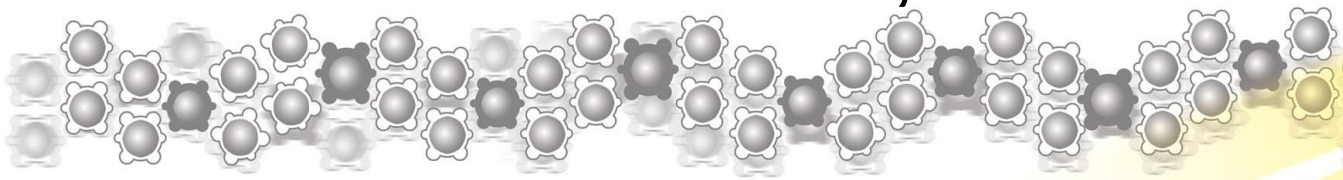
CHM
Center for Hierarchical Manufacturing
University of Massachusetts Amherst

Center for Hierarchical Manufacturing

An NSF Nanoscale Science and Engineering Center

Jim Watkins, Director
Mark Tuominen, Co-Director



www.umass.edu/chm

Contact: Jim Watkins, 413-545-2569, watkins@polysci.umass.edu

Center for Hierarchical Manufacturing (CHM) Vision and Research Focus

Vision: To realize the manufacture of nanotechnology-enabled devices for enhancements in computing, energy conversion and human health through the two and three dimensional integration of components and systems across multiple length scales

Research Focus: Generation of nanoscale structures using bottom up methodologies including directed self-assembly, high fidelity pattern transfer, 3-D replication, and novel deposition techniques that can be integrated into large-scale, top down production platforms for nanoelectronics and bionanotechnology

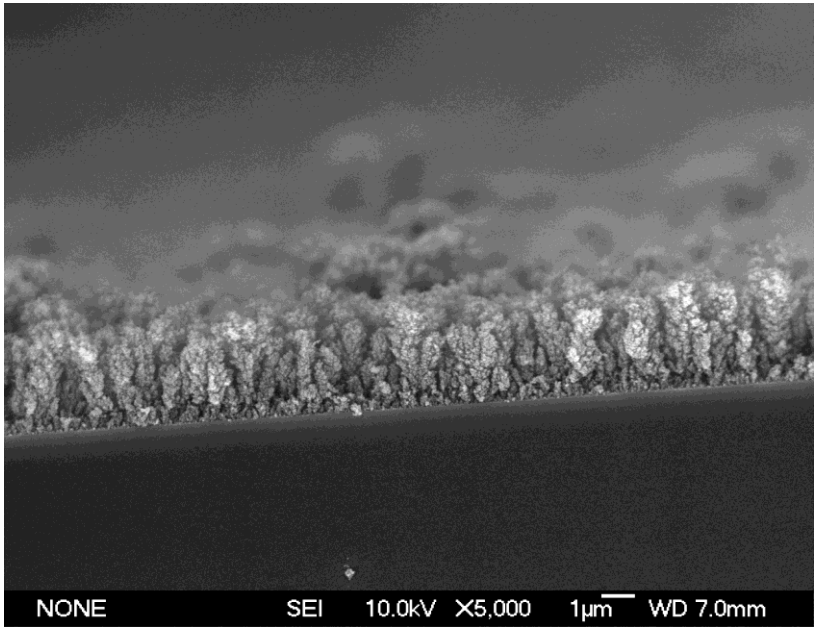
- New processes and tools for rapid, massively parallel fabrication of engineered nanoscale elements
- Assembling elements into active nanostructures and devices
- Integrating nanoscale components into larger scale systems

} **Hierarchical Integration**

HIGHLIGHT

Spray-on Crystalline Metal Oxide Semiconductor Nanostructures for Low Cost PVs and H_2 Generation

High surface area, nanostructured, crystalline metal oxide films are of interest for solar energy conversion via photovolatic cells and H_2 generation via photocatalytic water splitting. Researchers at the CHM in partnership with Inframat Corporation have developed a new ultra-low cost technology for spray on nanodendritic films of TiO_2, ZnO and other metal oxides.

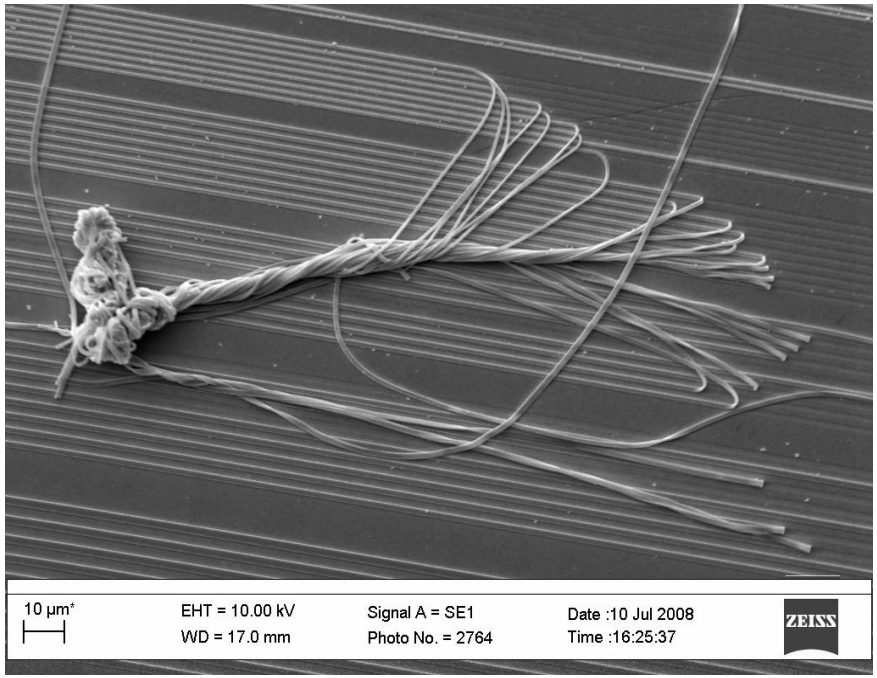


Professor J. Watkins, University of Massachusetts
with D. Reisner, Inframat Corp.

HIGHLIGHT

Binary Semiconductor Nanowires Through Templated Electrodeposition

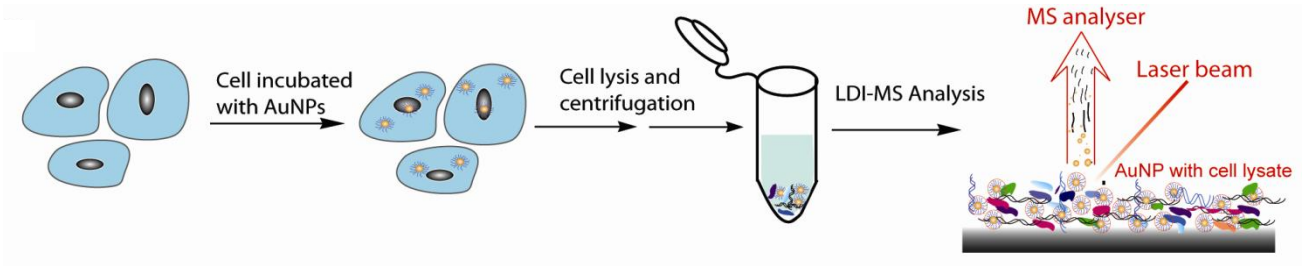
Nanoscale well-defined heterojunction semiconductor structures are desired for efficient photovoltaic devices. CHM researchers have created **nanowires** of cadmium selenide (CdSe) on indium tin oxide (ITO) substrate using a simple electrochemical deposition process and polymer templates created by nanoimprint lithography. The wires are ~400 nm wide and span length of the substrate (1 cm x 1 cm).



