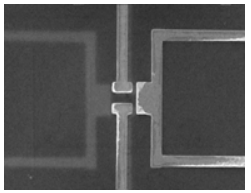
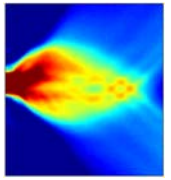
Nanoscale Electronics, Mechanics, and Systems (NEMS)

Thrust Leaders: Mike Lilly (SNL), Mike Nastasi (LANL)

Thrust Focus: Electronic and mechanical properties of nanosystems and issues related to integration of a wide variety of nanoscale materials.

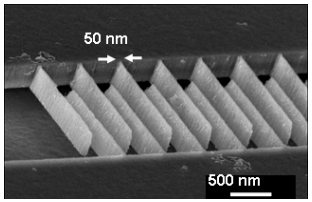


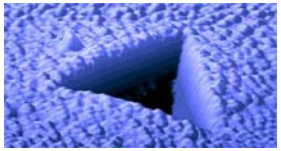


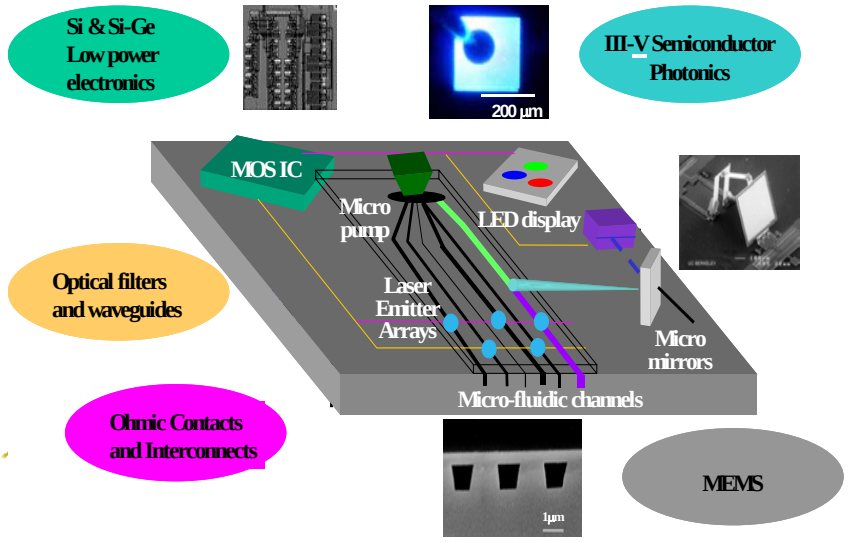
Scientific directions:

- **Control of electronic transport and wavefunctions using nanostructured materials**

- **Mechanical properties and coupling of nanostructured materials**







- **Exploration of new ways to integrate diverse classes of functional materials on the nanoscale**

Sandia National Laboratories

NEMS Thrust: Research

Ongoing research includes:

- plastic deformation, elastic and fracture properties on the nanoscale
- coherent transport and interactions of low dimensional systems
- coupled mechanical systems
- coupling of mechanical and electronic properties
- structural and electronic properties of nanowires
- investigation of materials interface properties

This research will be strongly supported by an effort in *nanofabrication* with an emphasis on *integration* of electrical and mechanical systems in addition to integration with composite nanomaterials and biological systems.

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

NEMS Thrust: Tools and Capabilities

Unique tools in this thrust include:

- molecular beam epitaxial growth of semiconductor heterostructures
- high current state of the art ion implanter
- new tools for nano-manipulation,
- *in situ* STM/TEM
- specialized growth techniques for films, nanowires and other nanostructures.

Discovery Platforms™

- The Cantilever Array Platform will provide mechanical tools optimized for nanoscience experiments.
- The Electrical Transport and Optical Spectroscopy Platform will enable reliable, high throughput electrical and optical measurements compatible with CINT fabrication and characterization equipment.

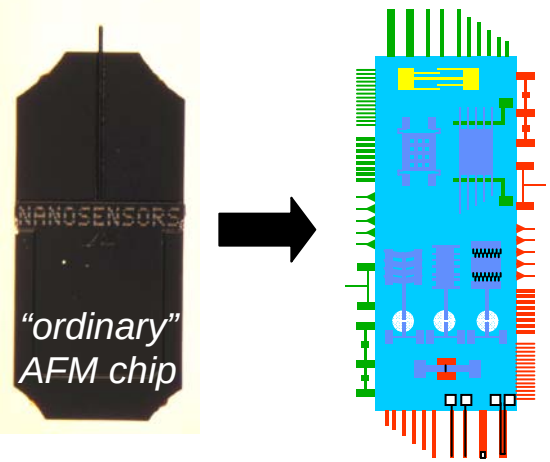
Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

Cantilever Array Platform

GOAL:

Provide a “simple” mechanics-based Discovery Platform™ that would enable users to readily perform experiments in nanomechanics, biomechanics, scanning probe microscopy, sensing, physics of coupled systems, etc.



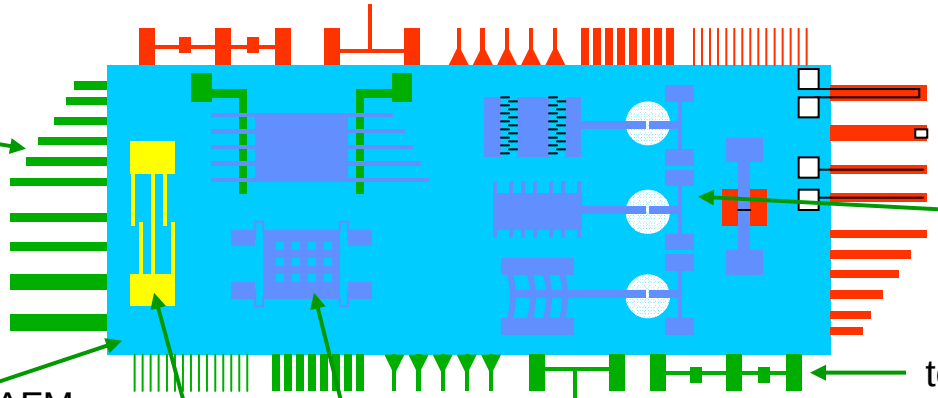
outside edges rimmed with cantilevers

inside there are a variety of structures, including MEMS

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

Cantilever Array Platform - Design



poly-Si beams of different force constant for AFM

Si nitride beams for scanning thermometry, etc.

