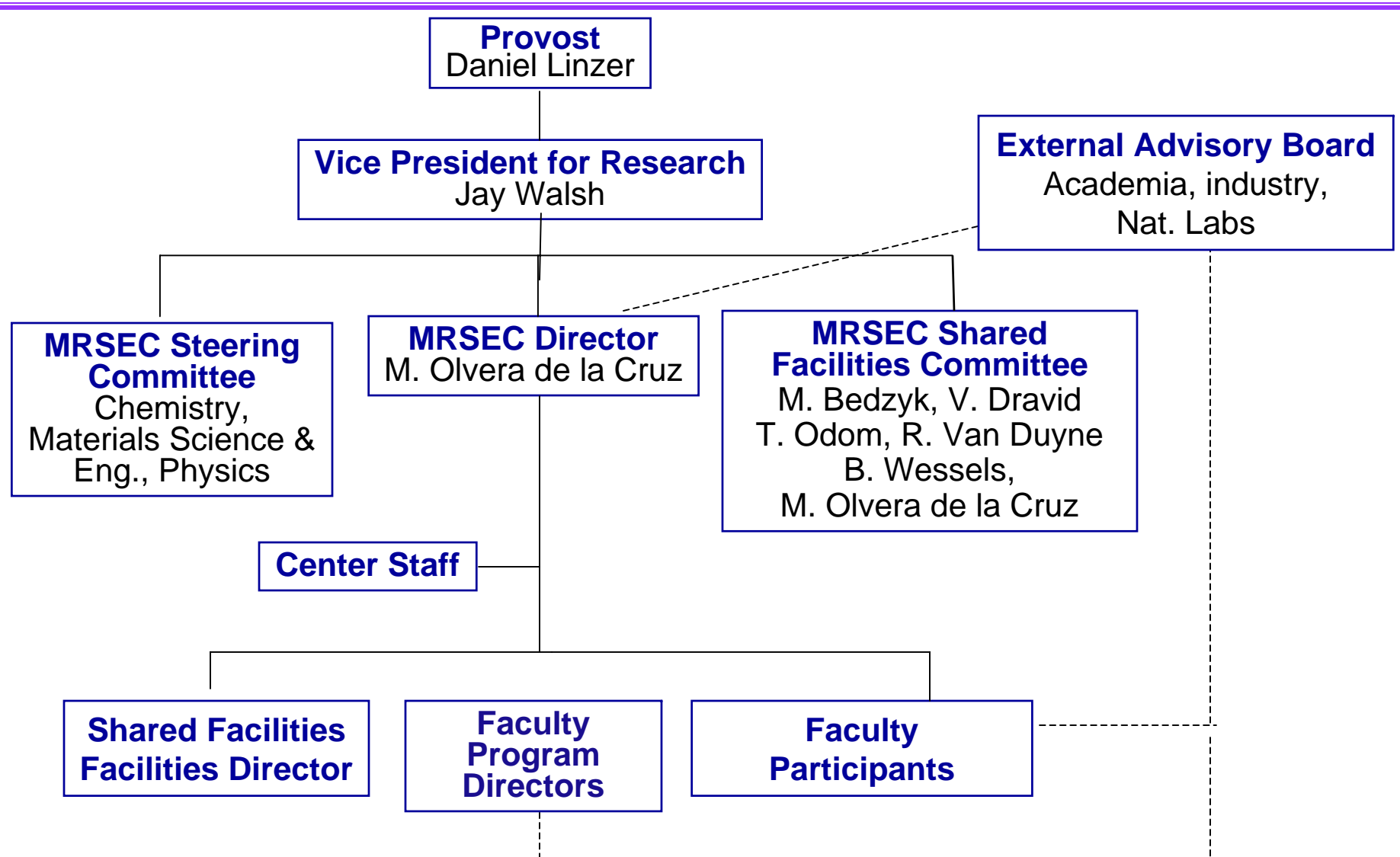
The Northwestern University Materials Research Science and Engineering Center develops and supports collaborative, interdisciplinary research and education in the science and engineering of **nano-scale multifunctional material structures.**

# MRSEC Program Goals

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1. To conduct **synergistic, innovative materials research**, which has active collaborations with industry, government labs, and academia.
2. To contribute meaningfully to a **creative, well-educated, diverse workforce** in materials research.
3. To provide **successful educational outreach** programs.
4. To create, innovate and support shared **experimental facilities**.
5. To provide effective means of **knowledge transfer**.

# Management



# Participating Senior Investigators by Department

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## Materials Sci.

