NINE – Prototyping A New Concept …

Discovery Science & Engineering Innovation Institutes

A new DOE – Academic – Industry partnership for science & engineering workforce development and innovation partnerships

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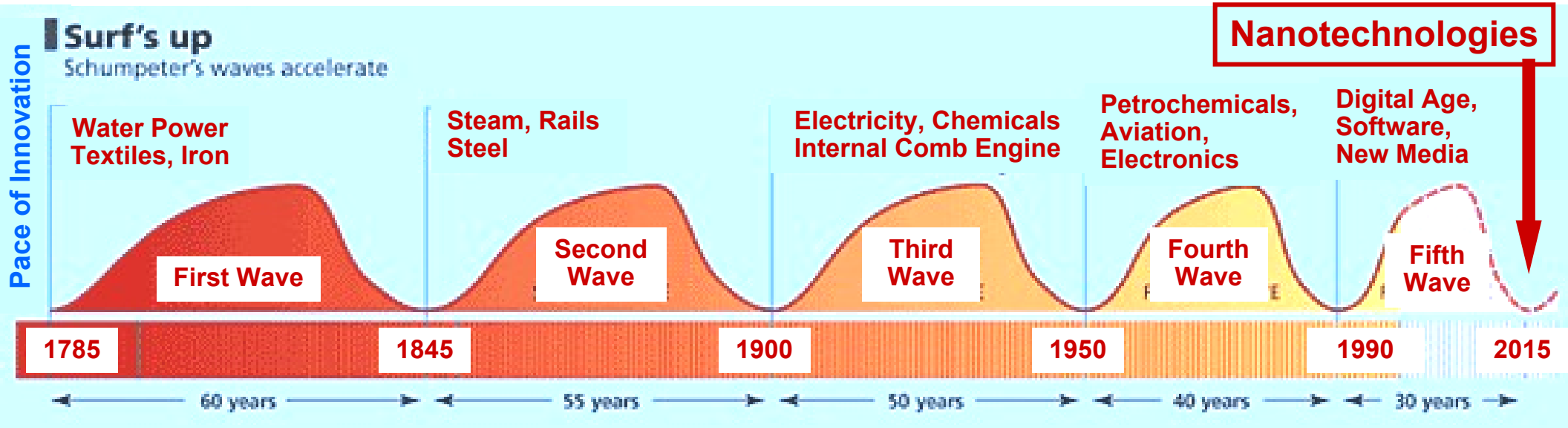
Technology Innovation Drives Global Leadership and Economic Prosperity

Schumpeter's Waves

Successive Industrial Revolutions Driven by Technology Innovation



- **Industrial cycles every 60 years, accelerating to 25**
- **Driven by synergistic technology innovations**
- **Good jobs, prosperity go to those who "catch the wave" early**

… and the US has always led the world in innovation. But …

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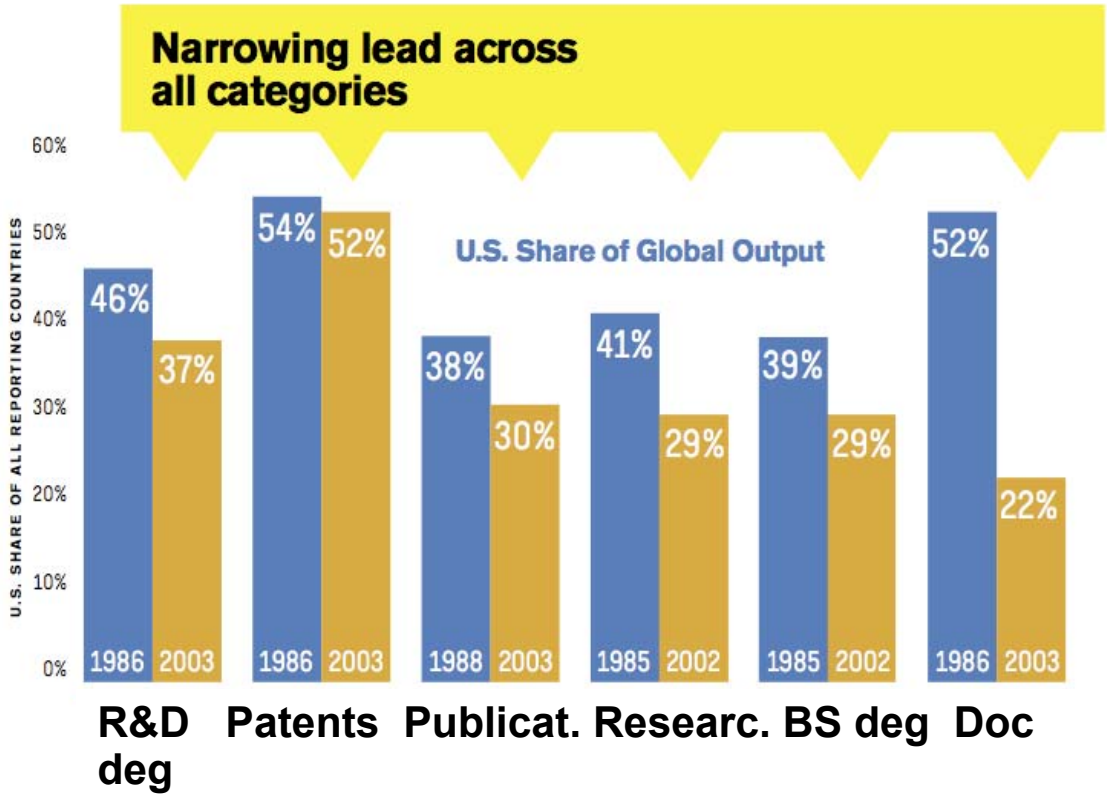
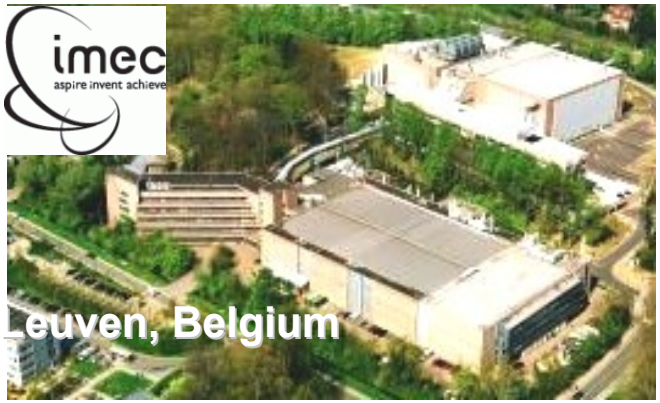
… the world has changed!

