NSF-MRSEC Legacy

Northwestern University Materials Research Science and Engineering Center (NU-MRSEC): Innovation and Impact

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May 21, 2013

MRSEC Directors Meeting

Center Timeline – 53 years of History

1960-1971

- **Advanced Research Projects Agency of the Department of Defense - Interdisciplinary Laboratory (ARPR-IDL)**
- Contract SD-67, Contract DAHC 15 67 C0213

1972-1996

- **National Science Foundation - Materials Research Laboratory (NSF-MRL)**
- DMR-7203019, DMR-7680847, DMR-7923573, DMR-8216972, DMR-8520280, DMR-8821571, DMR-9120521
- **NSF-MRL renamed as Materials Research Science & Engineering Centers (NSF-MRSEC) in 1993**

1996 - Present

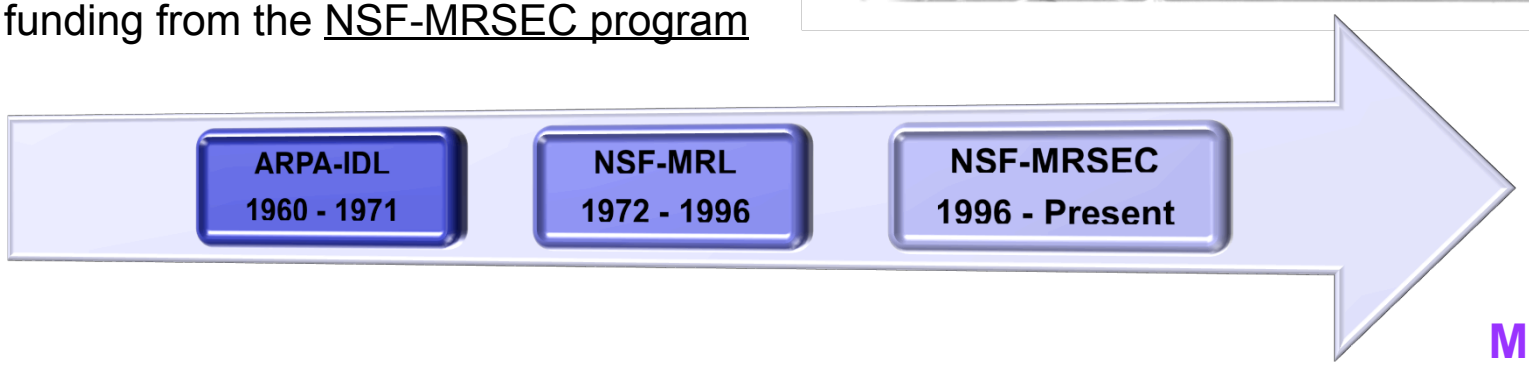
- **National Science Foundation - Materials Research Science and Engineering Center (NSF-MRSEC)**
- DMR-9632472, DMR-0076097, DMR-0520513, DMR-1121262

Center Origin

- **Northwestern University Materials Research Center** was established July 1, 1960 after the awarding of a major contract to NU by the Advanced Research Projects Agency (ARPA) of the Department of Defense for the establishment of an Interdisciplinary Laboratory (IDL) to perform basic research in materials

- In 1972, funding of ARPA-IDL was assumed by the NSF under the heading of the Materials Research Laboratory (MRL). At time of reorganization, the concept of a research thrust group was instituted as part of the MRL program and directed towards solving problems of such complexity and importance that required interdisciplinary efforts of many scientists

- In 1996, Northwestern University Materials Research Center received funding from the NSF-MRSEC program



Legacy – Research Breakthroughs

1970s

- **Artificial Superlattices** (J. E. Hilliard & J. Ketterson) [in 1978, 79 they reported enhanced magnetoresistance in modulated films ("The Discovery of Giant Magnetoresistance" 2007 Nobel Prize in Physics, Royal Swedish Acad. of Scie.)]