Barnett, Scott  
Bedzyk, Michael  
Chang, R.P.H.  
David, Vinayak  
Faber, Katherine  
Hersam, Mark  
Lauhon, Lincoln  
Marks, Laurence  
Mason, Thomas  
Olvera, Monica  
Shull, Kenneth  
Stupp, Samuel  
Wessels, Bruce

## Chemistry

Marks, Tobin  
Mirkin, Chad  
Nguyen SonBinh  
Odom, Teri  
Poepelmeier, Ken  
Ratner, Mark  
Schatz, George  
Scheidt, Karl  
Seideman, Tamar  
Van Duyne, Richard

## Physics

Cao, Hui  
Ellis, Donald  
Freeman, Arthur  
Ketterson, John  
*Motter, Adilson*

## Biomedical Eng

*Ameer, Guillermo*

## Cell Biology & Molecular Biology

*Marko, John*

## Chem & Biol Eng

Broadbelt, Linda  
Burghardt, Wesley  
Torkelson, John  
*Grzybowski, Bartosz*

## Mechanical Eng

Brinson, L. Catherine

## Electrical Engineering

Ho, Seng-Tiong

**12 faculty (underlined) were not funded in 2000-2005.**

**4 faculty (in red) are new since 2007.**

# Synergistic, Innovative Research

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**Participating Senior Investigators by  
Interdisciplinary Research Group (IRG)**

**IRG 1 – Multifunctional  
Oxide Ceramics**



V. Dravid, MSE

B. Wessels, MSE & ESE

S. Barnett, MSE

M. Bedzyk, MSE

D. Ellis, Physics

A. Freeman, Physics

S.T. Ho, ESE

T. Marks, Chemistry

T. Mason, MSE


K. Poeppelmeier, Chem.

# Synergistic, Innovative Research

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## Participating Senior Investigators by IRG

### **IRG 2 – Nano-structured Polymer Blends, Composites & Supramolecular Structures**



**K. Shull, MSE**

**L.C. Brinson, Mech. E.**

**L. Broadbelt, ChBE**

**W. Burghardt, ChBE**

**K. Faber, MSE**

**S. Nguyen, Chem.**

**M. Olvera de la Cruz, MSE**

**S. Stupp, MSE**

**J. Torkelson, ChBE**

# Synergistic, Innovative Research

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## Participating Senior Investigators by IRG

### **IRG 3 – Molecular Plasmonics**



R. Van Duyne, Chem.

**H. Cao, Physics**

**R.P.H. Chang, MSE**

**J. Ketterson, Physics**

**L. Marks, MSE**

**C. Mirkin, Chem.**

**T. Odom, Chem.**

**G. Schatz, Chem.**

# Synergistic, Innovative Research

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## Participating Senior Investigators by IRG

### IRG 4 – Hybrid Organic-Inorganic Nanoelectronic Materials



T. Marks, Chem.

L. Lauhon, MSE

M. Bedzyk, MSE

M. Hersam, MSE

M. Ratner, Chem.

T. Seideman, Chem.

J. Torkelson, ChBE

# Synergistic, Innovative Research

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## ***Multifunctional Nanoscale Material Structures***

### **2005 Seeds: Successful Growth**

**Seed Group – Self-organization in the Synthesis of nanostructure Materials** (*G. Schatz*)

**Seed 1 – Controlling Interfaces in Semiconductor Nanowires** (*L. Lauhon*)

**Seed 2 – Synthesizing Deuterium-Labeled Molecules** (*K. Scheidt*)

# Synergistic, Innovative Research

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## ***Multifunctional Nanoscale Material Structures***

**2007 Seeds (extra matching funds from NU)**

**Seed 3 – Nanocomposite Elastomers for Vascular Tissue Engineering** (*G. Ameer*)

**Seed 4 – Electrostatically “Patchy” Nanoparticle Coatings for Applications in Biomaterials and Flexible Electronics** (*B. Grzybowski*)

**Seed 5 – Analysis and Design of Genetic and Metabolic Control Systems of Bacterial Cells** (*J. Marko, A. Motter*)

# Future Plans for New Seeds

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The complementary abilities of **Ameer, Grzybowski, Motter and Marko**, together with the work on fiber self-assembly in the self-assembly seed and on gels in IRG 2, naturally lead to the possible formation of a **super seed** research group in functional biomaterials.

MRSEC will facilitate these interactions.

Maybe we will find a way also to include interactions with new hires in biomaterials: Huang, Szleifer and Joester.

# Research Goals

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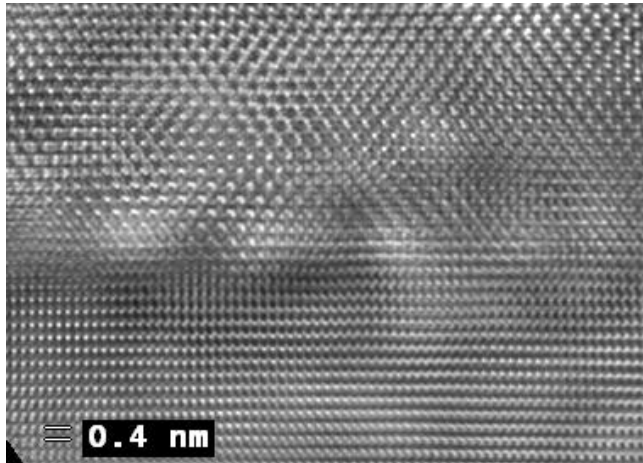
## **IRG #1: *Synergistic Linear and Nonlinear Phenomena in Multifunctional Oxide Ceramic Systems***

