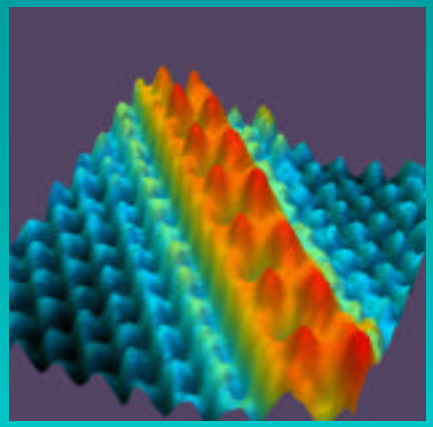


Meso/Micro/Nano Scale Technologies

Clayton Teague, Chief, APTD, MEL

John Evans, Chief, ISD, MEL

June 8, 1999

Contents of Presentation

- What we (MEL) have done in meso-scale area
- What is nanotechnology
- Nanotechnology is important
- Principal message
- Why is it important to industry and NIST?
  - Examples of industry/NIST work at all scales
- Challenges for NIST
- Long term needs at the nano-scale
- Short term needs at the meso/micro-scales
- Priorities
- Ideas
- Discussion topics

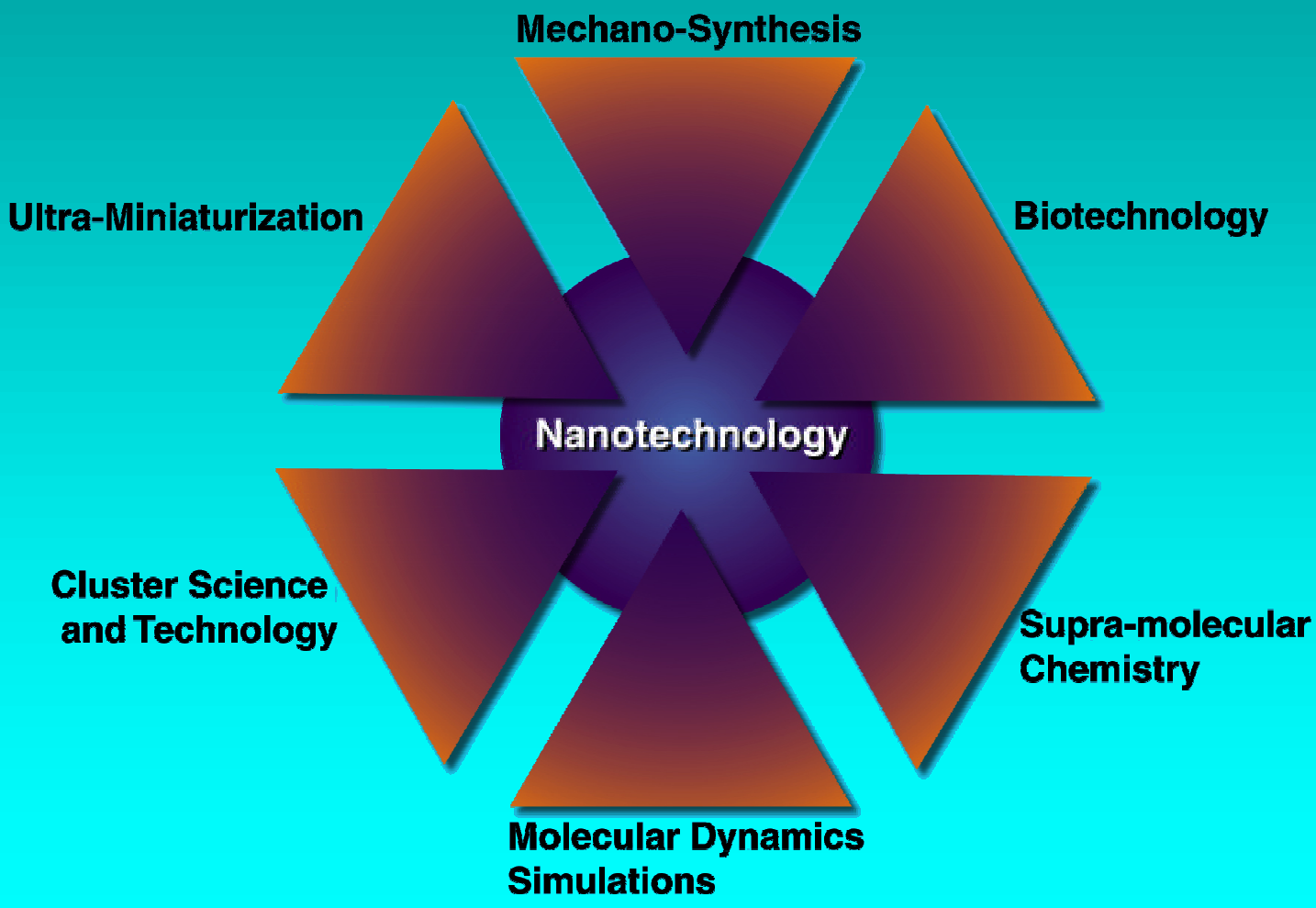
Background

- During past 9 months, MEL has explored measurements and standards needs of meso and micro-scale manufacturing
- Visited 20 companies
- Conducted and participated in three workshops jointly sponsored with DARPA and NSF
- Organized informal NIST-wide co-ordinating group for meso/micro/nano scale activities
- All feedback from these efforts points toward an exploding growth of nanotechnology
- We see a continuum of needs for NIST efforts from the macro-scale to the nano-scale

What is Nanotechnology?

- Technology on the scale of atoms -100 pm- up to biomolecular systems as large as cells - 10's μm
- "Top-down" - achieving increased miniaturization through extension of existing microfabrication schemes
- "Bottom-up" - capability to construct functional components, devices, and systems from building blocks of atoms and molecules

Nanotechnology Strategies



Nanotechnology is important!

- “We’ve got to learn how to build machines, materials, and devices with the ultimate finesse that life has always used: atom by atom, on the same nanometer scale as the machinery in living cells.” ***Richard Smalley, Nobel Laureate, 1995***
- “I believe nanoscience and nanotechnology will be central to the next epoch of the information age …” ***John Armstrong, formerly Chief Scientist of IBM, 1991***
- “If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering.” ***Neal Lane, Director OSTP, 1998***
- “Nanotechnology has given us the tools to make contact with the world of the molecule and the atom. … The possibilities to create new things appear limitless.” ***Horst Stoermer, Nobel Laureate***
- “… with nanodevices, … you could put all the information needed for some major fraction of your life (the equivalent of 1000 CDs) on your wristwatch. It’s one of those ideas that shifts the notion of how a life should be led.” ***George Whitesides, Prof. Of Chemistry at Harvard, 1998***

Why nano/micro/meso?

- Exciting diversity of new physical, chemical, mechanical, magnetic, and electronic phenomena
- Opportunities for dramatically new materials, products, and manufacturing processes
- Global competitive pressures and the ever-increasing demand for faster, smaller, less expensive products

Principal Message

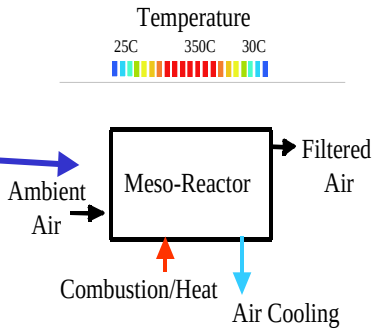
Materials → Structures → Devices → Circuits → Systems

For efficient advancement of nanotechnology need to connect enabling technologies across all scales (nano, micro, meso, macro)

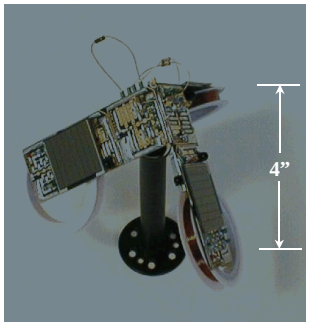
- knowledge of materials
- materials and device characterization methods
- fabrication technologies and processes
- measurement and test methods
- modeling & simulation tools

Meso-Machines - aka "*The Right Size*"-Machines

Air Purification/MesoSystems Inc.