Important trends have increased the urgency for a new approach



Foreign government, university, industry partnerships are addressing strategic technical areas

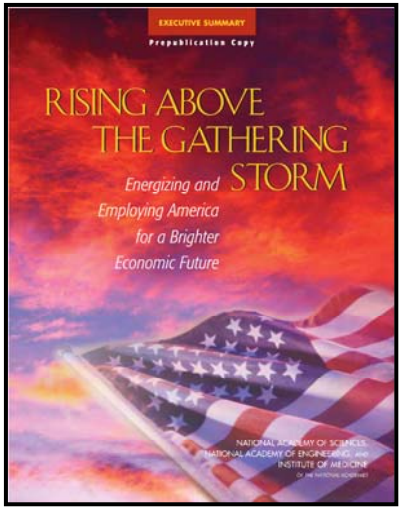


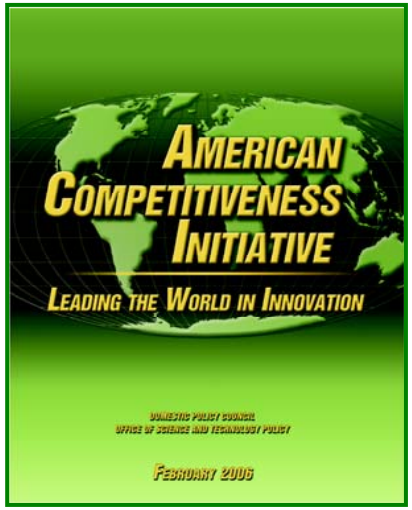
60% of engineering and physics Ph.D.s from US universities earned by foreign nationals

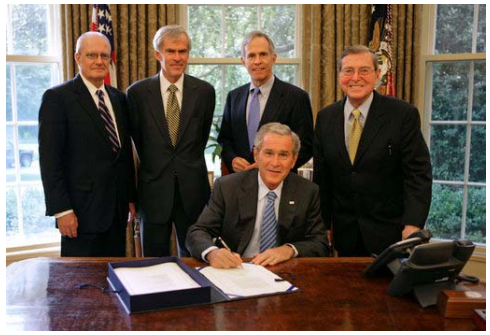
Industrial research labs no longer carry the innovation burden for the U.S.

Bell Laboratories

Preparing the U.S. for the Future







America COMPETES Act enacted 8/9/2007

<u>Assuring U.S. innovation leadership in a time of increasing global competition:</u>

- Reduce the cycle time for innovation - partnerships
- Develop future talent – depth & breadth, diversity, rich experiences
- Fully capitalize on existing investments
- Address critical national issues

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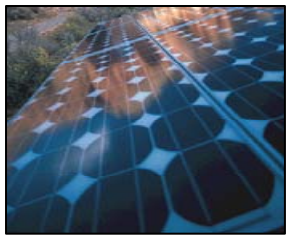
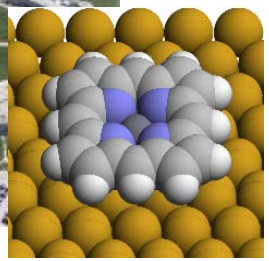
The Department of Energy can "Change the Game" in the U.S.

Assuring a sustainable energy future



Ensuring National Security

Nurturing the nation's S&T base



- Important national missions
- Unique national facilities around the country
- >21,000 DOE scientists & engineers
- The largest supporter of physical science research

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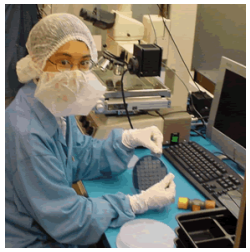
A vision for the next decade: Partnering for workforce development & innovation

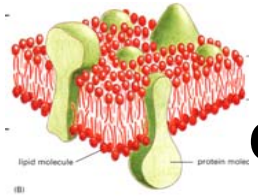
Discovery Science & Engineering Innovation Institutes

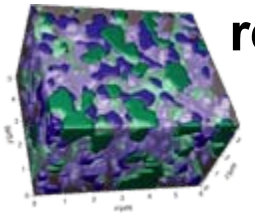
Young, diverse talent



Transformed education

Broad collaborations





Compelling national research

Lab & industry mentoring

State-of-the-art facilities

OUTCOMES

- Future science & engineering leaders
- New breakthroughs
- Outreach & expanded partnerships
- Enhanced lab vitality
- Enhanced economic competitiveness

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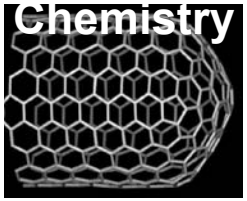
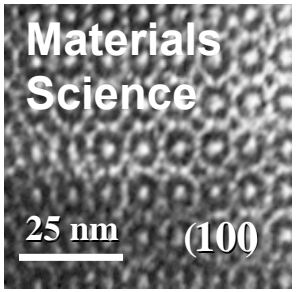
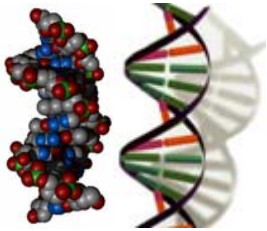
Prototyping the Innovation Institute Concept:
National Institute for Nano-Engineering

Nano-engineering will be a critical competitive hinge for the U.S.