### **GOAL OF IRG #1:**

**This group seeks to advance fundamental knowledge leading to the development of energy-efficient and novel multifunctional devices for electronic, optoelectronic, storage, sensor and information technologies.**

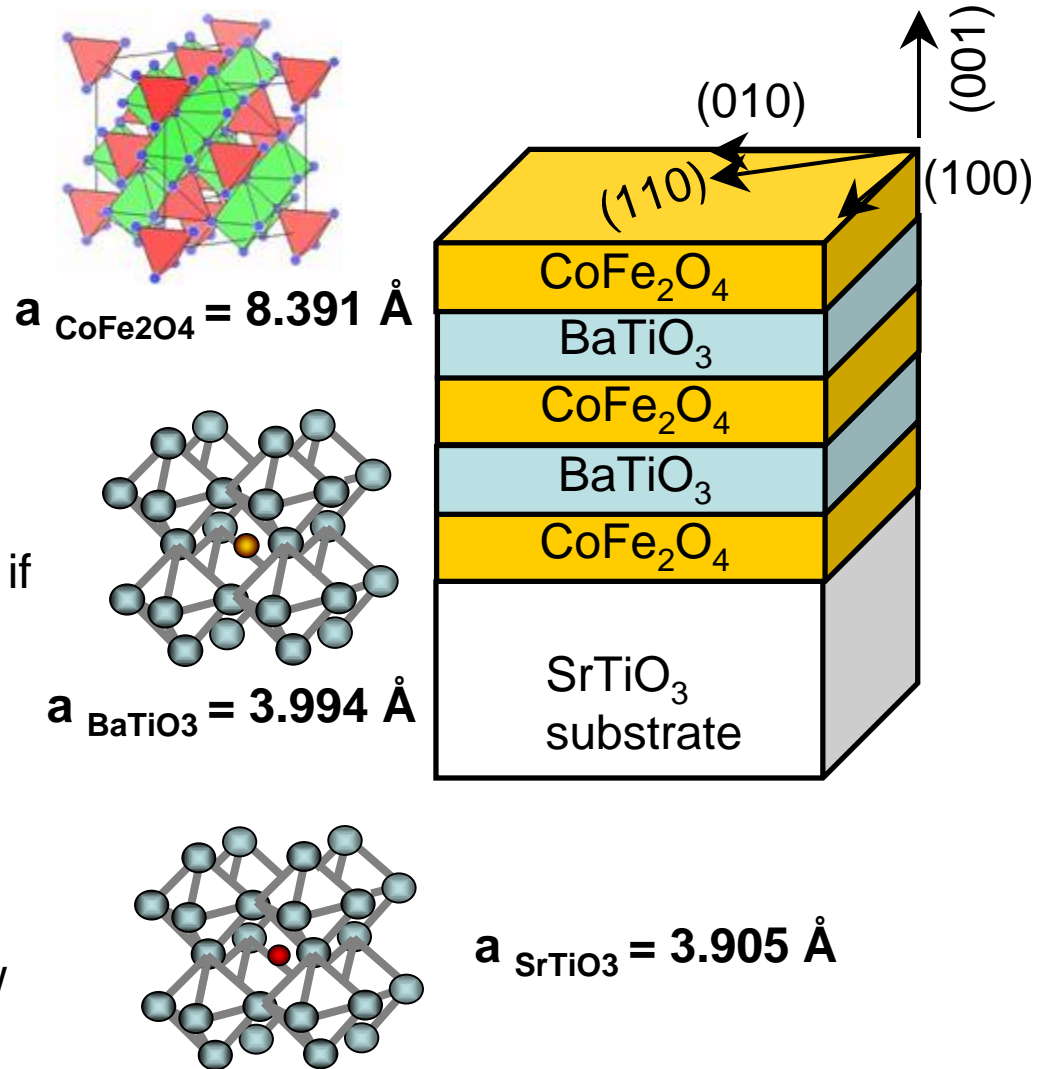
# Ferroic Multilayer Thin Film Strategy

G. Sterbinsky, J. Zheng and B. Wessels



HRTEM of the  $\text{Fe}_3\text{O}_4/\text{SrTiO}_3$  interface

Incorporating magnetic materials into electronic devices can add functionality if electric field control of magnetism is achieved. We use molecular beam epitaxy to create high quality heterostructures between ferroelectric perovskites and ferrimagnetic spinel ferrites with a magnetostrictive and piezoelectric coupling which should allow electrical control of magnetism.



