Solid-State Lighting & Nanotechnology

Presentation to

New Mexico Science, Technology, & Telecommunications Committee

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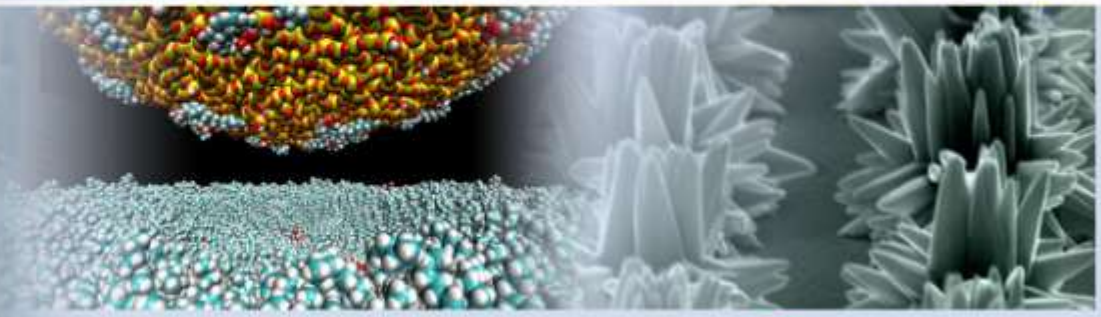
Sandia National Laboratories

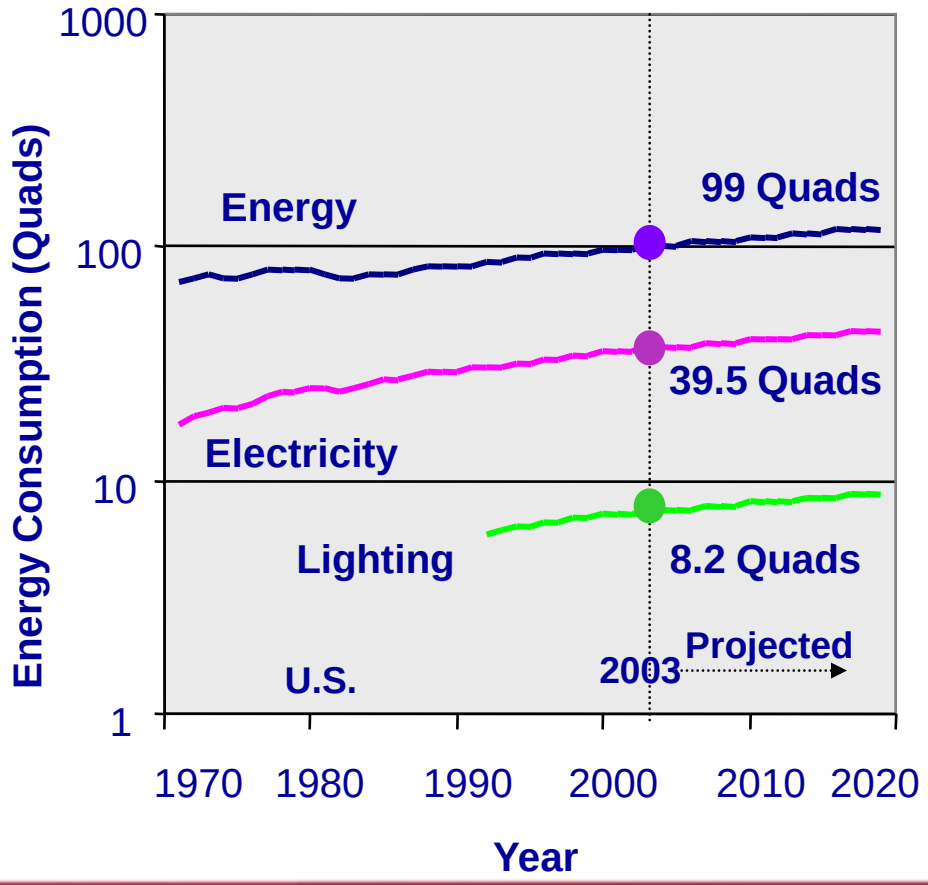
September 2, 2009



Sandia National Laboratories

Lighting is a large fraction of energy consumption and is low efficiency

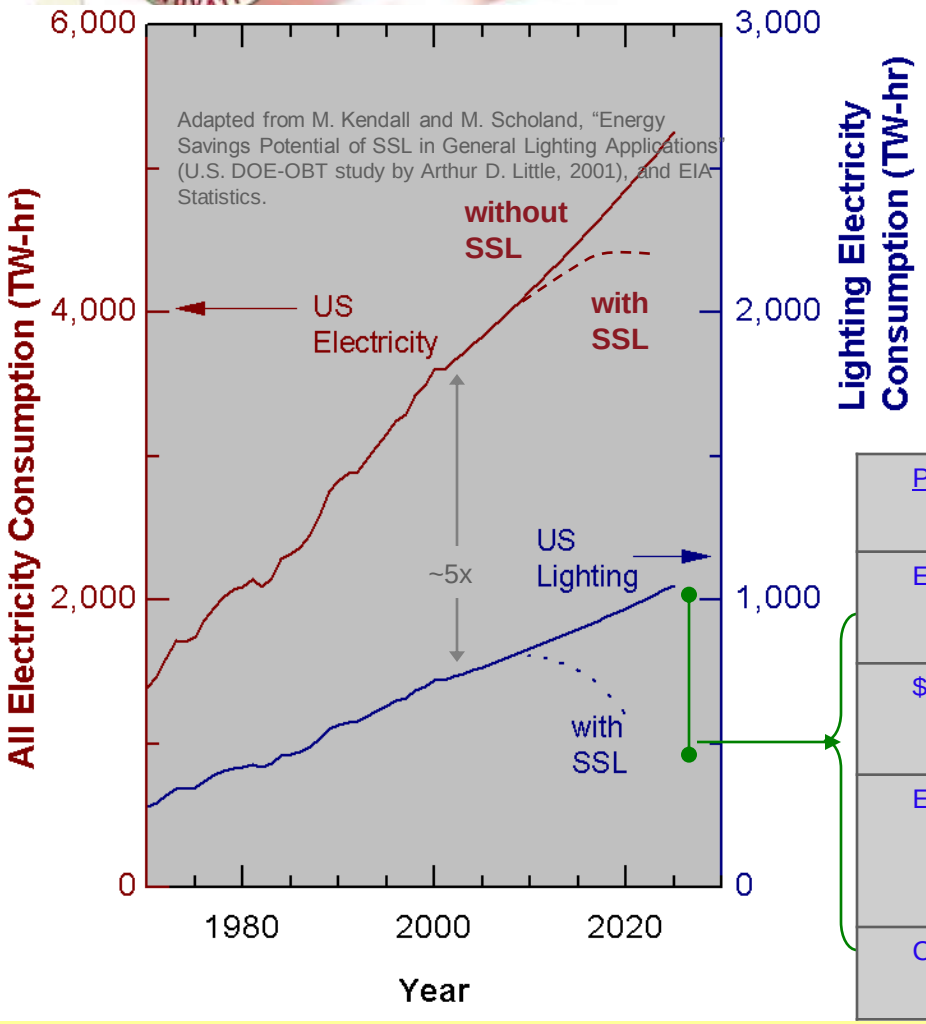
- ~22% of electricity consumption is for general illumination
- Lighting is a highly attractive target for reducing energy consumption!



