NIST's Center for Nanoscale Science and Technology

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CNST Center for Nanoscale Science & Technology

NIST Visiting Committee, February 5, 2014, Gaithersburg, MD

The Who, What, and How of the CNST

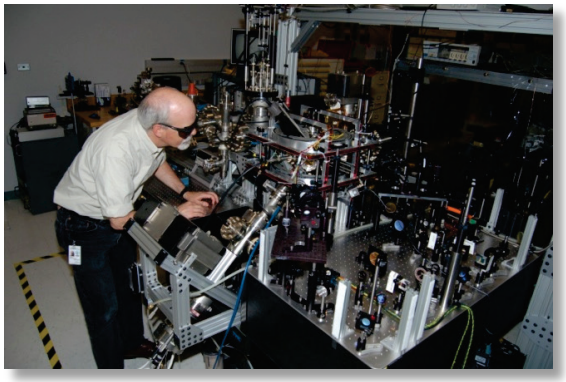
- Who are we?
  - The Center for Nanoscale Science and Technology (CNST) is NIST's nanotechnology user facility.
- What is our mission?
  - We help to enable innovation in nanotechnology by providing rapid access to the tools and processes needed to make and measure nanostructures.
- How do we do it?
  - We:
    - operate a national, shared-use facility for nanoscale fabrication and measurement,
    - develop innovative nanoscale measurement and fabrication capabilities,
    - support researchers from industry, academia, NIST, and other government agencies in nanoscale technology from discovery to production.

The CNST in Brief

- Established in 2007
  - Represents about 1/3 of NIST's total effort in nanotechnology
  - VCAT helped guide its direction and growth
- A User Facility with a unique, two-part, hybrid design
- The **NanoFab** is a shared resource with commercial state-of-the-art tools for nanofabrication, open to all
- The **NanoLab** advances nanotechnology by developing new measurement solutions, and supports the NanoFab with expert consultation
- **Budget**: $32M (FY2013)
- **Staff (Fall 2013)**: 106 (93 technical)
- Cooperative Agreement with the University of Maryland Nanocenter
  - Contributes to all phases of the CNST mission

Like NSF-supported, university nanocenters

Like DOE nanocenters



MARYLAND NANOCENTER

The CNST NanoFab

A national, state-of-the-art, shared resource for the fabrication and measurement of nanostructures:

- 60,000 ft^2 (5600 m^2) of labs and cleanroom
  - 19,000 ft^2 (1800 m^2) cleanroom;
    8,000 ft^2 (750 m^2) at class 100
  - Open (staffed) weekdays from 7 am to midnight
- Leverages the expensive tools needed for nanotechnology through cost sharing (charged "*a la carte*")
  - About 100 major tools, including advanced lithography (e-beam, ASML stepper), microscopy (FE-SEMs, FIBs, TEMs)
- Staffed with talented technical team who train and assist users, operate and maintain the tools, and develop and control the processes
- Connects external researchers to extensive measurement resources in the NIST Laboratories and Centers