# Research Goals

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**IRG #2: *Novel Processing Methods for Nanostructured Polymer Blends, Composites and Supramolecular Structures***

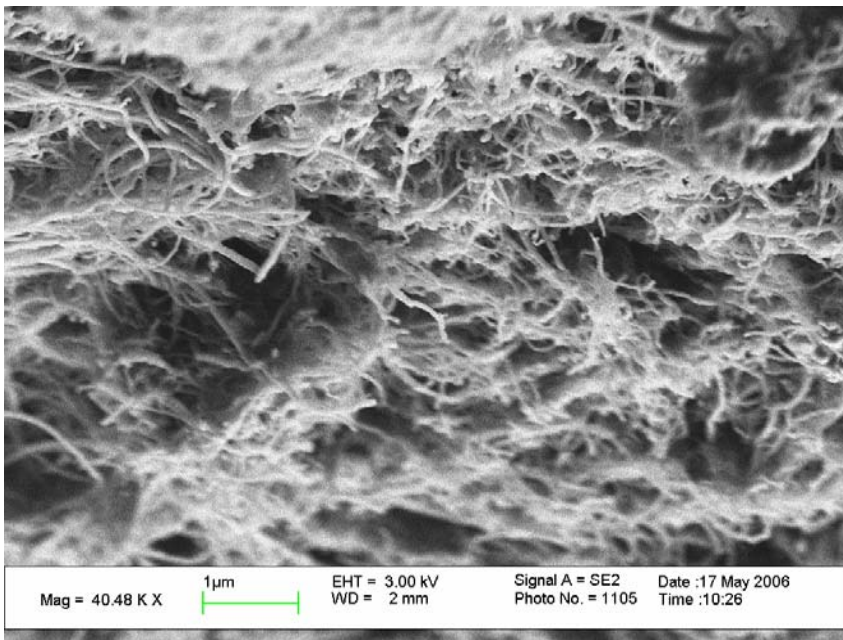
**GOAL OF IRG #2:**

**The primary goal of this group is to develop and produce materials with superior physical properties using self-assembly strategies that include polymers, peptides, ceramics, metals and structured composite materials.**

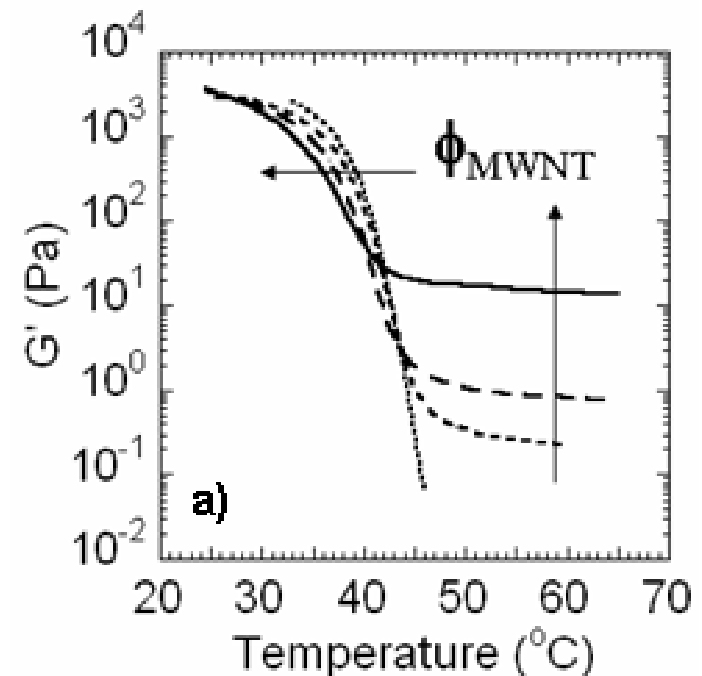
# Polymer Gel/Carbon Nanotube Composites

Andrew B. Schoch, L. Catherine Brinson, Kenneth R. Shull

The combination of a thermoreversible gel and carbon nanotubes creates a model system with a low viscosity solution at high temperatures that enables the dispersion of the nanotubes. At low temperatures a tough gel is formed that can be handled and tested for mechanical property enhancements.



SEM micrograph of MWNT/gel composite



Temperature dependent elasticity at different volume fractions of nanotubes

# Research Goals

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**IRG #3: *Molecular Plasmonics: Fundamentals, New Tools, and Devices***

## **GOAL OF IRG #3:**

**The primary goal of this group is to advance understanding of plasmonic phenomena at the single nanoparticle and single molecule levels; and to develop the new research tools necessary to accomplish this.**

# Research Goals

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## **IRG #4 *Hybrid Organic-Inorganic Nanoelectronic Materials from Molecules to Printable Thin Films***

### **GOAL OF IRG #4:**

**Synthesis, processing, characterization and theory will be employed to improve fundamental understanding and optimize process efficiency across multiple length-scales, and to enable novel technological advances in the area of hybrid organic/inorganic nanoelectronic materials.**

# High-Performance Thin Film Transistors

L. Wang, M.H. Yoon, G. Lu, Y. Yang, A. Facchetti and T.J. Marks

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Thin-film transistors, already indispensable in a number of portable electronics, would benefit from **optical transparency** and compatibility with **flexible, lightweight** plastics.