Efficiencies of energy technologies in buildings:

Heating:	70 - 80%
Elect. motors:	85 - 95%
Fluorescent:	**20-25%**
Incandescent:	**~5%**

Potential SSL pay-offs are enormous: Goal is massive adoption of 50% efficient SSL

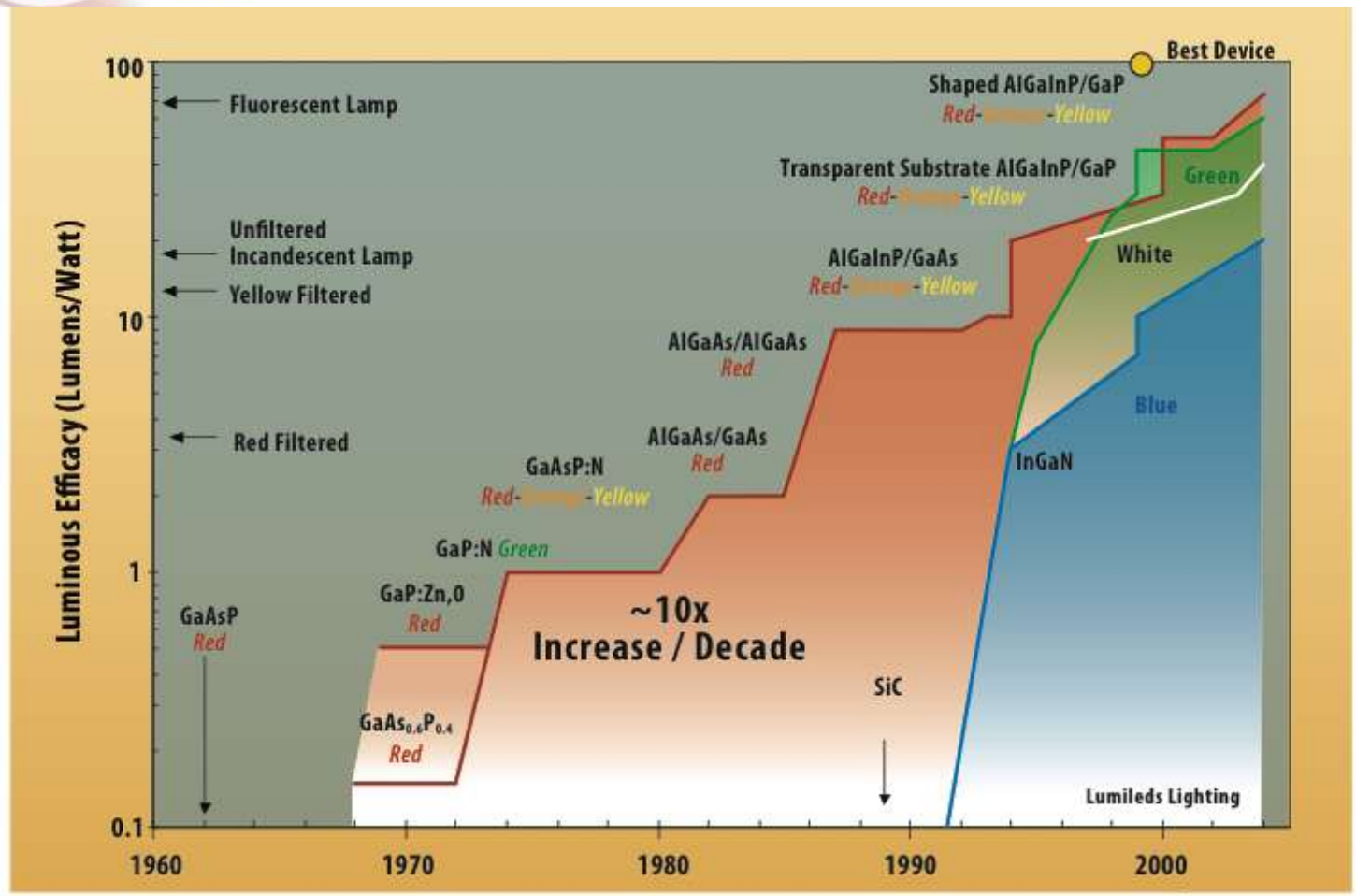


- SSL has the potential, by 2025, to:
  - decrease electricity consumed by lighting by >50%
  - decrease total electricity consumption by >10%

Projected Year 2025 Savings	US	World
Electricity used (TW-hr)	525/year	1,800/year
$ spent on Electricity	$35B/year	$120B/year
Electricity generating capacity (GW)	75	~260
Carbon emissions (Mtons)	75	~260

SSL is potentially **10X and 2X more efficient** than incandescent & fluorescent
•Red LEDs are 10X more efficient that red-filtered incandescents
•Payback time for LED traffic lights is < 1 year

LEDs Have Been Increasing in Efficiency (and Dropping in Cost)

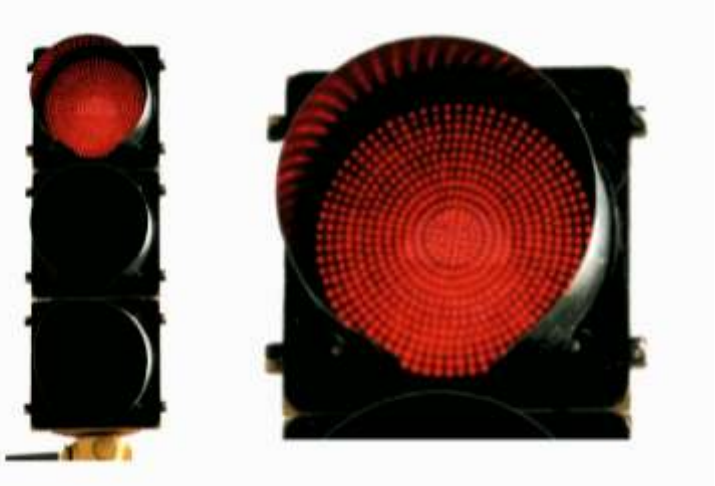


RED: lm/W has improved at 10X/decade, cost has decreased at 10X/decade.

(*Courtesy of G.A. Craford, LumiLeds)

LEDs Are Already Superior for Monochrome Applications

- Red LEDs are now 10X more efficient than red- filtered incandescents
- Today, ~70% of US red traffic lights are LED-based
- Payback time for LED traffic lights (all colors) is ≤ 1 year
- After that the cost savings are ***$1,000/year per intersection***



Sandia's Grand Challenge
R&D in Solid-State Lighting

Large

Sustained

Interdisciplinary

Industry participation

~$8.1M over 3+ years to build the fundamental science and technology base for solid state lighting research (2001-04)

Built on **several $100 M investment in compound semiconductor technology** over > 20 years

Interdisciplinary effort – semiconductor and phosphor materials growth and characterization, device physics, theory and simulation, etc.

Successful **teaming with industry**.

BES, NETL, EERE, LDRD, and DARPA have supported follow-on work.

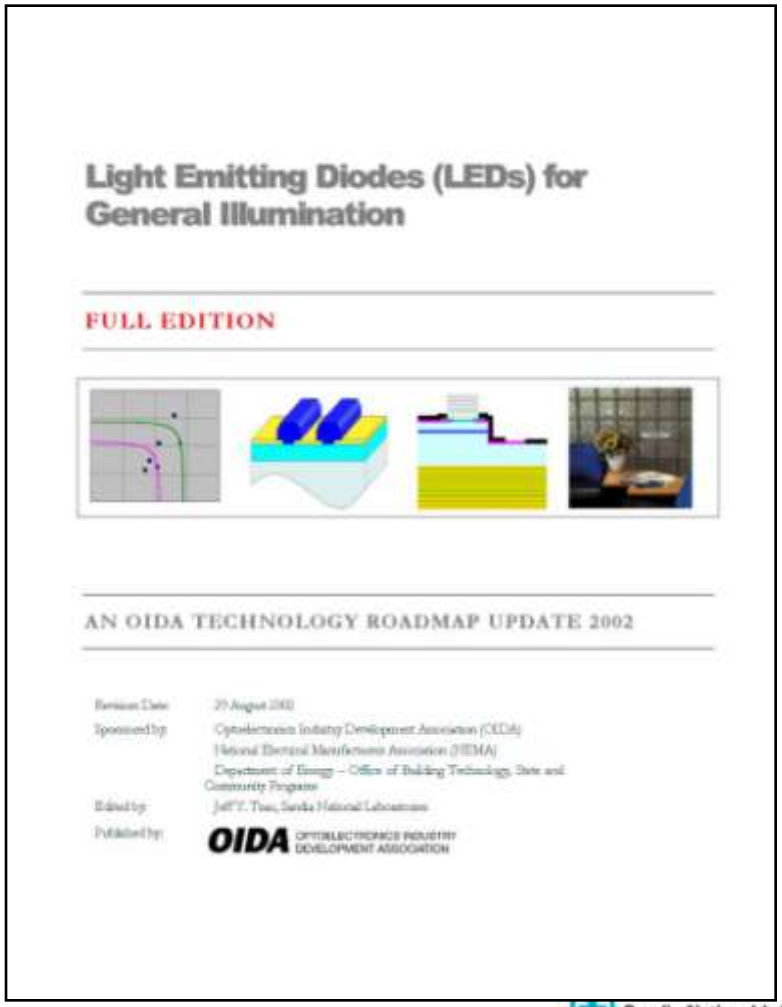
R&D need areas were identified in a 2002 DOE-OIDA Technology Roadmap report