We Listened to our Potential Industrial Users

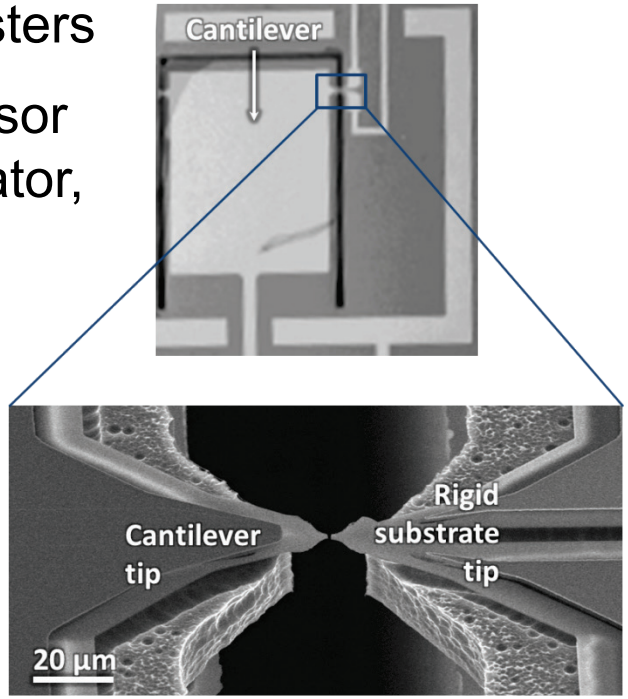
- NanoFab Characteristics Important to Companies
  - Rapid Access
  - Low Barrier to Access
  - Clear and Acceptable Intellectual Property Policies
  - State-of-the-art Equipment
  - Industrial Strength Control of Processes
  - Professional Staff that can:
    - Develop needed processes
    - Provide instruction on new tools
  - Flexible Access Model
    - Work Done by Company Staff
    - Work by NanoFab Staff
    - Work by Third Parties
    - Remote Jobs Submission

Using the CNST NanoFab

- Shared-use operation based on cost-reimbursement
  - Modeled after US National Nanofabrication Infrastructure Network (NNIN) supported by National Science Foundation (NSF)
- Open to all, including **industry**, government, and academia
- Rapid access: application to orientation in a couple of weeks
- Charges based on operating costs, similar to charges at NNIN
- Researchers may apply for reduced rates
  - If project advances CNST mission, rates similar to NNIN-NSF “academic” rates
- The NanoFab will train researchers in tool use
  - Alternatively, work can performed by NanoFab staff, or others, at additional cost
- Users maintain IP rights for sole and joint inventions
- Projects usually begin in a meeting with our NanoFab manager, relevant NanoFab process engineers, and NanoLab researchers.

CNST NanoFab Project Story: Lumedyne

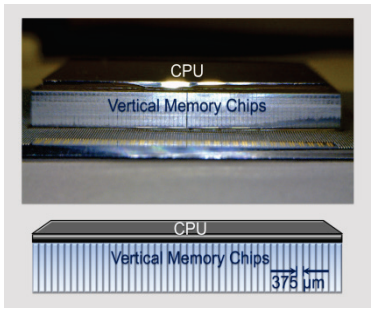
- Lumedyne Technologies: a San Diego-based startup developing high performance MEMS sensors and energy harvesters
- Trying to develop prototype of novel inertial sensor for navigation apps that combines MEMS oscillator, tunnel junction, and CMOS
  - Wafer structure and CMOS fabricated at foundry
  - Prior attempts at tunnel junction fab at both commercial and multiple academic nanofabs were unsuccessful
- Lumedyne met with NanoFab and Nanofabrication Research Group staff:
  - CNST team proposed design change to simplify fab

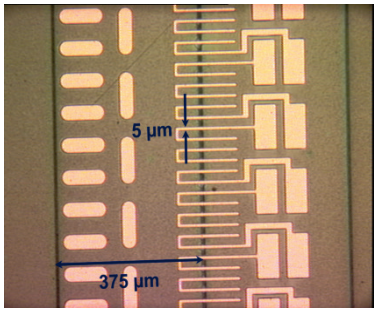


- NanoFab process engineer worked with Lumedyne to develop FIB process to create 10 nm to 40 nm gaps between pre-fabricated tips
  - Additional prototypes being made by NanoFab staff as “remote jobs”
- Plan is to transition gap fab to CMOS process, then incorporate into foundry process for production

CNST NanoFab Project Story: IBM

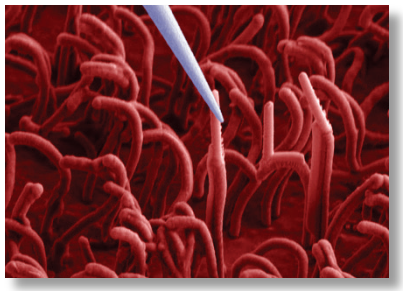
- IBM wanted to develop a process for identifying and correcting device misalignment in multi-wafer assemblies for next-generation supercomputers.
- They located device registration errors using CNST's laser lithography system's pattern recognition capability.
- They developed a process for post-metrology, direct-write lithography to correct for the registration errors in bonded wafer stacks, enabling assembly of a functioning supercomputer system module which attaches a stack of vertical memory chips directly to the CPU.
- They transitioned the process in-house by purchasing customized tools based on experienced gained in the CNST NanoFab.