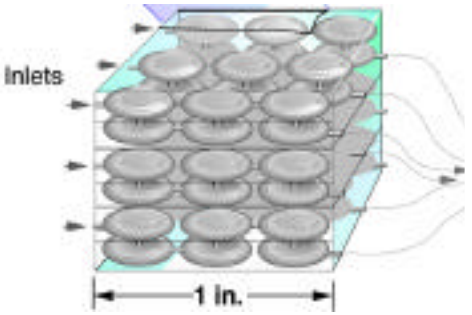


Nanosats/LANL



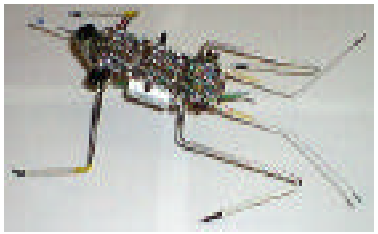
BWD Detection Pumps

Honeywell SARCOS



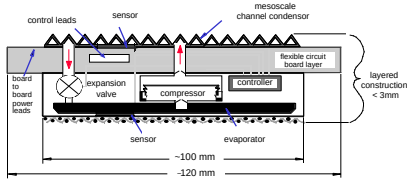
Situational Awareness

LANL Vanderbilt



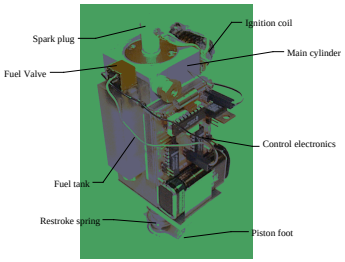
Cool Uniforms

UIUC Battelle/PNNL



All "terrain" machines

GTRI Sandia



Water Purification

MesoSystems LATA/MIOX Corp.