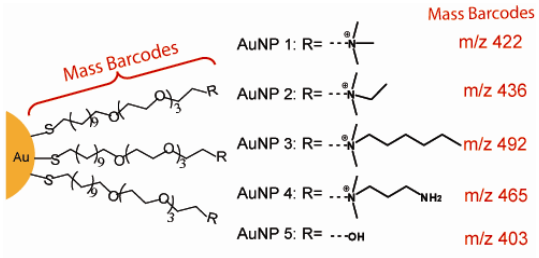
Professors D. Venkataraman and Ken Carter,
University of Massachusetts

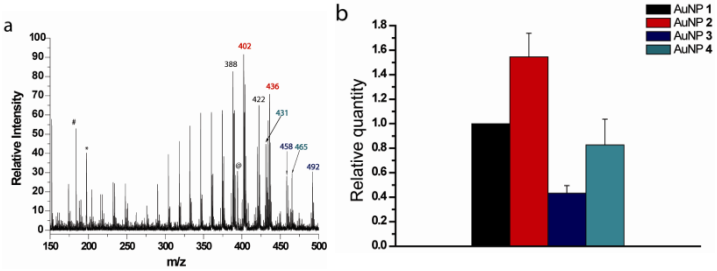
HIGHLIGHT

Multiplexed Screening of Cellular Uptake of Gold Nanoparticles Using Laser Desorption/Ionization Mass Spectrometry (LDI-MS)



The uptake of nanoparticles by living organisms from the environment is an area of increasing study. CHM scientists have developed a rapid and efficient means for tracking cellular uptake of gold nanoparticles using the gold core to greatly facilitate ligand ionization. These ligands provide barcodes that allow many particles to be followed simultaneously. This method will provide direct access to bio-distribution data: *in vivo* studies using zebra fish are underway.





4 particles tracked simultaneously

Professors Vincent Rotello and Richard Vachet,
University of Massachusetts

Center for Hierarchical Manufacturing

UMASS AMHERST

Fundamental Research

Technical Research Groups

TRG 1: Nanoscale Materials & Processes
TRG 2: Nanoelectronics
TRG 3: Bionanotechnology

Synergy & Collaboration

National Nanomanufacturing Network

Catalyst for Collaboration and Information Sharing
Web and Workshops
InterNano Digital Library & Clearinghouse

Translational Research

System-Level Process Test Beds

Identify Barriers to Implementation
Address Fundamental Research Challenges
Demonstrate Process Platform
Pursue Applications with Partners

Education & Outreach

Lesson Modules and Multimedia Content

Visual Learning Content for Education
K-12, Undergrad, Graduate, Workforce
Comprehensive Diversity Strategy

Technology Transfer

Industrial Partners Program

MassNanoTech Partners

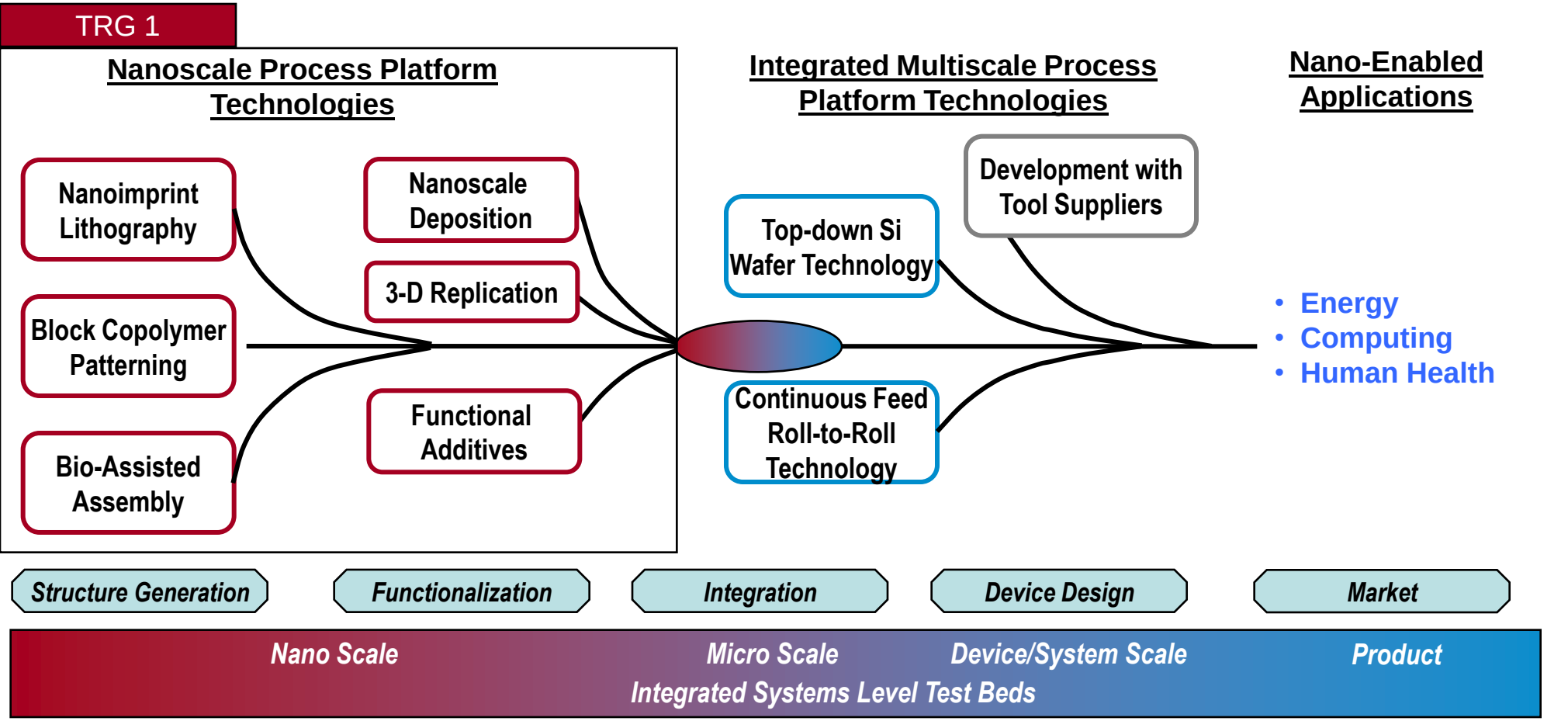
Societal Implications

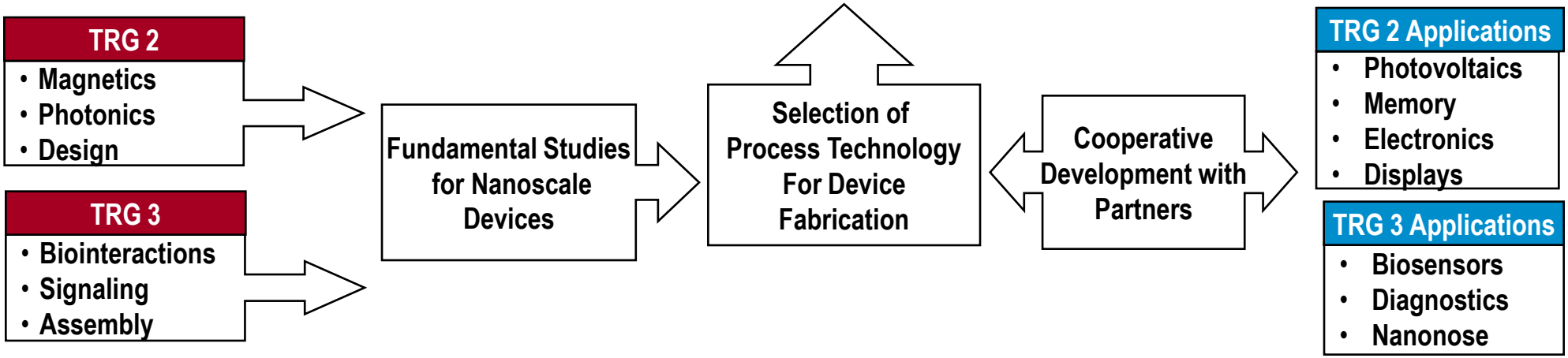
National Survey and Topical Workshops

Public Perception, Valuation, and Issues

Partners: Univ. of Puerto Rico - Rio Piedras ● Mt. Holyoke College ● Springfield Technical C. C. ● Binghamton University ● TIAX LLC ● Alcatel-Lucent