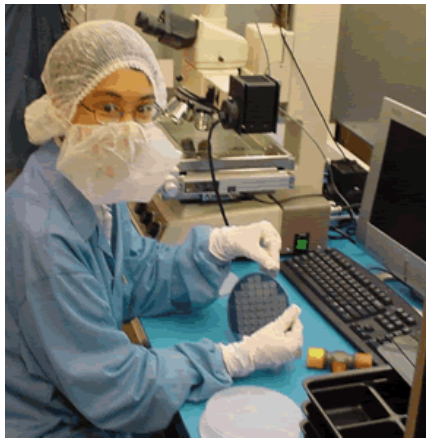


Theory & Modeling



- New electronics
- Sensors
- Catalysts
- High-performance materials
- Energy storage
- Photonics, plasmonics
- …

NINE Mission: Create the next generation of Nano-Engineering innovators and enable our nation to benefit from their innovations.



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NINE's Mission

Create the next generation of Nano-Engineering innovators and enable the nation to benefit from their innovations …

Students

Mentors

Facilities

Technical Depth ***Leadership***

Breadth

Multi-disciplinary Teams

Global Innovation Leaders

A new GUI approach!

A new result!

… through pre-competitive work on nationally important projects with Sandia facilities and mentors, University participation and Industry support and guidance.

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NINE is a nationwide network of partners…

… who are joining together to support innovation, workforce development and economic competitiveness in Nano-Engineering.

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NINE is designed to meet each partner's needs

- **Sandia, DOE, and the nation**
  - Innovative solutions to difficult national security problems, including defense, energy, workforce, economic security
- **University students and faculty**
  - Exciting large scale research opportunities for students and faculty, access to top facilities and Intellectual Property ownership
- **Industry**
  - Financial leverage for innovative pre-competitive research, IP in areas key to future markets and access to top new hires, part of a nationwide network of key companies

Nano Systems Are Key To Sandia's National Security Missions

Nuclear Weapons

Safe, Secure, Reliable Weapons

Homeland Security and Defense

Detection

k Management & Mitigation

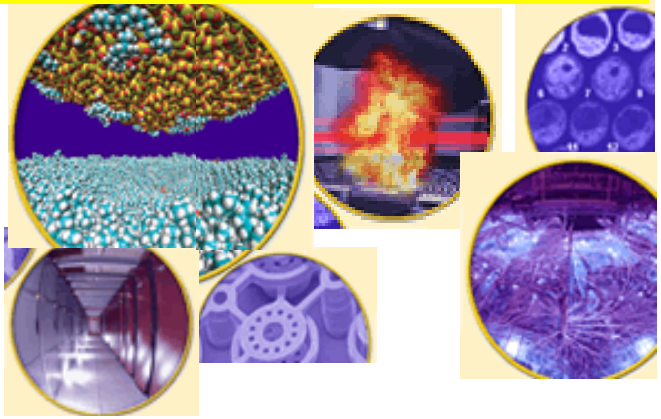
Energy & Infrastructure

Nuclea rEnerg y

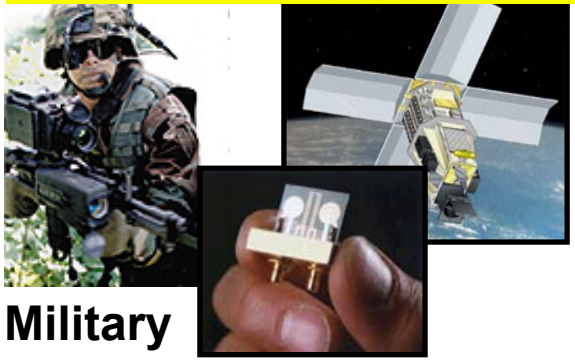
Fuel & Water

Global Security

Science, Technology and Engineering



Defense Systems & Assessments



Military Systems

Surveillance

National need has driven federal investment in nano technology at Sandia

MESA

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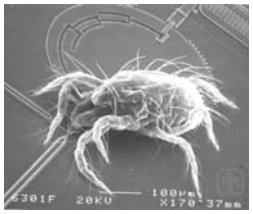
Small Technology Continuum At Sandia