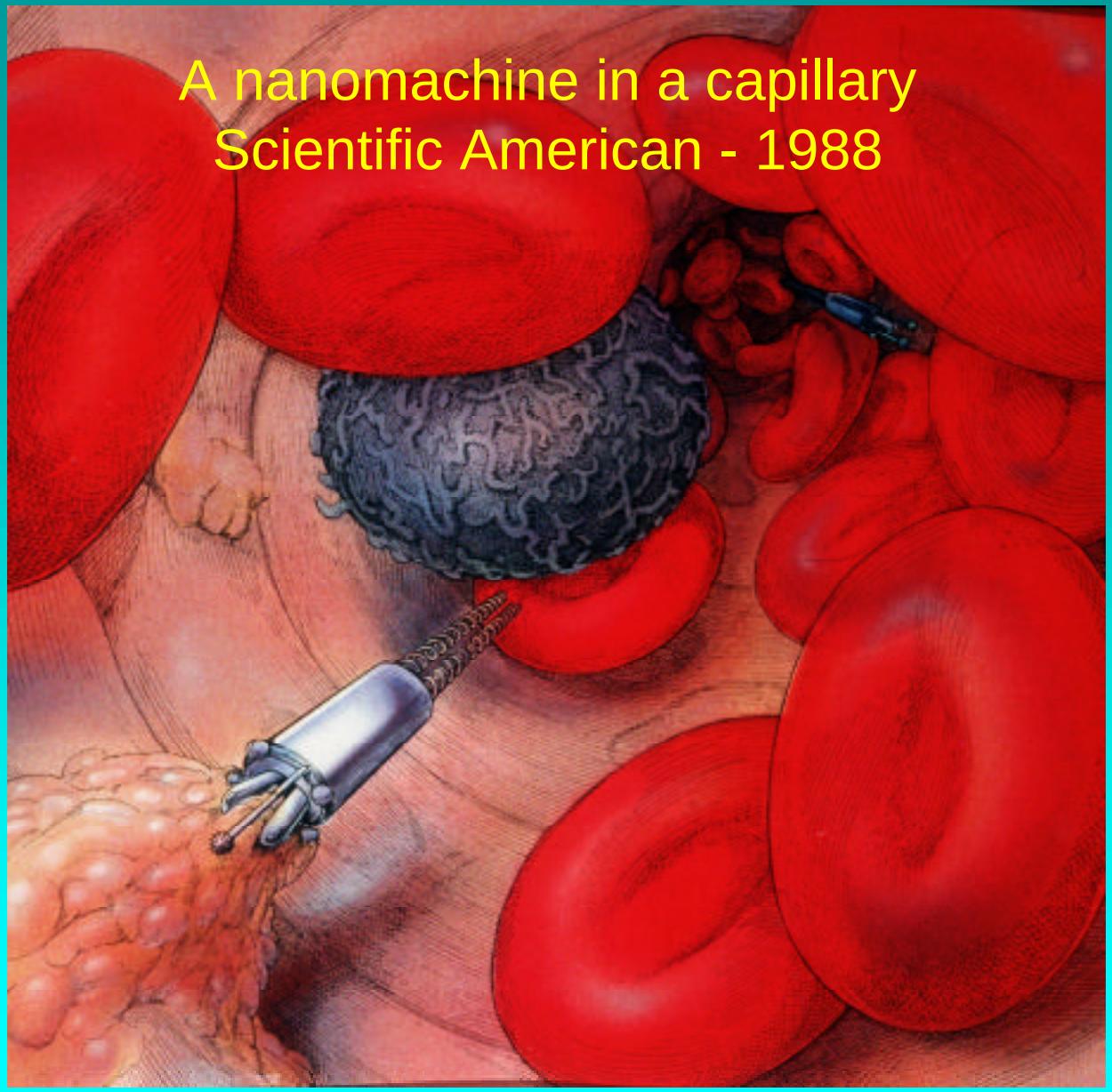
William Warren/DARPA

Defense Sciences Office DARPA

Mesoscale and Microscale Devices: Not so obvious

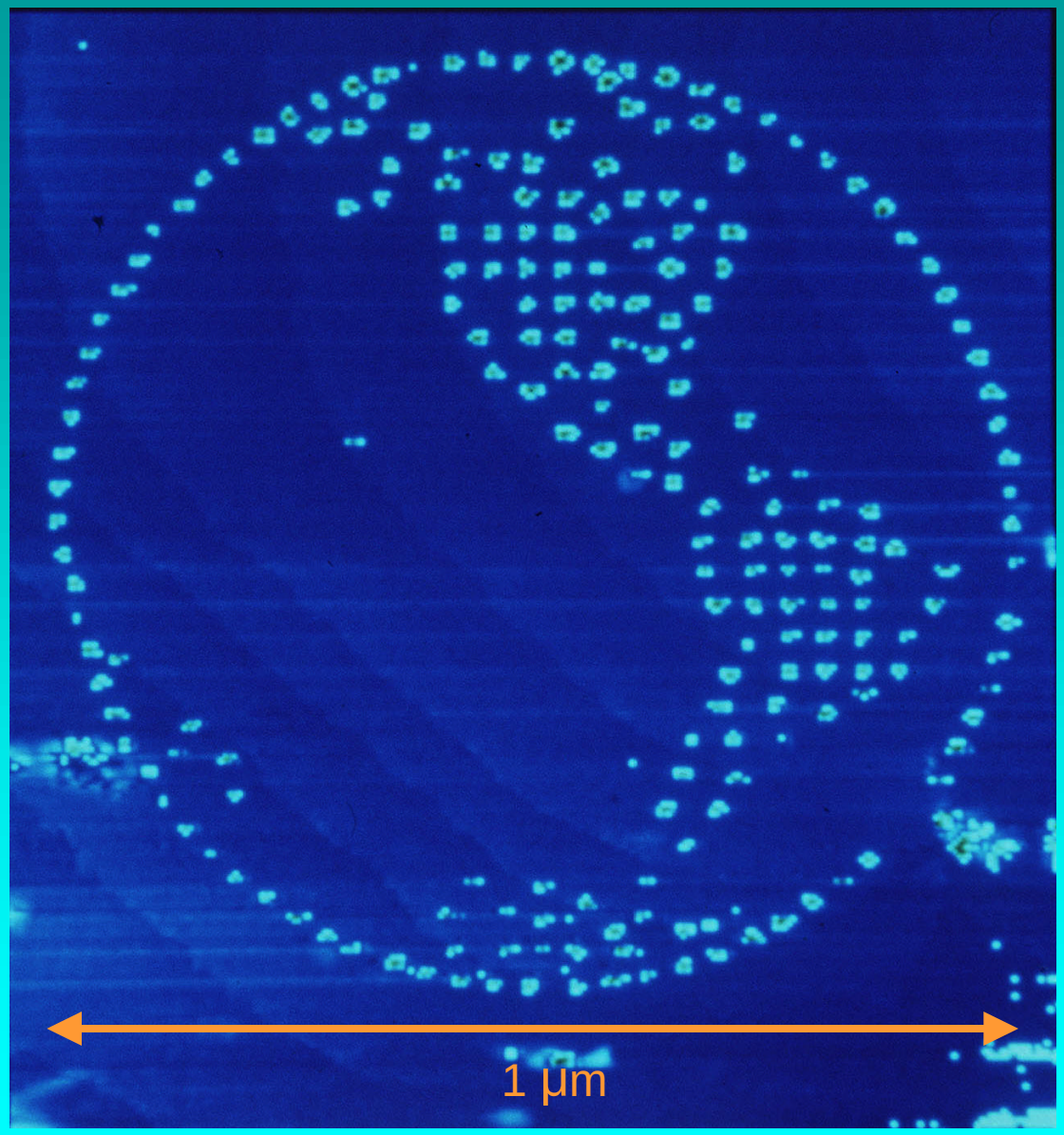
- Ball point pens, watches
- Hearing aids, pacemakers
- Fuel injectors
- RF Tags
- Surface mount electronics
- CD read heads
- Computer disk read/write heads
- Fiber optic connectors and switches
- Smart toys

A nanomachine in a capillary
Scientific American - 1988



A micro-submarine in a vein

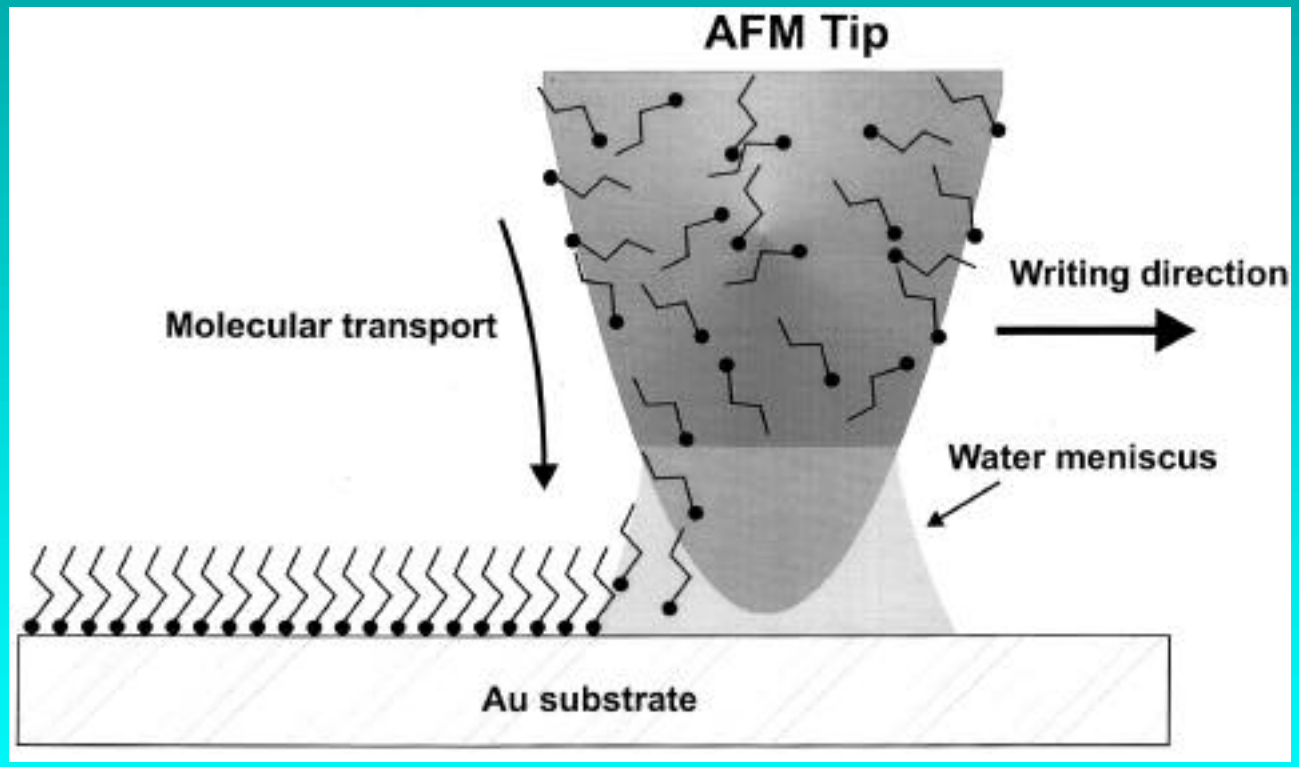
- Made by Rapid Micro Product Development - 1999
- microTEC - Germany