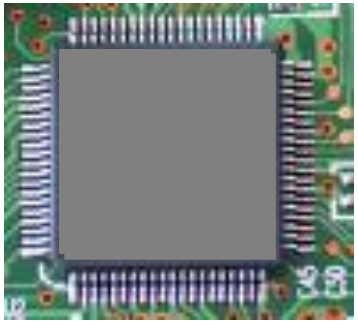
CHM Nanofabrication Platform



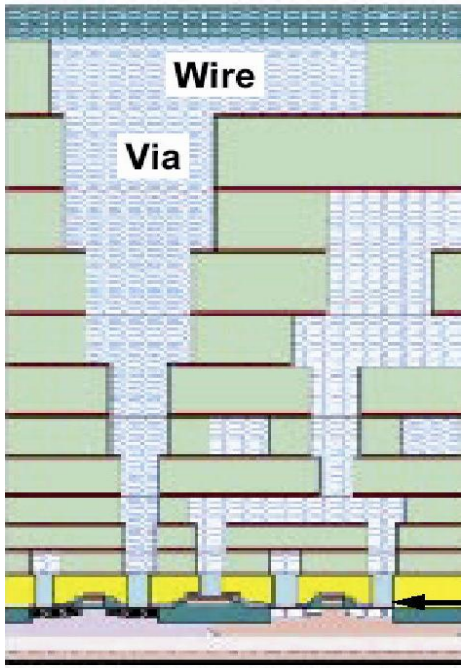


Nanofabrication and Integration Across Multiple Length Scales
Example: Next Gen ICs

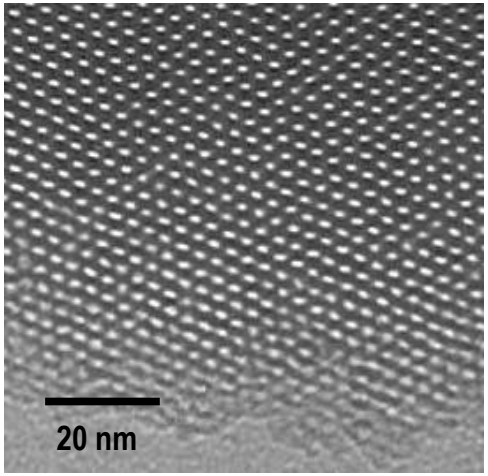
Chip
10^{-2} M



Interconnect Via
10^{-7} M



Porous ULK
10^{-9} M

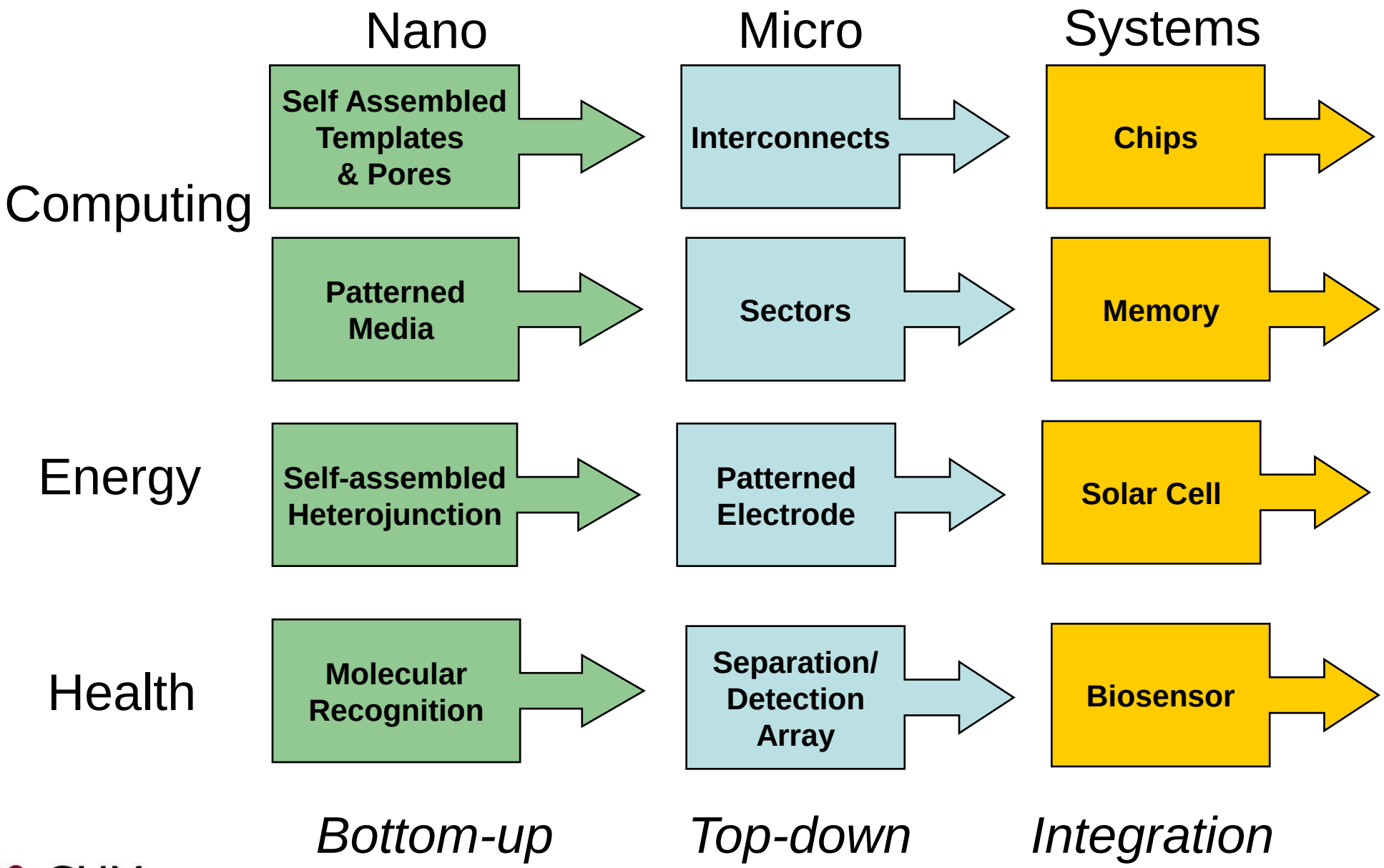


BCP Template for Airgap
10^{-8} M

IBM

A challenge that can only be solved by employing self-assembly
Top down meets bottom up

Bridging Manufacturing Lengths Scales Through Directed Self-Assembly and Nanopatterning



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Manufacturing of Nanodevices: High Level View of Overarching Challenges

- **Massively Parallel Generation of Well Defined Nanostructures**
  - Directed Self-Assembly
  - Nanoimprint and Capillary Force Lithography
  - Bio-assisted Assembly
- **Functionalization of Device Structures**
  - 3-D replication of self assembled templates
  - Deposition within nanoscale features
  - Incorporation of nanoparticles and QDs

} CHM Core Technologies

- **Integration into Viable or Existing Process Platforms**
  - Si-Wafer technology
  - Roll-to-roll processing
  - Insertion of one or more new nano processes

} CHM Test Beds

- **Rapid, Cost-effective, Defined Need**
  - Unique performance advantage = adaptation
  - Application verification

