Center for Integrated Nanotechnologies & Semiconducting Nanowires

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Arizona Nanotechnology: Small is Big
April 10, 2008

Center for Integrated Nanotechnologies

Sandia National Laboratories • Los Alamos National Laboratory

"One scientific community focused on nanoscience integration"

- World class scientific staff
- Vibrant user community
- State-of-the-art facilities
- A focused attack on nanoscience integration challenges
- Leveraging LANL/SNL capabilities
- Developing and deploying innovative approaches to nanoscale integration

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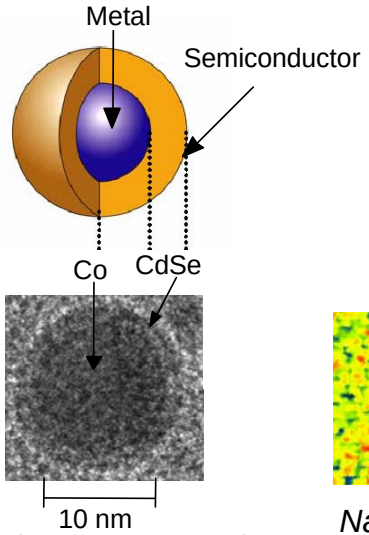
CINT's focus is on Nanoscience Integration

The science of nanomaterials integration

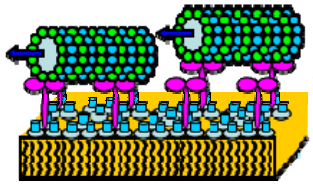
Combining diverse nanomaterials together into composite structures across length scales and into nanosystems to discover, understand, and design materials with novel properties and performance.

Bifunctional materials



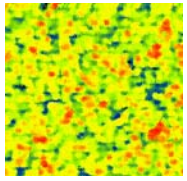
Combining ferromagnetic & semiconducting behavior

Directed assembly

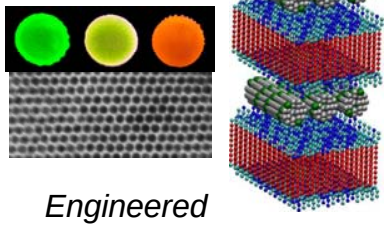


Microtubules + Motor Proteins

Nanocomposite materials

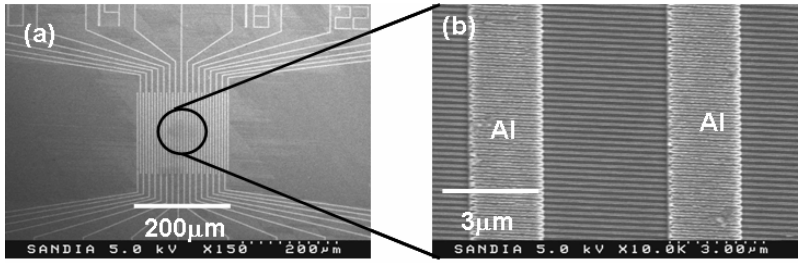


Nanoscale inhomgeneities



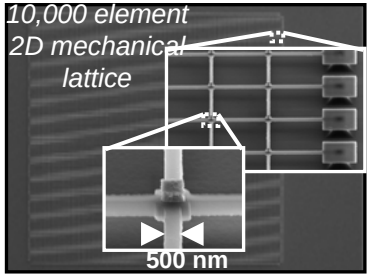
Engineered nanocomposites

Active nanosystems



Nanowire arrays

Switchable metamaterials



Nanomechanical arrays

Length scale

Nanoscale → **Micro/Macroscale**

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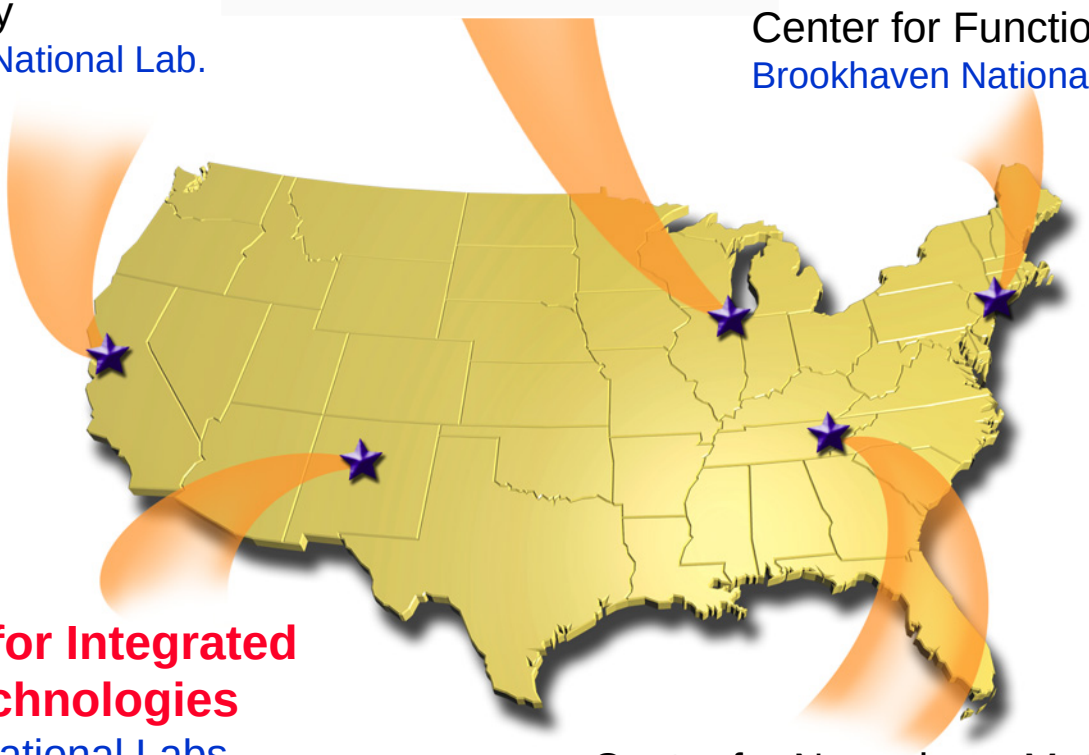
CINT is one of five Department of Energy Nanoscale Science Research Centers (NSRCs)