load cells for nano-mechanics studies

torsional oscillators

probes of in-plane force

platform is the size of an AFM chip (compatible with AFM's)

SiO_2 sacrificial structures

structures for magnetization studies

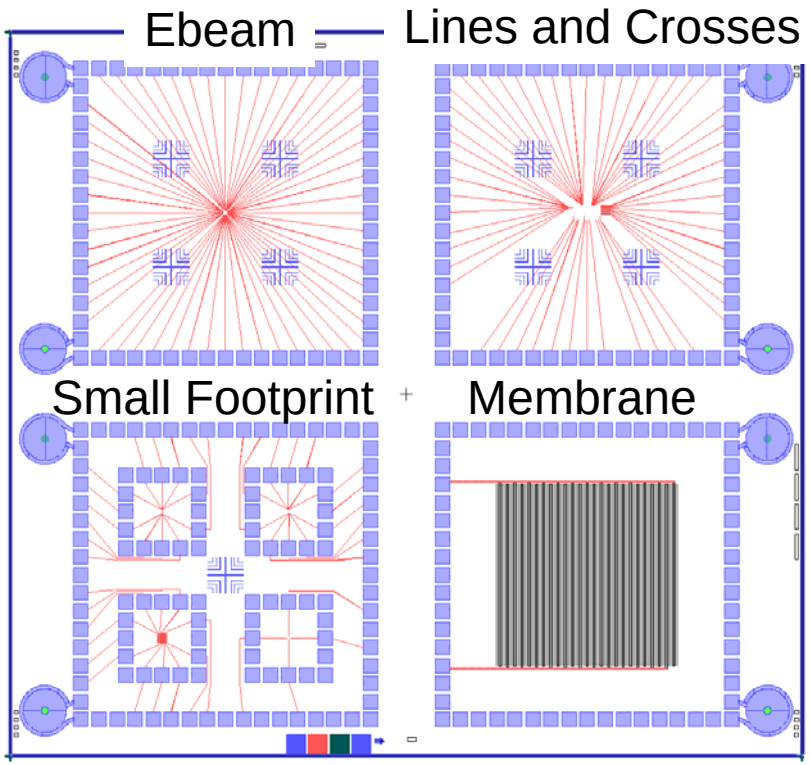
cantilever arrays for sensors, coupled oscillator physics, nanomechanics

Los Alamos NATIONAL LABORATORY

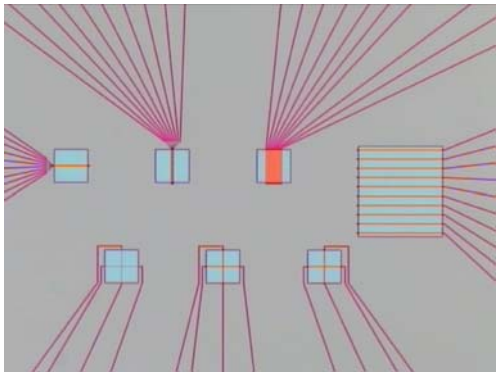
Sandia National Laboratories

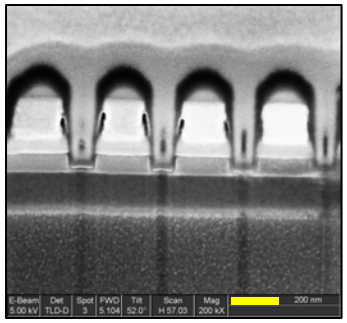
CINT Optics & Transport Discovery Platform

This platform will enable fundamental investigations of the electronic, optical, and transport properties of a wide variety of nanomaterials

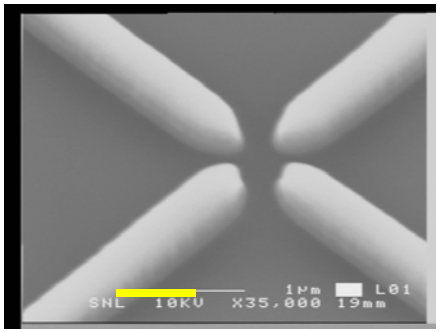


Feature sizes:
0.18 μm
0.35 μm
2.5 μm
25 μm





200 nm



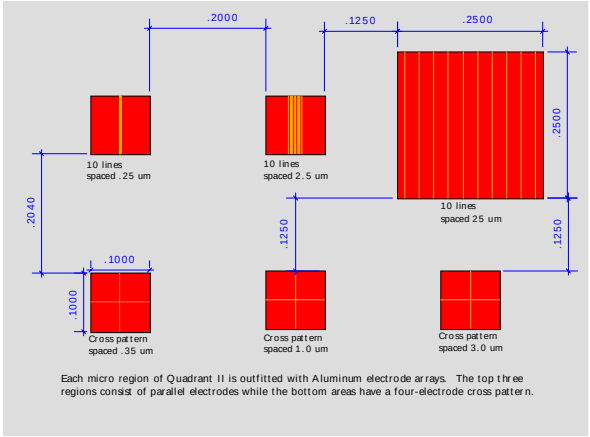
500 nm

Los Alamos NATIONAL LABORATORY

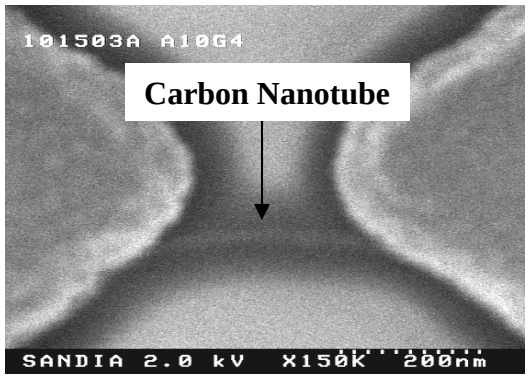
Sandia National Laboratories

Optics and Transport Platform - Examples

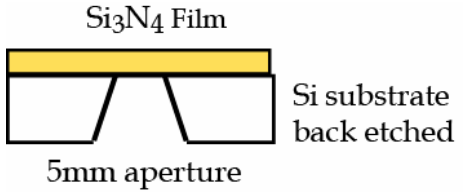
Disperse nanomaterials across electrode region