} CHM Partner Collaborations

Technical Research Group 1

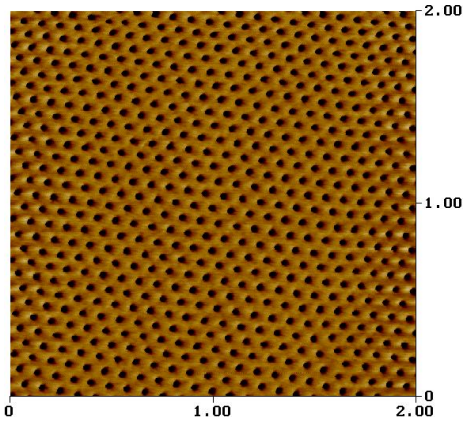
Nanoscale Materials and Processes

Co-Leaders: James J. Watkins, Thomas P. Russell

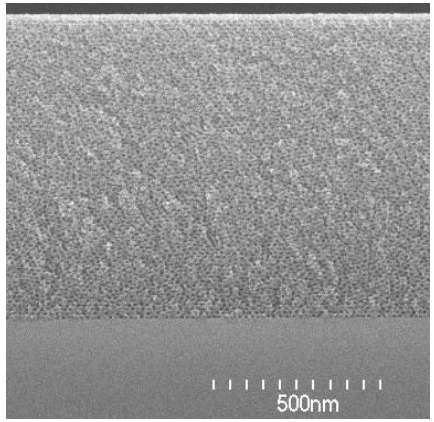
Participating Faculty: C. Cabrera (UPR) K. Carter, A. Crosby, T. Emrick, T. McCarthy J. Rothstein, S. Thayumanavan

Partners/Collaborators: Hitachi, Lucent-Alcatel, Molecular Imprints, NIST, Novellus Systems, Seagate, IBM, SCMaterials, TIAX LLC

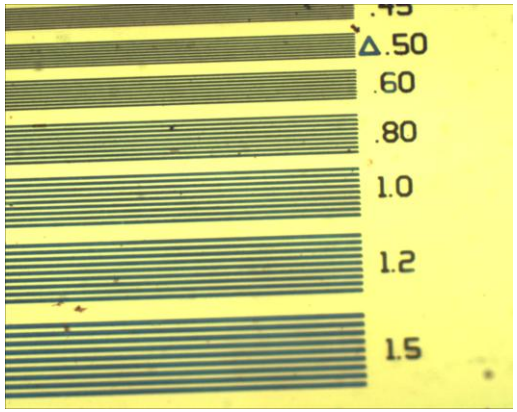
Goal: Focus on fundamental processes that underpin techniques for the fabrication of nanostructured materials that can be integrated with existing large-scale manufacturing processes



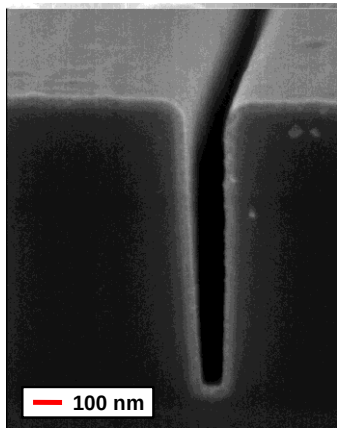
Block copolymer template arrays



Robust 3-D nanoporous films by 3-D BCP replication



Device elements from nanocontact molding



Conformal metal oxide deposition

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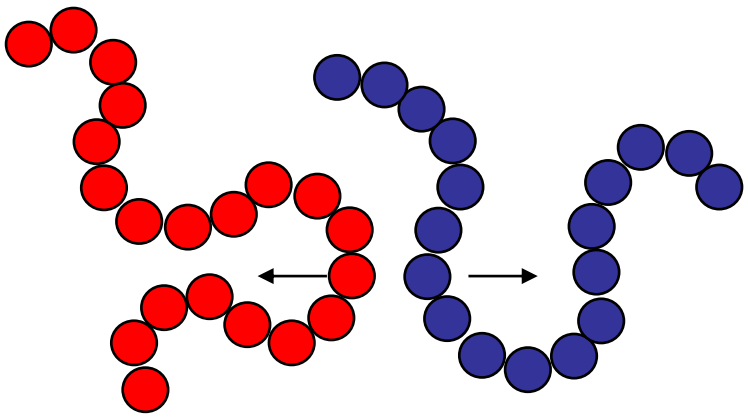
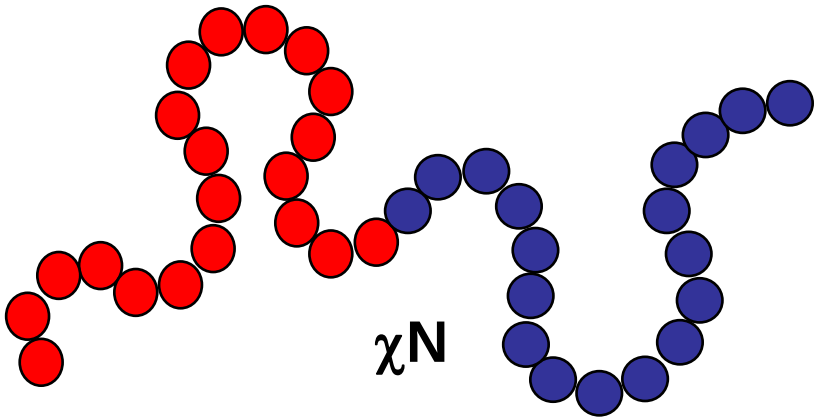
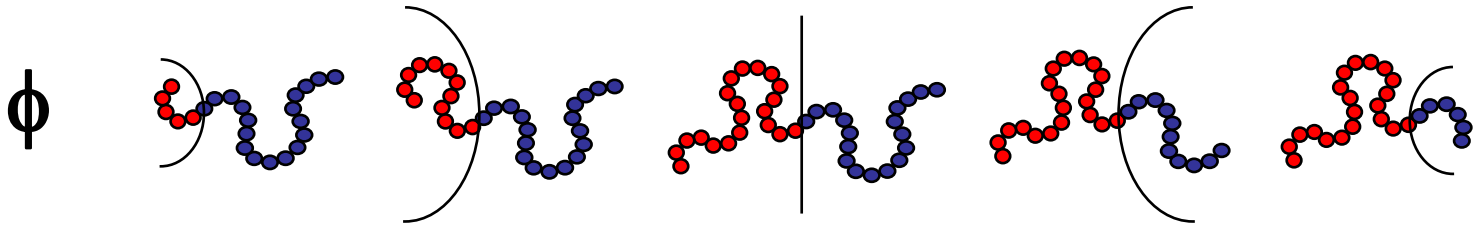
Block Copolymers Templates: Spontaneous Assembly upon Spin Coating, Complete Control of Morphology





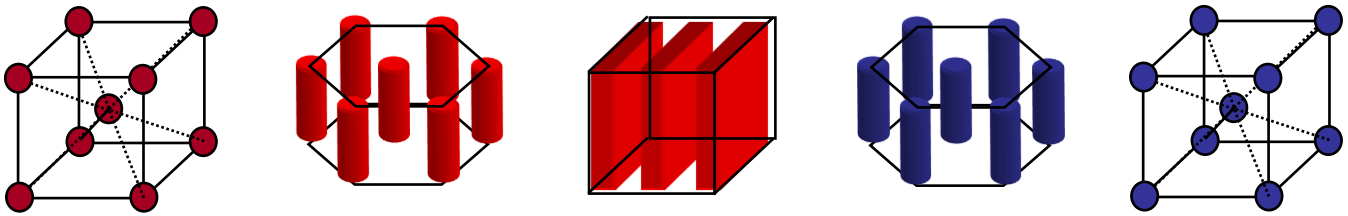
- Macroscopic Phase Separation

- Improved miscibility
- Microphase separation



- Chain architecture dictates interfacial curvature

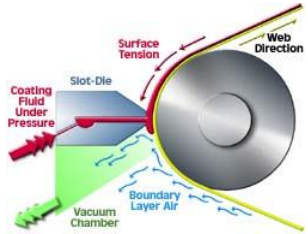
Spheres Cylinders Lamellae



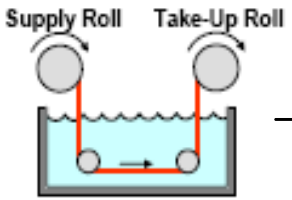
Nano Channels! ***Nano electronic devices!*** ***Nano optical devices!***