Center for Nanoscale Materials
Argonne National Lab.

Molecular Foundry
Lawrence Berkeley National Lab.

Center for Functional Nanomaterials
Brookhaven National Lab.



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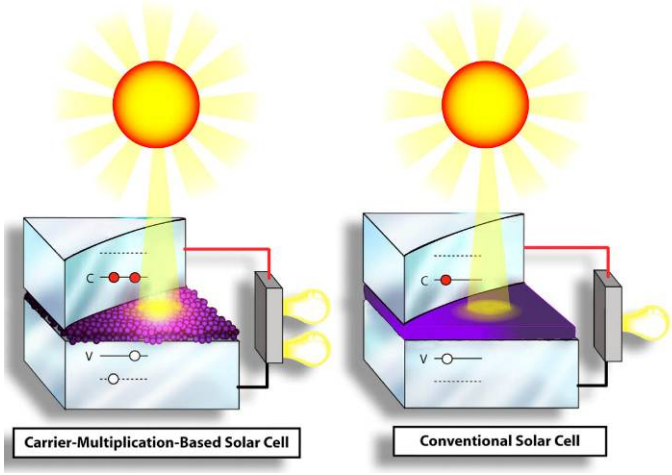
Los Alamos National Lab.

Center for Nanophase Materials Sciences
Oak Ridge National Lab.

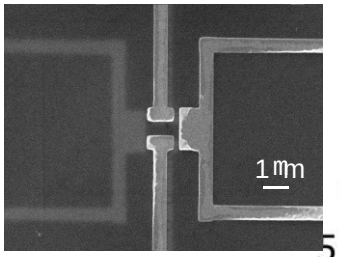
Nanoscience Integration Challenges address key challenges in integration

Energy Transfer

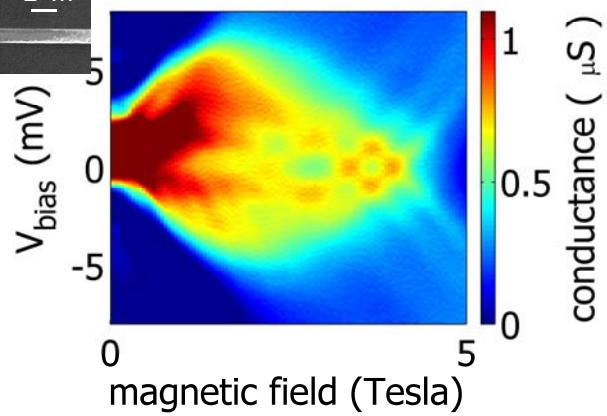
How do nanoscale systems detect, transfer, and transduce energy?



SEM of actual device



1-D tunneling in Double Quantum Wires



Emergent Properties

What are the collective properties of composite nanoscale systems?