SSL LED Tech Roadmap Topics

1 Substrates, Buffers and Epitaxy
- *1.1 Substrates*
- *1.2 Buffers*
- *1.3 Epitaxy Tools*
- *1.4 Epitaxy Processes*

2 Physics, Processing and Devices
- *2.1 Semiconductor Physics*
- *2.2 Device Processing*
- *2.3 LEDs and Integrated LEDs*
- *2.4 Directional Emitters*

3 Lamps, Luminaires and Systems
- *3.1 Phosphors and Encapsulants*
- *3.2 Lamps and Electronics*
- *3.3 Luminaires*
- *3.4 Lighting Systems*



The DOE-OIDA Roadmap identified out-year targets for LED-based SSL

Taken from the 2002 DOE/OIDA LED Technology Roadmap

TECHNOLOGY	SSL-LED 2002	SSL-LED 2007	SSL-LED 2012	SSL-LED 2020	Incande-scent	Fluore-scent
Luminous Efficacy (lm/W)	25	75	150	200	16	85
Lifetime (hr)	20,000	>20,000	>100,000	>100,000	1,000	10,000
Flux (lm/lamp)	25	200	1,000	1,500	1,200	3,400
Input Power (W/lamp)	1	2.7	6.7	7.5	75	40
Lumens Cost ($/klm)	200	20	<5	<2	0.4	1.5
Lamp Cost ($/lamp)	5	<5	<5	<3	0.5	5
Color Rendering Index (CRI)	75	80	>80	>80	95	75

The SSL community is about on schedule in 2009, except for COST

We will need R&D breakthroughs to achieve the later goals

LED general lighting products are starting to hit the market

Philips

Athenik

Gallium Lighting

Hess AG
(Germany)

Demonstration of energy savings and lighting quality

Installation of LLF 6” downlights in a Westfield, MA *Friendly’s Restaurant*

For ***General Illumination***, replacing conventional lighting will be harder

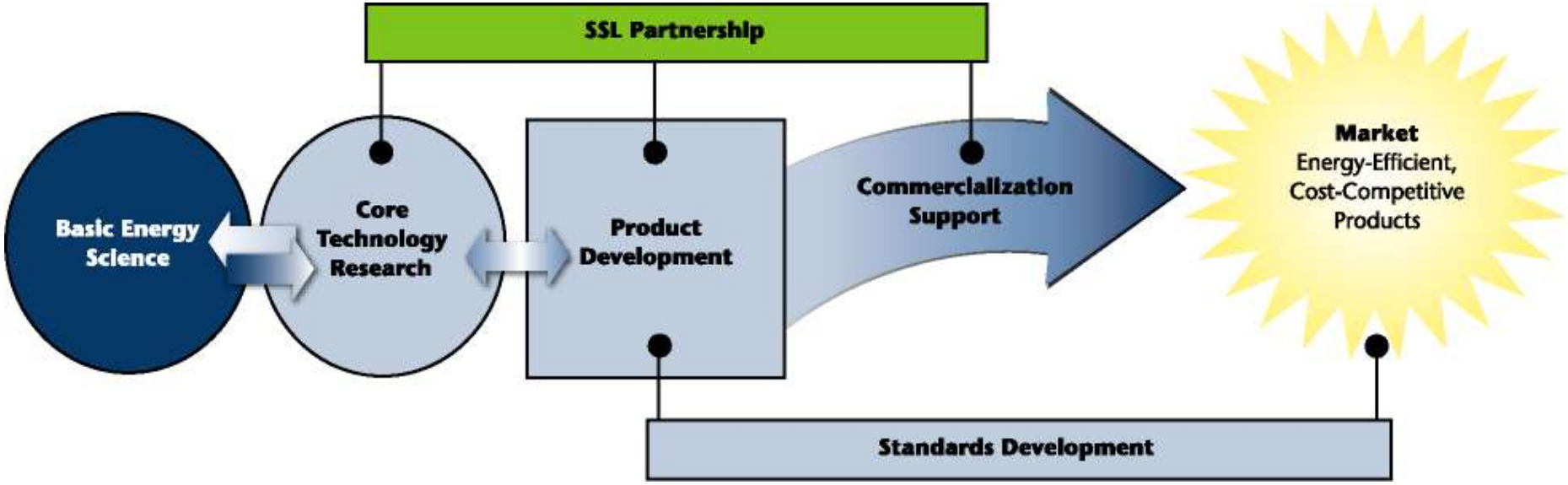
©Dialight

?

Technology breakthroughs must continue for white light SSL to compete with conventional lighting

A Five-Thrust Total SSL Program is being Implemented by DOE

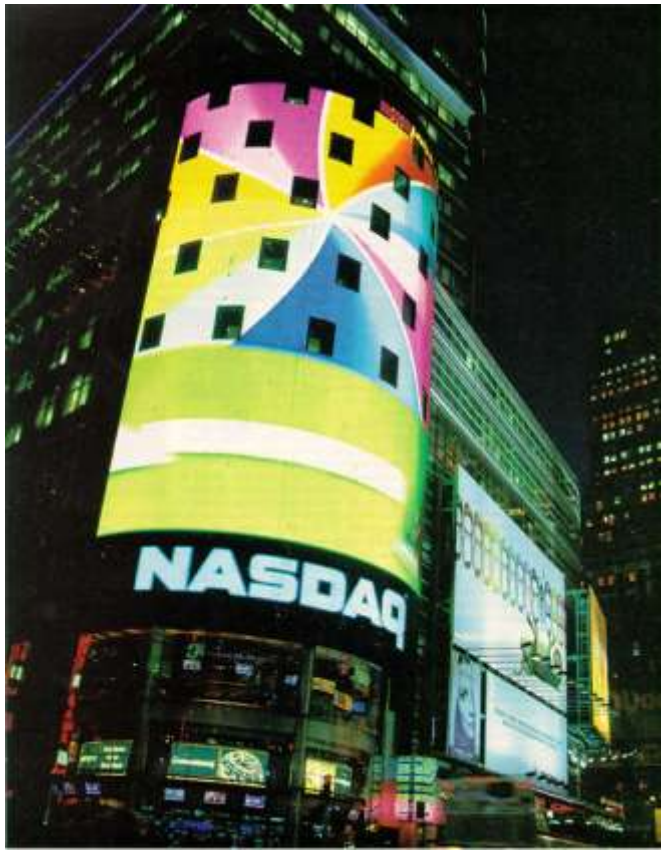
DOE/ Office of Energy Effiency and Renewable Energy



Sandia and its partners have or are proposing efforts in most of these areas, including:

- **Basic science**
- **Core technology**
- **SSL manufacturing equipment development**
- **Attracting manufacturing companies to New Mexico**

Have your cake and eat it too:
The Second Semiconductor Revolution



Disruptive Technology: Replacement of traditional lighting sources by solid state devices can have huge advantages:

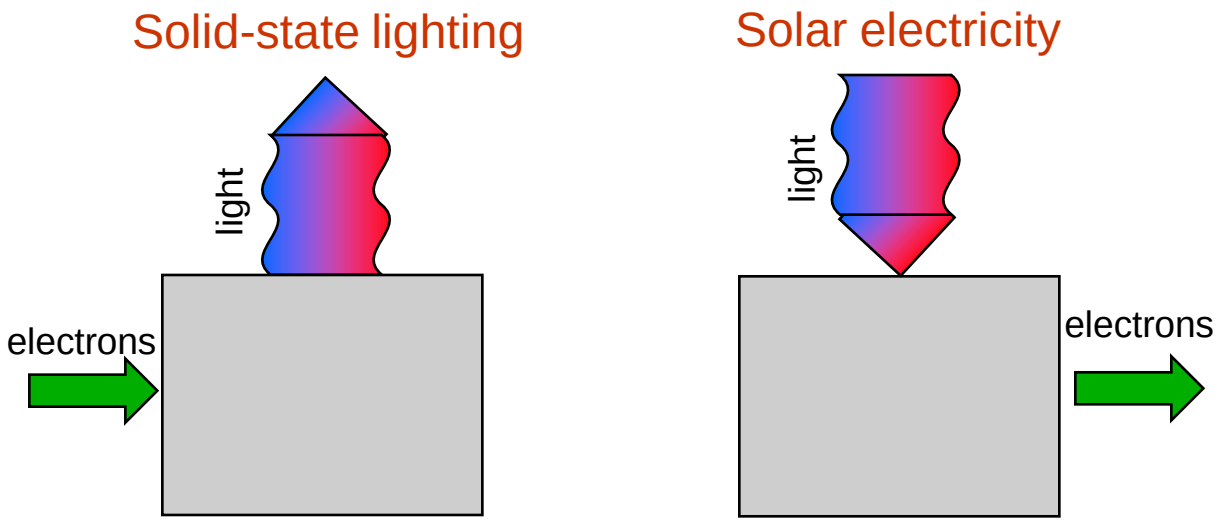
- 10% reduction in global energy use
- Compact
- Light weight
- Low radiant heat
- Shock resistant
- Long lifetime (up to 100,000 hours)
- Easily integrated w/ intelligence
- Exquisite control over brightness and color

– ***leading to completely new applications.***

Economic Impact: Lighting is a $40B worldwide industry. The market could become even larger with new applications.

The same materials used for solid-state lighting may have equal impact on solar electricity

- Solid-state lighting and solar photovoltaics are sort of “opposites”



- The properties that make materials ideal for solid-state lighting also make them very promising for solar electricity
- **Sandia is beginning a program to investigate very high efficiency solar electricity production using these materials**

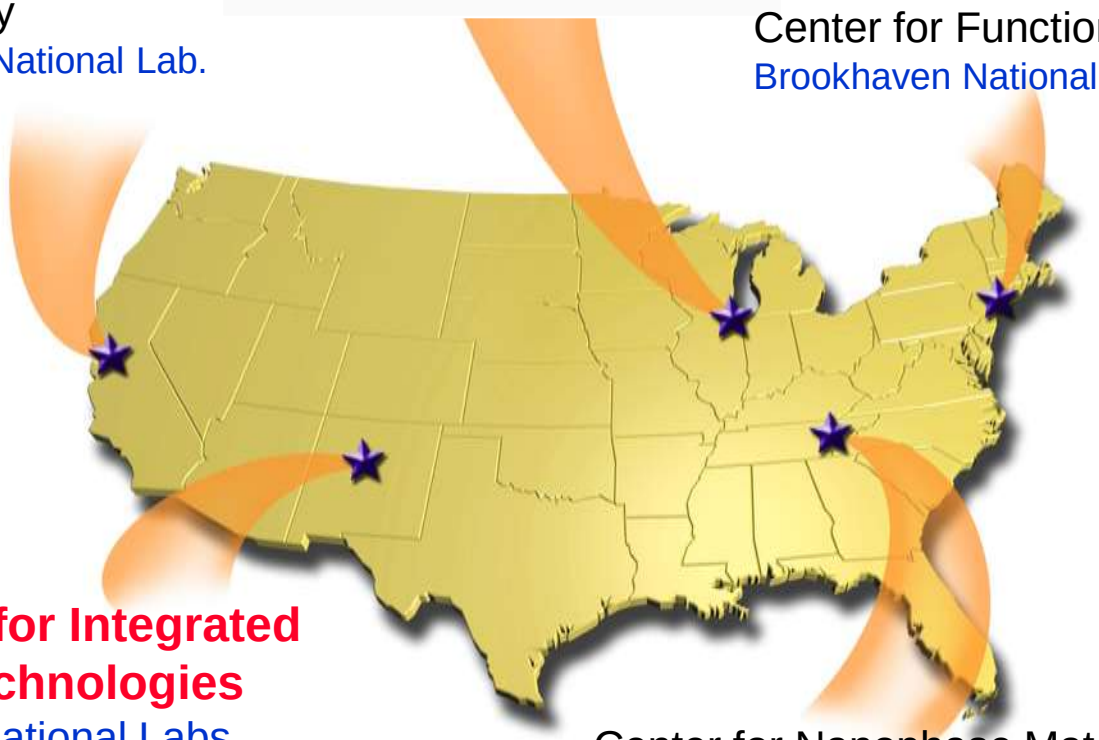
Nanotechnology & the Center for Integrated Nanotechnologies

The Center for Integrated Nanotechnologies (CINT) is one of five U.S. DOE Nanoscience Centers

Center for Nanoscale Materials
Argonne National Lab.

Molecular Foundry
Lawrence Berkeley National Lab.

Center for Functional Nanomaterials
Brookhaven National Lab.



Center for Integrated Nanotechnologies
Sandia National Labs.
Los Alamos National Lab.

Center for Nanophase Materials Sciences
Oak Ridge National Lab.

Center for Integrated Nanotechnologies

Sandia National Laboratories • Los Alamos National Laboratory

- Highly collaborative U.S. Dept. of Energy User Facility
- Access to tools and expertise
- Pre-competitive and proprietary research options
- Focused on nanoscience integration

"One scientific community focused on nanoscience integration"

CINT Core and Gateway Facilities serve as centers for Nanoscience Integration

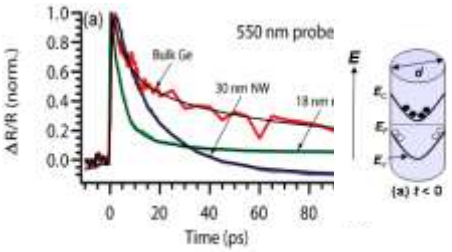
Core Facility in Albuquerque
96,000 sq. ft.

Gateway to Los Alamos
36,500 sq. ft.