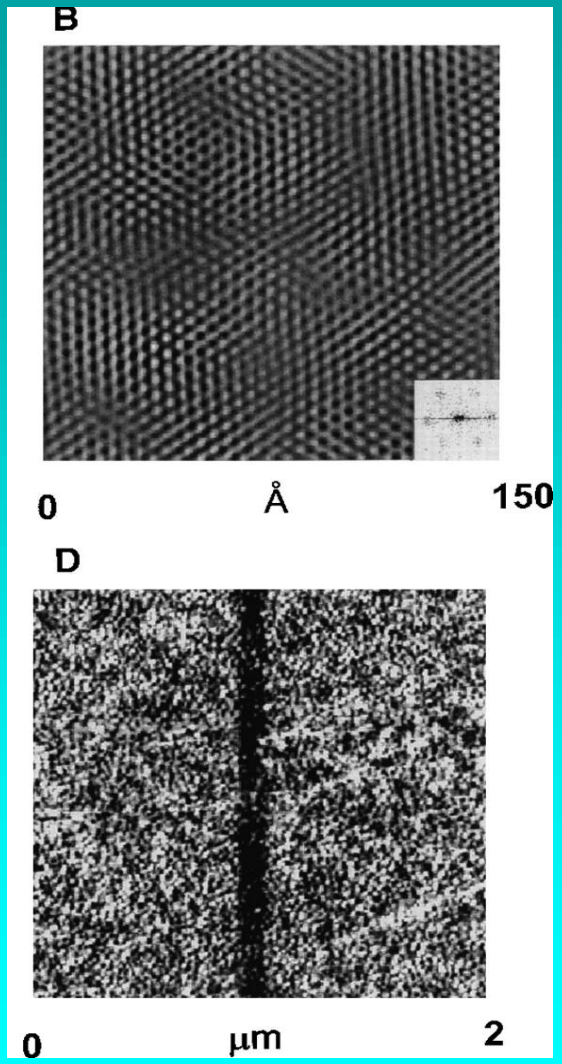


10 nm Gold dots on a gold substrate

Jonathan Mamin, IBM Almaden Research Center

Dip-Pen Nanolithography deposition of octa-decane-thiol molecules



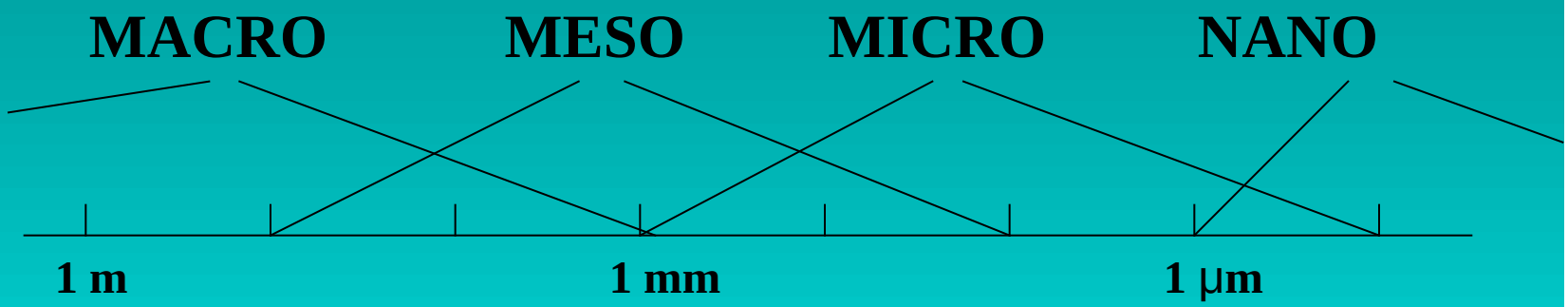


Richard D. Piner, Jin Zhu, Feng Xu, Seunghun Hong, Chad A. Mirkin; Science 283, 661(1999)

Nano/micro/meso-technology challenges for NIST

- Demanding process and measurement needs
  - Large number of processes
  - At nano-scale, atomic level manipulation and characterization; scientific and engineering challenges
  - Measurements need to be at least as good as what is being measured; composition, dimensions, forces, energies
- Diverse nature of materials
  - Inorganic, Organic, Biologic, Composites
  - Highly interdisciplinary
- Science, measurements, and technology rushing in parallel; all needed concurrently;
  - strong participation by industry

Manufacturing Size Scales



INDUSTRY:	**Large**	**Small**	**Large**	**Nascent**
PRODUCTION:	**Serial**	**Serial**	**Parallel**	**N.A.**
ASSEMBLY:	**Serial**	**Serial**	**Integrated**	**N.A.**
METROLOGY:	**Established**	**Holes**	**Optical, SEM**	**STM, AFM**
RESEARCH ARENAS:	**Product and Manufacturing Engineering; Applied and Basic Research**		**Applied + Basic Research**	**Basic Research**

Meso/Micro/Nanotechnology at NIST

- Microchannel chemistry
- Microwave sensors
- Optoelectronics
- Microelectronics
- Magnetics
- Quantum devices and nanostructures
- Spintronics
- Nanobiology
- Metrology at micro and nanoscales

Needs

- Long term: basic science for nanotechnology and nanomaterials, measurements, standards, enabling technology.
- Short term: critical needs at mesoscale and microscale in metrology, in assembly and packaging, in process science and particularly materials testing and materials data.

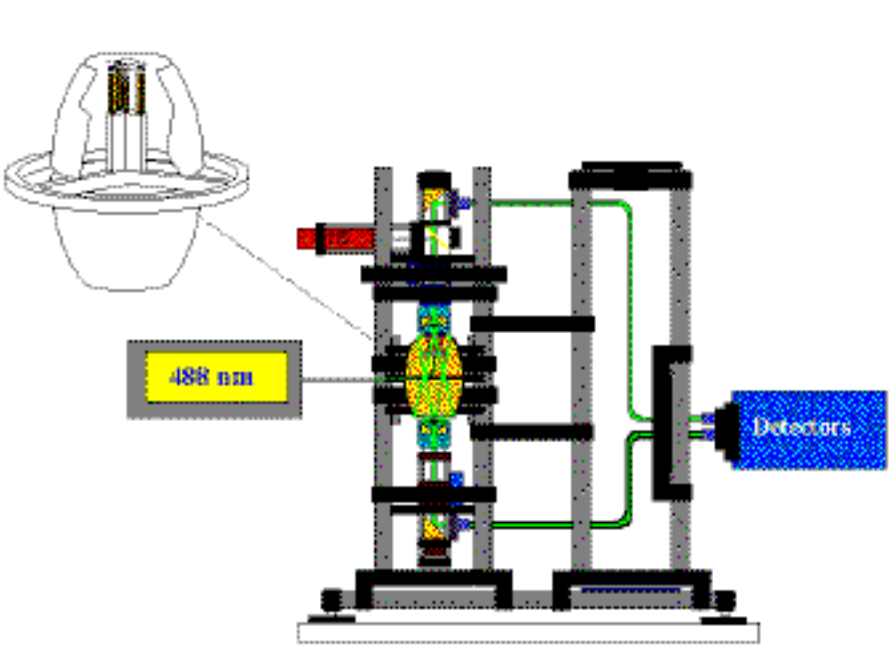
Priority Needs for NIST

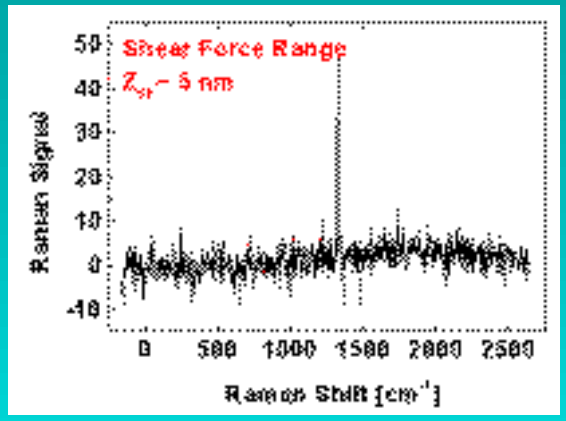
- Long Term:
  - Nanocharacterization: measurement methods, metrology, data
  - Nanomanipulation: manipulation and assembly
  - Nanodevices: enabling technologies
  - Magnetics industry support

Measurement Needs:

Molecular Spectroscopy & Imaging

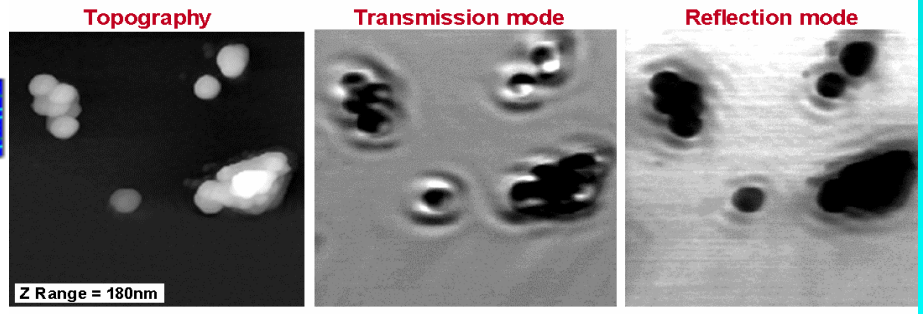
- Scanning Probe Microscopies
  - Nearfield Scanning Optical Microscopy
    - Raman, IR, visible spectroscopy at nanoscale resolution





- 100 nm Colloidal Au Particle Scattering of 488 nm Light.