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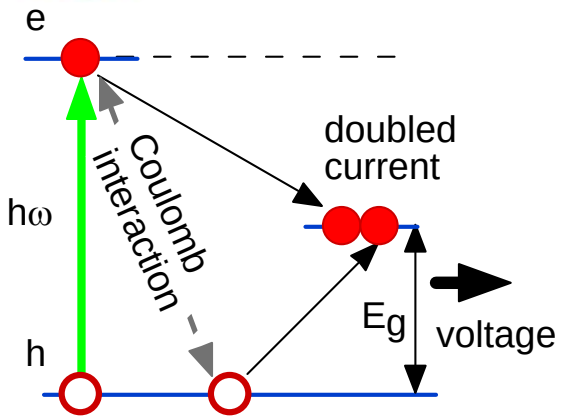
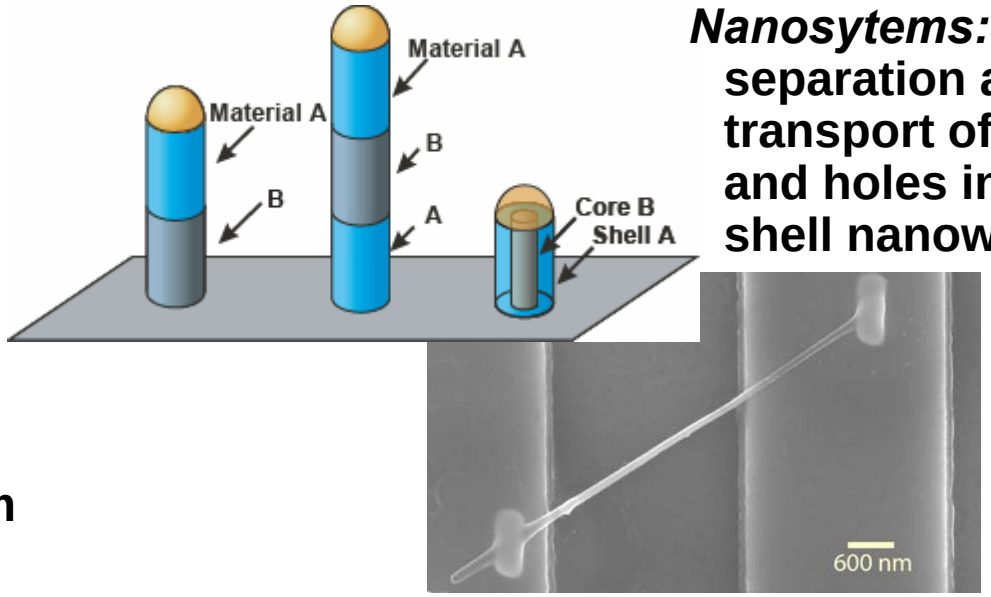
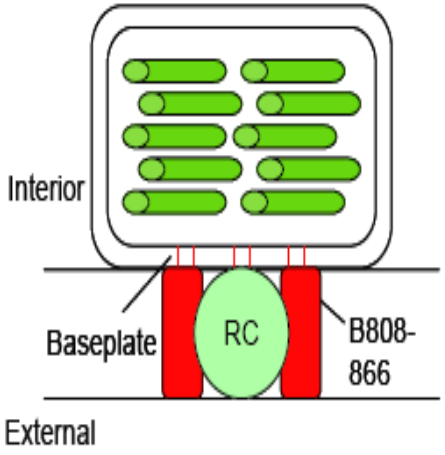
There is significant synergy across thrusts in the approach to the Energy Transfer Grand Challenge



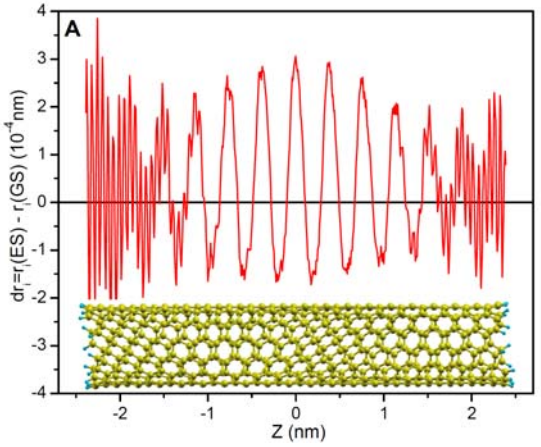
Nanophotonics: **Carrier multiplication in quantum wires and epitaxial QDs.**



Nanosytems: **Efficient separation and transport of electrons and holes in core-shell nanowires.**



Soft/Bio: **Assemblies of synthetic light-harvesting nanomaterials.**



Theory & Simulation: **The description of these processes at the quantum and molecular level.**

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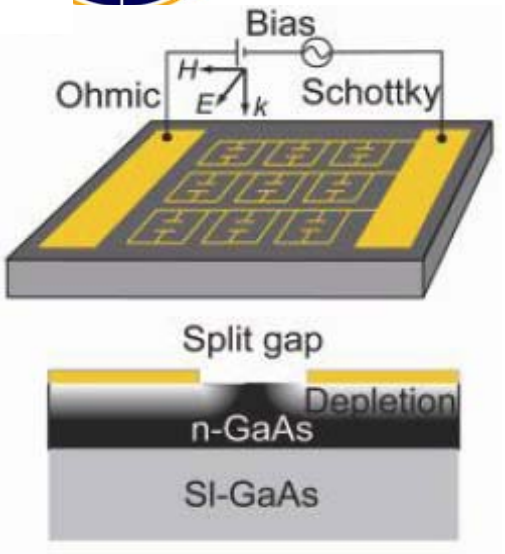
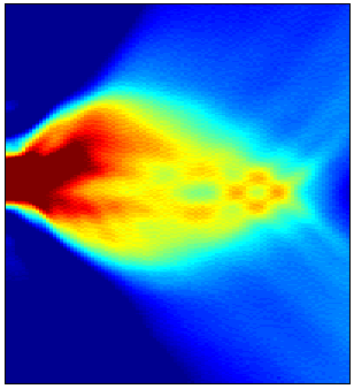
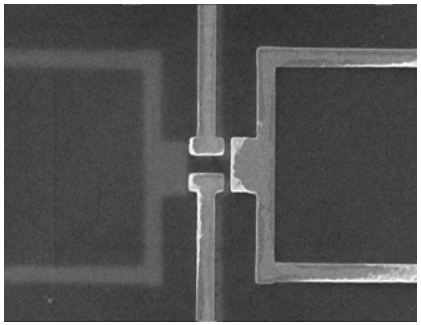
The CINT thrusts approach the Emergent Properties Grand Challenge in diverse ways