1980s

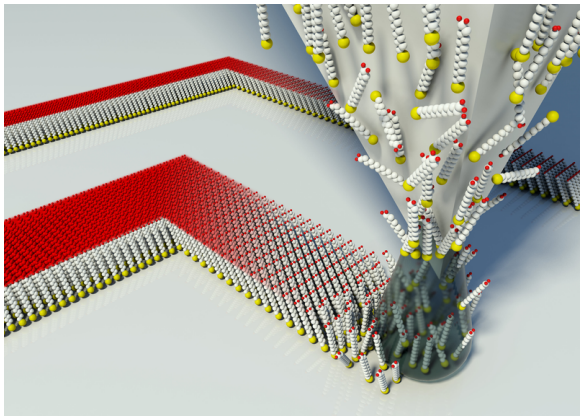
- **Electronic Structure Calculations: FLAPW** (A. J. Freeman) [*Phys. Rev. B* 1981: 1,454 cit.]

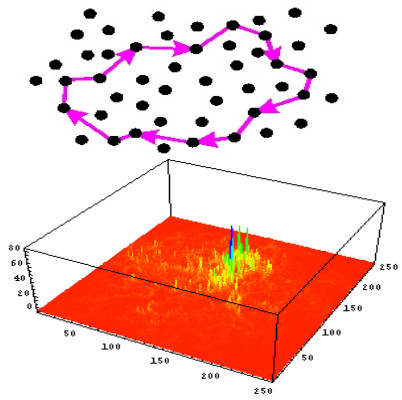
1990s

- **DNA Methods for Rationally Assembling Nanoparticles** [*Nature* 1996: 2,876 (4,076) cit.]
- **Dip Pen Nanolithography** (C. Mirkin) [*Science* 1999: 1,761 cit.]
- **Random Lasing Phenomenon** (H. Cao, S. T. Ho & R.P.H. Chang) [*PRL* 1999: 730 (1,016) cit.]

2000s

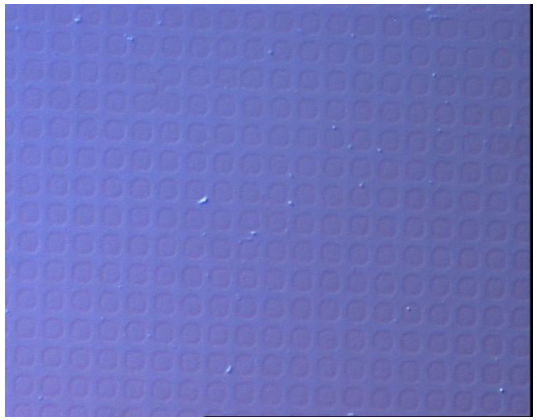
- **Novel Transparent Oxides** (IRG effort)
- **Density-Gradient Ultracentrifugation** (M. Hersam & S. I. Stupp) [*Nat. Nano.* 2006: 833 cit.]



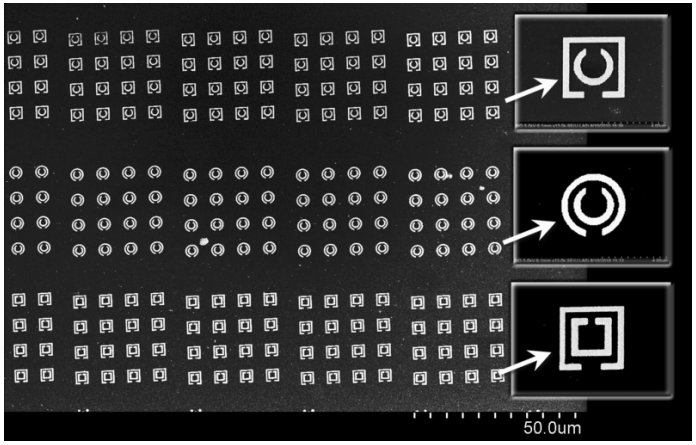


Dip-Pen Nanolithography (DPN)