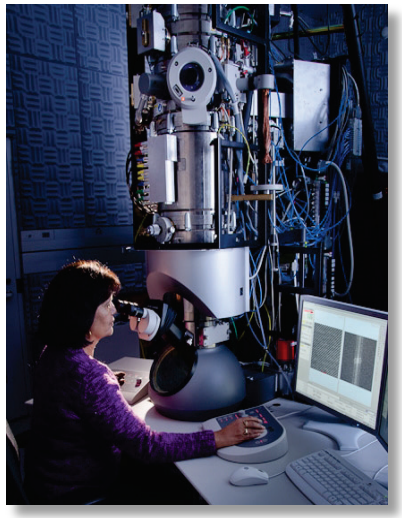


The CNST NanoLab

- Responds to user needs for measurement and fabrication beyond current commercial state-of-the-art, with current priorities in:

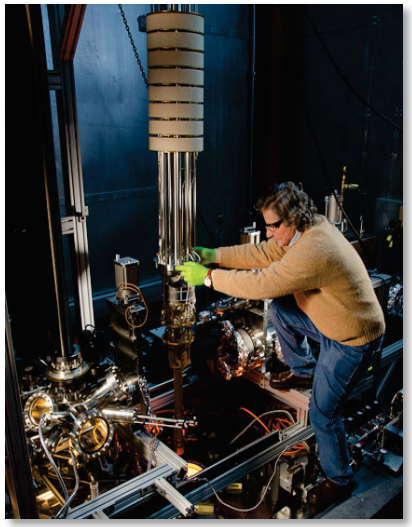


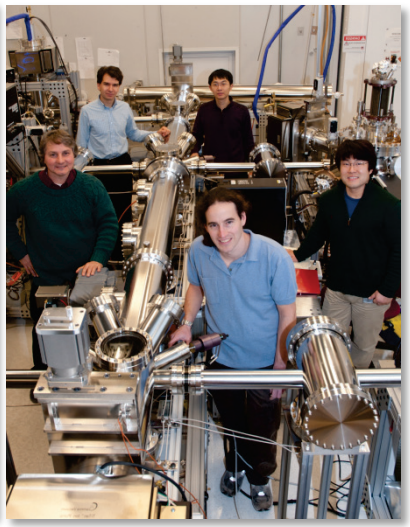
  - **Nanomanufacturing and Nanofabrication**: Top-down and bottom-up fabrication and assembly
  - **Future Electronics:** Nanoscale devices, architectures, interconnects
  - **Energy:** Conversion, storage, and transport at the nanoscale
- Provides access to advanced equipment and measurement ***through collaboration***
- Designed to be agile; priority areas will change with NIST and national nanotechnology needs
- Integrated tightly with the NanoFab, providing expert consultation and beyond-state-of-the-art measurements
- Complements and supports the NIST metrology and engineering laboratory programs

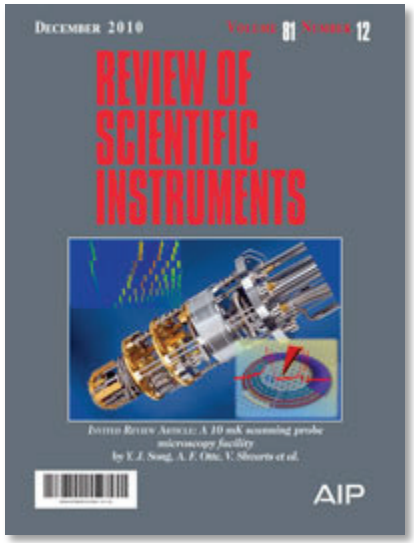


A CNST NanoLab Success: Quantum Electronics

- Key measurement need for future electronics: high-resolution imaging and spectroscopy
  - As materials and devices are reduced to the nanoscale, energy levels become quantized, leading to new properties
  - High spatial and energy resolution measurements required to understand and exploit such systems