Things Natural

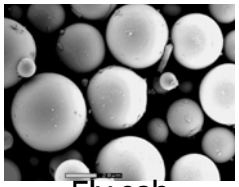


Dust mite

200 μm

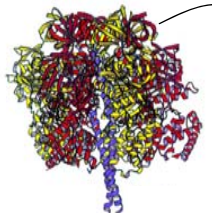
Ant
~ 5 mm

Human hair
~ 50 μm wide



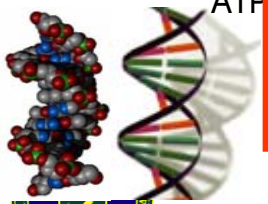
Fly ash
~ 10-20 μm

Red blood cells
with white cell
~ 2-5 μm

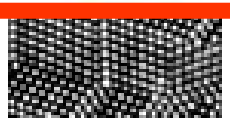


~10 nm diameter

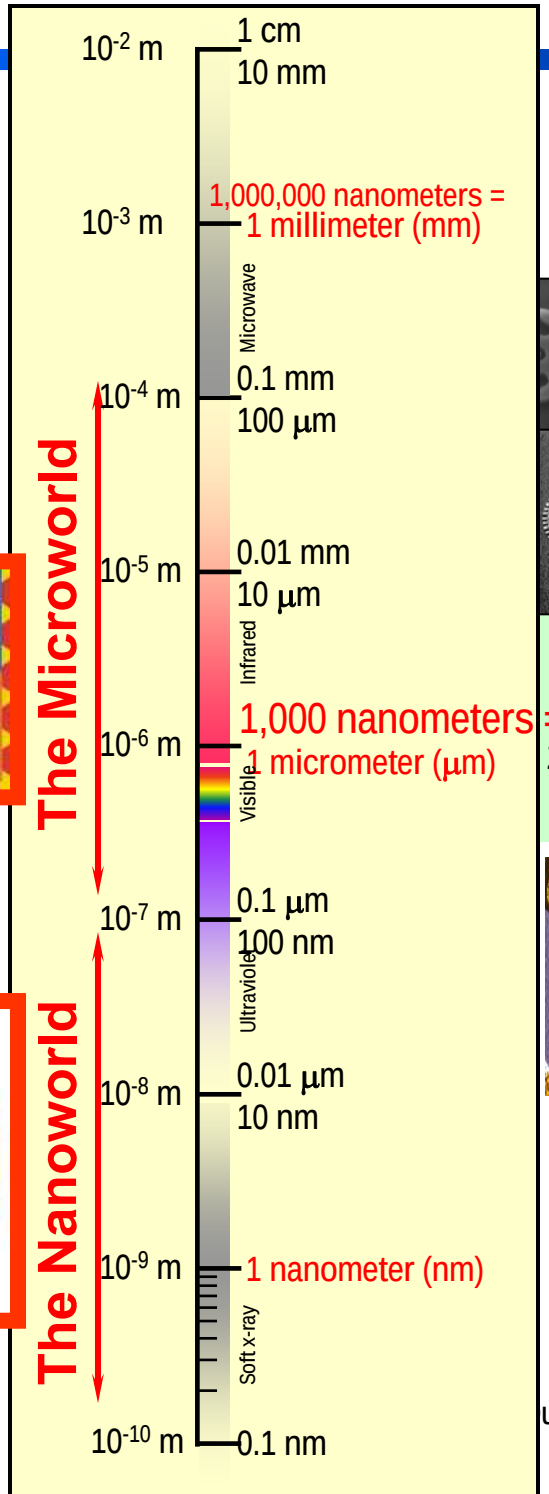
ATP



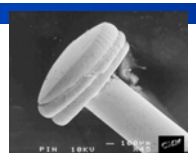
DNA
~2-1/2 nm diameter



Atoms of silicon
spacing ~tenths of nm



Things Manmade

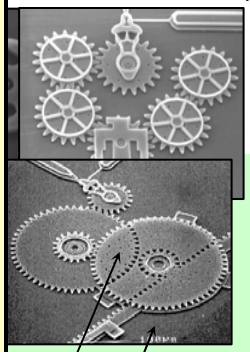


Head of a pin
1-2 mm

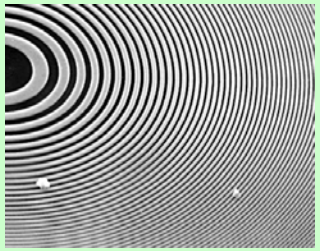
MicroElectroMechanical devices
10 -100 μm wide

0.75B in facilities

$150M/yr R&D

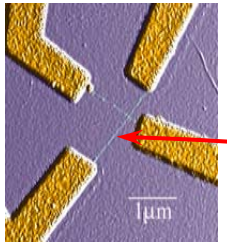


Red blood cells
Pollen grain

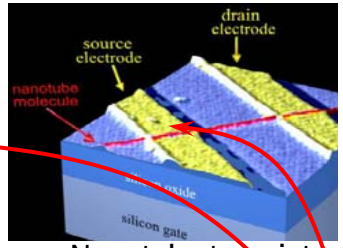


Zone plate x-ray "lens"
Outermost ring spacing
~35 nm

Mechanical, Electrical, & Optical



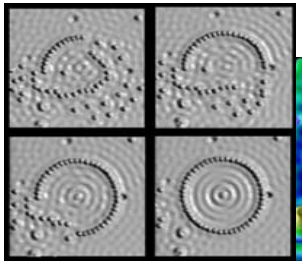
Nanotube electrode

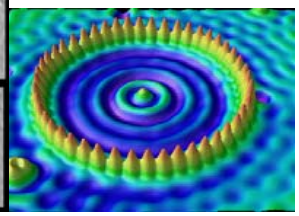


Nanotube transistor

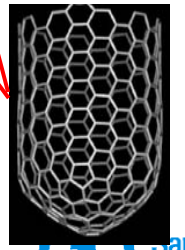
Materials

- Organic
- Inorganic





uantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon nanotube
~2 nm diameter

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Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 03-05-02

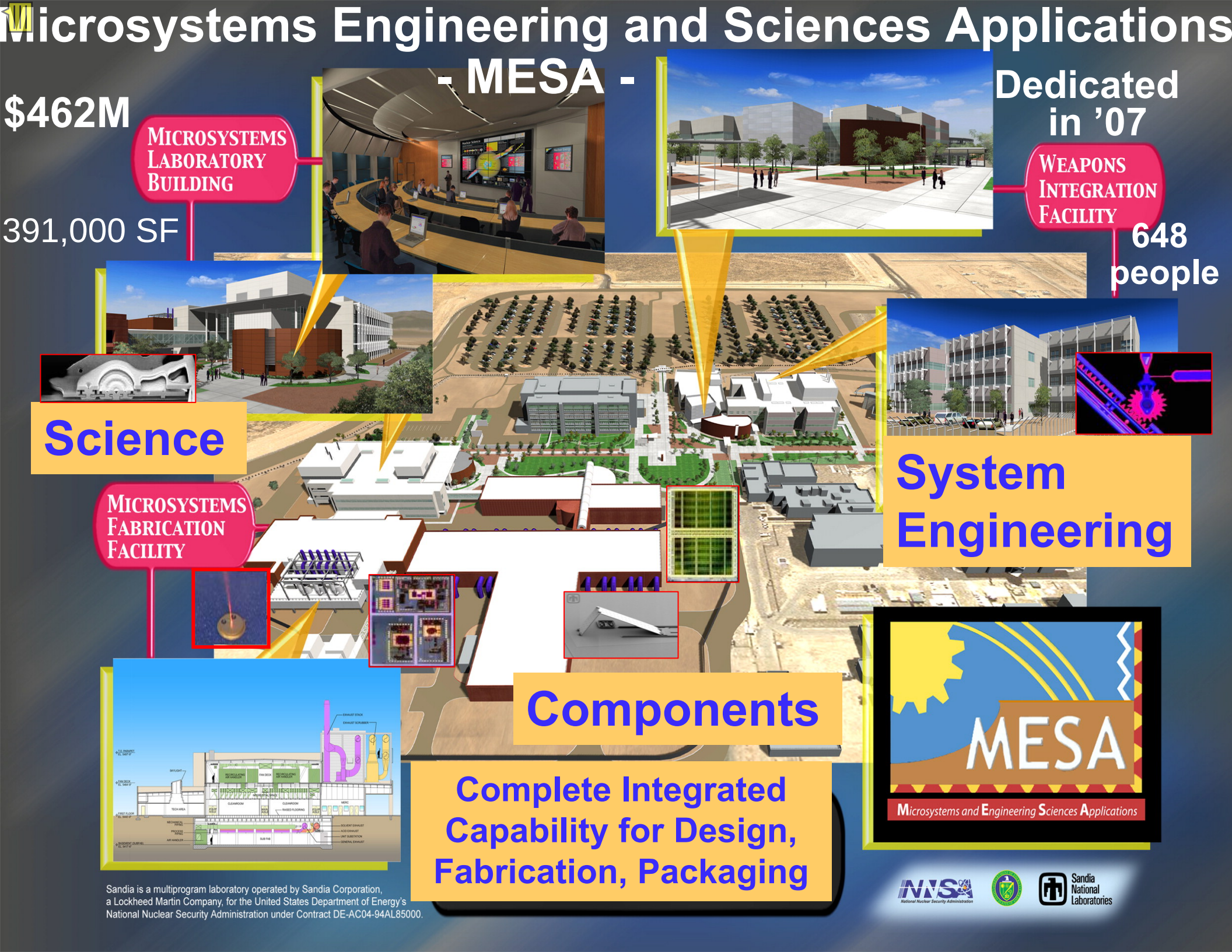
Microsystems Engineering and Sciences Applications - MESA -