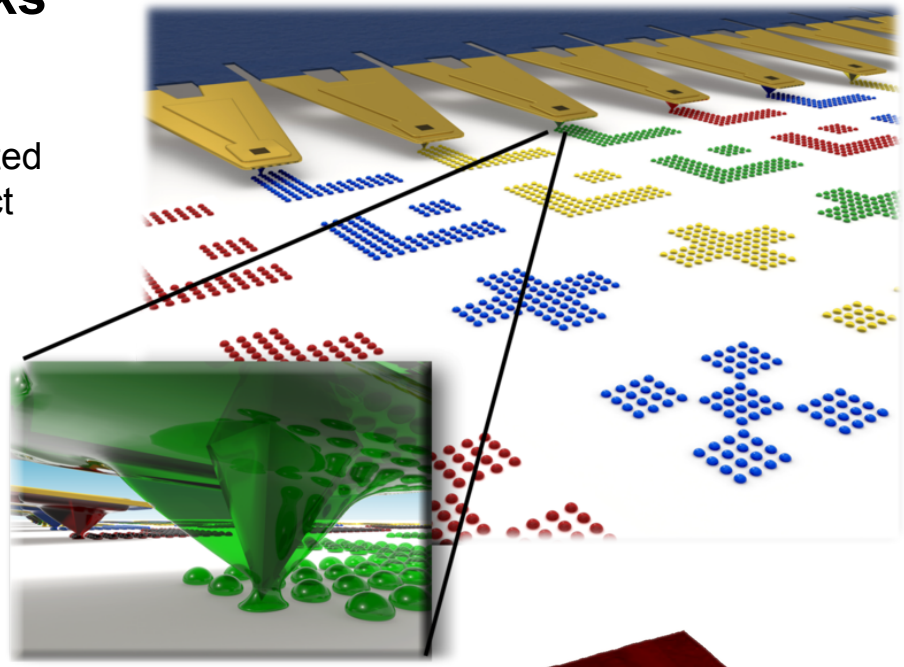
- **DPN is a scanning probe lithography technique where an atomic force microscope tip is used to pattern directly on a range of substances with a variety of inks**

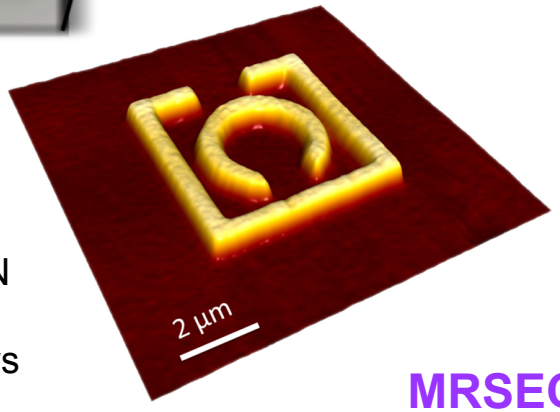


Streptavidin (4nm thickness) deposited using microcontact printing



Gold on silicon metastructure fabricated with top-down DPN methods





SEM image of DPN fabricated gold metastructure arrays

Random Lasing Phenomenon

VOLUME 82, NUMBER 11 PHYSICAL REVIEW LETTERS 15 MARCH 1999

Random Laser Action in Semiconductor Powder

H. Cao and Y. G. Zhao*
Department of Physics and Astronomy, Materials Research Center, Northwestern University, Evanston, Illinois 60208-3112

S. T. Ho
Department of Electrical and Computer Engineering, Materials Research Center, Northwestern University, Evanston, Illinois 60208-3118

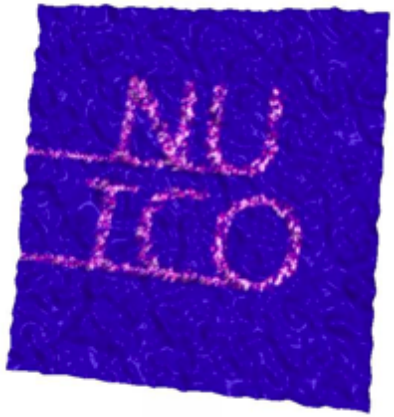
E. W. Seelig, Q. H. Wang, and R. P. H. Chang
Department of Materials Science and Engineering, Materials Research Center, Northwestern University, Evanston, Illinois 60208-3116
(Received 9 September 1998; revised manuscript received 16 December 1998)