- A unique, ultra-low-*T* scanning probe system
  - 10 mK base temperature
  - 15 Tesla magnetic field (vertical)
  - ΔE ≈ 10 μeV
  - Extensive sample and tunneling tip prep

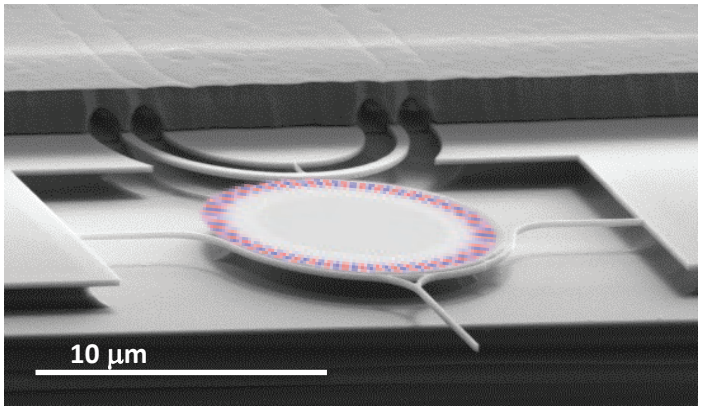
Y. J. Song, *et al.*, *Rev. Sci. Instrum.* **81**, 121101 (2011)

Low Temperature Scanning Tunneling Microscopy /Spectroscopy: A Tool for Graphene Research

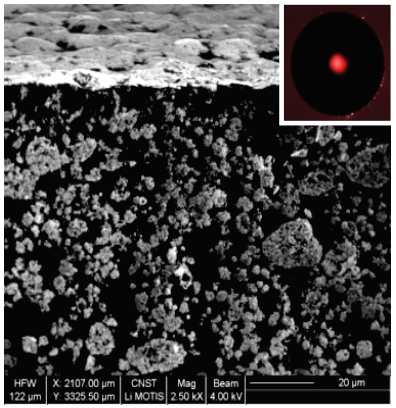
- In collaboration with Georgia Tech, Columbia University, Nanoelectronics Research Initiative, NIST Physical Measurement Laboratory
  - Faculty, postdocs, students participate
  - Other NIST groups: Dave Newell, Curt Richter, Angie Hight-Walker, Eric Cockayne
- Outcomes
  - Publications: 33 (LT-STM, ULT-STM, and theory)
    - Nature, Nature Physics, Science, Nano Letters, PRL
  - STEM Education: 2 Undergrads, 4 PhDs, 13 Postdocs
  - Tech Transfer
    - Invited *Rev. Sci. Instrum.* article (33 pages, 130 refs)
    - Janus sells the co-designed dilution refrigerator (JDR-500); McAllister Technical Services sells manipulator and isolators
    - Recent postdoc hired by Intel
  - Standards and new NanoFab processes
    - NIST project on graphene resistance standard
    - Unique graphene device fabrication for SPMs

Our tour will only give a small glimpse of the NanoLab's diverse program

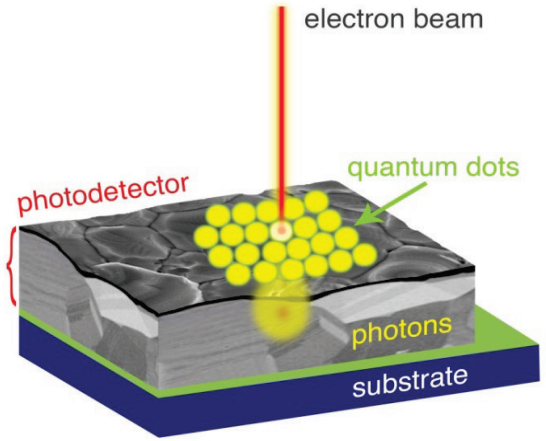
Active and inactive catalyst particles can be observed and analyzed to optimize carbon nanotube growth