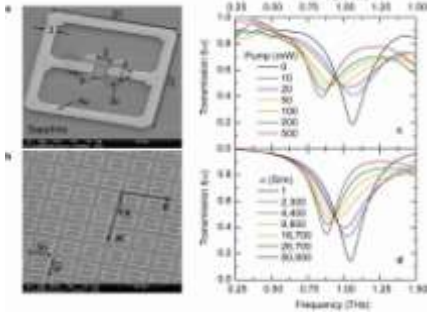
CINT Special Strengths Include

Ultrafast photonics

Carrier Dynamics

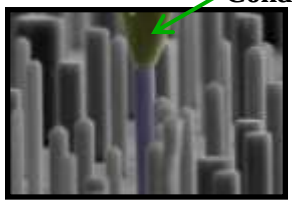


THz Metamaterials

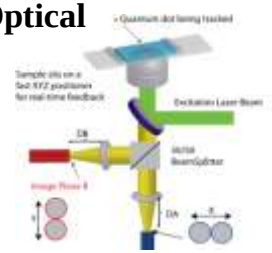


Nano-manipulation & scanning probes

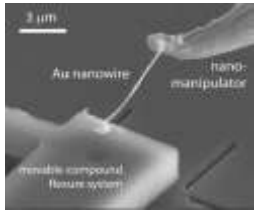
Electrical



Optical



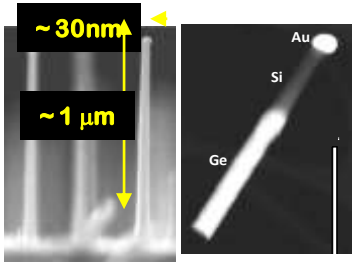
Mechanical



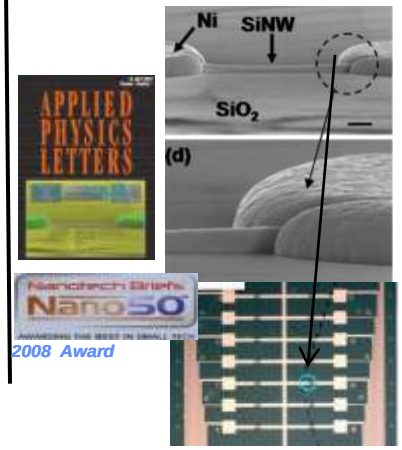
CINT user C. Volkert project

Nanofabrication

Synthesis



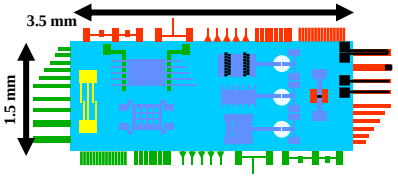
Directed Assembly



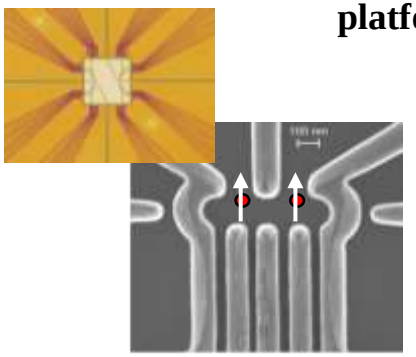
Discovery Platforms™

(Microsystems to interrogate nanomaterials)

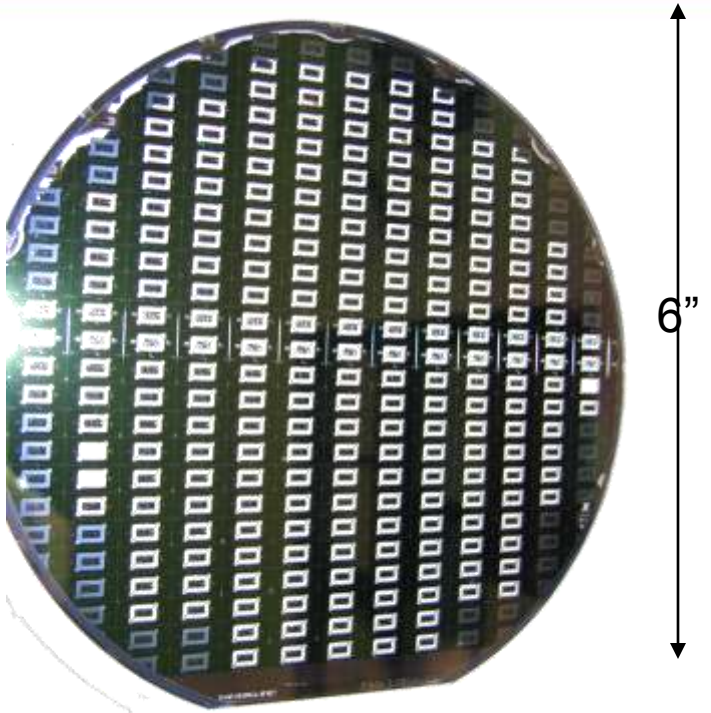
Cantilever Array platform



Quantum Computing Transport platform



CINT has partnered with Sandia's MESA to develop Discovery Platforms™ as unique nanoscience tools

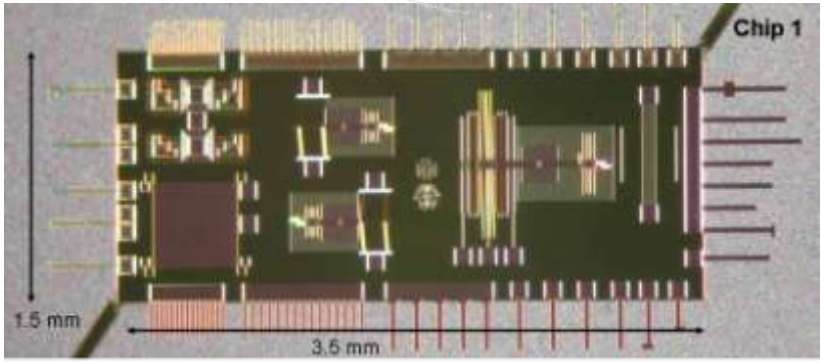


Microsystems and Engineering Sciences Applications (MESA) Complex
274 people, 131,000 GSF
16,600 ft ^{2} Class 10 and 100 cleanroom

Cantilever Array Platform

Mechanics at nanoscale

- cantilever beam sensing
- coupled oscillator arrays
- force actuators
- *in situ* microscopy

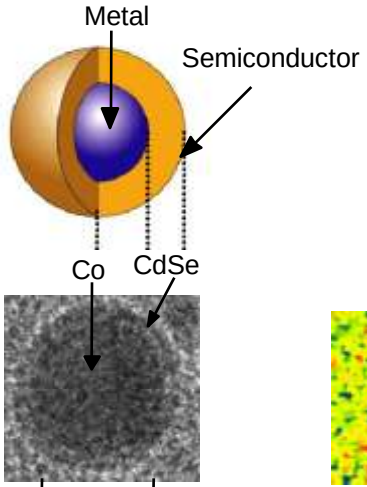


CINT's focus is on Nanoscience Integration

The science of nanomaterials integration

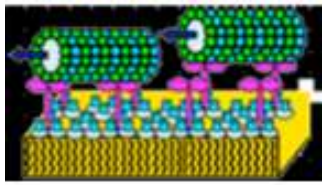
Combining diverse nanomaterials together into composite structures and systems from the nano to microscale to discover, understand, and design new properties and performance of materials.

Bifunctional materials



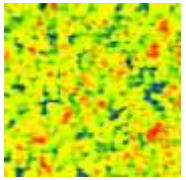
Combining ferromagnetic & semiconducting behavior