We report the first observation of random laser action with coherent feedback in semiconductor powder. Since the scattering mean free path is less than the emission wavelength, recurrent light scattering arises and provides coherent feedback for lasing. Discrete lasing modes have been observed above the threshold. The dependence of the lasing threshold intensity on the excitation volume agrees with the random laser theory. Laser emission from the powder could be observed in all directions. This observation also provides direct evidence for the existence of recurrent scattering of light. [S0031-9007(99)08739-6]

PACS numbers: 42.55.Px, 42.25.Fx, 71.55.Jv

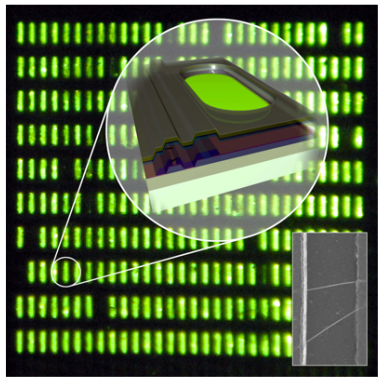
Novel Transparent Oxides

- High-conductivity and low-cost transparent conducting oxide (TCO) thin films developed at NU-MRSEC are desired in optoelectronic devices, including light-emitting diodes (LEDs), photovoltaics (PVs), and eletro-optical (EO) modulators.

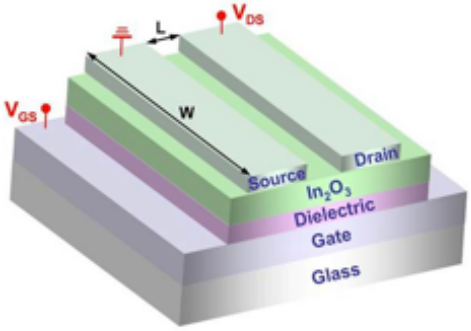


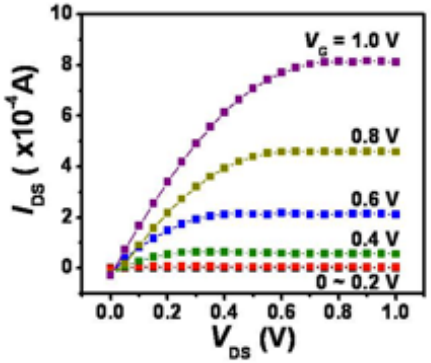
Conductive AFM image of transparent conductive pattern "NU TCO" written with Ga Focused Ion Beam in Ion Assisted Deposition-In_2O_3

- NU-MRSEC develops high-mobility transparent oxide semiconductors (TOSs) films and high-dielectric constant transparent oxide insulators (TOIs) to realize flexible transparent thin film transistors (TFTs) with low operation voltage and low power consumption for portable devices.



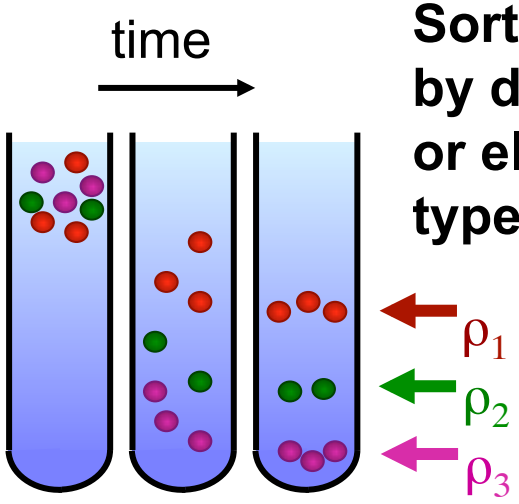
Active Matrix OLED display driven by In_2O_3 nanowire transistor