- *Simultaneously Recorded Images (3500 nm x 3500 nm) of 100 nm Colloidal Au Particles on a Silanized Glass Substrate.*

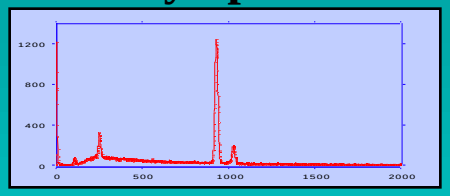


- Standing Waves have a period of $\lambda/2$ and extend beyond topography.
- Light scattered from the spheres modulates the total field emanating from the tip.

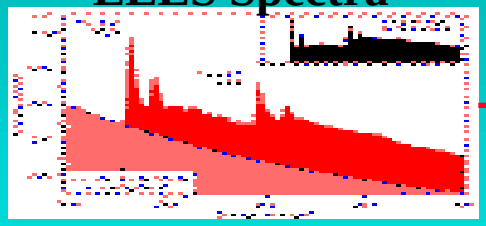
Measurement Needs: Material Characterization

Multidimensional ASTEM Analysis

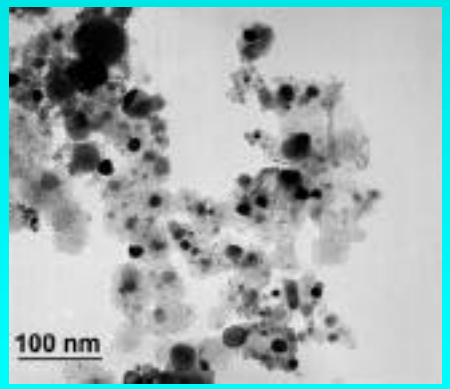
X-ray Spectra



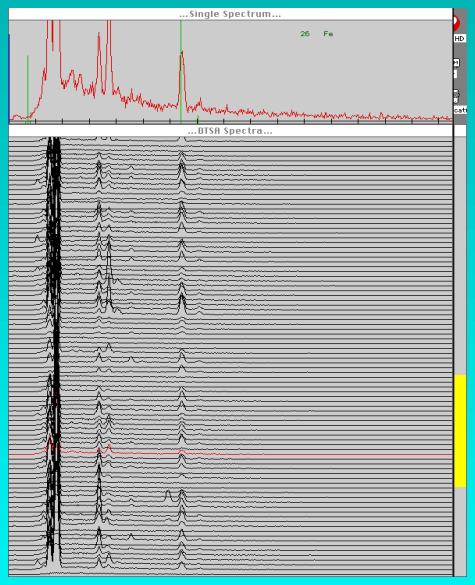
EELS Spectra



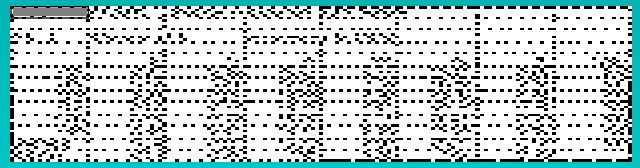
Images



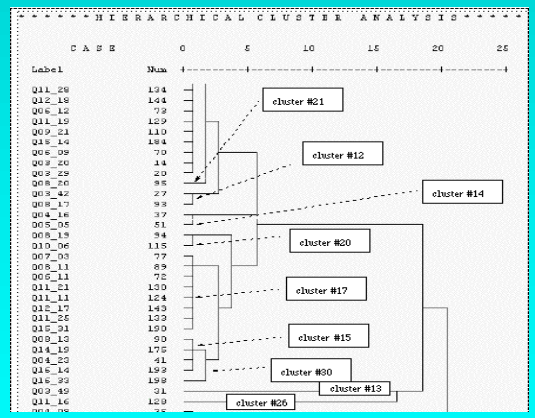
PolyPlot



Quantitative Chemical Analysis



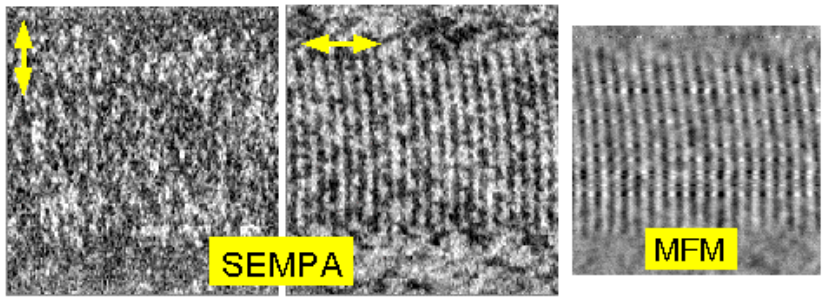
Multivariate Analysis



Particle Morphology

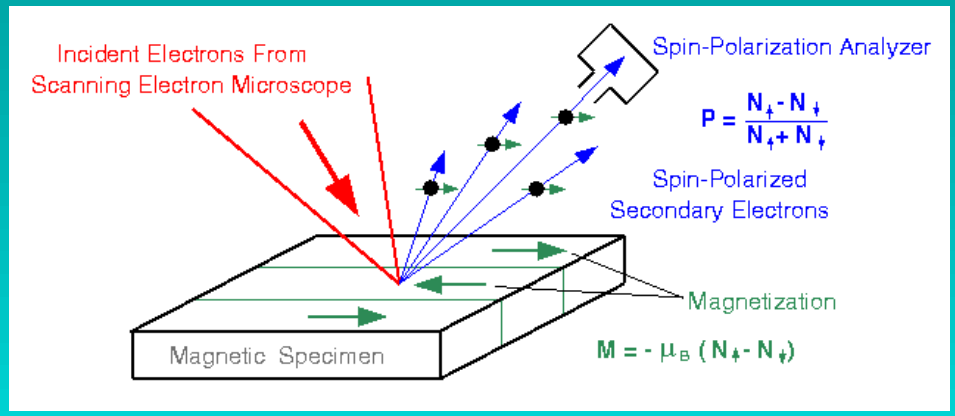
Start particle list
((PARTICLE 1) (INDEX 112) (AREA 63) (BDR (326 120 337 129)) (X_V 1059)
(L_X_V (332 124)) (L_N_V (334 122)) (N_V 515) (AV_V 741.19) (SIGMA 143.9)
(R_SIGMA 0.2) (ABS_DEV 117.3) (C_MASS (332.3364 124.7579)) (A_L_I -30.8)
(A_W_L_I -32.2) (FERET_MAX 12.04675 160 (326 126) (337 121))
(FERET_MIN 7.428223 60 (333 129) (332 121)) (DMAP_MAX_RADIUS 3)
(DMAP_MAX_CENTER (334 124)) (PERIMETER 48)
(POINTS (((334 124)))))