Transistors with these qualities would be major advance if they could be fabricated by a scalable, **large-area process**.

We have adopted a hybrid approach in developing **'invisible'** thin film transistors that heterogeneously integrate a transparent, inorganic semiconductor with a large carrier mobility and a nanoscopic, organic gate dielectric.



Photo of a 70-device array of fully transparent inorganic-organic hybrid thin film transistors on a 1"x1" glass substrate. The edges of the glass substrate are marked in green for clarity.

MRSEC

# Shared Facilities, Labs and Equipment

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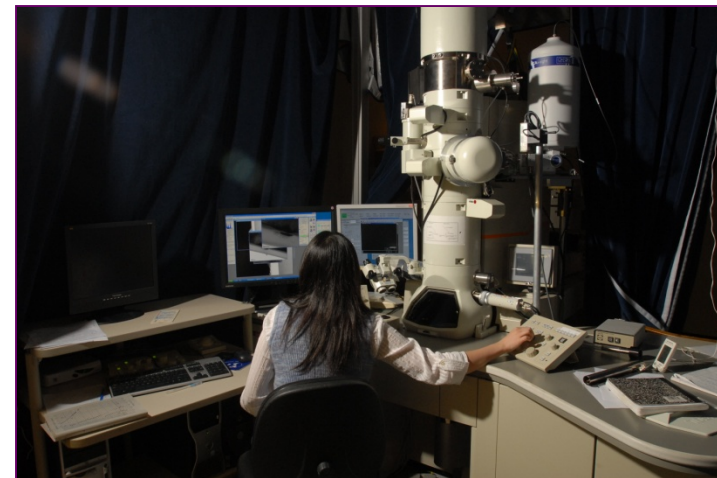
## Labs

- Shared experimental facilities available to on and off-campus researchers
  - 25,000 sq. ft.
  - 80% of facility fees paid from funds outside MRC (i.e. grants and discretionary funds)
  - Facilities open to **industrial partners**



## Equipment

- 500 faculty and students use the equipment
- Most of the equipment is housed in MRC
- Equipment Cost Budget
- Equipment purchases or upgrades



# Shared Experimental Facilities and Laboratories

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**Advanced Optical Facility** (J. B. Ketterson)

**Center for Atom Probe Tomography (NUCAPT)** (D. Seidman)

**Central Laboratory for Materials Mechanical Properties (CLaMMP)**  
(D. Dunand & K. Faber)

**Electron Probe Instrumentation Center (EPIC)** (V. P. Dravid)

**High Resolution Electron Microscopy and Surface Structure Facility**  
(L. Marks)

**Magnet and Low Temperature Facility** (J. B. Ketterson)

**Materials Processing & Crystal Growth Facility (Cleanroom renovation plans)** (B. Wessels)

# Shared Experimental Facilities and Laboratories

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**Optical Microscopy & Metallography Facility** (K. Shull)

**Surface Science Facility** (Y.-W. Chung)

**Jerome B. Cohen X-ray Diffraction Facility** (M. Bedzyk)

**Advanced Thin Film and Laser Laboratory** (R.P.H. Chang)

**Ceramics Laboratory** (S. Barnett)

**Charge Transport Laboratory** (M. Hersam)

**Impedance Spectroscopy Laboratory** (T. Mason)

**Polymer Characterization Laboratory** (J. Torkelson)

**Biomaterials Laboratory** (D. Joester)

# Creative, Well-Educated Workforce

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## Research Experience for Teachers (RET)

(L. Lauhon, Dir.):

- Started at NU (1993).
- High School and college science teachers in 8 week summer program.
- Participants can earn 6 graduate credits at NLU.



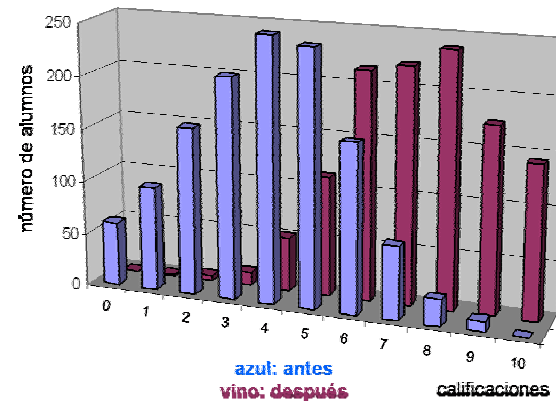
Materials and Engineering Design Honors (K. Faber, Dir.):  
RETs teach in the NU Center for Talent Development a materials course using the Materials World Modules (MWM) kits developed in the MRC.