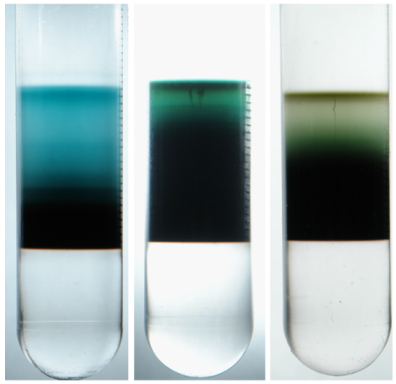
Full transparent TFTs using IAD-In_2O_3 TOS channels with high mobility of ~120 $cm^2/V•s$ at 1V

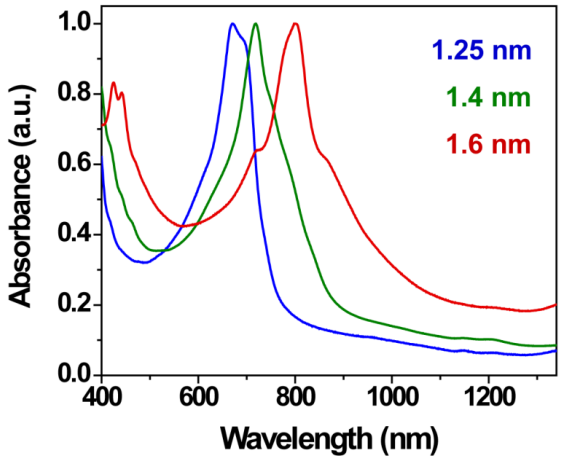
Density Gradient Ultracentrifugation (DGU)



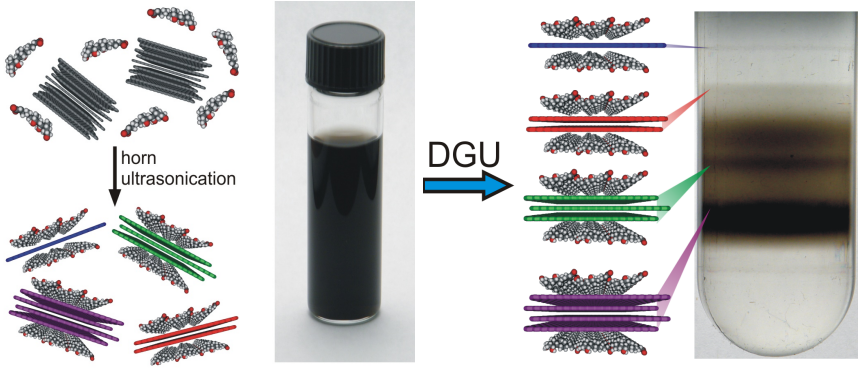
Sorting CNT by diameter or electronic type

- **Single Walled Nanotubes (SWNTs) by Diameter:** DGU allows for diameter refinement of metallic SWCNTs with +/- 0.1 nm precision.