Near-field optical sensor for high-bandwidth, high-sensitivity (1 fm/$\sqrt{Hz}$) displacement measurement



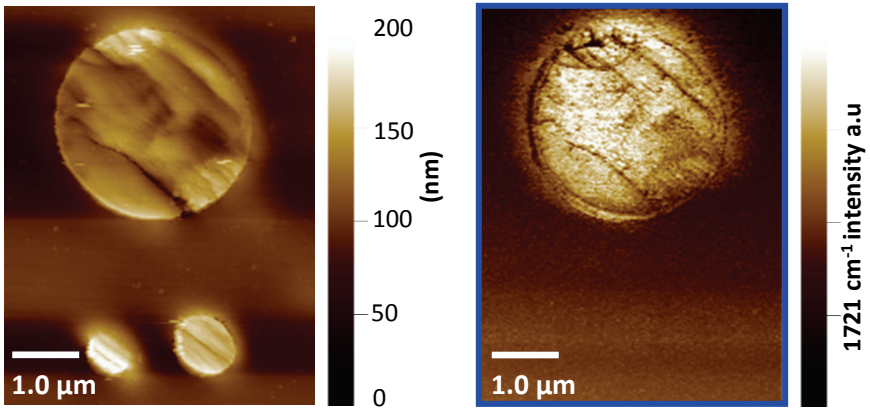
A laser cooled ion source provides a new FIB imaging and nanofabrication technology



A layer of quantum dots provide addressable nanoscale optical sources to probe the structures of photovoltaics

Height

PTIR 1721 cm^{-1} (5.81 µm)



Nanoscale chemical composition measurements are done with resolution comparable to AFM using the Photothermal Induced Resonance (PTIR) technique

Participating Institutions

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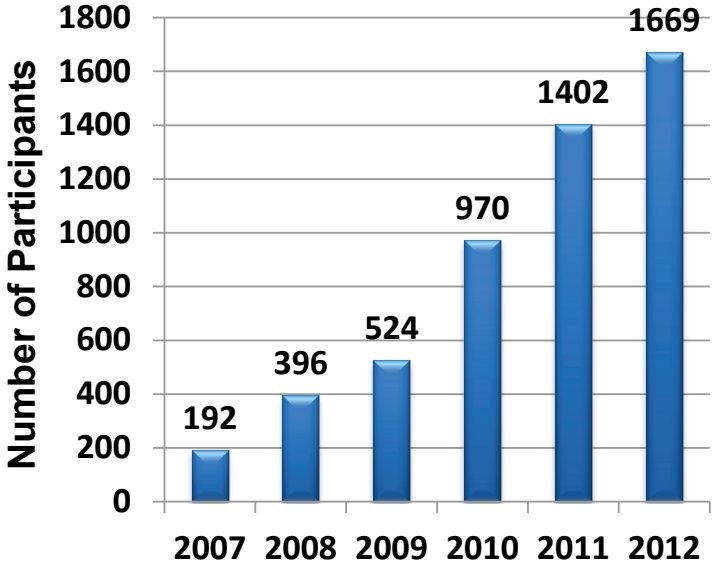
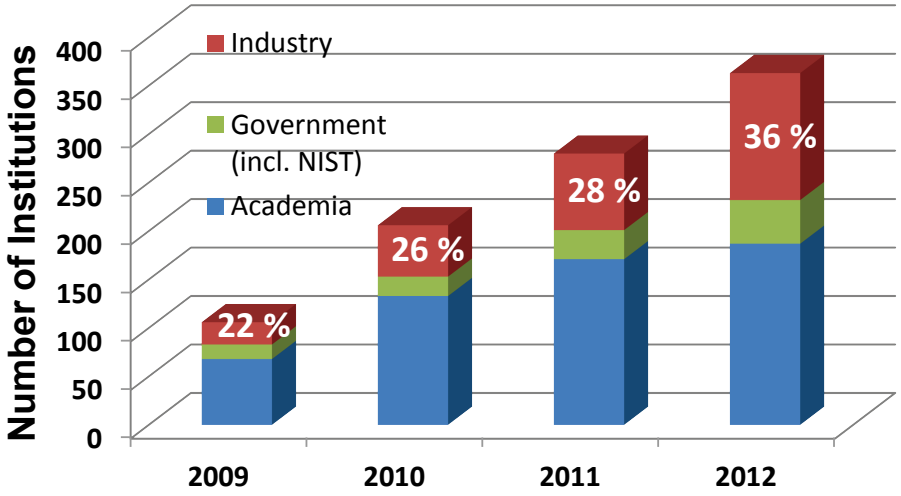
Research Participation has Grown Rapidly