# Educational K-12 Outreach

## International Outreach

### Materials World Modules, Spanish

- Spreading science literacy
- In 2007, NASA support is helping to expand the program into Puerto Rico
- 2005 Chihuahua workshops
  - Initially trained 50 high school teachers
  - Modules have now been used in 35 schools
  - 120 teachers
  - 1200 students



# International Collaborations

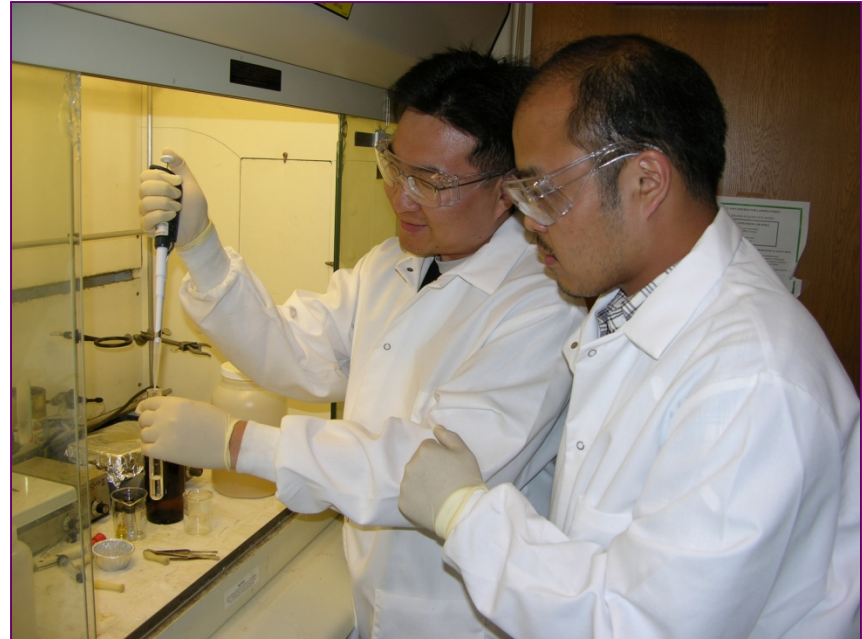
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## BK21

Suwon, Korea

Ajou University

- 20 Ajou University students completed studies in 2006
- 26 Faculty Participants
  - Nanotechnology
  - Biotechnology
  - Medicine
- 22 industrial firms in Korea on joint project collaborations
- Feb. 2007, Mark Hersam gave intensive lectures on the topic of nanotechnology to Ajou students
- Renewed for seven more years



# International Collaborations

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## Riga, Latvia

### *Institute of Solid State Physics*

- Collaboration with IRG 1 (Ellis).
- Partnership began in 2004.
- Nine conference presentations.
- Five publications.
- MRSEC is hosting three research scientists from ISSP in 2007.



# New MRSEC International Visitors

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**Bose National Center, Calcutta, India**

*Prof. Anita Mehta*

**CINVESTAV, Mexico**

*Physics Department*

*Prof. Pedro Gonzalez-Mozuleos*

**Kyoto Institute of Technology, Japan**

*Department of Macromolecular Science and Engineering*

*Prof. Qui Tran-Cong-Miyata*

Plans for a **Materials World Network** collaboration with Japan

# Industry / National Lab Interface

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## Workshops/ Seminars/Colloquia

- Symposium on Atomic-Scale Modeling (July 25)
- Mark Stevens, Sandia (July 26)
- “Optically/Electronically Functional Polymers and Molecular Assemblies” Colloquium Series

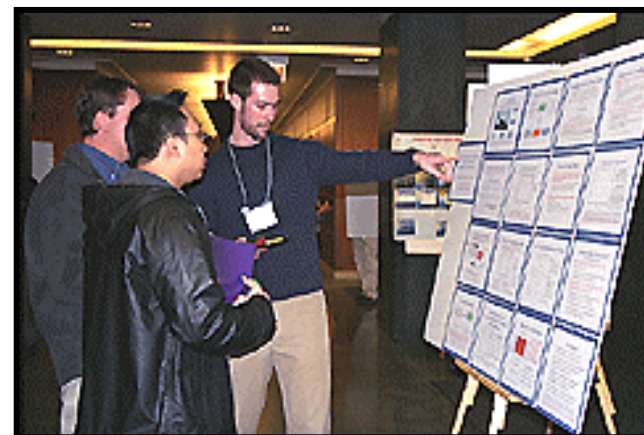
## Student Internships

- NREL (Mariana Bertoni), transition metal oxides
- New: Sigma Aldrich

## Visitors

- Industrial visitors in Torkelson lab: SSSP
- Visitors attending workshops, meetings
- Use of Shared Facilities

**Licensing** of patents through Technology Transfer Office.



# Industry / National Lab Interface

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## Collaborations with Industry