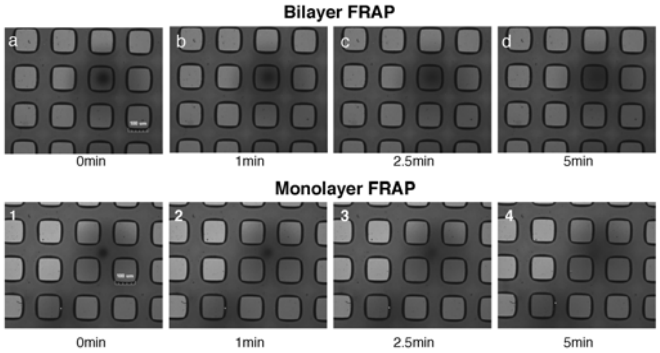


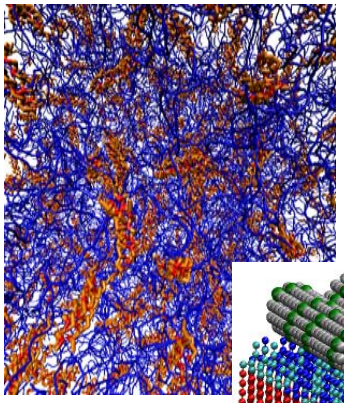
Nanophotonics: **Active electromagnetic metamaterials**

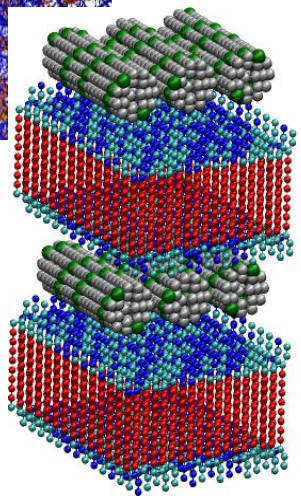


Nanosystems: **Collective phenomena in 2D electron gases**









Theory & Simulation: **Electronic phase separation, protein folding, magnetic ordering, nanoscale quasiparticle properties**

***Soft/Bio*: Nanoscale material assemblies that mimic biological functionality**

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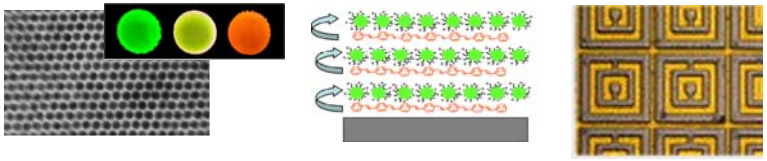
Science Thrusts provide broad expertise

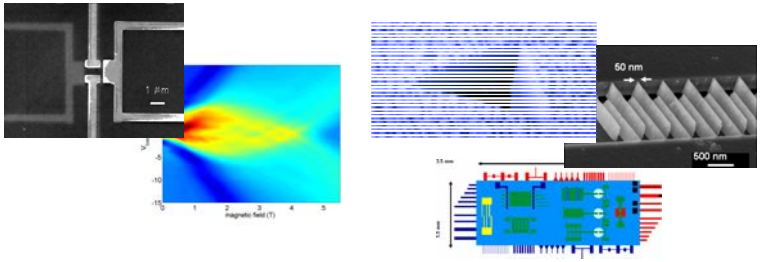
Nanophotonics & Optical Nanomaterials

Synthesis, excitation and energy transformations of optically active nanomaterials and collective or emergent electromagnetic phenomena (plasmonics, metamaterials, photonic lattices)



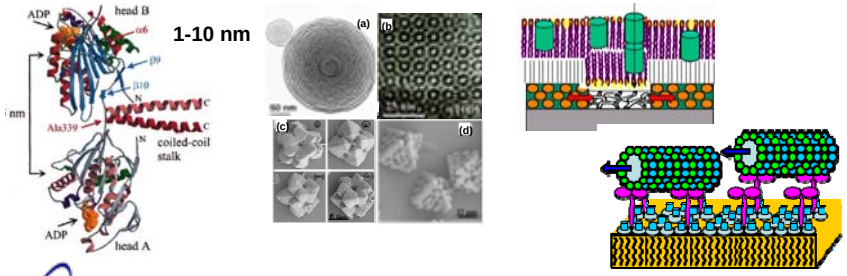
Nanoscale Electronics, Mechanics & Systems

Control of electronic transport and wavefunctions, and mechanical coupling and properties using nanomaterials and integrated nanosystems