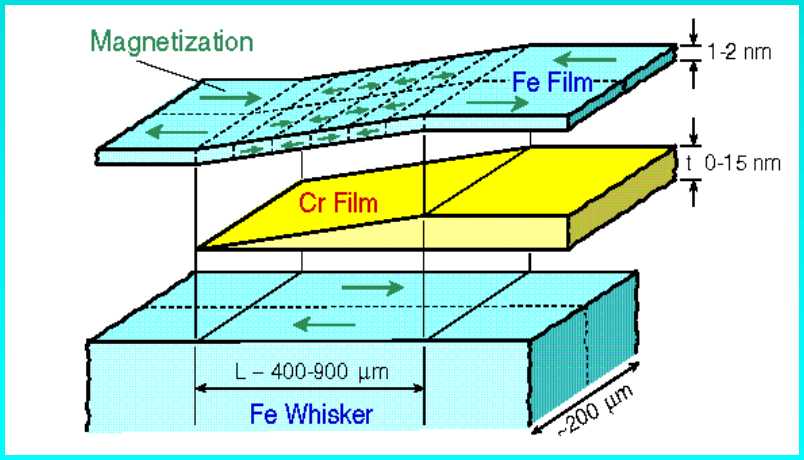
Measurement Needs: Magnetics



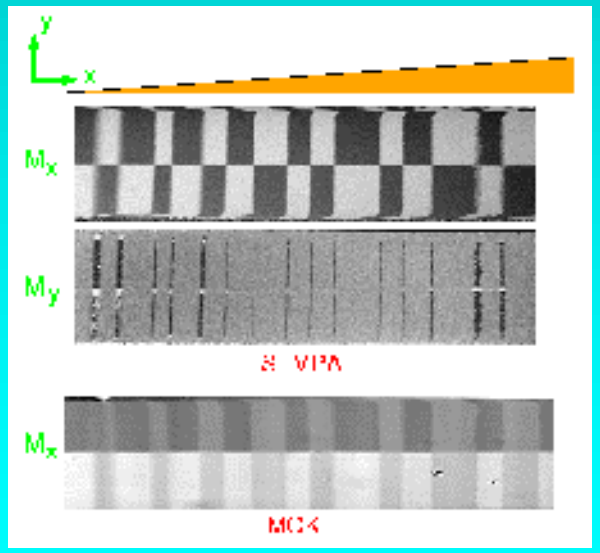
200 kfci media (0.125 μm bits)

Comparing SEMPA and MFM measurements on the same material

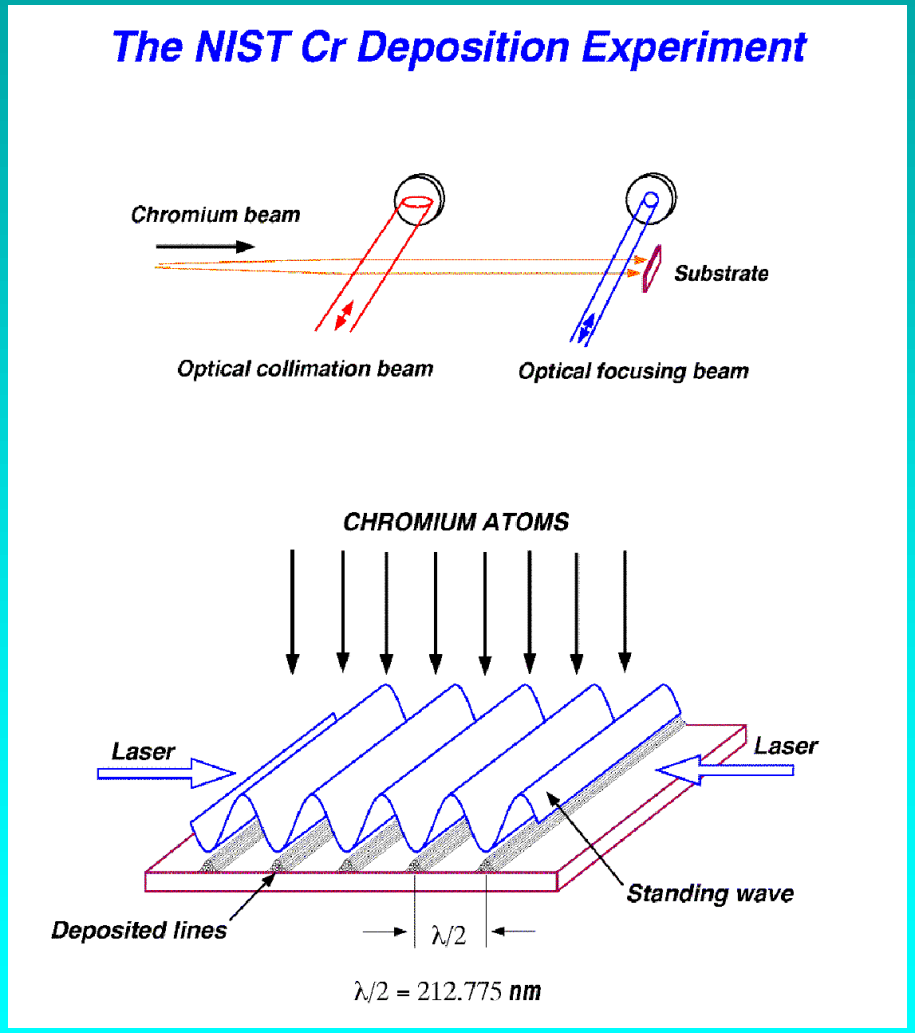


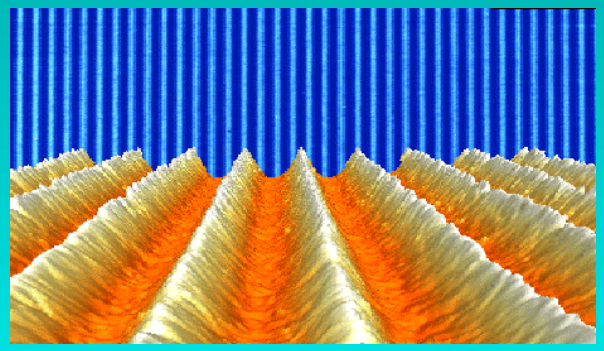


Measuring magnetic exchange coupling effects due to single atom layer thickness changes in films



Measurement Needs: Dimensional Metrology

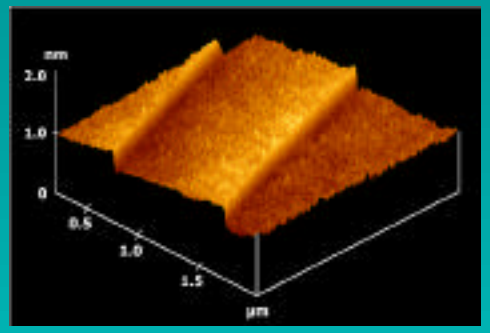


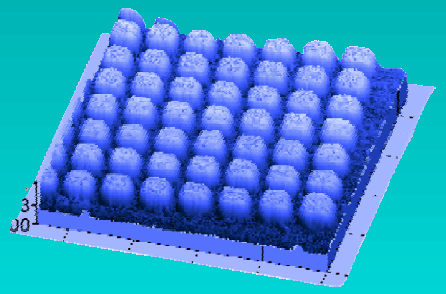


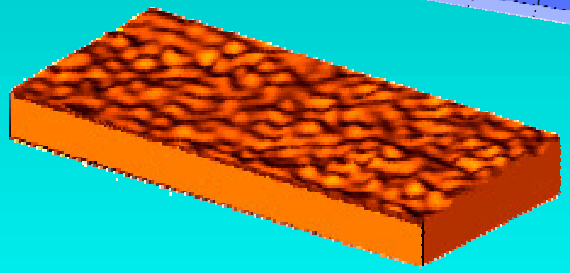
- Create a "nanoruler" directly traceable to the wavelength of light.
- Nanoscale accuracy and precision over millimeter distances.