Directed assembly

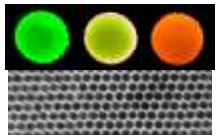


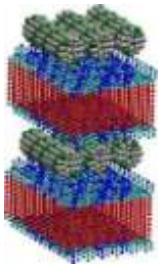
Microtubules + Motor Proteins

Nanocomposite materials



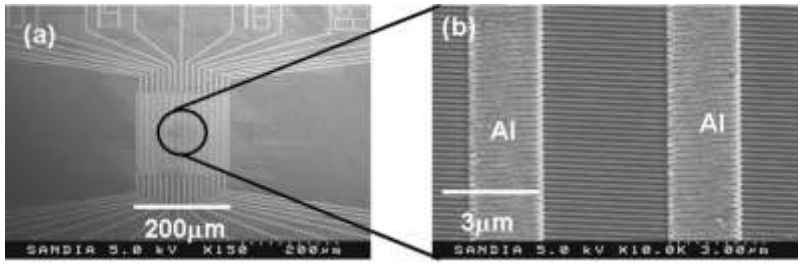
Nanoscale inhomgeneities





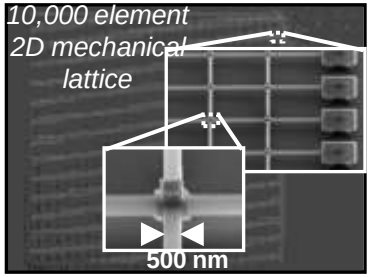
Engineered nanocomposites

Active nanosystems



Nanowire arrays

Switchable metamaterials



Nanomechanical arrays

Length scale

Nano **Micro**

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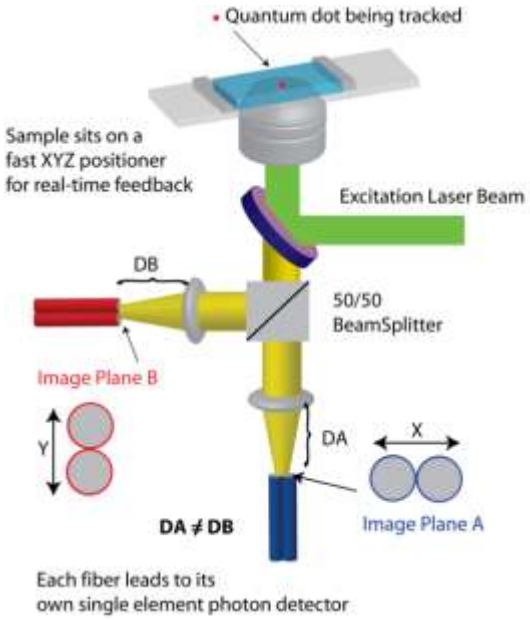
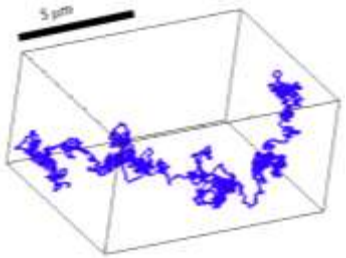
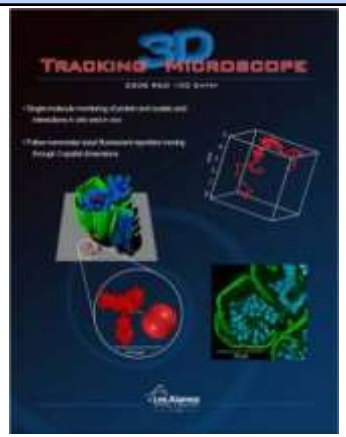
3D Tracking of Individual Quantum Dots

Advanced Instrument Development……..



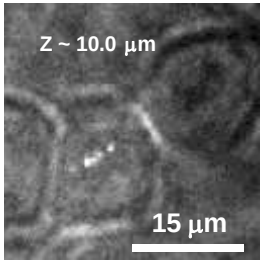


2008
R&D 100 Award



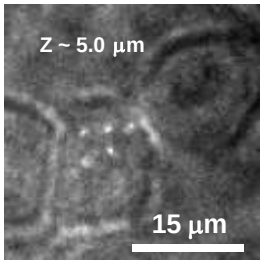
Leads to Unique CINT Science

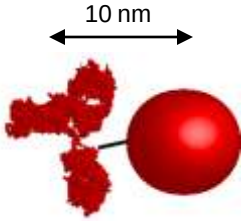
Following three dimensional intracellular transport of quantum dot labeled IgE, an important signaling molecule for the allergic response



top membrane

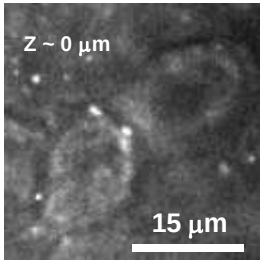
cell interior





qdot labeled IgE

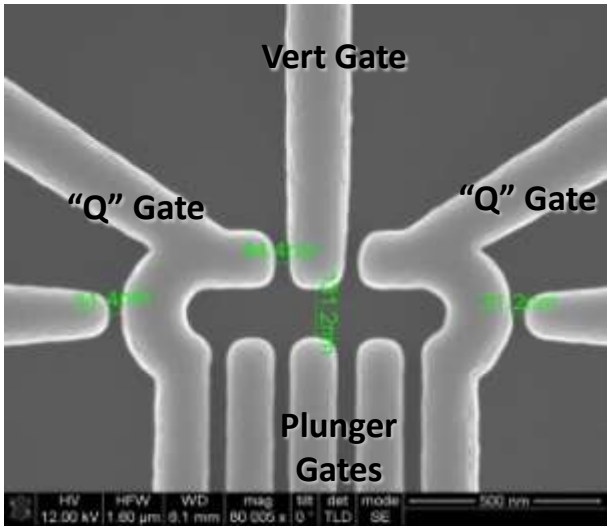
bottom membrane

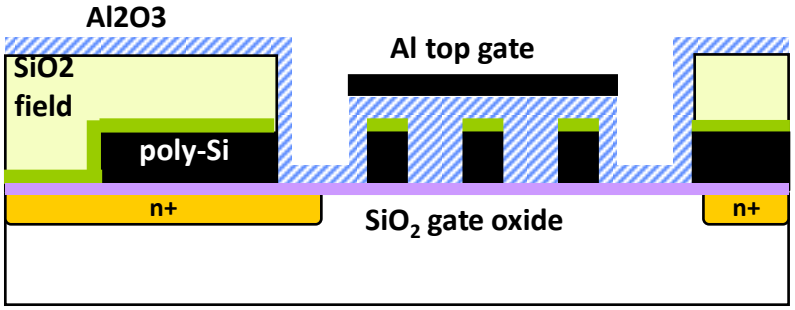


J. Werner, P. Goodwin, N. Wells, G. Lessard, CINT
Diane Lidke, University of New Mexico

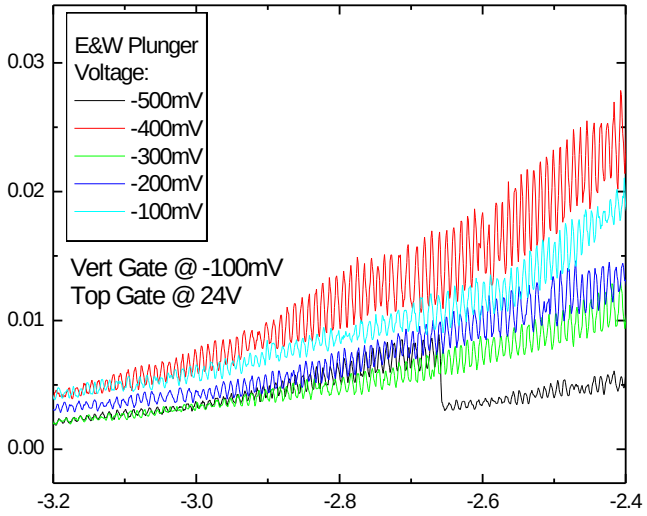
Quantum Information Science and Technology Platform

***Grand Challenge* => develop silicon qubit hardware and plans to extend physical qubits to a logical qubit**





Double quantum dot in CINT discovery platform



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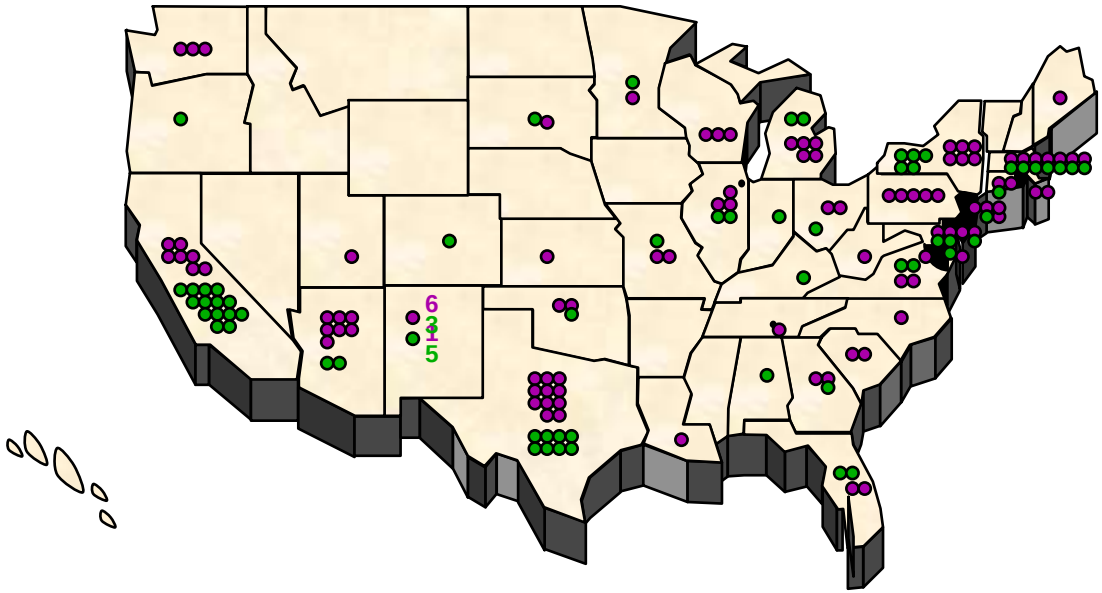
CINT has attracted widespread interest