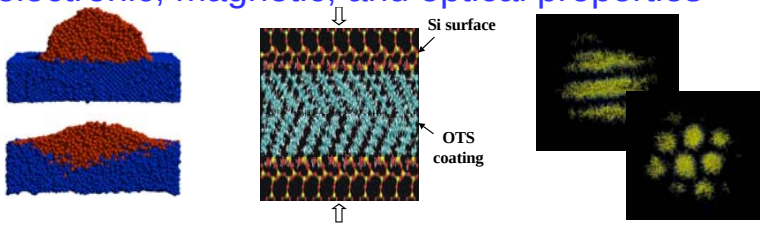
Soft, Biological, & Composite Nanomaterials

Solution-based materials synthesis and assembly of soft, composite and artificial bio-mimetic nanosystems



Theory & Simulation of Nanoscale Phenomena

Assembly, interfacial interactions, and emergent properties of nanoscale systems, including their electronic, magnetic, and optical properties



Discovery Platforms: Unique User Capabilities For Nanomaterials Research

Discovery Platforms = "chips" that allow Users to:

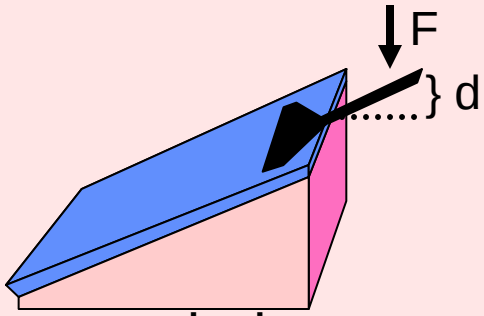
•Stimulate

•Interrogate

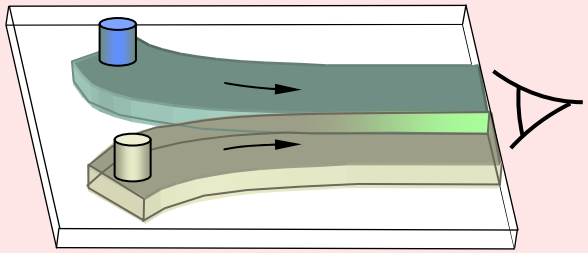
•Exploit

nanomaterials in microsystem environments

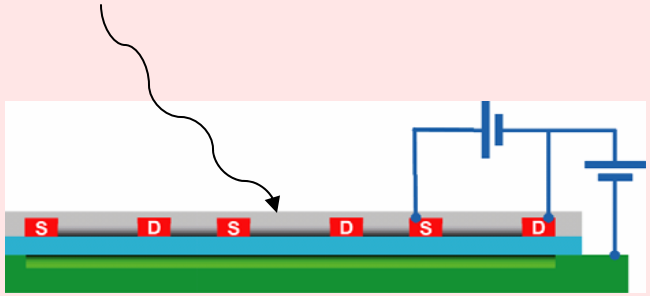
CINT provides the platforms



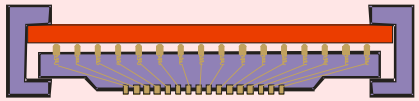
nanomechanics



microfluidics



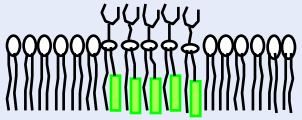
optical, transport

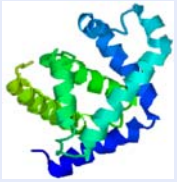


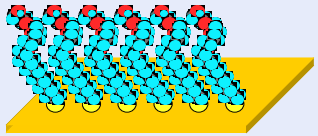
CINT instrument

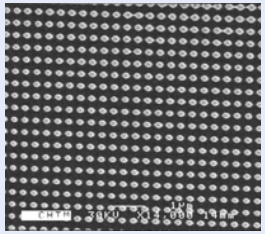
packaging

Users provide the materials









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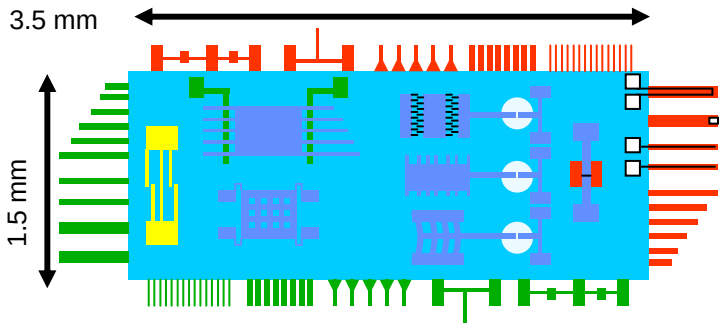
Discovery Platforms™ are available for experiments

These platforms will evolve, based on CINT scientist and user input.