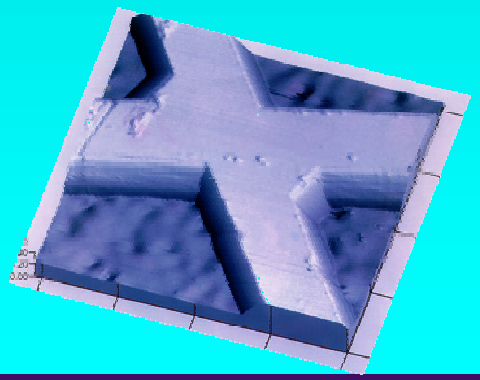
Measurement Needs: Dimensional Metrology

- Step Height
- Pitch
- Roughness
- Linewidth









Priority Needs for NIST

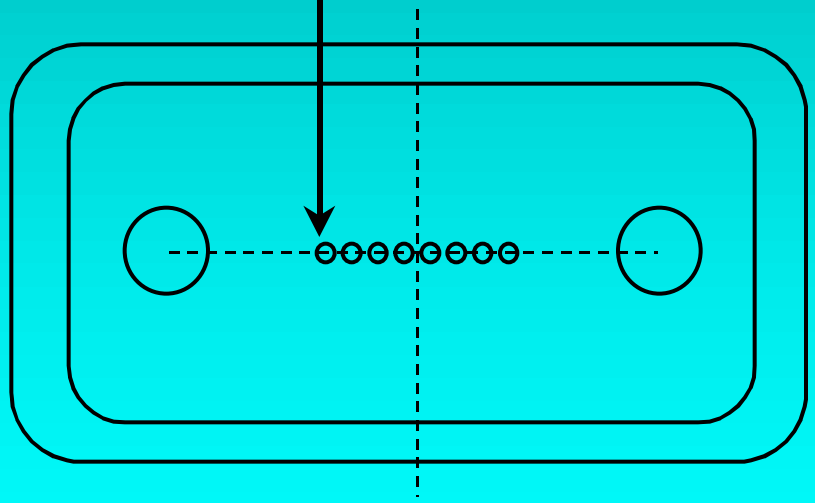
- Short Term:
  - Meso/micro metrology
  - Assembly and packaging
  - Science base for products and processes, particularly materials testing and materials data