- Integrate BaTiO<sub>3</sub> on Si (Wessels, SBIR)
- Gelcast nano-sized spinel powders (Faber, Shull, SBIR; included grad student support)
- Investigate nano-reinforced epoxy-matrix composites (Brinson)
- Model new materials for Li-ion batteries & solid oxide fuel cells (Freeman)
- Apply computational techniques to photovoltaic materials development (Freeman)
- Model cyclic peptide nanotube structure and transport for antibiotic development (Schatz)

## Collaborations with National Labs

- ANL/APS – experimental facilities to characterize ferroelectrics, ferromagnetics
- ANL (Schatz, Odom)– model optical properties of plasmonic structure
- WPAFB (Hersam & T. Marks), organic electronics; full grad student support
- NIST (Mason) – model electric/ dielectric properties of electroceramics
- NREL (Mason, Poepelmeier) – synthesis of novel thin film oxides
- LANL & LLNL (Motter) computation/ experiment – increase biomass production

# Partnerships and Collaborations

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## The Art Institute of Chicago

- Collaborative study of how materials science impacts art and art conservation (x-ray facility, Surface Enhanced Raman Spectroscopy)
- Funded by the Mellon Foundation
- RET participants worked on project

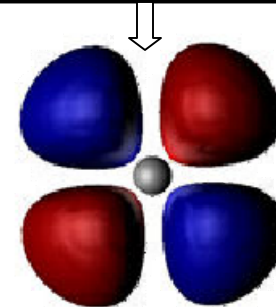
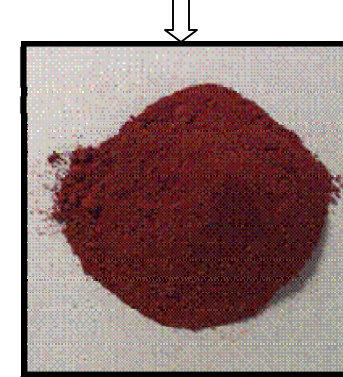


Image of Winslow Homer's *The Water Fan* is courtesy of the Art Institute of Chicago.

# Faculty Involved in MRSEC Win National Medal of Science

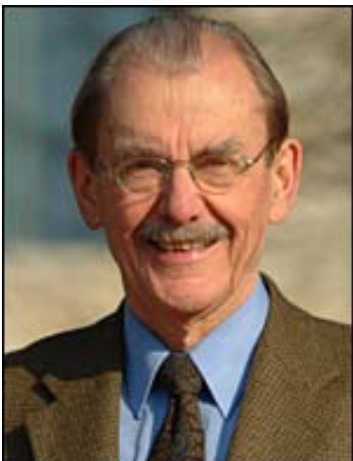
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**TOBIN MARKS**

**Chemistry**

***funded MRSEC member in IRG #1  
and collaborator with IRG #3***



**JAN D. ACHENBACH**

**Civil and Environmental Engineering**

***Achenbach's research group  
benefits from the use of MRSEC's  
shared facilities***



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# Industrial Relationships

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**Kathleen Stair, Industry Liaison MRC & Senior lecturer  
MSE (lab & senior proj. instructor & facility  
manager).**

**Ph.D. NU MSE (MRC), Amoco Corp, MRC outreach**



**OUTREACH GOALS:** strengthen and expand relationships with outside collaborators.

- Create Industrial **Executive** board.
- Create Industrial **Affiliates** program.
- Coordinate **annual meeting on August 30<sup>th</sup>** with other centers; invite industrial associates.
- Create **forum** (at annual meeting) for Executive board input.
- Continue exchanges: student **internships** and industrial **visitors.**

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## MRSEC Interactions with Industry

2006 to 2007 total: 18

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<b>3M</b>	Polymer processing	IRG 2
<b>Bettis Atomic Power Lab</b>	Compound semiconductors	IRG 1
<b>Boeing</b>	Composites	IRG 2
<b>BP Solar</b>	Photovolatics	IRG 1
<b>Caterpillar</b>	Porphyrins, phthalocyanines	IRG 3
<b>Dow Chemical</b>	Materials/displays/organic electronics	IRG 3
<b>Dow Corning</b>	Materials	IRG 3
<b>Ethertronics Inc.</b>	Plasmonics	IRG 3
<b>Lyntech, Inc.</b>	Powder processing	IRG 2
<b>Milliken</b>	Polymer blends & nanocomposties	IRG 2
<b>Motorola</b>	Printed electronics	IRG 3
<b>OrganicID</b>	Organic electronics	IRG 3
<b>RHK</b>	Scanning probe microscopy	IRG 3
<b>Scripps Research Institute</b>	Self-assembly	Seed
<b>Solutia</b>	Polymers	IRG 2
<b>SVT Associates</b>	Epitaxy	IRG 1
<b>TIAX Inc.</b>	Method Development	IRG 1

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## MRSEC – Related Intellectual Property

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IRG1: “Low-Voltage Organic Electro-Optic Modulators Using Transparent Conducting Oxides as Electrodes,” **Marks, T.J.**; Ma, J.; Xu, G.; **Ho, S.T.**, Appl. No. 60/834,593 (filed 8/1/2006)

IRG1: “Organic Light-Emitting Diodes and Methods for Assembly and Emission Control.” **Marks, T.J.**, U.S. Patent 7,094,121 (8/22/2006).