CHM Test Bed Example:
Self-Assembled Templates for Device Applications

Strongly Segregated BCP/Surfactant Blends on Flexible Substrates



sub-micron coating

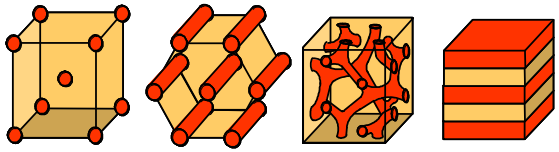


phase selective functionalization or etch

PVs, flexible electronics, displays

H+ additives

H+ homopolymers



increase segregation strength

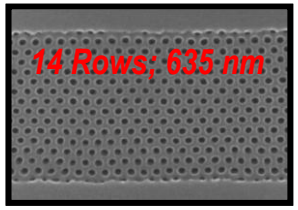
$\chi N \uparrow$

etch contrast

5 nm resolution resists and etch masks

ion complexation

Directed Assembly of BCPs with Long Range Order on Si Wafer



metal deposition

data storage

Test Beds are designed to address barriers (fundamental and applied) to practical implementation and integration of nanofabrication strategies

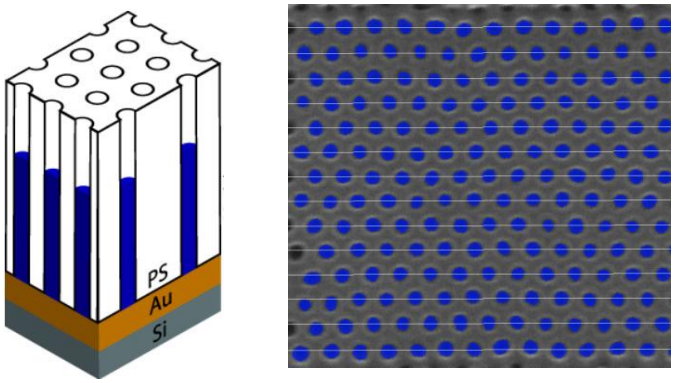
Technical Research Group 2

Nanoelectronics

Co-Leaders: Andras Moritz, Mark Tuominen

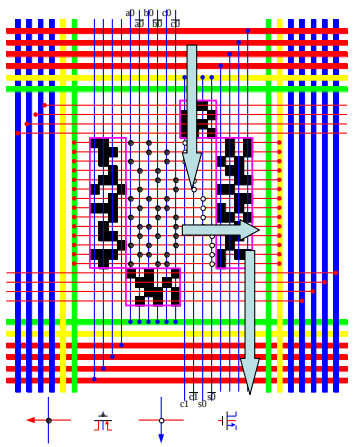
Participating Faculty: M. Achermann, M. Barnes, K. Carter, J. Hudgings (Mount Holyoke College), A. Moritz, L. Mountziaris, M. Rotea, T. Russell, M. Inoue (Toyohashi), R. Katiyar (UPR Rio Piedras)

Goal: Hierarchical nanoelectronics for future high performance data storage and processing systems, energy conversion devices and sensors