Alec Talin, Sandia

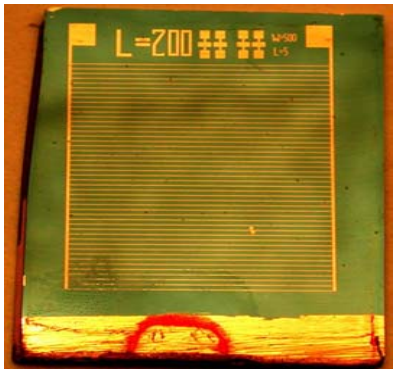


Bottom contact FET for spectroscopy in complex materials



- Use SiN window quadrant
- Perform additional processing
- Coat with material of interest

D. Basov, UCSD



Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

NEMS Scientific Members

- **Mike Lilly (SNL)-Thrust Leader.** Nanoelectronics, with emphasis on the role of interactions in coupled nanoelectronic structures and 2D bilayers, coherent electronic effects in nanostructures, 2D electron physics, the quantum Hall effects, transport in quantum wires, single photon detectors and quantum computing.
- **Mike Nastasi (LANL)-Thrust Leader.** Nanomechanics and nanostructured functional materials with an emphasis on synthesis, modeling, theory, and experiment, developing a fundamental understanding of how stresses evolve from atoms residing at surfaces and interfaces in nanostructured materials, how these stresses promote unique and novel mechanical, electronic, and magnetic properties.
- **Elshan Akhadov (LANL)-Integration Lab Co-Manager**. Integration and miniaturization with an emphasis on micro- and nanoscale device fabrication.
- **David M. Follstaedt (SNL).** Understanding the deformation and mechanical properties of metals with highly refined nanostructures
- **Sean Hearne (SNL)- Integration Lab Manager**. Understanding the mechanical response of nano-materials to applied loads and the sources inducing intrinsic stress in nano-materials and the integration of nano-enabled components into micro-devices.
- **Jianyu Huang (SNL).** *In situ* electron microscopy of nanostructured materials, with emphasis on conducting integrated studies on the microstructure and electrical, mechanical, and thermal properties of individual nanostructures, such as carbon nanotubes, nanowires, and other bulk nanostructured materials.
- **Quanxi Jia (LANL).** Complex functional materials, with an emphasis on multiferroic nanocomposite metal-oxide films, nanostructured multilayer structures, and their derived novel devices
- **Amit Misra (LANL).** Nanomechanics, with emphasis on fundamental understanding of the mechanical response of nanoscale and nano-composite materials, strain-derived new atomic arrangements at interfaces and novel physical behavior of nanoscale materials.

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

NEMS Scientific Members

- **S. Thomas Picraux (LANL).** Nanostructured electronic materials, with an emphasis on the synthesis, characterization and properties of semiconducting nanowires, as well as their integration into microscale systems
- **John Reno (SNL)**. Nanostructured electronic materials, with an emphasis on the synthesis of AlGaAs based materials
- **John P. Sullivan (SNL).** Nanomechanics, including the synthesis and characterization of micro- and nanomechanical structures for the study of phenomena associated with the motion, displacement, or vibration of structures, defect-controlled internal dissipation in resonant mechanical structures, sensing and probing using mechanical structures, the coupling of mechanical structures to each other and with electrical and optical systems, and phonon transport at small length scales
- **J. Greg Swadener (LANL).** Nanomechanics, studying aspects of nanoscale deformation not present in the bulk including, length scales, dislocation and twin bursts, atomic scale fracture, the relationship between bone hierachal nanostructure and mechanical properties and the relation between membrane mechanical properties and cell functions
- **Brian Swartzentruber (SNL).** Kinetics and thermodynamics of nanoscale structures with an emphasis on obtaining a fundamental understanding of mass transport processes and the stability of nanostructures, and developing novel implementations of scanning-probe-like instruments for direct and precise nanomanipulation for top-down construction of unique nanostructures, for 3d-electronics, sensor, and ‘NEMS’ applications.
- **A. Alec Talin (SNL).** Nanofabrication, integration, and materials/device characterization, using both traditional and emerging techniques, such as nanoimprint lithography, for directed growth of nanostructures, and a range of electrical and optical characterization tools to link synthesis with performance.

Los Alamos NATIONAL LABORATORY

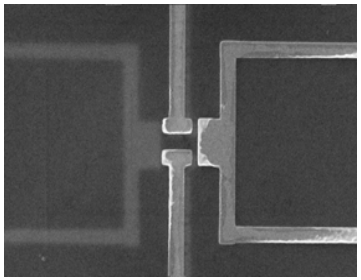
Sandia National Laboratories

Mike Lilly (SNL)-Thrust Leader. Nanoelectronics, with emphasis on the role of interactions in coupled nanoelectronic structures and 2D bilayers, coherent electronic effects in nanostructures, 2D electron physics, the quantum Hall effects, transport in quantum wires, single photon detectors and quantum computing.

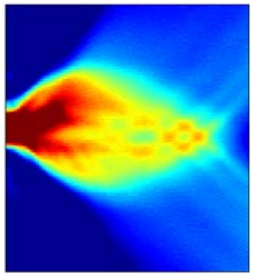
Quantum Transport and Single Electron Physics

CINT Science

SEM of a double quantum wire in a GaAs bilayer



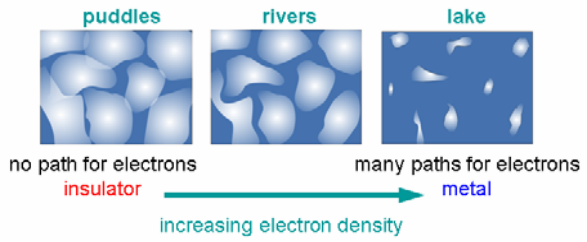
1D Spectroscopy



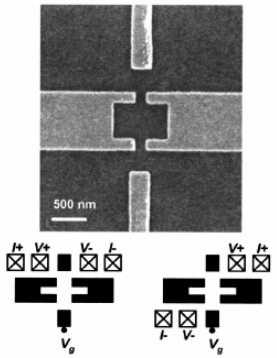
- Coherent transport in double wires
- Single electron charge and spin measurements
- Quantum dots with integrated charge detectors for quantum computing

User Projects

Percolation in dilute 2D electrons with Sankar Das Sarma (University of Marland)



Coupled nanoelectronics with Jon Bird (SUNY Buffalo)