Cantilever Array Platform

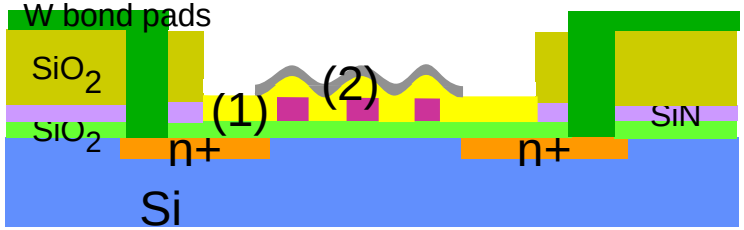


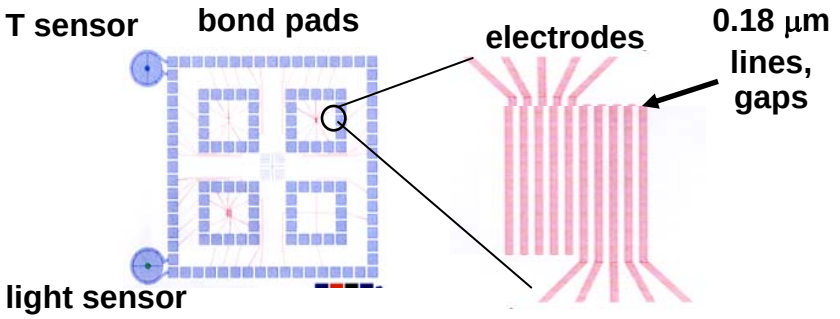
Electrical Transport & Optical Spectroscopy Platform

Ver. 2 for Quantum computing

Post processing:

n+ polysilicon gates define by EBL & RIE





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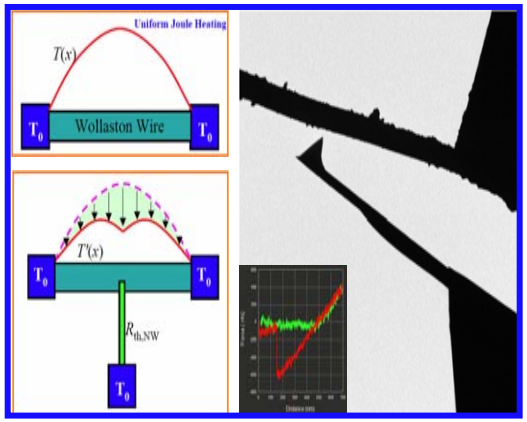
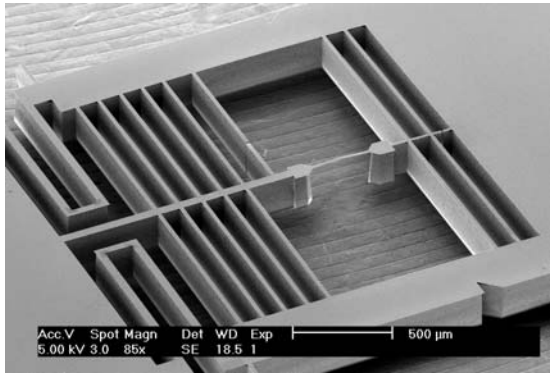
New instrumentation is essential for progress in nanoscience integration

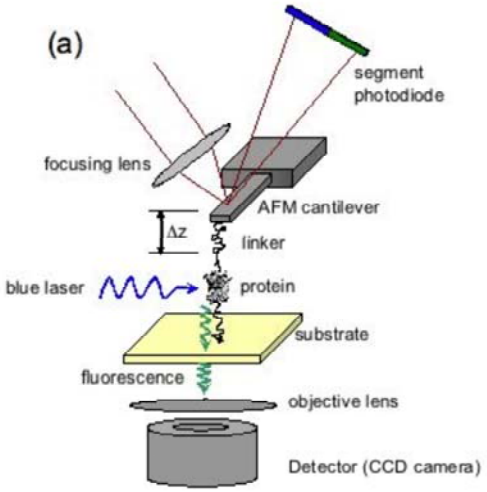
TEM/SPM

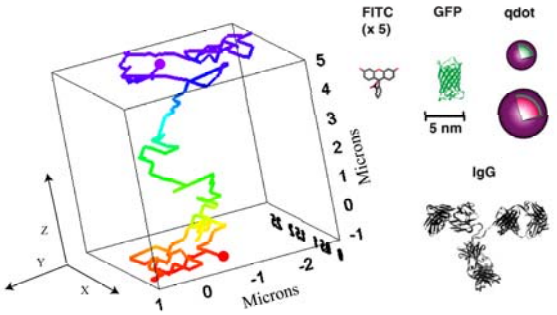


In situ tensile tester

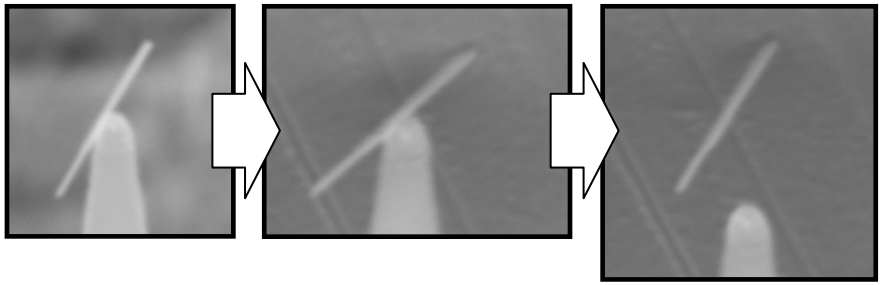


Single protein force spectroscopy





3D single particle tracking



Nanomanipulation for placement of nanostructures

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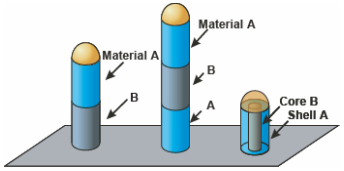
Nanowires—Synthesis, Integration & Applications