User Proposal Cycles:

2006: 175 submitted; 130 accepted (74%)
2007: 101 submitted; 79 accepted (78%) +13 Rapid Access (2007)
Spring 2008: 172 submitted; 160 accepted (93%)
Fall 2008: 119 submitted; 107 accepted (90%) +13 Rapid Access (2008)
Spring 2009: 109 submitted; 95 accepted (87%) + 11 Rapid Access (2009)



Over 425 researchers involved in 362 approved projects, representing 36 States and 14 Foreign Countries

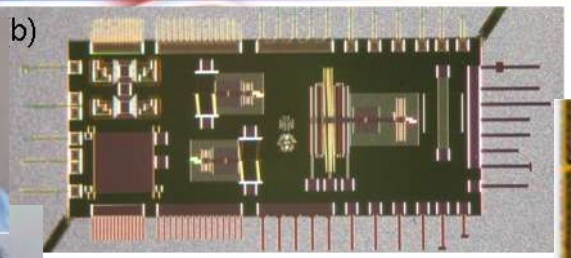
CINT is a DOE/BES National User Facility

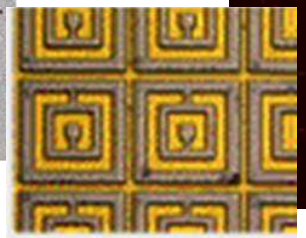
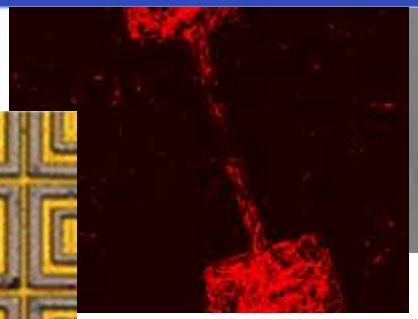
- No-fee access based on scientific quality
- Proposal Review Panels prioritize requests
- Mechanisms for proprietary work (CRADA)
- Spectrum of user modes
  - Access to equipment
  - Collaborative research
  - Short & long term projects (1 year, renewable)
- Rapid Access Proposals

http://CINT.sandia.gov **or** http://CINT.lanl.gov

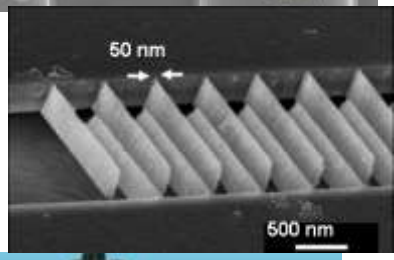
CINT will play a leading role in nanoscience integration

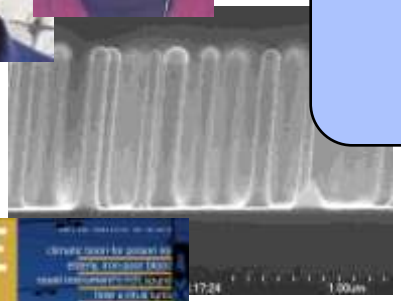








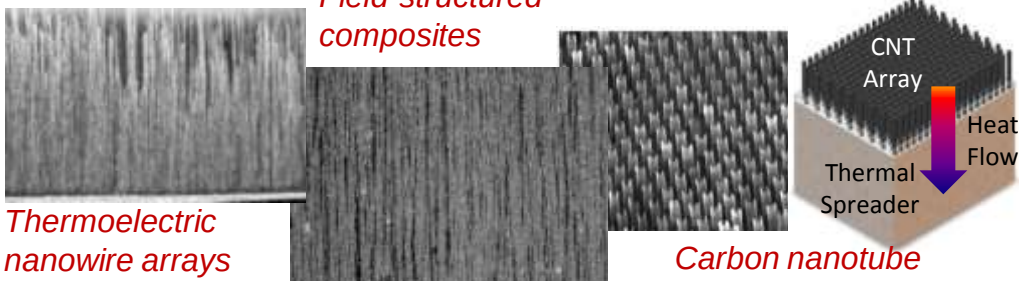
Nanoscience Integration


Users
Outreach
Partnering

Science Thrusts
New Tools

SNL/LANL
Capabilities/
Facilities

Nanotechnology at Sandia beyond CINT

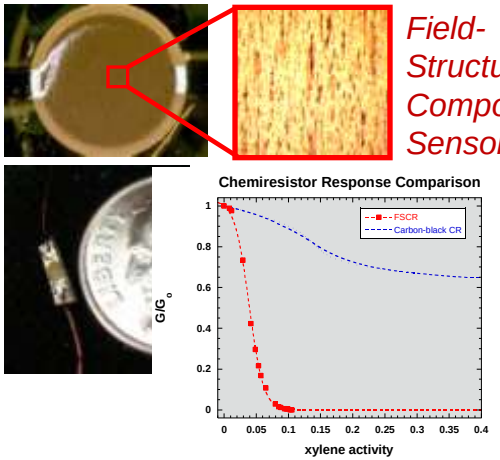


Field-structured composites

Thermoelectric nanowire arrays

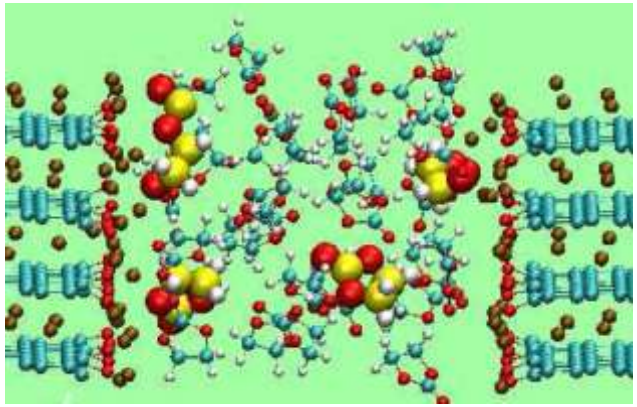
Carbon nanotube arrays

Materials for Thermal Management



Field-Structured Composite Sensors

Materials for Sensors



Materials for Energy Storage

Nanotechnology Summary

- Nanotechnology has a very exciting future
- New Mexico is a leader in nanoscience and nanotechnology
- CINT is attracting leading researchers to New Mexico to collaborate

Can New Mexico leverage these strengths to its economic advantage?

The New Mexico Green Grid Initiative

An Approach to the
Next-Generation Smart Electrical Grid
Incorporating Renewable Energy Sources

Sandia National Laboratories

Green Grid

Make New Mexico a national leader in developing and demonstrating the next-generation "Green Grid" - a smart energy grid with variable and intermittent renewable energy

This initiative could:

- Move New Mexico towards energy independence
- Bring significant Federal R&D investment to NM
- Develop new smart grid technologies that could lead to clean manufacturing of Green Grid components in NM
- Bring VC investment into NM to build out the first Green Grid system in the U.S.