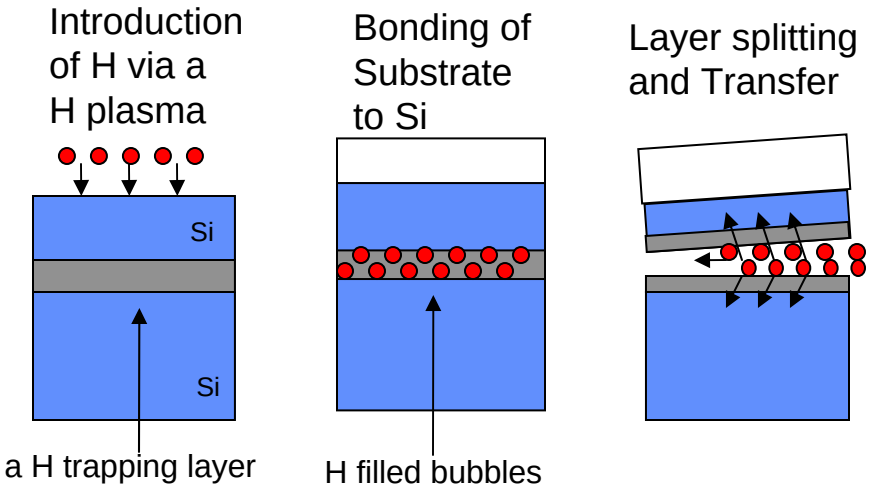
- Many-body physics in low dimensional electron systems
- Quantum wire charge detectors
- Advanced GaAs heterostructures (2D electrons, bilayers, novel devices)

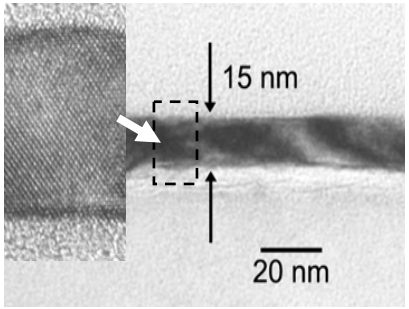
Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

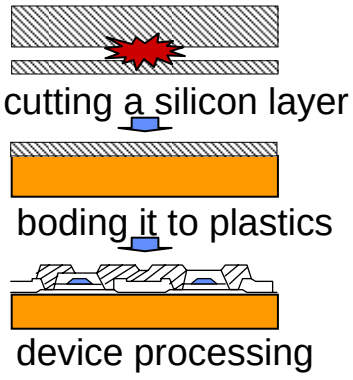
Mike Nastasi (LANL)-Thrust Leader. Nanomechanics and nanostructured functional materials, developing a fundamental understanding of how stresses evolve from atoms residing at surfaces and interfaces and how these stresses promote unique and novel mechanical, electronic, and magnetic properties.

Integration of Single Crystalline Si Nanolayers

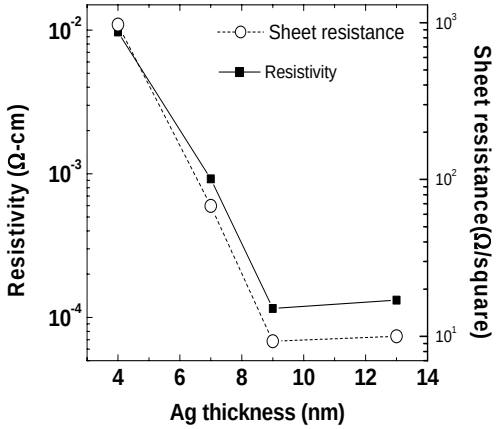




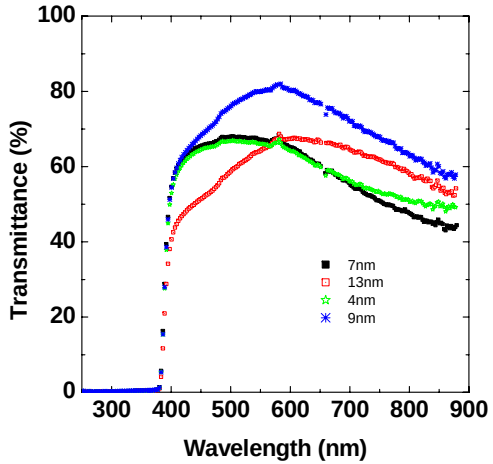
The lift-off of a high-quality defect-free Si layer of less than 20 nm,



Metal Nanoparticle Carrier Injection in TCO
(in collaboration with T. Alford, ASU)



Electrical resistivity and sheet resistance as function of Ag thicknesses in ZnO



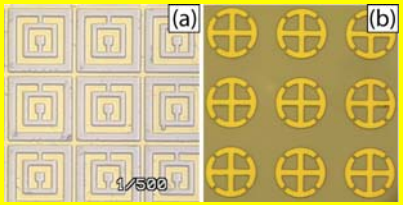
ZnO transmittance as function of Ag thicknesses in the visible region.

Sandia National Laboratories

Elshan Akhadov (LANL)- Integration Lab Co-Manager. Integration and miniaturization with an emphasis on micro- and nanoscale device fabrication.

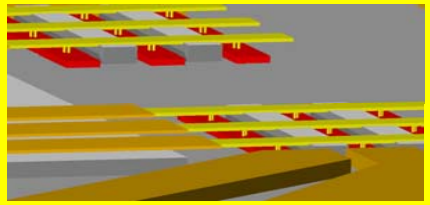
Metamaterials:

Understand metamaterials to build functional devices



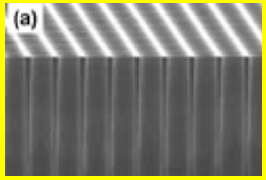
Integration of Si nanowires into functional devices:

Integrate Vertical and horizontal nanowires into devices



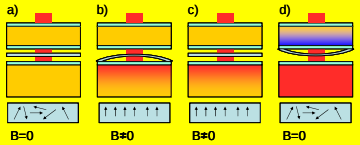
High Dielectric Strength MicroCapacitors:

Investigate polymer blends' electric properties for high dielectric strength capacitors.



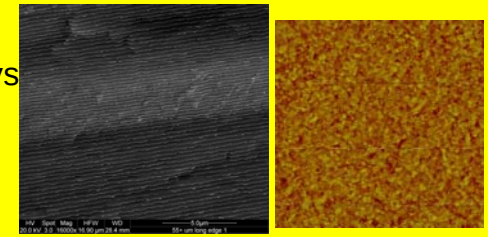
Solid state cooling:

Fabricate miniature solid-state cooler using magneto-, electro -calorics and Peltier devices



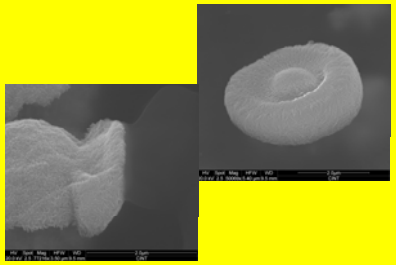
Gamma Ray Optics:

Manipulate Gamma rays using multilayered structures



In-situ metal growth:

Understand growth of nanostructured metal clusters using environmental SEM for in-situ process monitoring.