Semiconductor nanowires will enable previously unattainable control of electronic properties for integrated nanosystems

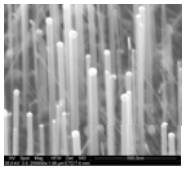
Tom Picraux (LANL), Sean Hearne, Alec Talin (SNL)

Si, Ge and Si/Ge heterostructure growth

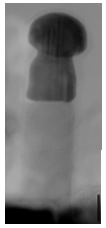
CVD NW growth with in situ doping



Ge NWs

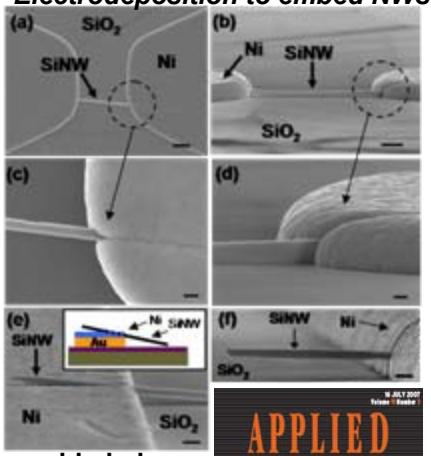


Si/Ge axial heterostructured NW

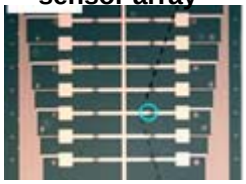


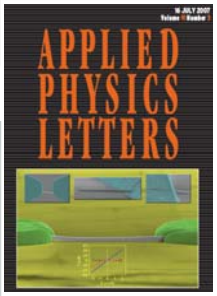
Integration by directed assembly

Electrodeposition to embed NWs



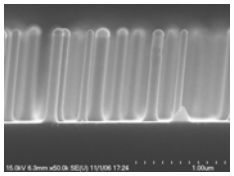
Assembled planar sensor array

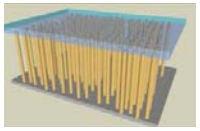


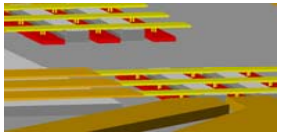


Vertical arrays

Crossbar architecture for high density electronics & sensing

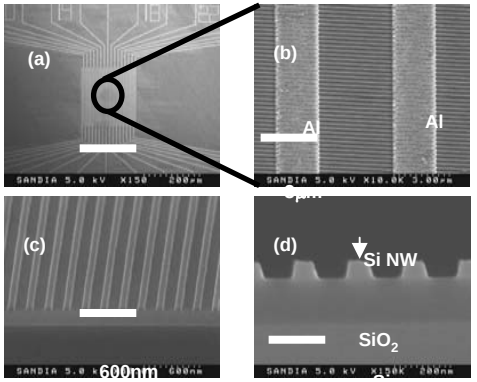




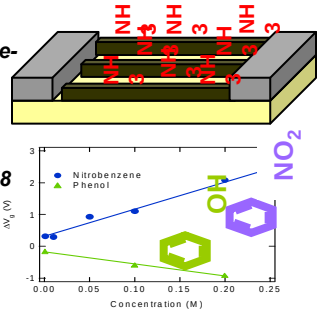


Nanowire sensing

Nanoimprint-formed Si NWs



ΔV_g is proportional to e-donating/withdraing character of analyte molecules (Hammett parameter – σ_p)
Nitrobenzene, σ_p = 0.78
Phenol σ_p = -0.37;



Future impact

- **National security: ultra sensitive chem/bio sensors; low power electronics**
- **Energy applications: high efficiency thermoelectrics**
- **Industrial competitiveness: future nanoscale electronic and photonic devices**