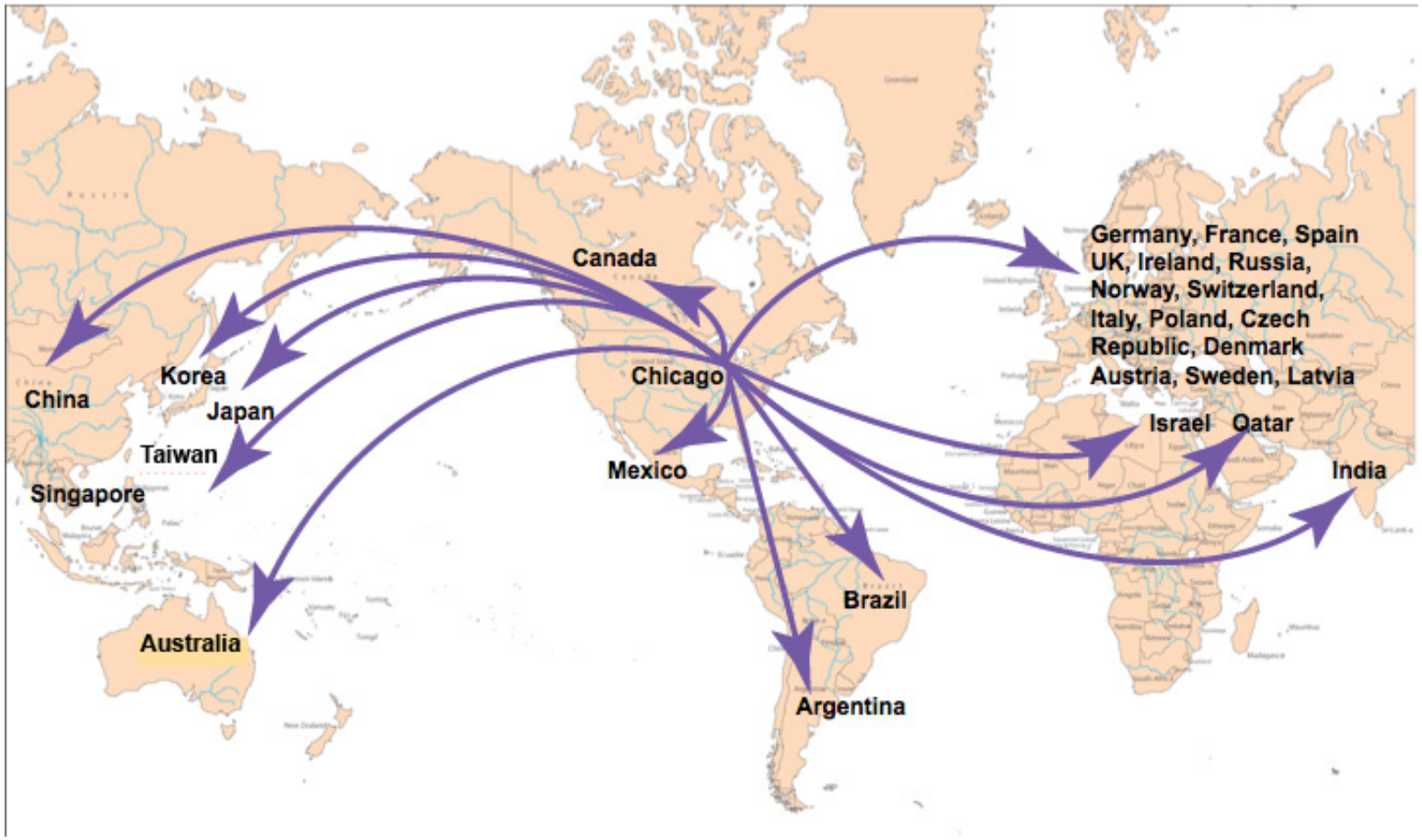
- **SWNTs by Chirality:** DGU iterations yield relatively large quantities of ultrapure SWNTs.



- **DGU of Graphene:** DGU also enables sorting by the number of graphene layers.

MRSEC

Legacy – International Collaborations



Legacy – Nucleating New Centers

IRG - High Tc Superconducting Materials **IRG -** Unconventional Superconductivity in Heavy Fermion Materials	1992	**NSF Science and Technology Center for Superconductivity** **UIUC/Chicago/Northwestern/Argonne**
IRG – Electroactive and Magnetoactive Molecular Materials	2001	**Northwestern University Nanoscale Science & Engineering Center (NU-NSEC)** **NSF**
MRSEC Outreach/Materials World Modules	2004	**National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT)** **NSF**
IRG – Synergistic Linear and Nonlinear Phenomena in Multifunctional Oxide Ceramic Systems **IRG –** Novel Processing Methods for Nanostructured Polymer Blends, Composites and Supramolecular Structures	2007	**Argonne/Northwestern Solar Energy Research Center (ANSER)** **DOE**
MRSEC IRG research	2009	**International Materials Institute for Solar Energy and Environment** **NSF**
MRSEC/Art Institute of Chicago/Mellon Exploratory Grants – Art Conservation	2013	**Northwestern University/Art Institute of Chicago Center for Scientific Studies in the Arts (NU-ACCESS)** **Mellon Foundation**