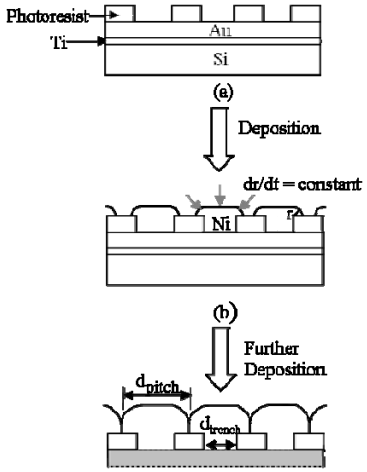


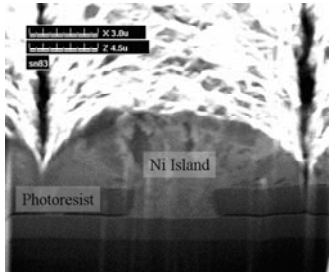
Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

Sean J. Hearne (SNL)-Integration Lab Manager: Understanding the mechanical response of nano-materials to applied loads, the sources inducing intrinsic stress, in nano-materials, and the integration of nano-enabled components into micro-devices.

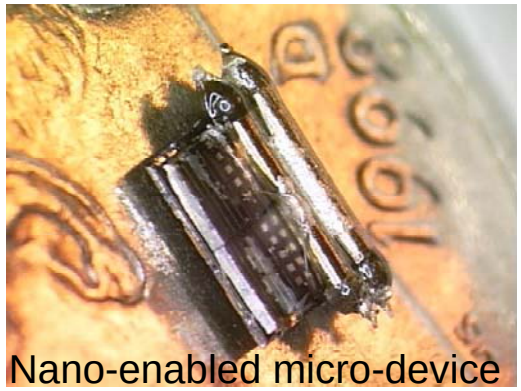
Intrinsic stress



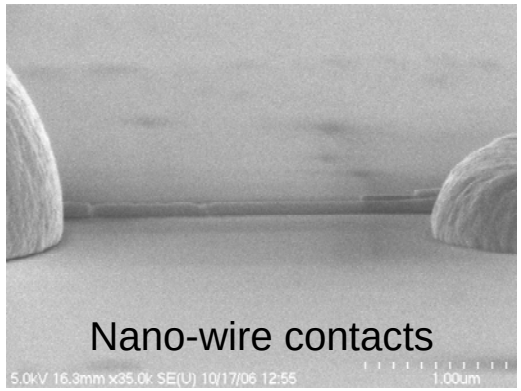


Stress measurements during thin film growth.

Integration

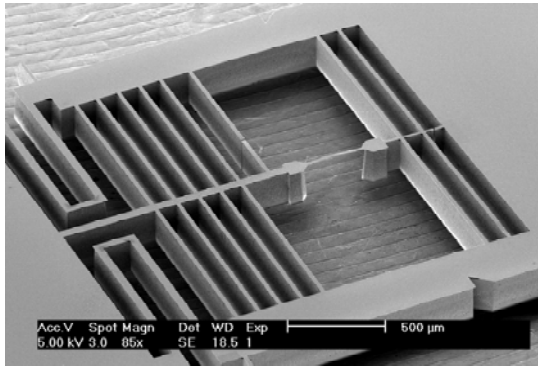


Nano-enabled micro-device



Nano-wire contacts

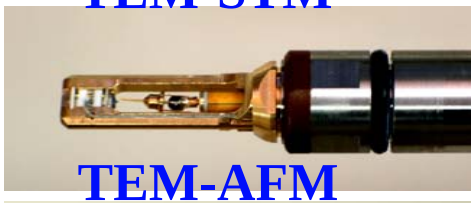
Applied stress



Tensile testing in situ of a TEM.

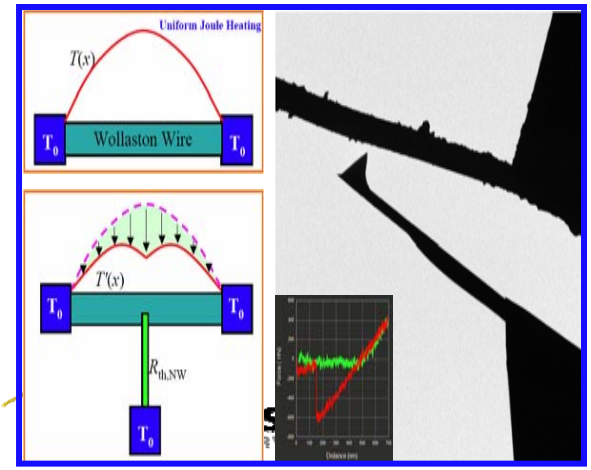
Jianyu Huang (SNL). *In situ* electron microscopy of nanostructured materials, with emphasis on conducting integrated studies on the microstructure and electrical, mechanical, and thermal properties of individual nanostructures, such as carbon nanotubes, nanowires, and other bulk nanostructured materials.

TEM-STM



TEM-AFM

TEM-Indentor



In-Situ Structure and Property Correlation of Nanostructured Materials by Using a TEM-SPM Platform

- **Set up a TEM-SPM platform for in-situ nanomechanics and nanoelectronics studies.**
- **Develop a TEM-SPM platform for in-situ thermal property studies.**
- **High temperature deformation mechanisms and strength of carbon nanotubes.**
- **Deformation and strengthening mechanisms in Au, Si nanowires.**
- **Thermal and thermal electric property of Bi, BiSb nanowires.**
- **Creating an *in-situ* electron microscopy center for simultaneous structure and property studies of nanostructured materials.**

Sandia National Laboratories

Quanxi Jia (LANL). Complex functional materials, with an emphasis on multiferroic nanocomposite metal-oxide films, nanostructured multilayer structures, and their derived novel devices

- To grow nanocomposite and nanostructured metal-oxide films using pulsed laser deposition (PLD). Examples of metal-oxides include, but not limited to, insulating, dielectric, semiconductive, ferroelectric, ferromagnetic, piezoelectric, multiferroic, metallic, and superconductive materials.