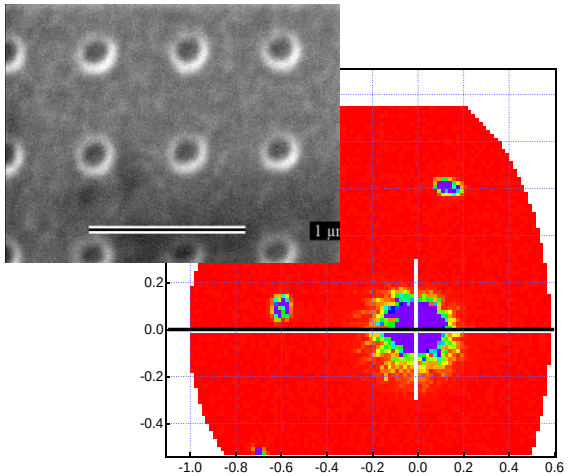


Perpendicular Magnetic Media

1-Bit Full Adder

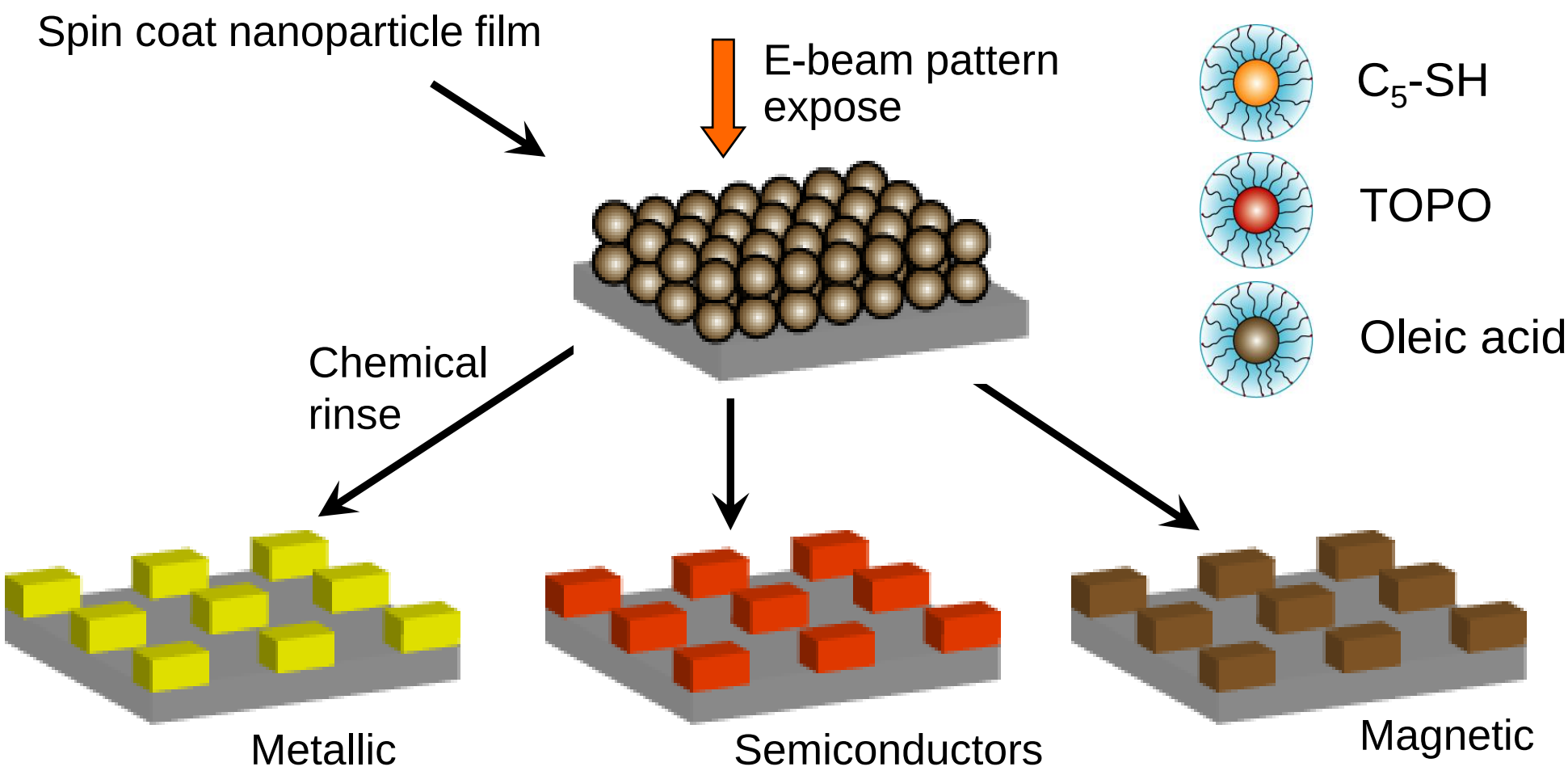


Nano Circuits

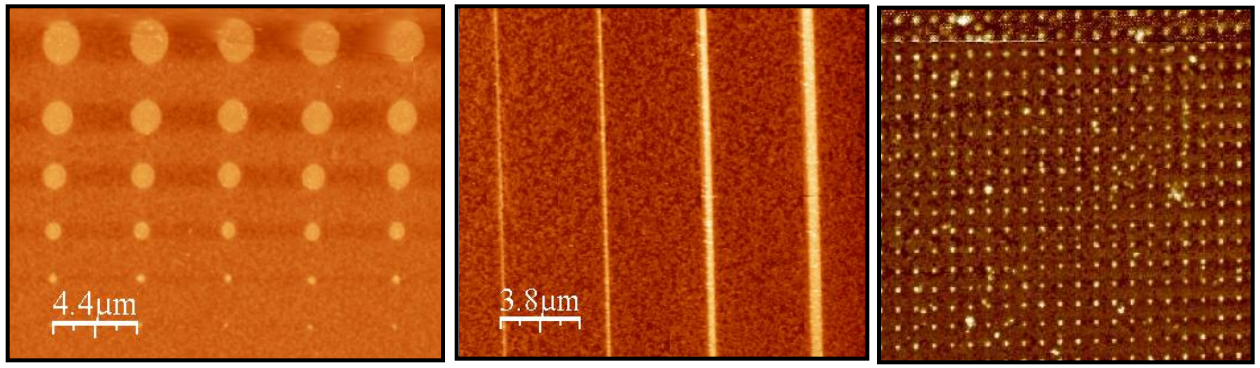


Nano Photonics

Direct-Write Nanoelement Fabrication Process

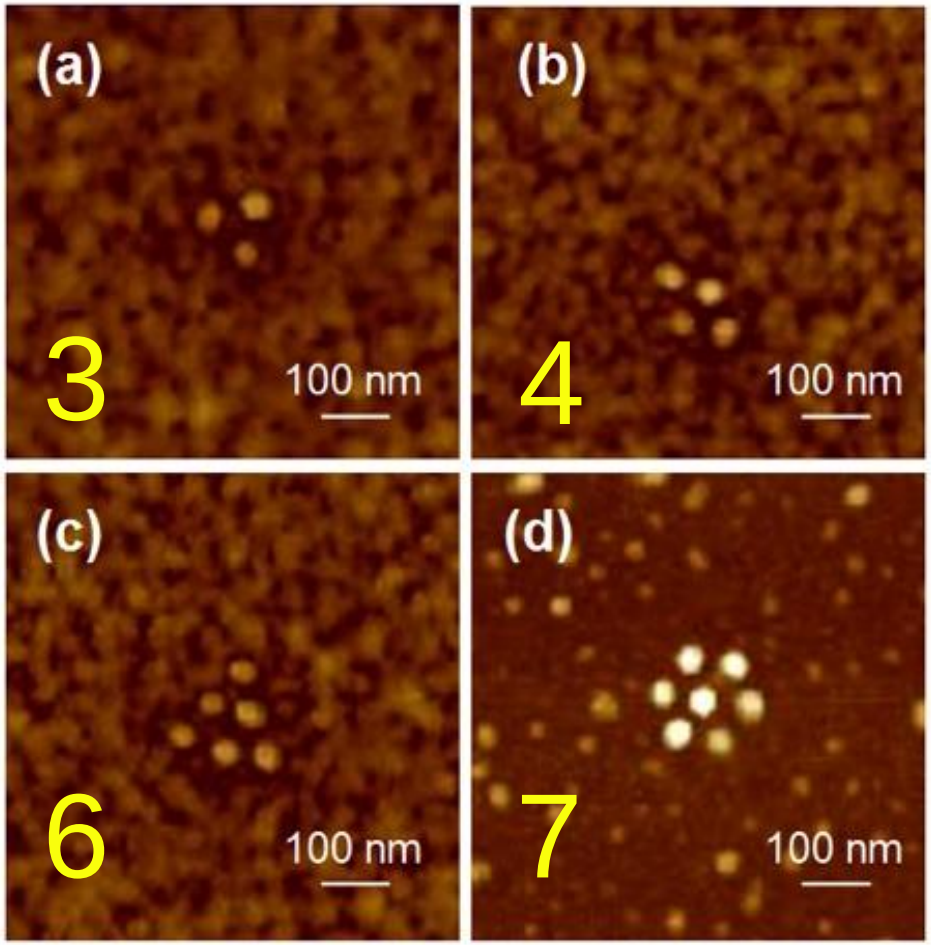


Structures formed from 6 nm Fe_3O_4 nanoparticles (alt. FePt, CdSe, Au)

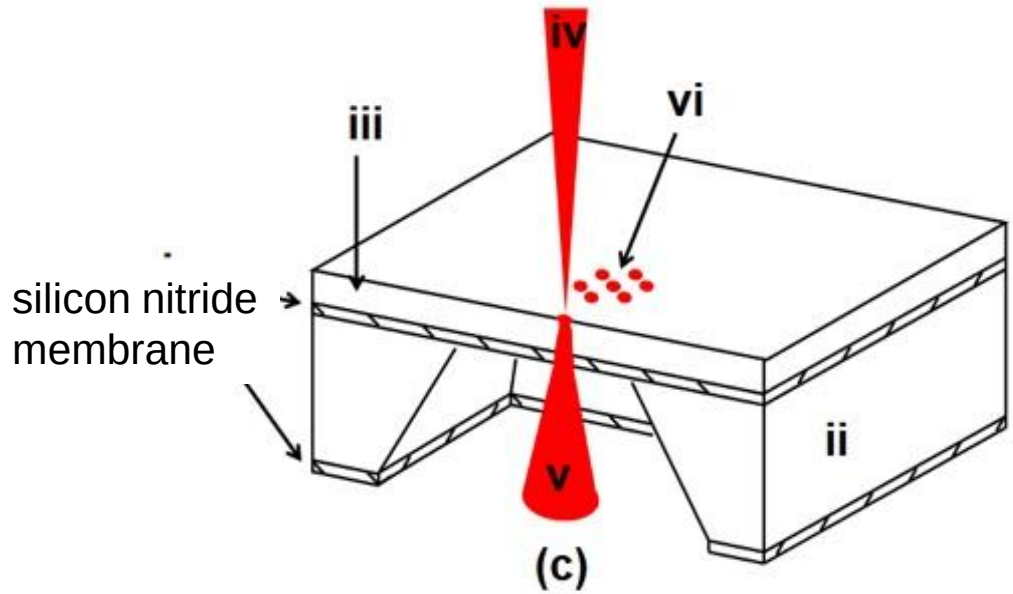


30 nm dot array from Fe_3O_4 nanoparticles

Nanomagnet Multi-Bit Cluster Prototypes

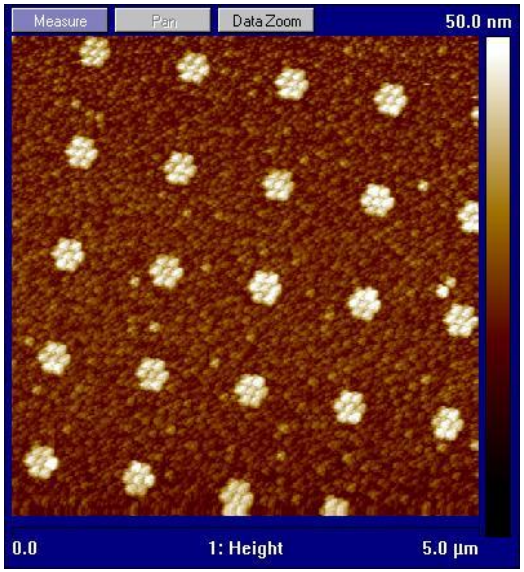


Qijun Xiao, et al. J. Appl. Physics (2008)