Legacy – Services/Leadership

1989 – President of Materials Research Society (Chang)

1991 – Founding President of International Union of Materials Research Societies (Chang)

1993 – Worked with NSF-DMR to launch the Materials World Network for joint proposal funding with international NSF peers in materials research (Chang)

2007 – Chair, Division of Materials Research Advisory Committee, National Science Foundation (Olvera)

2009 – Member, Board of Physics and Astronomy, National Research Council, National Academy of Sciences (Olvera)

2009 – Member, President's Council of Advisors on Science and Technology (Mirkin)

2010 – Chair, Condensed Matter and Materials Research Committee, National Research Council (Olvera)

Legacy – Outreach in STEM Education

1993 – Inception of Materials World Modules

- interdisciplinary modules based on topics in materials science, including *Composites, Ceramics, Concrete, Biosensors, Biodegradable Materials, Smart Sensors, Polymers, Food Packaging, and Sports Materials, Solar Cells, Nanotechnology, Drug Delivery*
- designed for use in middle and high school science, technology, and engineering, and math classes and have been **used by over 100,000 students in schools in 49 states**
- based on principles of inquiry and design and emphasizes active, hands-on learning
- **Nation-wide field tests show 2 sigma in learning gain**
- helps teachers to meet **National Science Education Standards and State Standards**

MWM Materials World Modules
An Inquiry & Design-Based Science, Technology, Engineering, and Mathematics (STEM) Educational Program

Legacy – Outreach in STEM Education

1993 – Inception of Research Experience for High School Science Teacher program (REST) at NU-MRSEC

- since expanded to other MRSECs and continued as the current Summer Research Experience for Teachers (RET) program

1997 – Masters Program in Materials Technology Education (Olvera/Chang)

- A two-year integrated graduate program combining course work in the Materials Science & Engineering Department and the School of Education
- Prepare graduate students to teach at the community college level and train the materials technologists of the future
- Partnership with Northwestern's Preparing Future Faculty (PFF) program
- Each student received a mentor from a local community college and gained teaching experience while they participated in research at Northwestern and with an industrial partner

Legacy – International Outreach

2005 – Introducing Materials World Modules (MWM) in Mexico and Qatar

- Started in 2005 in the State of Chihuahua, collaborations with NU-MRSEC is helping MWM-Mexico to expand its impact around the whole of Mexico
- Spanish modules: *Sports, Concrete, Composites, Biosensors, Biodegradables, Introduction to Nanotechnology*
- MWM has been working with Qatar schools during the past 2 years

Legacy – Building Infrastructure

10 facilities and 6 laboratories in 25,000 square feet of space

- Each specialize in fields of microscopy, mechanical behavior, x-ray diffraction, optics, ceramics, surface science, device fabrication, metallography, biomaterials

149 instruments available

- Examples: SEM, TEM, e-beam evaporator, furnaces, ATX-G, 4-circle diffractometers, LEAP (local electrode atom-probe), servo-hydraulicmachine

DND-CAT at the Advanced Photon Source (APS) in Argonne.