$462M

391,000 SF

Dedicated in ’07

648 people



Complete Integrated Capability for Design, Fabrication, Packaging

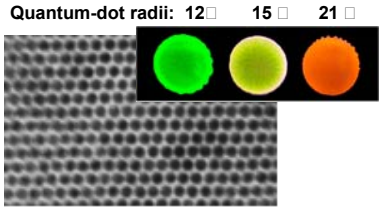
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under Contract DE-AC04-94AL85000.

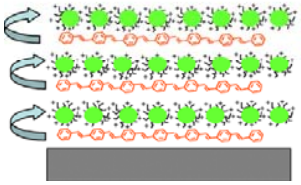
NNSA National Nuclear Security Administration

Sandia National Laboratories

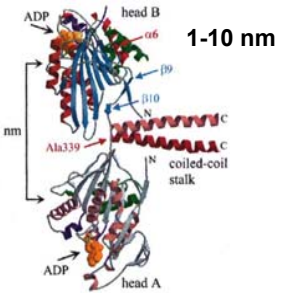
The Center for Integrated Nano Technologies' thrust areas provides a broad base of expertise

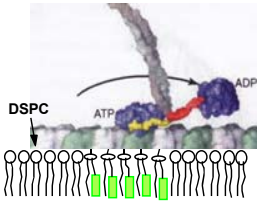
Nanoelectronics & Nanophotonics:
Precise control of electronic and photonic wavefunctions



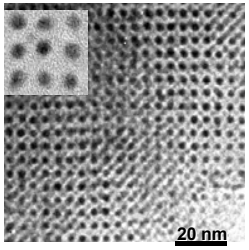


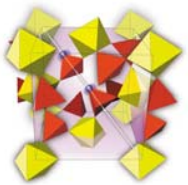
Nano-Bio-Micro Interfaces:
Biological principles & functions imported into artificial bio-mimetic systems





Complex Functional Nanomaterials:
Relationships between synthesis, structure and complex and emergent properties

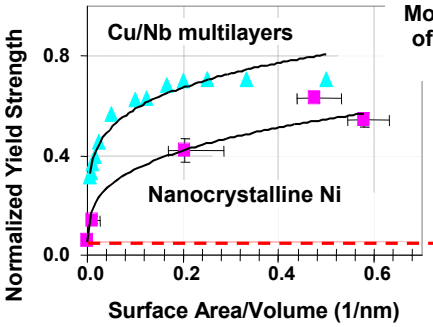


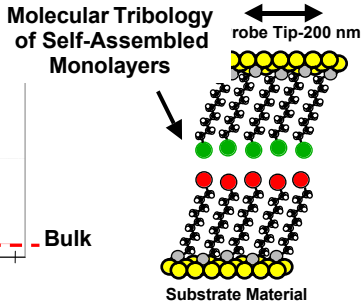


Nanometer Unit Cell- ZrW_2O_8

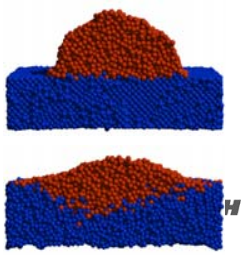
Underconstrained lattice Ğleading to Negative Thermal Expansion

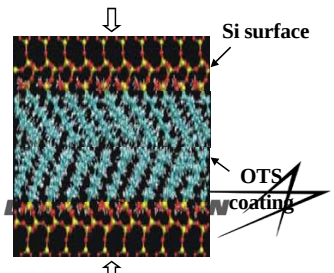
Nanomechanics:
Understanding the mechanical behavior of nanostructured materials

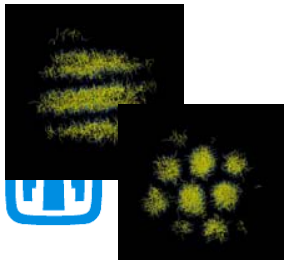




Theory & Simulation:
Theoretical, modeling and simulation techniques for multiple length and time scales and functionality







NINE builds on Sandia's strong science & technology infrastructure

Workforce Development & Innovation Partnerships

NATIONAL INSTITUTE FOR NANO ENGINEERING

"Sandia's facilities are unique in combination and provide the ability to produce prototype nano-micro technology systems involving multiple facilities and capabilities, a difficult opportunity for universities to provide their students." – **David Duquette, RPI and Kevin Jones, Univ.of Florida.**