- Prototyped using **high-resolution e-beam lithography** and **pulse-reverse electrodeposition**

- 77K substrate
- Collimator



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Technical Research Group 3

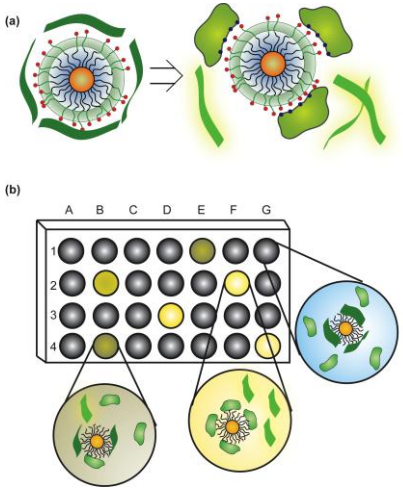
Bionanotechnology

Co-Leaders: **Surita Bhatia and Vince Rotello**

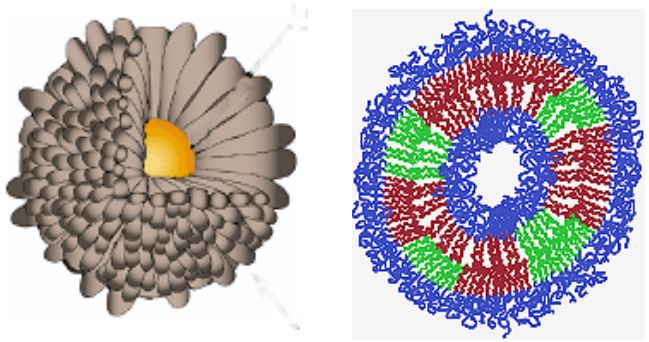
Participating Faculty: **H. Bermudez, T. Emrick, T. Mountziaris, M. Muthukumar, G. Tew, S. Thayumanavan**

Partners and Collaborators: **University of Puerto Rico, SUNY Buffalo, UMass-Baystate Biomedical Research Institute**

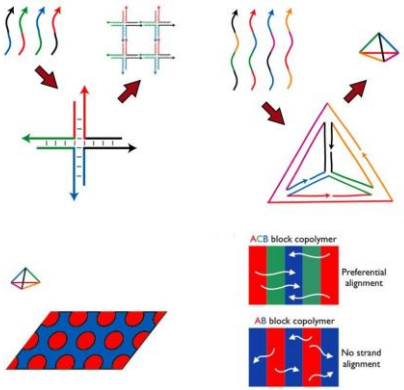
Goal: **Creation of new nanostructured materials through bioassembly and development of new biosensors and biodevices**



Chemical nose

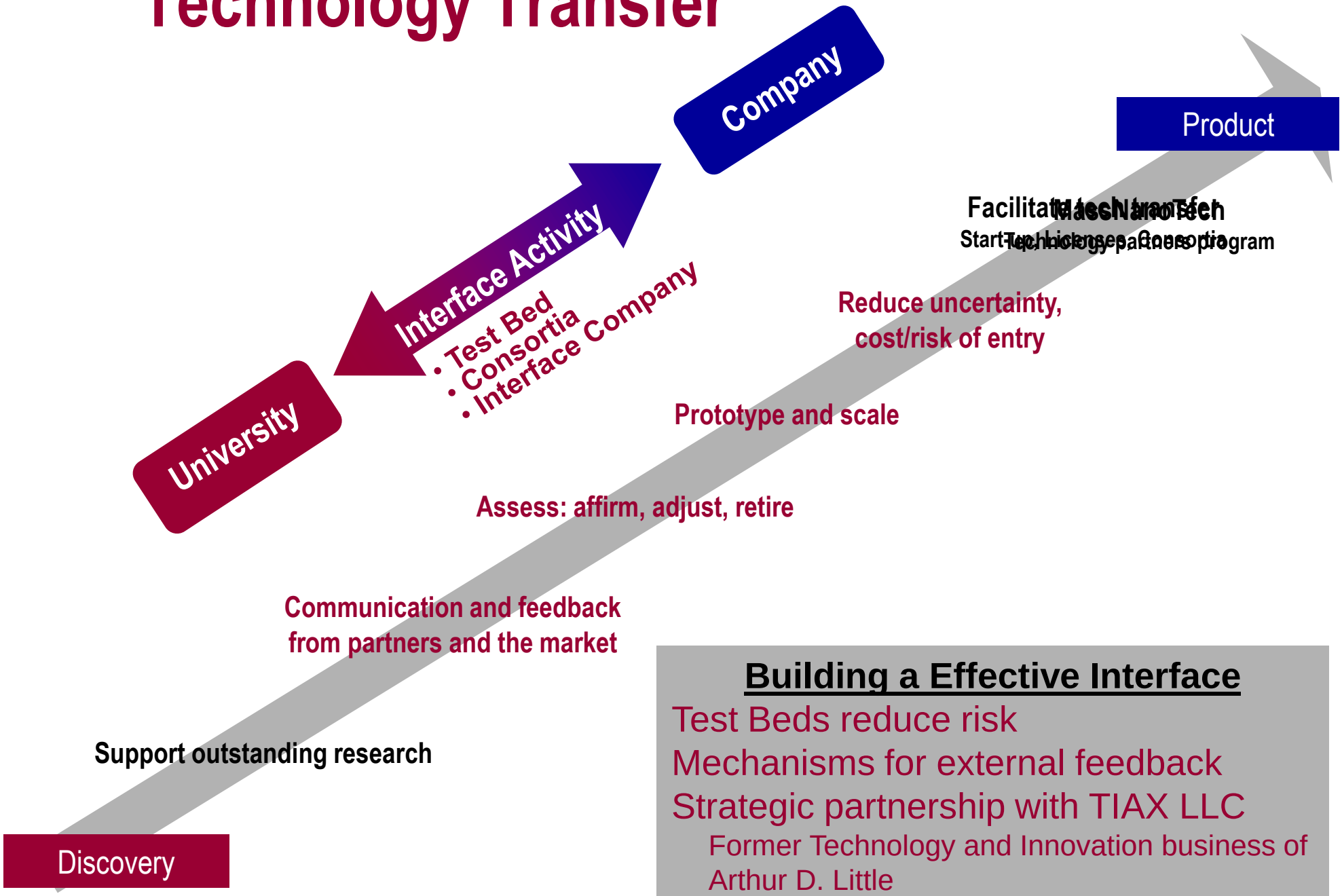


Functionalized nanoparticles, vesicles and assemblies



DNA directed assemblies

Technology Transfer



Building a Effective Interface

- Test Beds reduce risk
- Mechanisms for external feedback
- Strategic partnership with TIAX LLC
  - Former Technology and Innovation business of Arthur D. Little
- MassNanoTech Partners promotes industry collaboration

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Participating Organizations: Center Related Activities and Research

$700 K in new research funding in nanotech

UMassAmherst

Springfield Technical Community College
Liberal Arts • Technology • Business • Health
Your Path to Life-Long Learning

Universidad de Puerto Rico 1903

Mount Holyoke

TIAX

Lucent Technologies
Bell Labs Innovations

NIST
Polymers Division

Novellus

Seagate

SRC Semiconductor Research Corporation

IBM

AMD Smarter Choice

Molecular Imprints, Inc.