Only materials-based bean line jointly supported by industry and academia

Support from NU Office for Research

$390K total funds during 6 years of the grant (DMR-1121262)

90% of the funds: equipment award

Full or partial funding for equipment

10% of the funds: personnel

Partial salary support for Facility Director and technicians

Legacy – Job Creation

Company Name	Year of Establishment	Estimated Number of Employees	City, State
Plextronics	2000	40	Pittsburg, PA
Nanosphere	2000	115	Northbrook, IL
Nanoink Inc.	2001	100	Skokie, IL
Nanotopic Inc.	2005	7	Skokie, IL
Polyera	2006	14	Skokie, IL
NanoIntegris	2007	6	Skokie, IL
Nanosonix, Inc.	2008	5	Skokie, IL

Translating scientific discoveries into marketable technologies and job creation

Nanosphere

PLEXTRONICS
Light. Power. Circuitry.™

NanoIntegris

Polyera

Nanotope
The Next Regeneration

Legacy – Institutional Culture

Northwestern Innovation Strategy

Excellence in Materials Research & Education

+

Regional, Societal, Industrial and Global Outreach

+

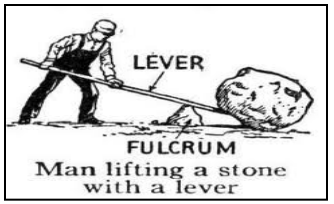
Engagement with Corporate Partners

+

Leveraging Top Business School (Kellogg)

+

Coalition and synergy among all stakeholders



Out-of-the-box initiatives

Legacy – Institutional Culture

Small Business Evaluation and Entrepreneur's (SBEE) Program

- Partnership between the Kellogg School of Management and McCormick School of Engineering
- New technologies developed by NU researchers are presented to Kellogg students at open forums
- Participation by NU MRSEC faculty & students

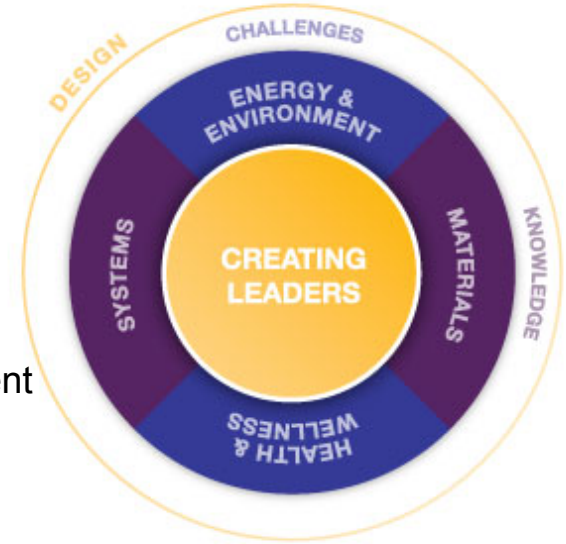
Kellogg MBA students:

- Assess the viability of commercialization
- Choose projects with best promise for success
- Work with the inventor to develop a business plan
- Formally present plan to potential investors or at business plan competitions

Legacy – Institutional Culture

Northwestern McCormick School of Engineering: The Great Intersection

- **Creating Leaders**
- **Materials**
- **Systems**
- **Health & Wellness**
- **Energy & Environment**



Whole-brain Engineering:

- Graduate students have the opportunity to learn essential management skills, in partnership with the Kellogg School of Management. They connect with their peers across disciplines to create a network that extends beyond their domain.

- McCormick educates engineers who have superior technical skills combined with divergent, creative thinking skills: whole-brain entrepreneurs, designers, communicators, and, ultimately, leaders who thrive at the great intersection, whether in industry, academia, or beyond.

Materials part of the long-term strategic plan of Northwestern's Engineering School

Legacy: Innovation and Impact

- **Innovation:** NU-MRSEC anticipates future needs of basic science, educational outreach in U.S. society
- **Impact:** NU-MRSEC provides opportunity to recruit best new faculty and students and creates a pipeline of world-class training for the next generation of scientists, which ensures U.S. competitiveness in global workshop and technological leadership
- **Impact:** NU-MRSEC provides infrastructure and instills culture of shared experimental facilities on campus
- **Impact:** Center longevity promotes program value and facilitates buy-in from Northwestern to invest in materials education and research facilities
- **Impact:** Excellence in materials research bridges the scientific and business programs at Northwestern
- **Impact:** MRSEC program provides the platform to promote diversity at student, postdoc, and faculty levels
- **Impact:** NU-MRSEC creates jobs