Center for Integrated Nanotechnologies

Discovery science & user support

High performance computing

Platforms & codes

Microsystems & Engineering Sciences Applications

Technology development & product realization

Office of Basic Energy Sciences

NNSA National Nuclear Security Administration

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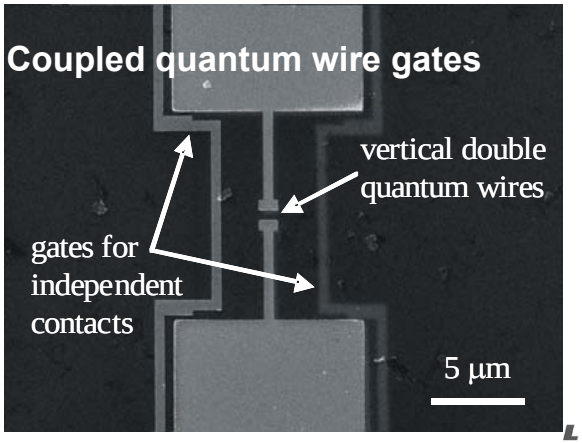
Sandia has initiated NINE

- $7.5M seed funding
- 14 projects
- ~40 students, ~18 faculty
- Six industry partners
- Twelve university partners

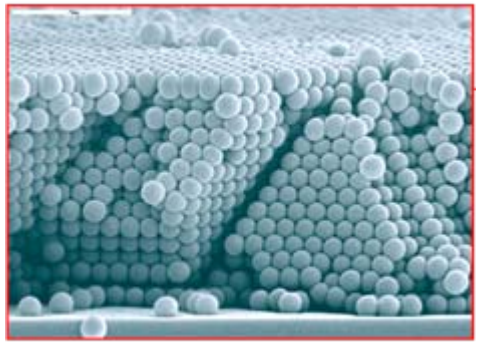
<u>Three theme areas have been initiated with the NINE partners</u>

Nano-based energy technologies

Next-generation Nanoelectronics



Nanomaterial processing & manufacturing



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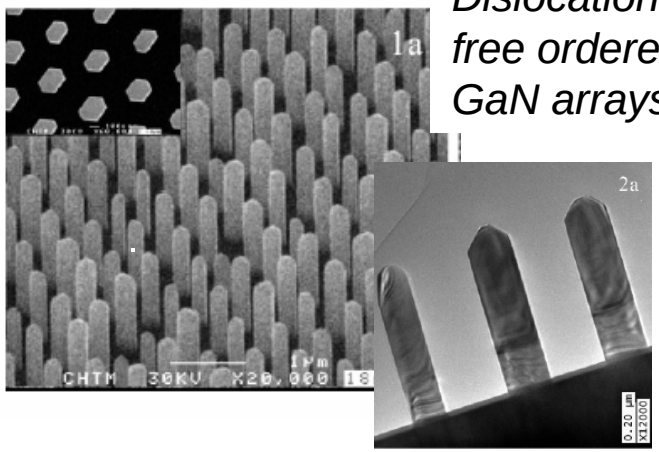
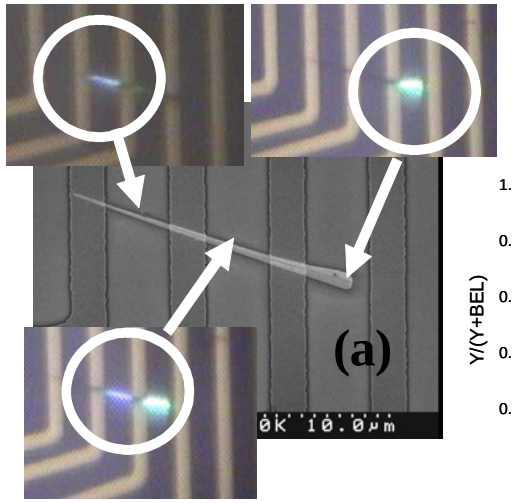
Nano-electronics & photonics for the 21st Century