SME

Massachusetts Technology Collaborative

ENS Evolved Nanomaterial Sciences, Inc

ENVIRON

imec

Panasonic ideas for life

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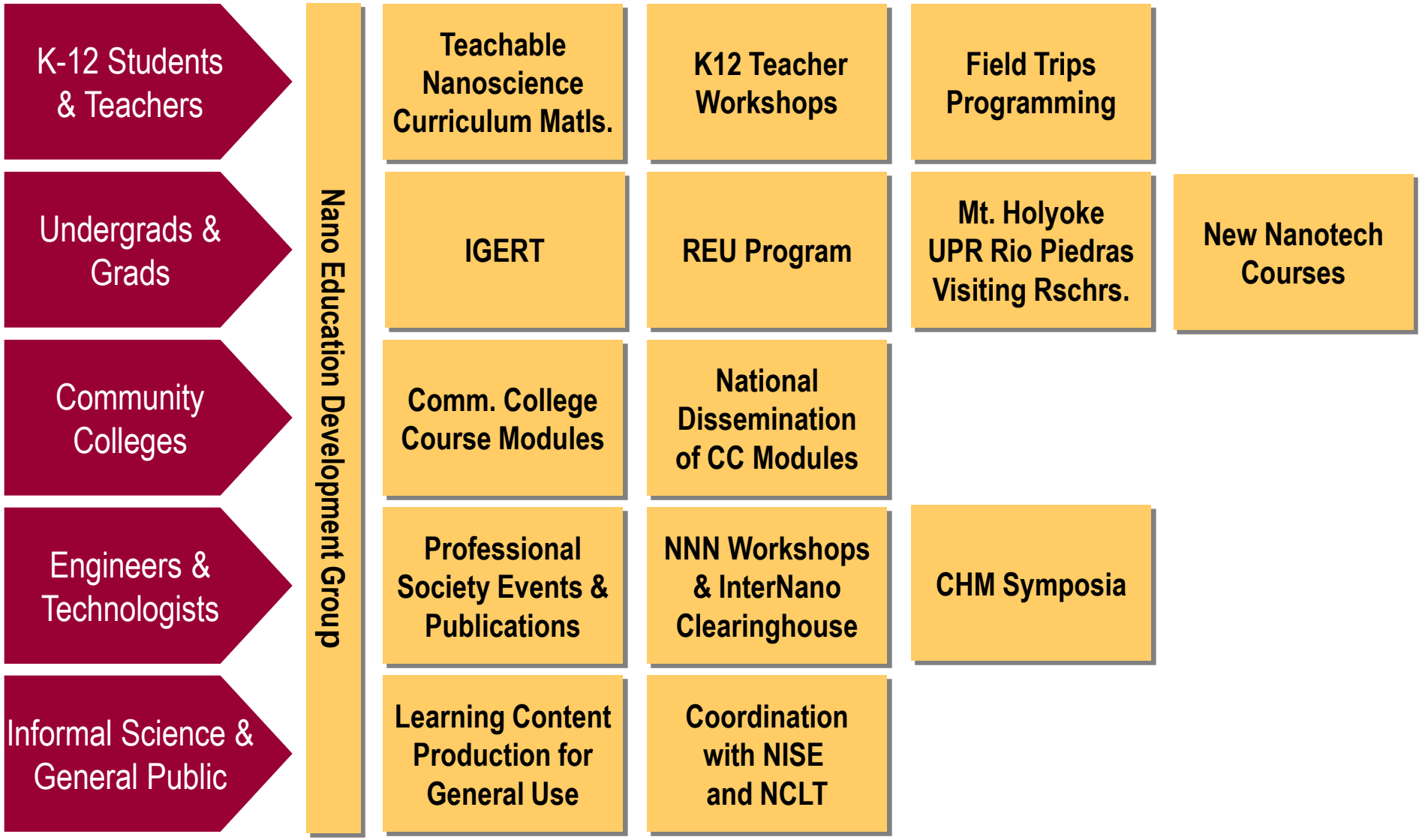
University of Massachusetts Amherst

CHM: Education & Outreach



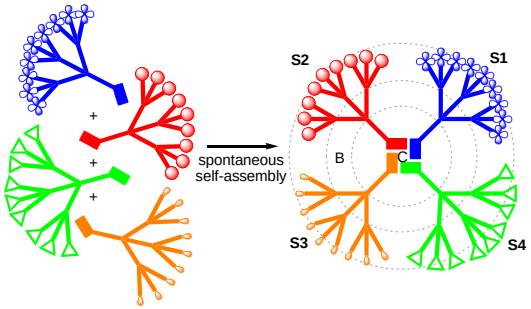
Partnership with University of Puerto Rico

NSF Institute for Functional Nanomaterials (IFN)

Cluster I:
Functional Dispersed Nanostructures

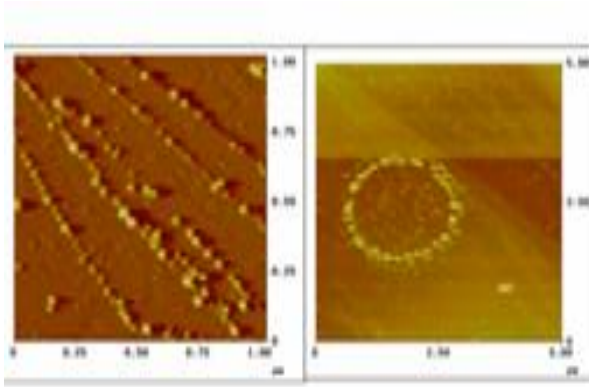
Cluster II:
Functional Nanostructures at the Interface

Cluster III:
Multifunctional Nanostructures



Schematic representation of a Self-assembled Multifunctional Dendrimer; (S1-S4) Surface functional groups, like targeting agents, drugs, imaging agents, etc.; additional functional elements include branching units (B), internal core (C).

Figure 14. Membrane electrode assembly (anode/polymer electrolyte membrane/cathode).



Pd-wire and Pd-ring structures on HOPG

Partnership with CHM UMass Amherst
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Funded by NSF

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- Network of US centers & projects with a nanomanufacturing focus
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- Information clearinghouse (*cyber-space*)

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CHM Researchers Featured on Small

National Nanomanufacturing Network: The organic nanowires featured on this month's cover of Small are the work of researchers at the University of Massachusetts Amherst's Center for Hierarchical Manufacturing.

Nanostructured Microspheres Produced by Supercritical Fluids Extraction

A recent paper addresses two major challenges in drug formulation: drug solubility and sustained release for greater therapeutic effectiveness, reduction of side effects, and improvement of patient's comfort and compliance.

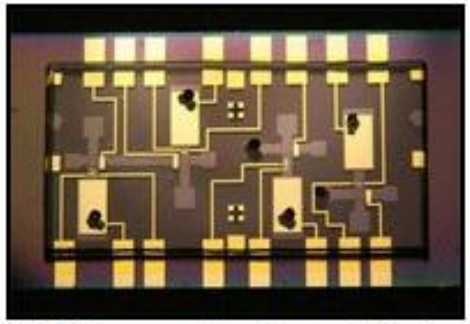
NanoScience + NanoEngineering 2009 Call for Papers

National Nanomanufacturing Network: SPIE NanoScience + NanoEngineering 2009 will be held August 2 - 6 in San Diego, CA. Abstracts are now being accepted.

Nanofabrication User Facilities: Approaches for Successful Technology Research, Development, and Transition

Written by Jeff Morse
October 07, 2008

In this resource-conscious R&D environment, can you improve your company's chance



Gold Nanopore Membrane Chip for Biosensing
From "Nanoscale Sensing and Control of Biological Processes"...

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Events

- Small Tech Conference & Expo
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- IEC TC 113/WG 3
  November 10, 2008
- National NanoEngineering Conference (NNEC)
  November 12, 2008

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