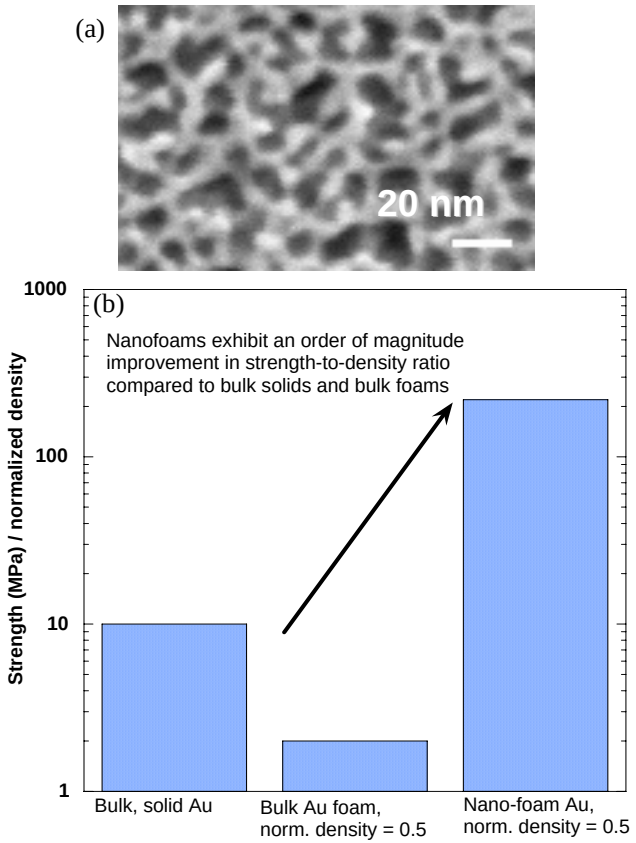
- To tune the physical properties of nanocomposite metal-oxide films through strain engineering

- To study the fundamental mechanisms of the lattice-strain and size effect on the properties of nanocomposite metal-oxide films

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

Amit Misra (LANL). Nanomechanics, with emphasis on fundamental understanding of the mechanical response of nanoscale and nano-composite materials, strain-derived new atomic arrangements at interfaces and novel physical behavior of nanoscale materials



(a) SEM micrograph of a Pt nano-foam;
(b) Histogram showing the significant increasing in strength of a nano-foam compared to bulk foam and solid bulk metal.

Mechanics of Nanoscale Materials

•Mechanical behavior of as-synthesized and ion -irradiated noble metal nano-foams.

• Exploration of the energy dissipation mechanisms in high surface (or interface) area-to-volume ratio materials.

Los Alamos NATIONAL LABORATORY

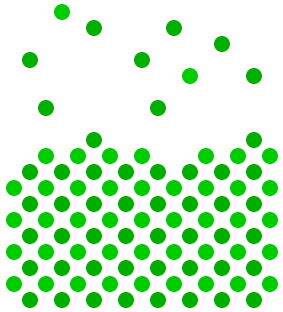
Sandia National Laboratories

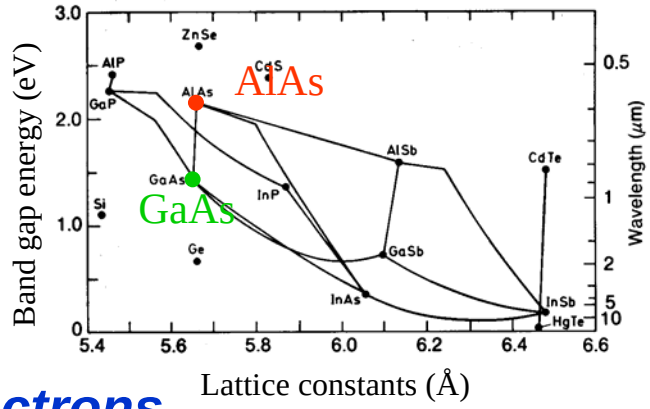
S. Thomas Picraux (LANL). Nanostructured electronic materials, with an emphasis on the synthesis, characterization and properties of semiconducting nanowires, as well as their integration into microscale systems

John Reno (SNL). Nanostructured electronic materials, with an emphasis on the synthesis of AlGaAs based materials

GaAs heterostructures for nanoelectronics and optics

- 2D electrons
- Double quantum wells and multi-layered structures
- Quantum cascade lasers

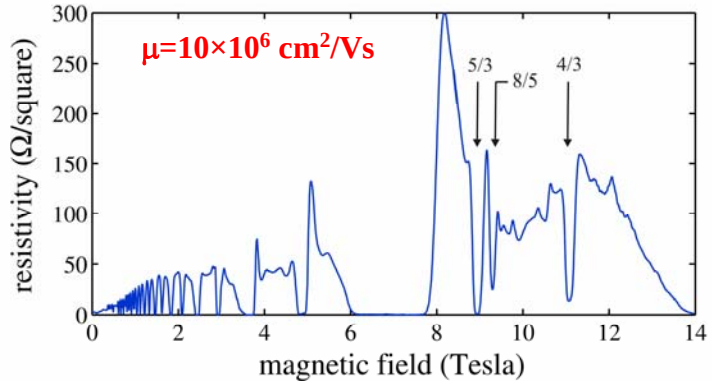




High mobility 2D electrons

Length scales at low temperature

Quantum interference: 100 um
Ballistic transport: 10 um
Size quantization: ~ 500 Å



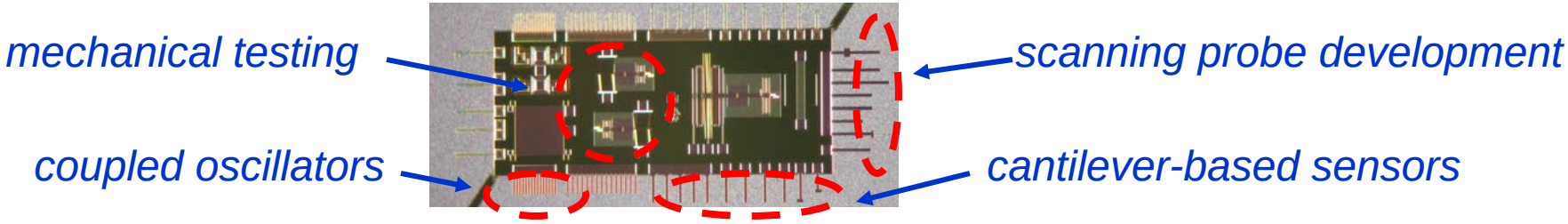
Material enables science: interaction studies, coherence in nanoelectronics and engineered properties.