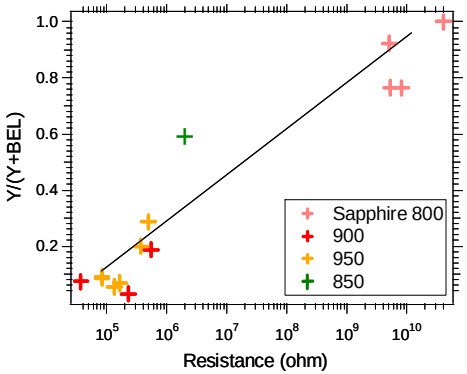
PI: Alec Talin



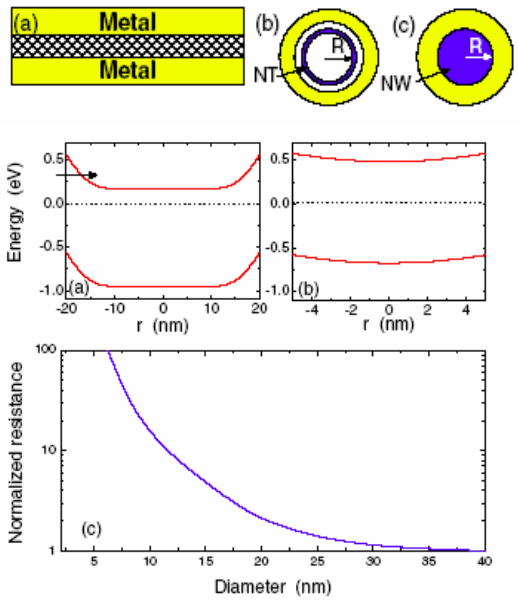
Dislocation-free ordered GaN arrays

Ordered growth and integration





GaN and Ge NW devices for electrical/optical characterization



modeling contact resistance in nanotubes and nanowires

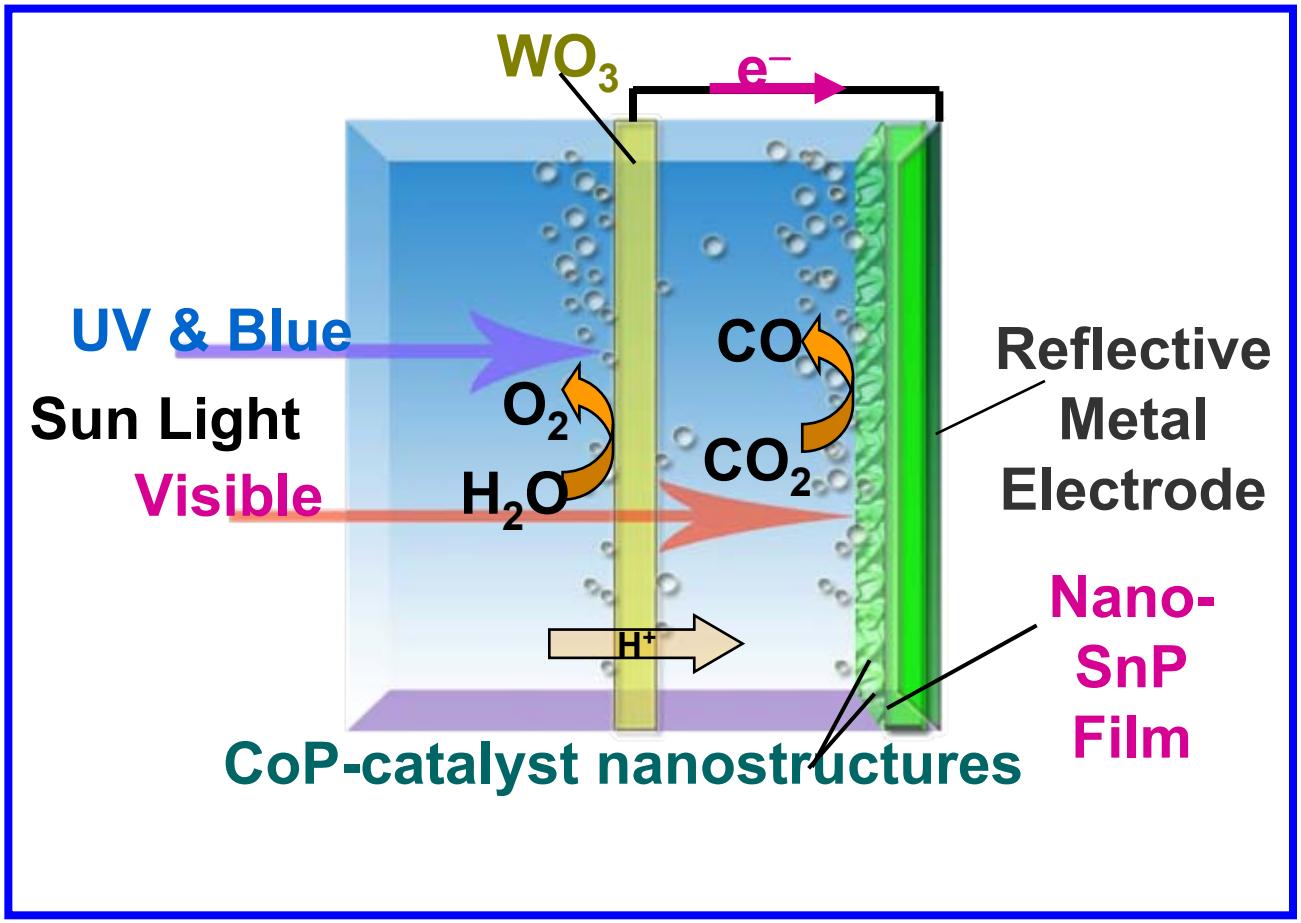
Leonard & Talin, PRL 97, 2006

State-of-the-art fabrication, test, and modeling of nanodevices

Nanoscale circuit simulation

CO_2 Reduction Using Biomimetic Photocatalytic Nanodevices PI: Jim Miller

Approach: CO_2 Recycling through Bio-inspired Photochemical Reduction to CO



Technical Objectives:
1.) To design, fabrication, and characterize photoactive catalytic nanostructures.
2.) Incorporate nanostructures into stand-alone device.

Partners

Praxair

UC Davis

Nanoexa

$H_2O + CO_2 \rightarrow CO + O_2$

Nano-Macro Tandem Solar CO Cell

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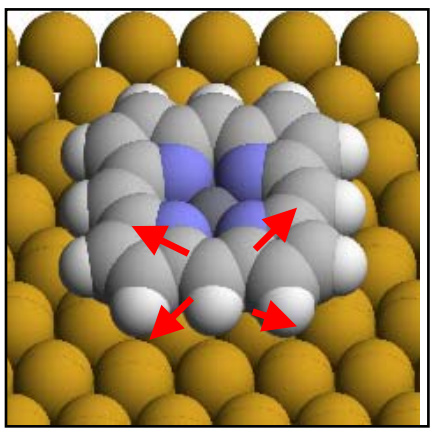
Electronic Structure Calculations to Predict Nano-optoelectronics and Nanocatalyst Functions - PI: Kevin Leung

Problem: Improve predictive capability for DFT methods to model nanocatalysis using transition metal complex or oxide, impact education and national security

Current challenges	Approach	NINE partner
photo-catalysist, e.g., Co-doped anatase	quasi self-interaction corrected DFT (SIC-DFT)	Prof. Nicola Spaldin UCSB, Materials Dept.
FeO, Fe-nanocatalyst	self-consistent DFT+U	Prof. Nicola Marzari, MIT

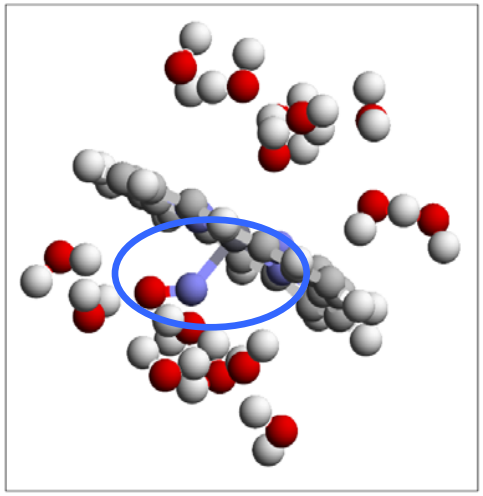
DFT+U success: porphyrin on electrodes: [Leung *et al.* JACS 2006]