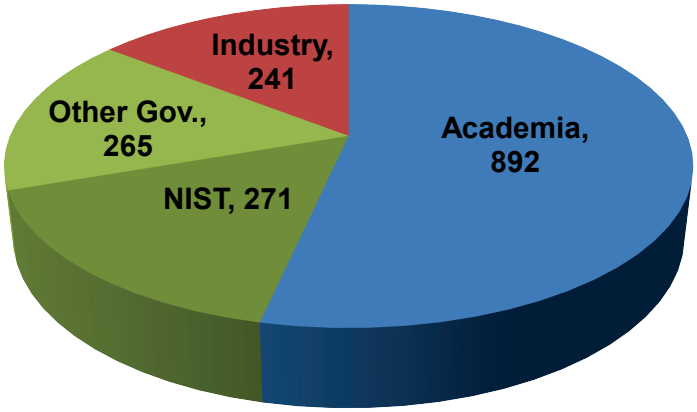
Research Participants By Fiscal Year



Participating Institutions By Fiscal Year



FY2012 Research Participants



FY2012 Institutions (363)

Companies:	131
Universities:	187
Gov. Labs:	45
States + DC:	40

STEM is not part of our mission, but CNST does a great deal of technical education

- About 1600 person-hours/year of technical instruction on NanoFab tools/processes
- Postdoctoral Training
  - Currently 38 postdocs; during ramp-up, trained 47 postdocs; 50% went to Academia, 25% went to Industry, 25% went to National Labs
- Students
  - Currently ~12 students/year; during ramp-up, trained 29 students
  - New CNST-NSF NanoFab-Community College Internship Program
    - Begins this spring with Hudson Valley Community College
    - Montgomery College and University of the District of Columbia programs in preparation.
- Visiting Fellows
  - Currently, 8 Visiting Fellows
  - During ramp-up, 14 former Visiting Fellows

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Thank you!

Questions?