Los Alamos NATIONAL LABORATORY

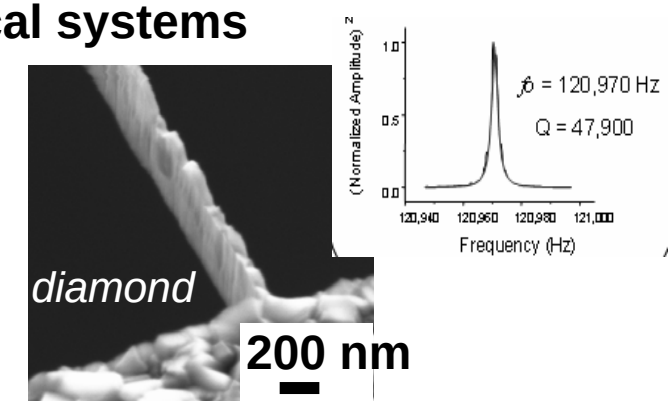
Sandia National Laboratories

John P. Sullivan (SNL). Nanomechanics, synthesis and characterization of micro- and nanomechanical structures, the study of phenomena associated with motion, displacement, or vibration of structures, defect-controlled internal dissipation in resonant mechanical structures, coupling of mechanical structures to each other and with electrical and optical systems, and phonon transport at small length scales

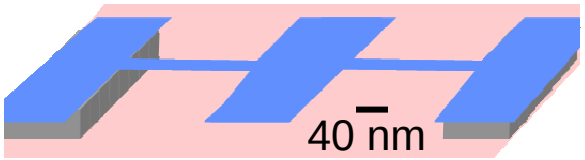
- **Micromechanical platform for nanomechanics, sensing, scanning probe microscopy: Cantilever Array Discovery Platform™**



- **Defect relaxation processes in mechanical systems**
  - ***resonant mechanical systems for internal dissipation***
  - ***internal friction of nanostructured materials***



- **Phonon transport in small systems**
  - ***designing nanosystems for phonon transport studies***



Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

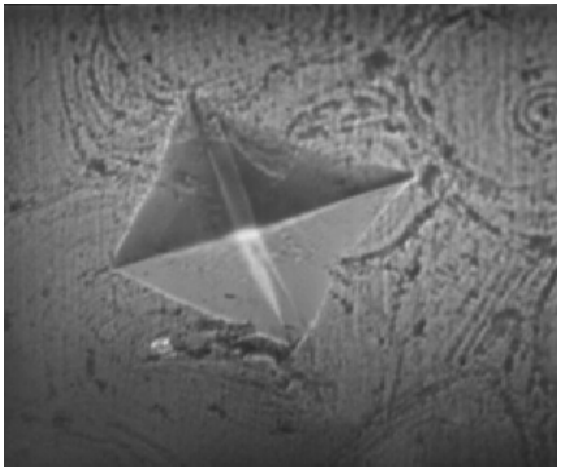
•**Greg Swadener (LANL).** Nanoscale deformation, dislocation and twin bursts, atomic scale fracture, the relationship between bone hierachal nanostructure and mechanical properties and the relation between membrane mechanical properties and cell functions

Deformation in Nanoscale Volumes

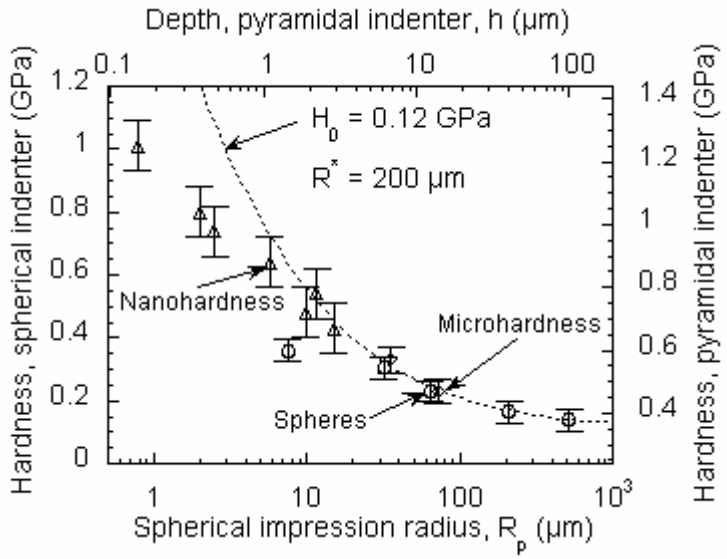
- Determine size effects and length scales
- Explore deformation bursts at the nanoscale
- Develop mechanistic models

Defects and Fracture at the Atomic Scale

- Model dynamic fracture and effects of defects
- Nanocrystal anisotropic elastic and plastic properties
- Model semiconductor nanowire and defect structures