$-E$

"Mn(III)" → Mn(II)

on Au electrode



Further DFT+U improvement needed for NO gas sensor [Leung et al. 2007] **(pertinent to CO_2 reduction in water too!)**

engage NINE partners to improve DFT modeling methods, help meet energy and environment challenges, e.g., via modeling CO2 sequestration reactions

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Nanoengineering for Solid State Lighting

PI: Mary Crawford

Objective: to achieve significant energy efficiency advances in Solid State Lighting (SSL) through application of nanoengineering and nanoscience to InGaN-based semiconductor materials and LEDs

Strategic Partner: Rensselaer Polytechnic Institute including Professor Fred Schubert, Professor Christian Wetzel and Professor Shawn Lin

Description of Effort: Two subtasks address major technical challenges to achieving energy efficient LEDs across the visible spectrum

(1) Nanoscale engineering to enhance light extraction of LED materials and devices

→ novel nanostructured graded index materials

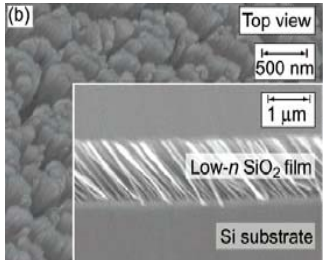
→ advanced light extraction strategies (e.g. photonic lattice and surface plasmon approaches)

(2) Nanoscience studies of InGaN to improve internal quantum efficiency (IQE)

→ study and control of nanoscale InGaN materials properties that impact luminescence processes

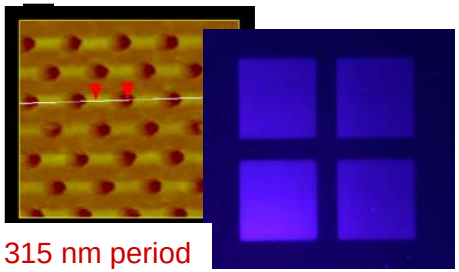
→ focus on critical challenges of low efficiency green materials and "efficiency droop" at high currents

Novel graded index films based on dielectric nanorods



Low index dielectric nanorod arrays through oblique angle deposition

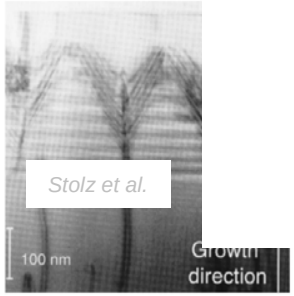
Photonic lattices for light extraction



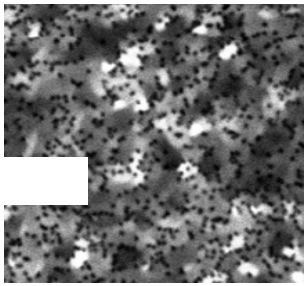
315 nm period

Light extraction from 2 x 2 lattice array

Investigation of nanoengineering of "V-defects" on threading dislocations for enhanced IQE of InGaN



TEM image of V-defects in InGaN multi-quantum wells



Top view cathodoluminescence image of InGaN QWs with V-defects

Potential Impact: achieving LED efficiency goals set by the SSL roadmap would enable U.S. electricity consumption to be reduced by 10% (50% reduction of electricity for lighting), saving ~$25B/ year

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Results of the NINE Technical Workshop

The Industry Partner's top areas :

- Nano Approaches to Sense & Control – Active Nano-Composites and Smart materials
- Low Cost, Self-Powering Sensors for Extreme Environments
- Atomic Layer Control, Nano-Patterning, Scalable Directed Self Assembly for IT, Photonics, Plasmonics and Manufacturing
- Nano-Engineered Chemical Processing
- Energy Management and Harvesting – including ultra caps & batteries

… with emphasis on applying two enabling technologies:

- Predictive Modeling of Materials and Characterization
- Learning From Nature: Biomimetic Processing and Sensing

University partners had similar priorities except sensors for extreme environments.

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2008 NINE Summer Program

A spectrum of opportunities for students

- 42 students from 22 universities were touched by the NINE program
- 33 (80% grad students) did nano-engineering research with mentors in 10 Sandia Centers and one industry site, 9 were NanoExpo students
- Also one-day opportunities for USAF cadets & NSF-sponsored students (12)
- Summer Program offers hands-on activities and experiences
  - Tours of technical facilities, presentations from other NINE students
  - Lab experiences – Making & measuring Nanoparticles, work with AFM and TEM
  - Training and practice in effective communications
  - Seminars in business, accounting, Intellectual Property, Innovation, Nanotech Markets, Ethics and Social Issues in Nanotechnology
  - NINE Student Workshop – presentations by students on their research
  - Nanofest: Nano-engineering and our Global Energy Future
- Also helped with NSF/UNM/Academy Nano-camp (27 students, 12 teachers)
- NINE Technology Workshop – 70 researchers from Gov/Univ/Industry determined the technical focus for 2009 NINE projects

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Things we want to accomplish …

Workforce Development as part of Innovative Projects

- Train top grad students to be global innovation leaders
- Excite undergrads about science and engineering, nanotechnology, and the chance to make a difference
- Motivate US citizen undergrads to get advanced degrees

… and do this through work on nationally important, mission-relevant projects that will benefit from the involvement of innovative students and their mentors.

Next Steps for NINE

- Complete realization of NINE – NINECO formed 10/27/08
- Technical Workshops and Working Groups – Priorities, Calls for Proposals, Proposals
- Contributors select projects to be funded
- Fund $1M/yr, multi-year nano-engineering projects with teams of researchers from Sandia, universities, industry
- Get approval from DOE for NINE to become the first DSEII

With approval by DOE, NINE can begin full operation in FY10.

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