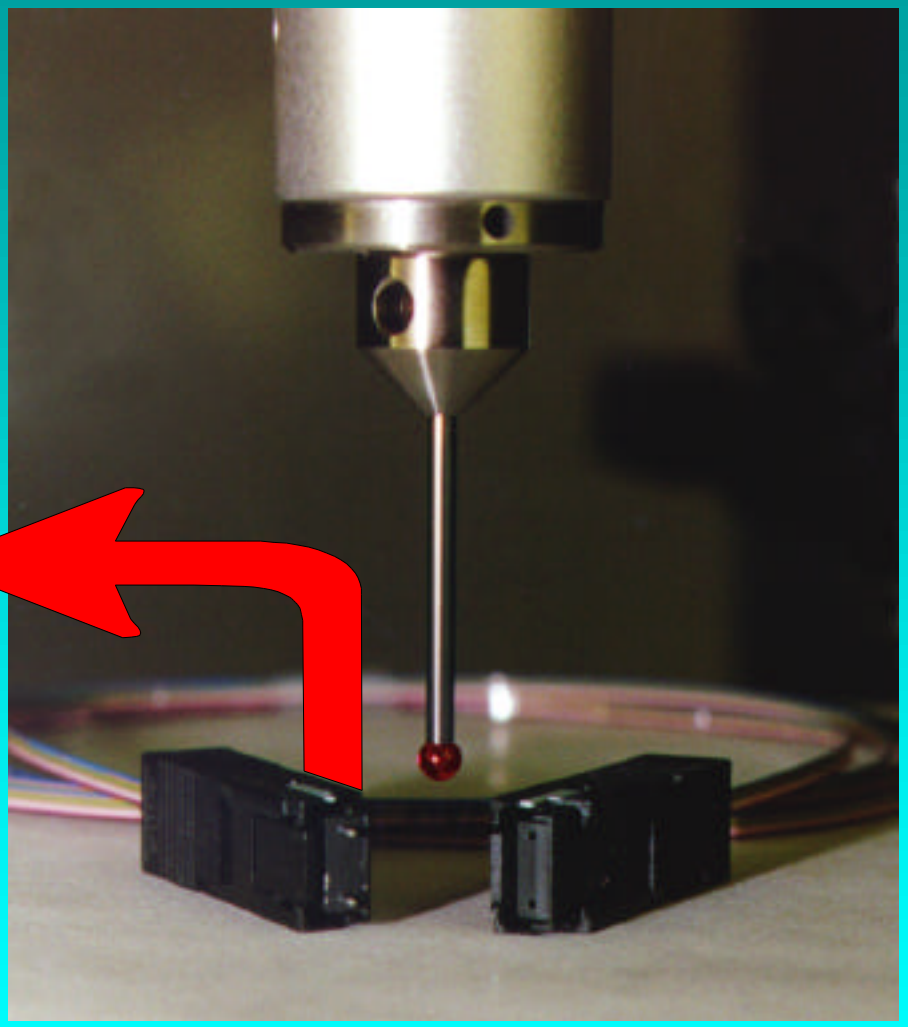
Meso/Micro Metrology

Fine CMM Probe

Diameter: $\left(125^{+1.5}_{-1.0}\right)\mu m$

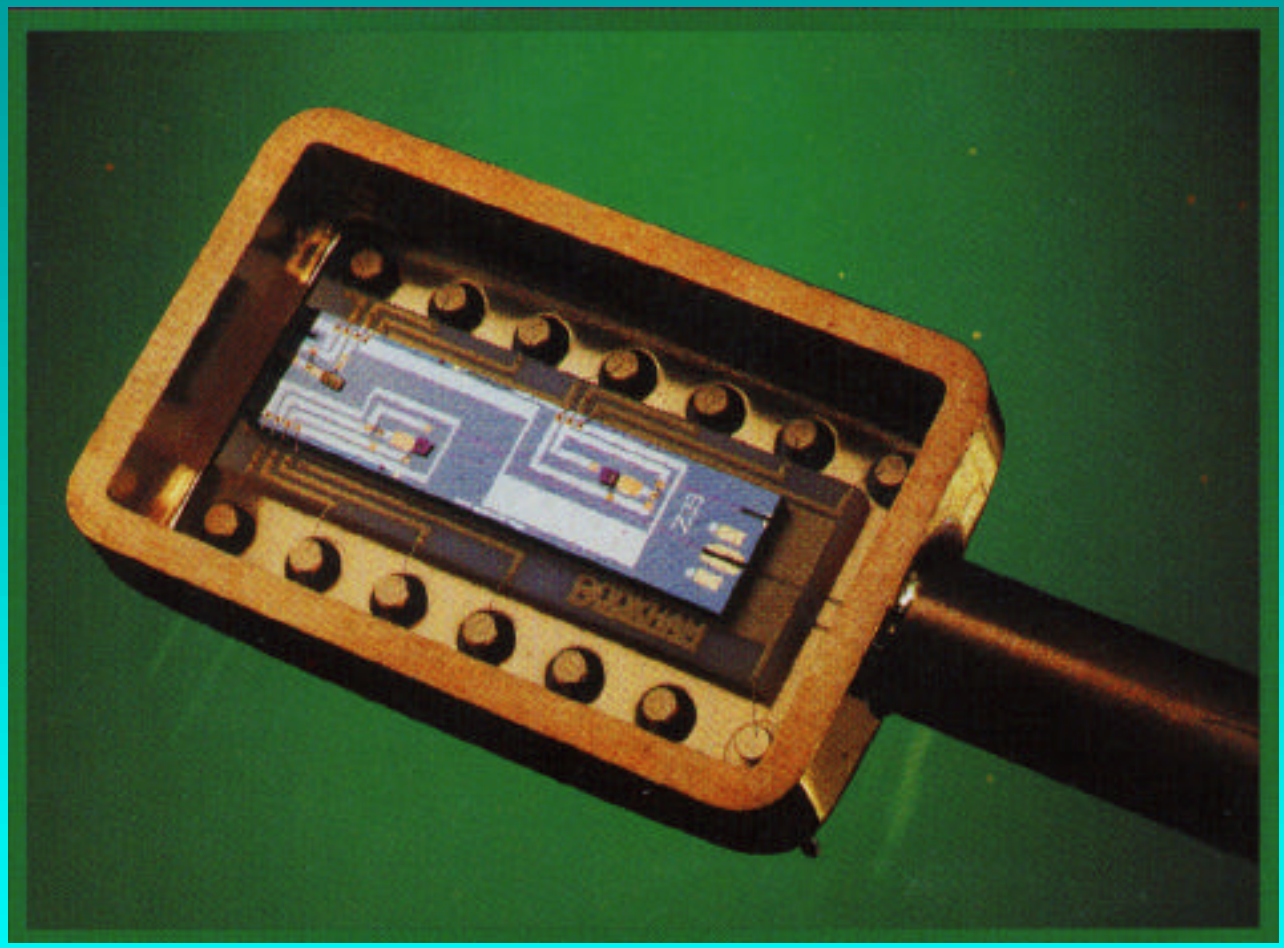
Position Tol: ± 1.5 µm





Meso/Micro Metrology

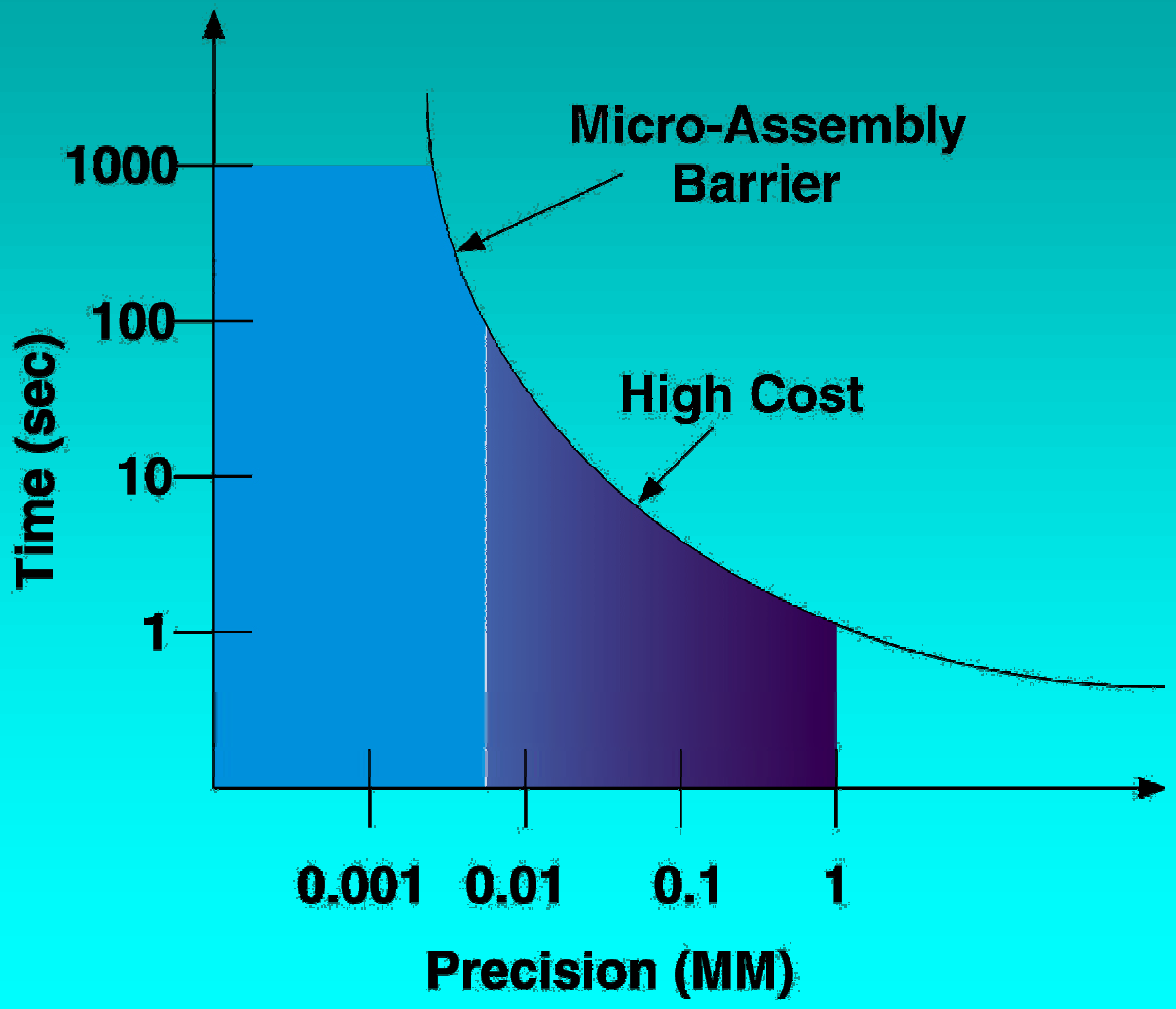
- NIST can provide:
  - Suite of optical, mechanical, electrical, and magnetic measurement techniques for dimension, materials properties, and mechanical properties
  - Calibration services for force to micro and nanoNewton levels and torque to pico N-m
- This is a “hole” in our support for industry that is critical in the near term.



Bookham Technology Transceiver, example of integrated optics.
Photonics Spectra Feb. 1997

Photonics Industry Problem

Cost of Assembly



MesoMicro Assembly and Packaging

- NIST can provide
  - Information exchange
  - Sensors (measurement technology) for microrobotics and microstages
  - Chemical and materials data
  - Performance measures and testing methods
  - Proactive role in creating interim de facto standards to help US industry and eventually supporting normative standards process

Ideas from Informal Coordination Group

- Shared facilities for all Labs
- NIST serve as coordinator for distributed regional technology and fabrication center
- Leverage resources by
  - collaboration with NSF, DARPA, NASA, DOE
  - joint research with universities
  - cost share with industry

Discussion Topics

- Needs
- Priorities
- Ideas
- Information, contacts, directions, needs, opportunities...