IRG 1: “Strip-Loaded Electro-Optic Waveguide Modulators in Ferroelectric Thin Films,” **B. Wessels**, P. Tang, D. Towner, A. Meier (patent application issued 5/29/07)

IRG1: “Group III-V Diluted Magnetic Semiconductor Materials and Related,” **B. Wessels**, A. Blattner (pending).

IRG2: “Method of producing an exfoliated polymer-clay nanocomposite through solid-state shear pulverization,” **Torkelson, J.M.**, U.S. Patent # 7,223,359 (5/2007).

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## MRSEC – Related Intellectual Property

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IRG 3: N-Type Thiophene Semiconductors, Inventor: **Tobin J. Marks**, U.S. Patent 6,991,749 B2 (1/31/2006)

IRG 3: “Photosynthesis of Silver Nanoprisms,” **Mirkin, C.A.**; Xue, C., Disclosure #: NU 26095 (6/17/ 2006)

IRG3: “Two qubit gate based on a multi-terminal double-barrier Josephson junction,” Nevirkovets, i.; Shafraniuk, S.; **Ketterson, J.B.**, in process.

IRG3: “Ultrastable Substrates for Surface-Enhanced Raman Spectroscopy: Al<sub>2</sub>O<sub>3</sub> Overlayers Fabricated By Atomic Layer Deposition Yield Improved Anthrax Biomarker Detection,”

Inventors: **Richard Van Duyne**, Xiaoyu Zhang, Jing Zhao, Alyson Whitney (NU), Jeffrey Elam (ANL) Provisional Application Serial No.: 60/856,601 filed 11/3/2006, Not licensed

Seed: “Nanofiber Formation of Self-Assembling Peptide Amphiphiles Containing Diacetylene Crosslinking Functionality,” **Stupp, S.**; Hsu, L., Provisional application # 60/857,931 (11/9/2006).

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## MRSEC Interactions with National Labs 2006 to 2007

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<b>ANL</b>	Ferroelectric thin-film processing/characterization	1
<b>ANL</b>	Grazing angle X-ray techniques and X-ray nano diffraction	1
<b>ANL</b>	Magnetics	1
<b>ANL</b>	EXAFS, XANES	3
<b>ANL</b>	Computational nanophotonics & theory	3
<b>ANL</b>	Electromagnetic radiation from plasmonic structures	3
<b>ANL</b>	Brownian motion of trapped plasmon-resonant particles	3
<b>BNL</b>	Nanoelectronic theory and modeling	3
<b>LLNL</b>	Cell metabolism	Seed
<b>LANL</b>	Cell metabolism	Seed
<b>NIST</b>	Gas sensing measurement	1
<b>NIST</b>	Modeling of oxide structures	1
<b>NIST</b>	Polymer Theory	1,2
<b>NIST</b>	SPM	3
<b>NREL</b>	Thin film oxides	1
<b>NREL</b>	Synthesis of novel oxides	1
<b>SNL</b>	Silicone gels	2
<b>WPAFB</b>	Organic Electronics	3

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# INDUSTRY/NATIONAL LAB STUDENT INTERACTIONS

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- **Student Internships**

- One student to each of the following:

- DuPont

- NREL

- Applied Thin Films

- GE Global Research

- Abbott Labs

- BAS (two students)

- new* Sigma Aldrich (2007 Crown Family Internship )

- Argonne

- **Industrial Visitors**

- **Special Events: NU Symposium on Atomic-Scale Modeling, July 25, 2007**

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# NU-MRSEC External Advisory Board

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**Robert Bianco**, Goodrich

**David Cahill**, University of Illinois at Urbana-Champaign

**T.C. Chen**, IBM Fellow and VP S&T, T.J. Watson Research Center

**George Crabtree**, Dir. MS Div., Argonne National Laboratory

**Juan de Pablo**, University of Wisconsin-Madison

**Mary Galvin-Donahue**, Air Products

**Eric Isaacs**, Dir. Cen. for Nanoscale Mat'ls, Argonne National Laboratory

**Shashi Jasty**, Sigma Aldrich

**Jennifer Lewis**, University of Illinois at Urbana-Champaign

**Michael Radler**, The Dow Chemical Company

**Duncan Stewart**, Hewlett Packard Laboratories

**Thomas Witten**, University of Chicago

**Pierre Wiltzius**, University of Illinois at Urbana-Champaign