This will require:

- A partnership between the Green Grid Collaboration, Governor, State Legislature, and Federal government

Green Grid

Components:

- Energy Generation and Transmission
- Energy Storage
- Pilot Projects

Thrusts:

- Technology Development
- Demonstration Project
- Clean Energy Export
- Clean Manufacturing

Federal-State-Industry-Japan Partnership

- DOE – critical expertise
- State-wide diverse projects:
  - Albuquerque
  - Los Alamos County
  - NMSU
  - Roosevelt County
  - Taos County

- Japan-NEDO collaboration
  - Demonstrate & compare technologies
  - Share data
  - Provide funding

Sandia National Laboratories · Los Alamos National Laboratory · NM State · The University of New Mexico · New Mexico Tech

Summary

- New Mexico has all the necessary characteristics to develop and implement the next-generation Green Grid.
- Governor Richardson established New Mexico Green Grid Initiative in Fall 2008 (prior to ARRA)
- New Mexico State Legislature established Research Application Center to lead NMGGI
- METI/NEDO collaboration – 1st large activity in US
- The American Recovery and Reinvestment Act (stimulus) provides a tremendous opportunity to jumpstart the NM Green Grid Initiative

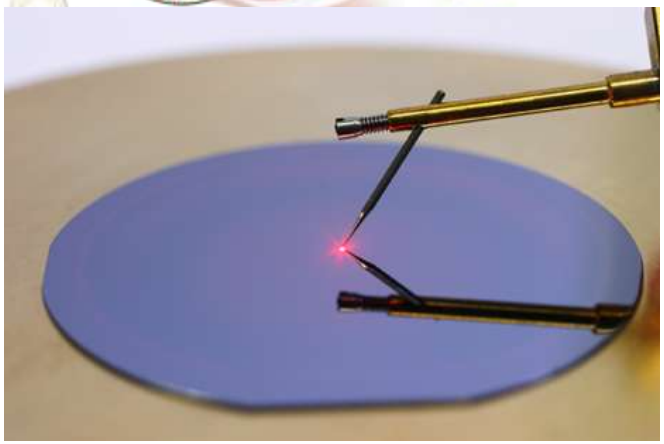
Extra Slides

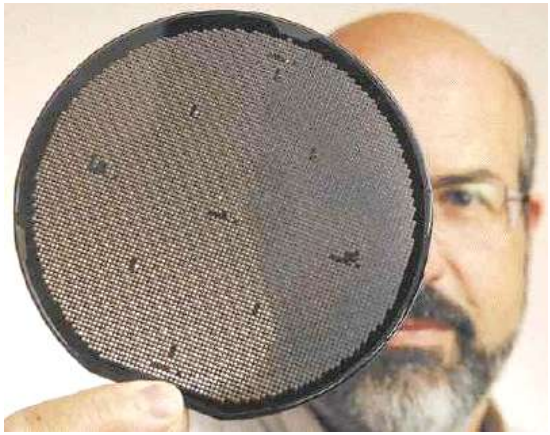
EFRC for Solid-State Lighting (SSL) Science
Jerry A. Simmons & Mike Coltrin
(Sandia National Labs)

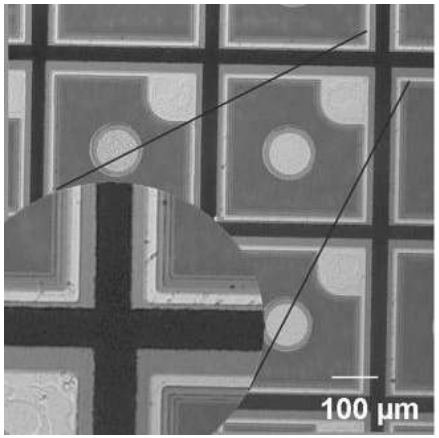
Goal: Improve the energy-efficiency in the way we light our homes and offices, which currently accounts for 20% of the nation's electrical energy use. Solid-State Lighting (SSL) has the potential to cut that energy consumption in half – or even more.

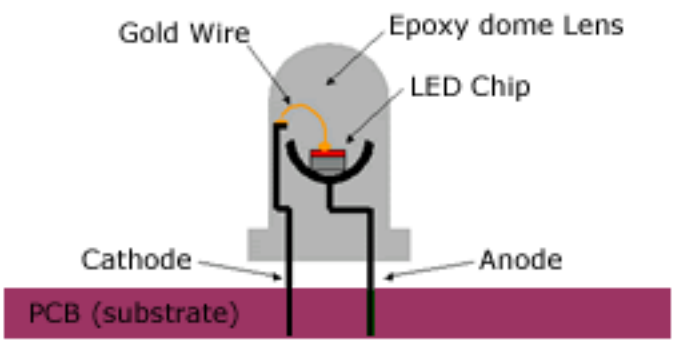
Research plan: Investigate conversion of electricity to light using radically new designs, such as luminescent nanowires, quantum dots, and hybrid architectures; study energy conversion processes in structures whose sizes are even smaller than the wavelength of light; understand and eliminate defects in SSL semiconductor materials that presently limit the energy efficiency.

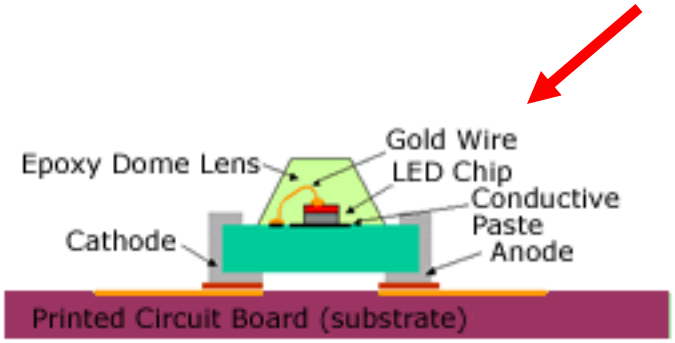
LEDs are grown on semiconductor wafers, then patterned,diced, and packaged











Rocket science is expensive!

Why New Mexico?

New Mexico has all the necessary characteristics to develop and implement the next-generation Green Grid:

- Ability to develop the required new technologies
- An alliance of all the relevant organizations
- Small enough population to make state-wide implementation practical
- Renewable Energy Transmission Authority (RETA) 1st in nation
- Ability to implement a demonstration project
- Growing VC investment in New Mexico
- Relatively strong state economy
- Strong leadership in the State
- Good connections nationally

Partnership Roles

- New Mexico State Government:
  - Establish non-profit to oversee and support Green Grid Initiative
  - Issue and support RFI for demonstration project
- New Mexico Municipalities:
  - Contributing partners in Green Grid demonstration projects
- Universities and Laboratories
  - Sandia and LANL technical expertise
  - Development and testing of technologies
- Federal Agencies:
  - DOE support of major programs eg. SEGIS & SEGIS -ES
- Utilities, Industry and Venture Capitalists:
  - Utilities partner in analysis, design, & demonstration project
  - Partner in demonstration project & statewide Green Grid
  - Suppliers of technologies and R&D
- Other organizations:
  - Development and implementation of Green Grid technologies

NM/Japan Partnership Enhances Green Grid

- Japanese leadership in advanced grid development
  - National goal of 25% electric production from PV by 2030 drives need to address high penetration issues
  - In-country demo and test projects provide unique data
- Ministry of Energy (METI) oversees several MOUs with NM
  - Advanced Institute of Science and Technology (AIST) with State of NM, Los Alamos National Lab, Sandia National Labs
  - Collaborations underway in nanotechnology, nuclear energy
  - Further collaborations being defined in photovoltaics, smart grid
- New Energy Technologies Development Org. (NEDO):
  - US$2B budget to fund METI projects
  - Proposed green grid projects at multiple NM sites
- 2 NEDO Demonstration sites
  - Residential – Los Alamos County
  - Commercial - Albuquerque
  - NEDO workshop Sept. 15 to announce to industry