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Supplemental Slides

Future Directions: Address Unmet Needs

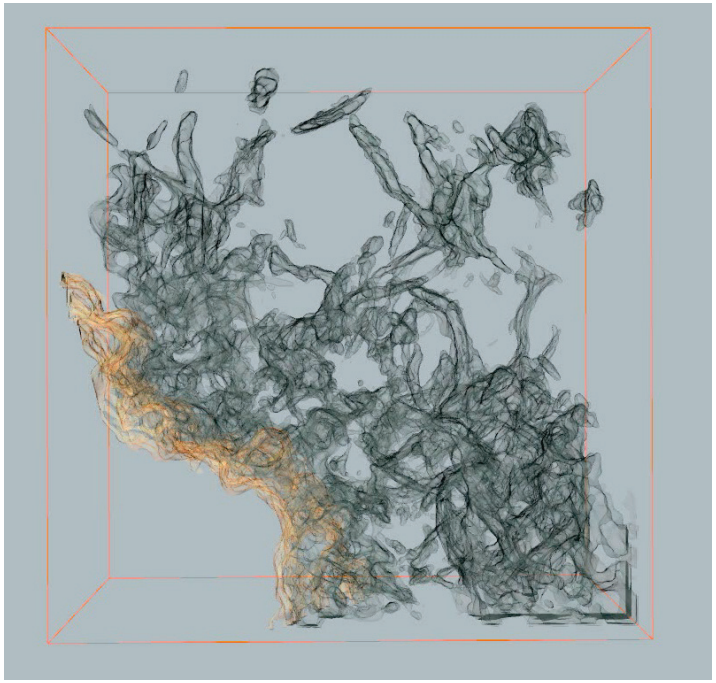
- User demand to add capability and capacity is high, and increasing rapidly, in two areas:
  - Nano-Bio-Medical Technology
    - Supporting the convergence of the life sciences, physical sciences, and engineering
    - Addressing the needs of a large, regional biotechnology community
  - Remote Facility Access
    - Making our tools and processes available to the national community
    - Enabling innovation in underserved regions
      - Adopting a “NetFlix” approach to providing nanofabrication solutions and leveraging high bandwidth communication to enhance access to nanoscale imaging and measurement

CNST NanoFab Project Story: Plasmonix

- NanoFab Manager received call from Jim Russo, an engineer at Plasmonix, a local startup focused on improving diagnostic assays.
- They needed a process for fabricating multilayer thin films with plasmonic top layers that interact with fluorophores;
  - To be applied to commercial fluorescence-based microarrays to increase assay sensitivity.
- CNST worked with Jim to develop methods to fabricate desired plasmonic structures on practical substrates, including plastic and glass.
- Devices successfully increase fluorophore intensity, improving sensitivity of immunoassays by a factor of a hundred;
  - Company working with partners to test device in typical microarray settings and scale up production.

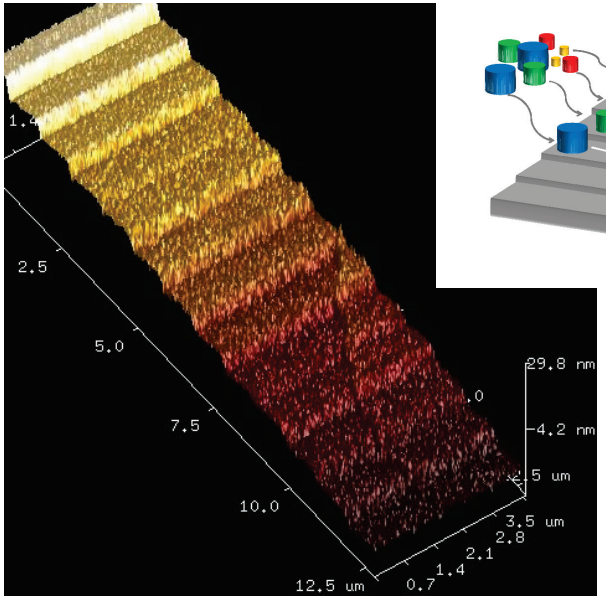
- Following NanoFab project's success, Plasmonix chosen as 2013 Maryland Incubator Company of the Year for Technology Transfer.

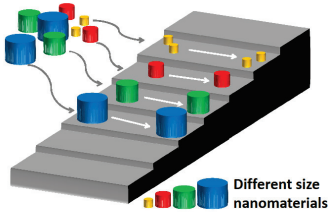
High-Throughput Nanoscale Measurements for Manufacturing

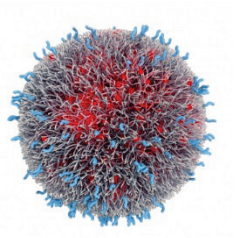


Carbon Nanocomposite Manufacturing

- High-resolution characterization
- Electromagnetic properties modeling
- High-speed, non-contact microwave measurements for quality control







http://web.mit.edu/newsoffice/2012/cancer-particle-0404.html

Nanoparticle Characterization

- Size, shape, charge, surface properties, etc. must be known
- Precise, nanofabricated structures enable fast, accurate measurements