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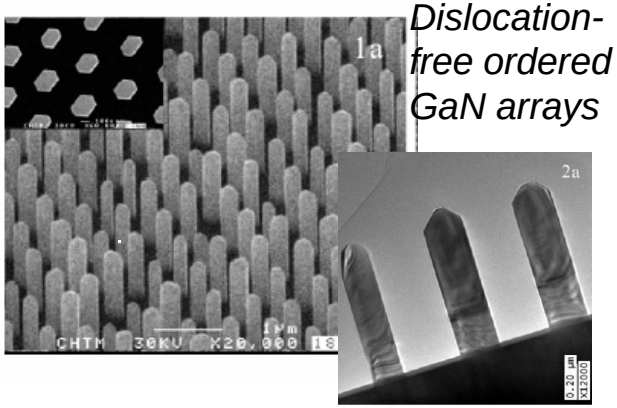
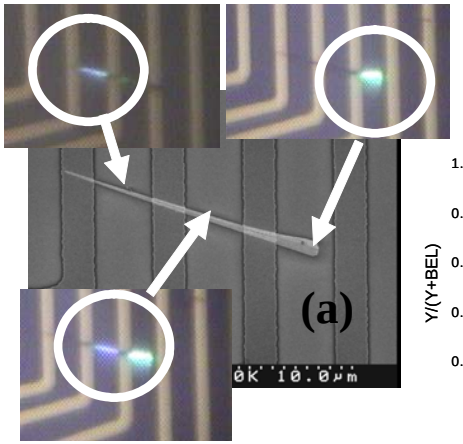
NNEDC Project: Nano-electronics and photonics for the 21st Century

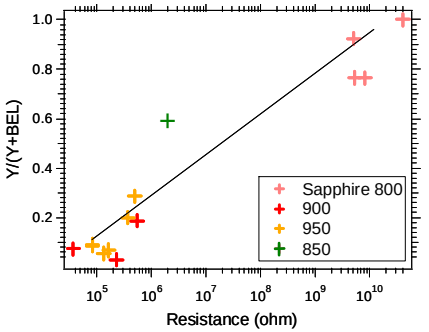
A. Talin

Ordered growth and integration

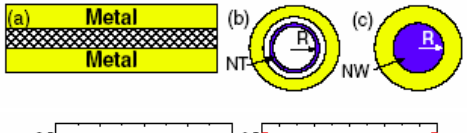


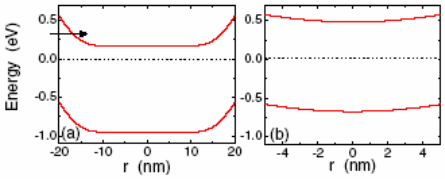
Dislocation-free ordered GaN arrays



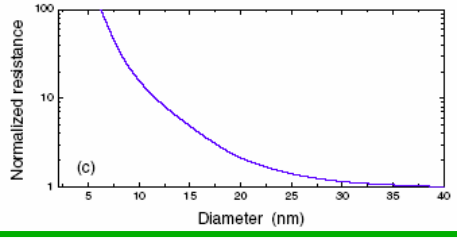


GaN and Ge NW devices for electrical/optical characterization





modeling contact resistance in nanotubes and nanowires



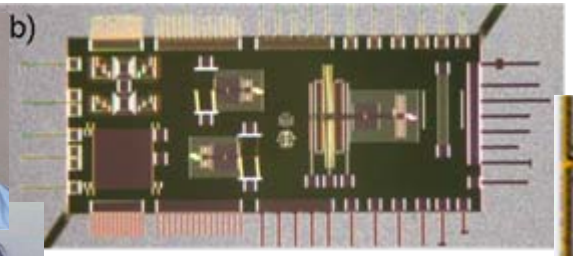
Leonard & Talin, PRL 97, 2006

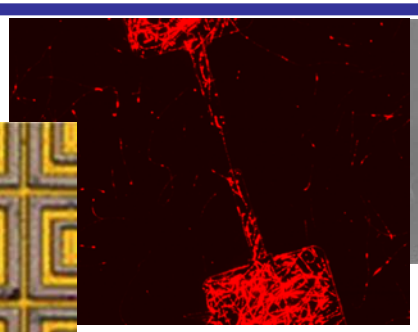
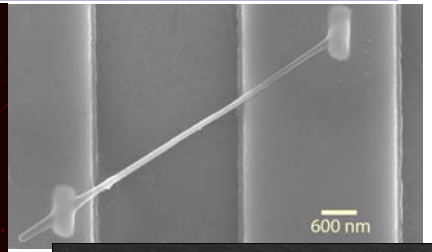
State-of-the-art fabrication, test, and modeling of nanodevices

Nanoscale circuit simulation

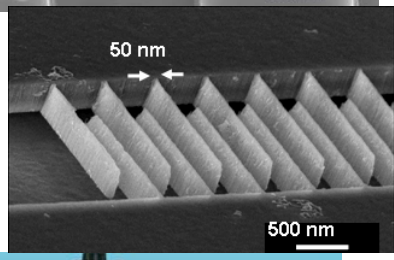
CINT will play a leading role in nanoscience integration

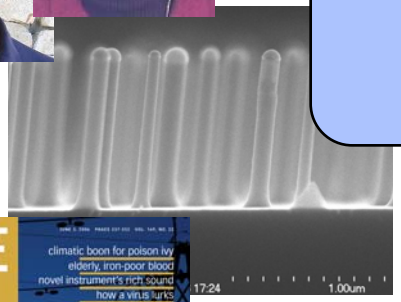










Nanoscience Integration

Users
Outreach
Partnering

Science Thrusts
Grand Challenges
New Tools

SNL/LANL
Capabilities
And Programs

Los Alamos NATIONAL LABORATORY
Sandia National Laboratories