Indentation fracture of cortical bone



Dislocation model of spherical indentation

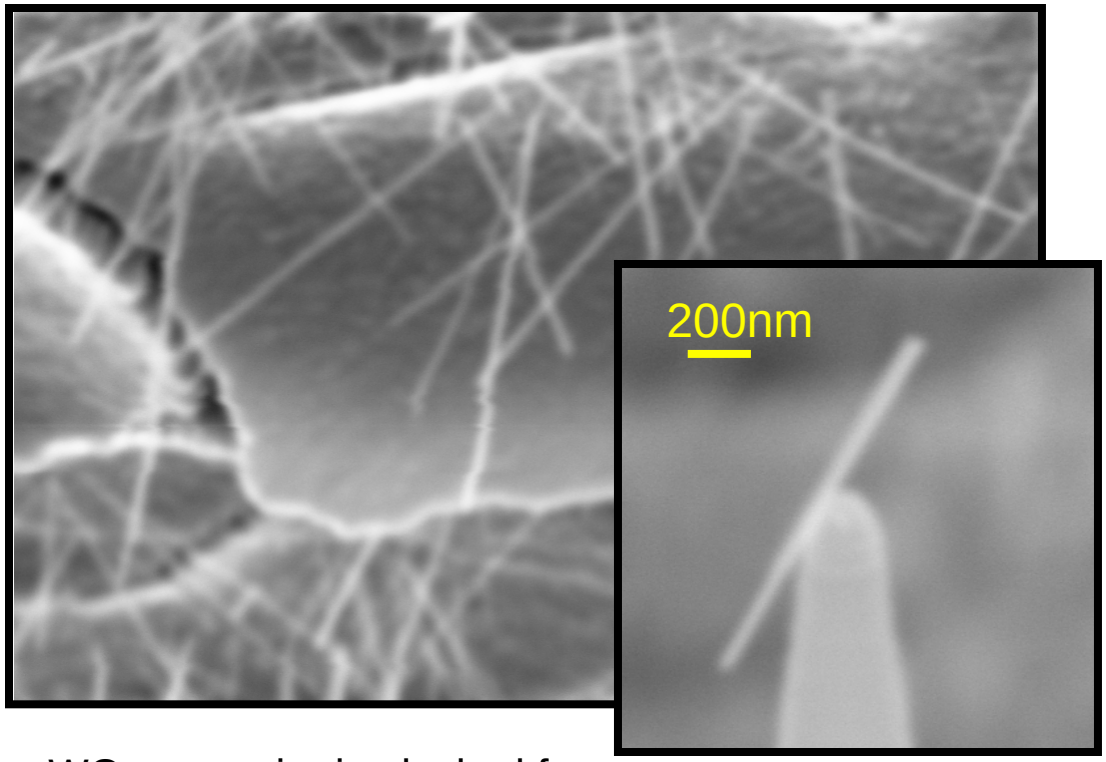
Biomechanics and Biomaterials

- Combine nanoscale indentation and contact mechanics to determine flexibility and adhesive properties of lipid membranes
- Explore relation between properties and membrane functions such as cell/protein interactions and transduction
- Examine relationship between bone hierarchal nanostructure and mechanical properties

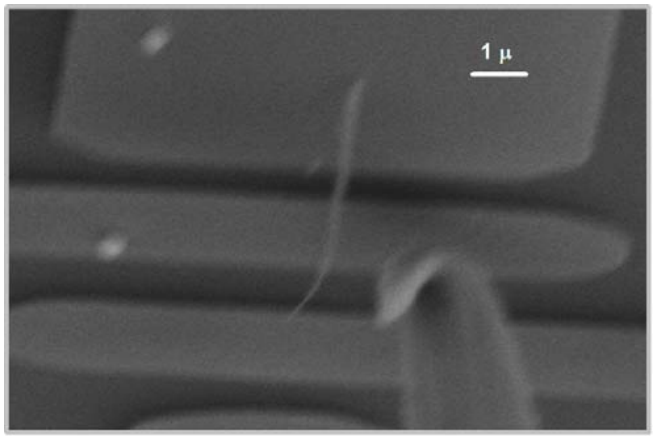
Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

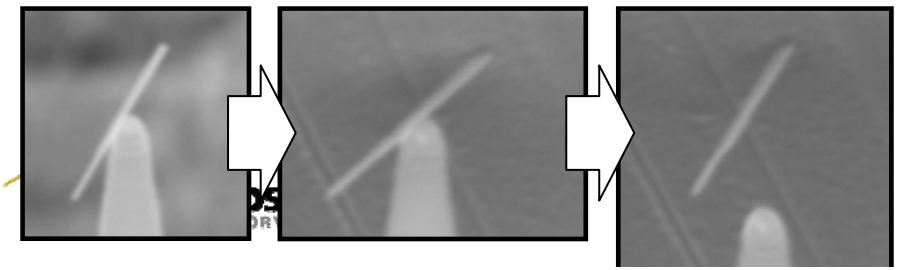
Brian Swartzentruber (SNL). *Kinetics and thermodynamics of nanoscale structures and developing novel implementations of scanning-probe-like instruments for direct and precise nanomanipulation for top-down construction of unique nanostructures, for 3d-electronics, sensor, and 'NEMS' applications*



WO_3 nanowire is plucked from as-grown substrate and placed on gold surface.



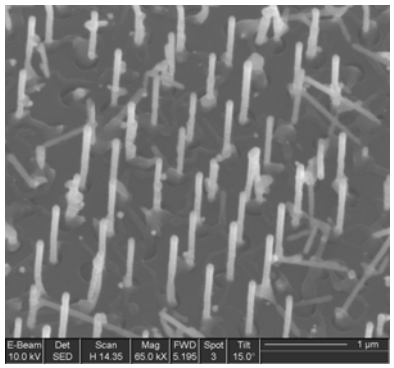
Ge nanowire placed across Au contacts



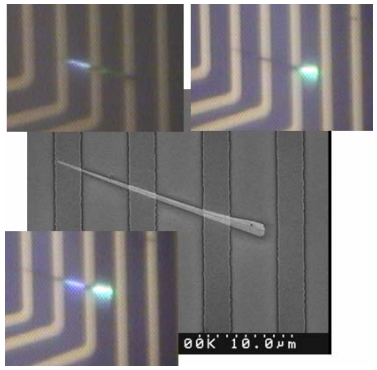
Possibilities: Fabricating novel prototype electronic elements by placing whiskers across lithographically defined gate structures; using the probes as movable gate and contact electrodes; and building unique electronic components from individual nanostructures.

Alec Talin (SNL). Nanofabrication, integration, and materials/device characterization using nanoimprint lithography for directed growth of nanostructures, and a range of electrical and optical characterization tools to link synthesis with performance.

1. Lithography-directed nanowire growth

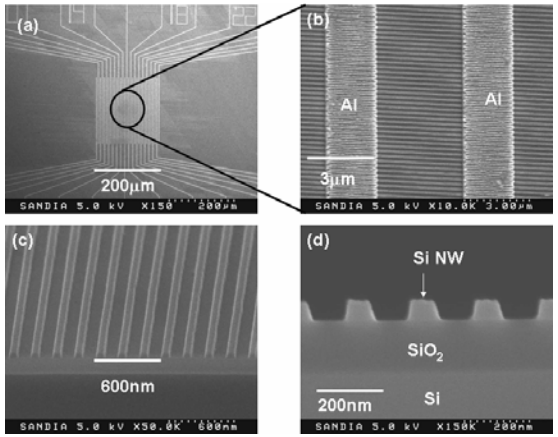


VLS grown Si nanowires in NIL patterned Si/SiO_2 vias with Au catalyst (with P. Yang, Berkeley)



Individual GaN nanowire contacted with top metal electrodes and interrogated with spatially resolved PL (nanowire grown by G. Wang, SNL)

3. Chemical and biological sensing



These NIL defined Si nanowire chemical sensors will be used to evaluate the performance of various functionalization schemes as well as charge transfer on molecular scale

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories