An Overview of Nano/Micro/Meso Scale Manufacturing at NIST

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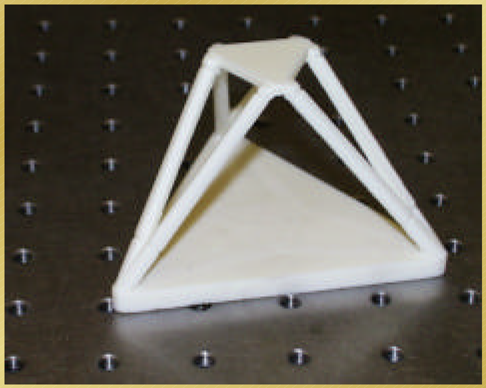
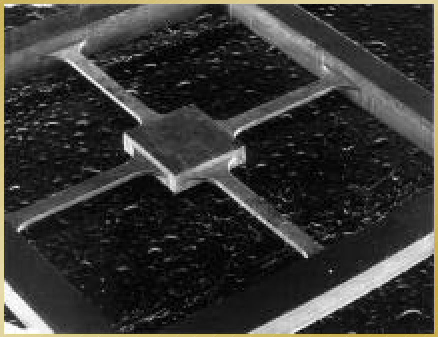
March 15, 1999
NanoTribology: Critical Assessment and Research Needs Workshop

Intelligent Systems Division
Automated Production Technology Division
Precision Engineering Division

Manufacturing Engineering Laboratory

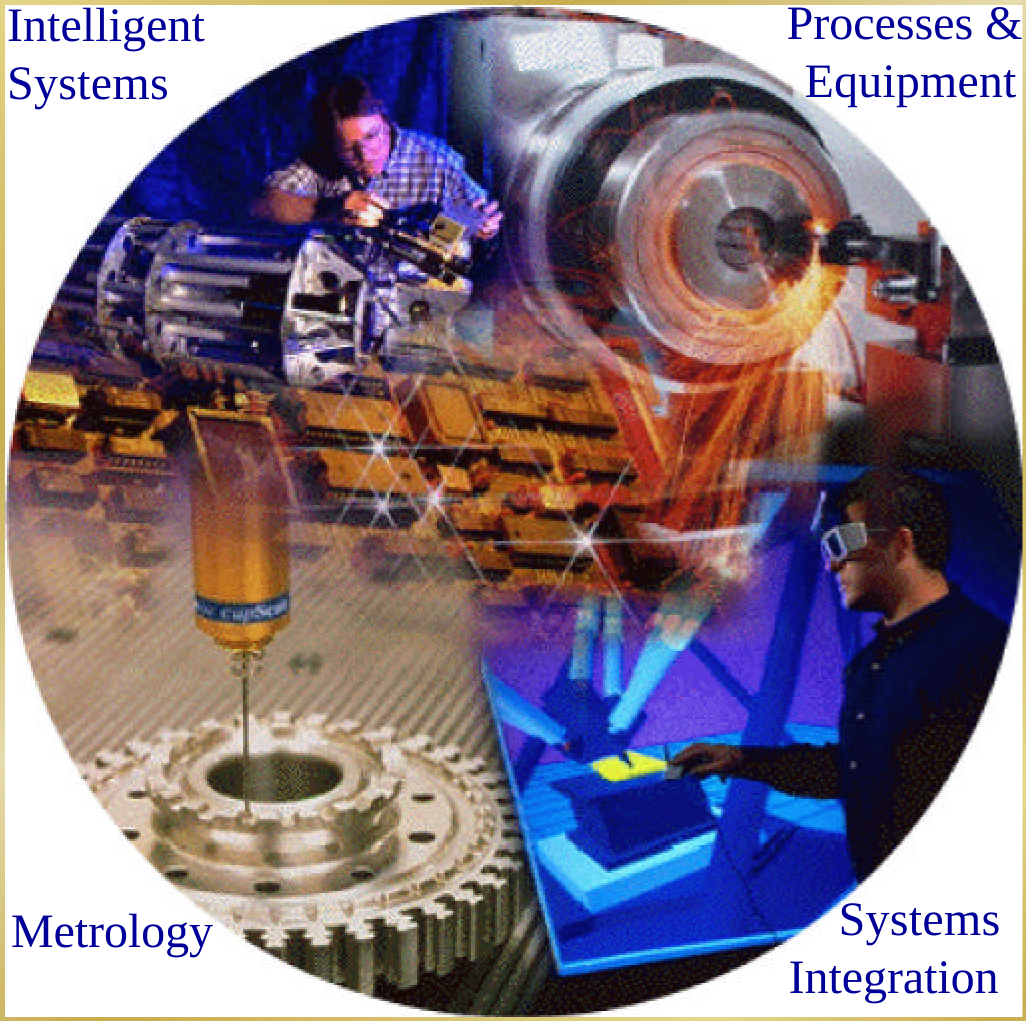


Outline



- FY99 Micro-Meso Scale Manufacturing Exploratory Project
- Some Examples of Meso/Micro/Nano Manufacturing Activities
- FY00 Strategic Program in Nano Manufacturing

MEL Overview



FY99 Micro-Meso Scale Manufacturing Exploratory Project

- Visited 20+ companies and laboratories
  - Specific Measurements, Standards and Data Needs
- Co-sponsored Two Workshops
  - One with DARPA and one with NSF
- Attended conferences in MEMS, Nanotechnology, Photonics...
- Developed a final report / trip report

Prioritized Needs for NIST Efforts

- Meso and Micro
  - Dimensional and Mechanical Metrology
  - Assembly and Packaging Technology and Standards
  - Providing a Science Base for Materials and Processes, emphasizing materials testing methods and properties data

NIST mission: Measurement, standards, data and infrastructure technology

Needs at the Nanoscale

- Nanocharacterization: measurement, metrology, data
- Manipulation and Assembly
- Enabling Technologies for Nanodevices
- Support for Magnetics Industry

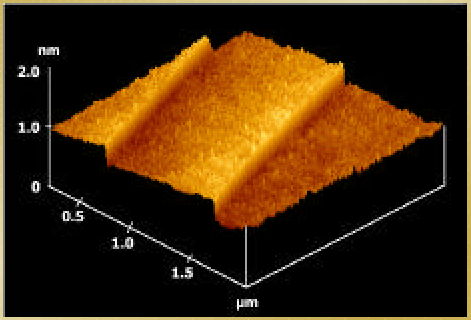
Key Issue : *Nanometrology* which is part of Nanocharacterization and Nanomanipulation

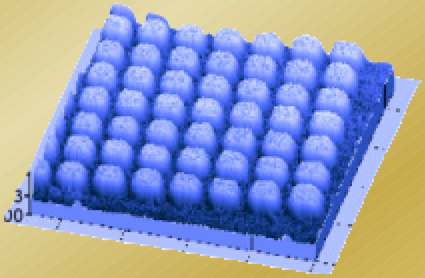
Meso/Micro Metrology

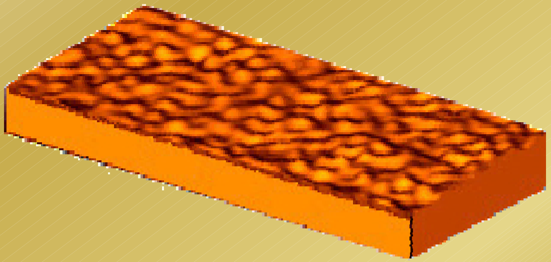
- NIST can provide:
  - Suite of optical, mechanical, electrical, and magnetic measurement techniques for dimension, materials properties, and mechanical properties
  - Calibration services for force to micro and nanoNewton levels and torque to pico N-m

- This is a "hole" in our support for industry that is critical in the near term.

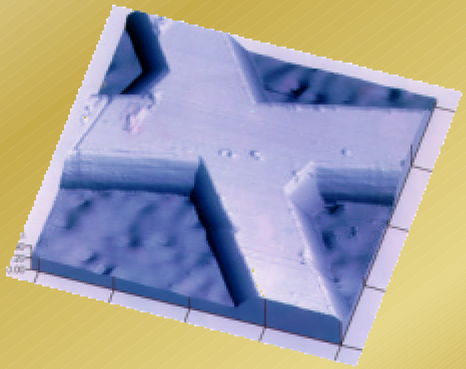
Measurement Needs: Dimensional Metrology





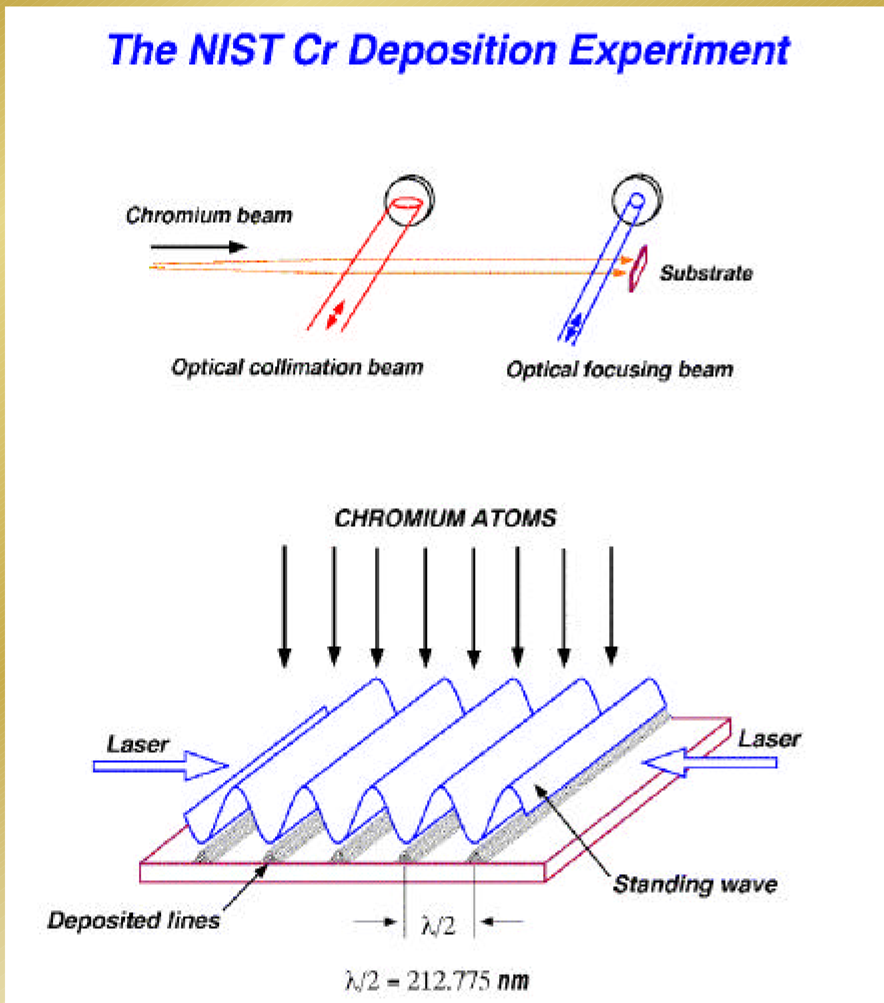


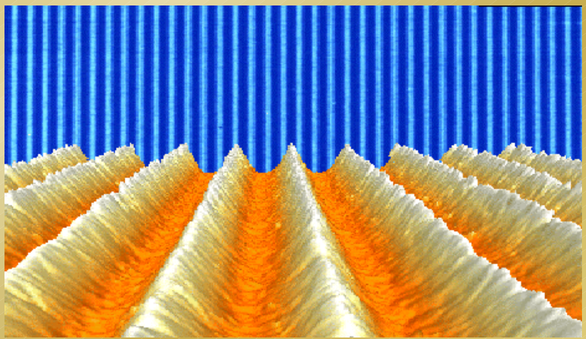
- Step Height
- Pitch
- Roughness
- Linewidth



Physics Laboratory

Measurement Needs: Dimensional Metrology





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

Data Implications of Meso-Machines

Tolerance Challenges

- Need support for linkage between product function and tolerance specifications
- Need comprehensive tolerance definitions supporting improved tolerance analysis

Tightly coupled product/process/material definitions

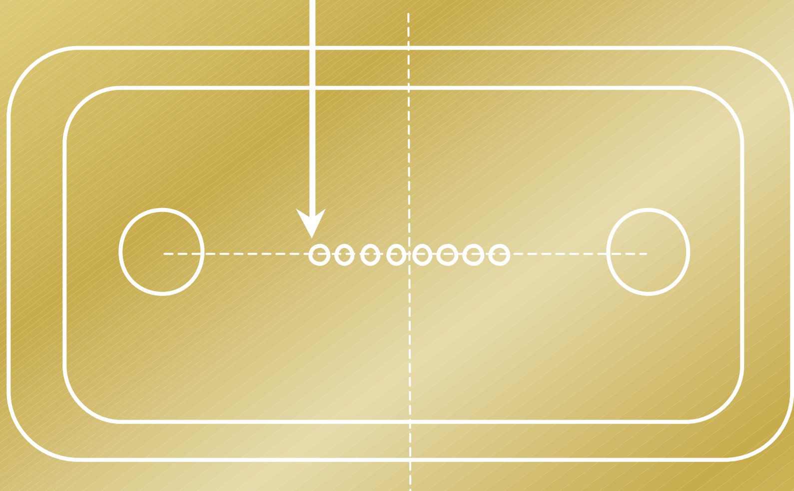
- Need for high fidelity process characterization models
- Incorporate materials and process model predictions earlier in design cycle

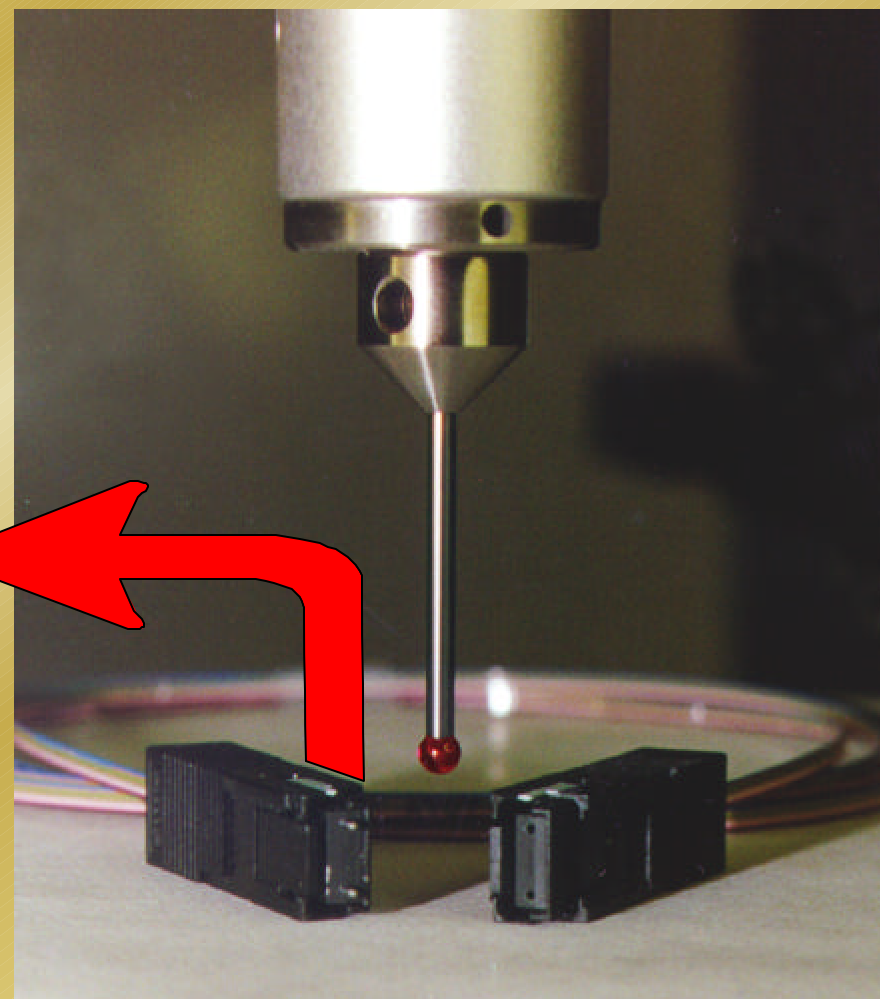
Meso/Micro Metrology

Fine CMM Probe

Diameter: $(125^{+1.5}_{-1.0})$ μm

Position Tol: ± 1.5 μm

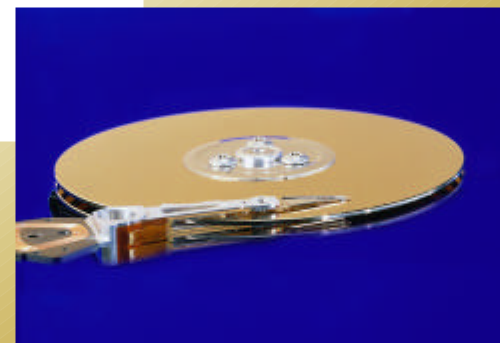




Examples of Industrial and NIST work at Meso-scale

Stents laser micromachined by Potomac Photonics

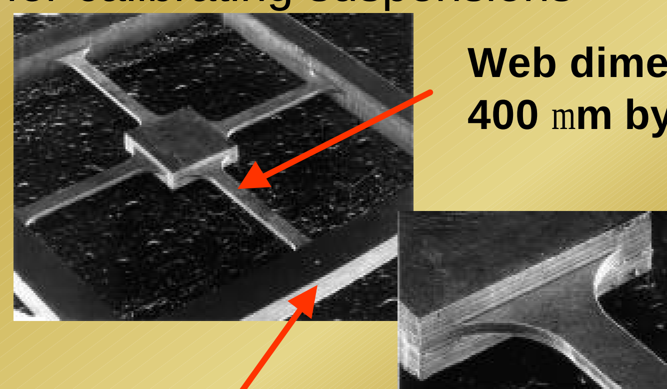
Hutchinson Technology Inc. suspensions for disk drives



μN and nN-m resolution calibration needs

NIST micromechanically machined STM components

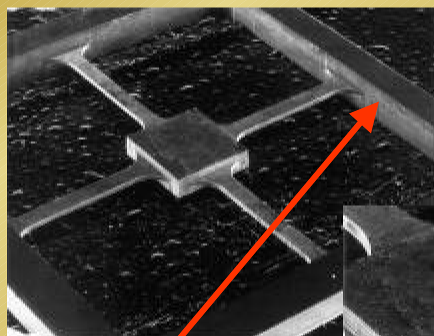
NIST fabricated prototype force transducer for calibrating suspensions

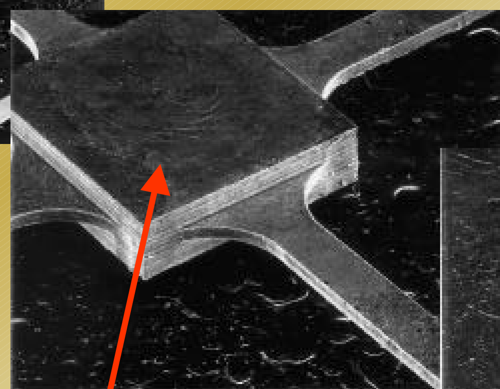


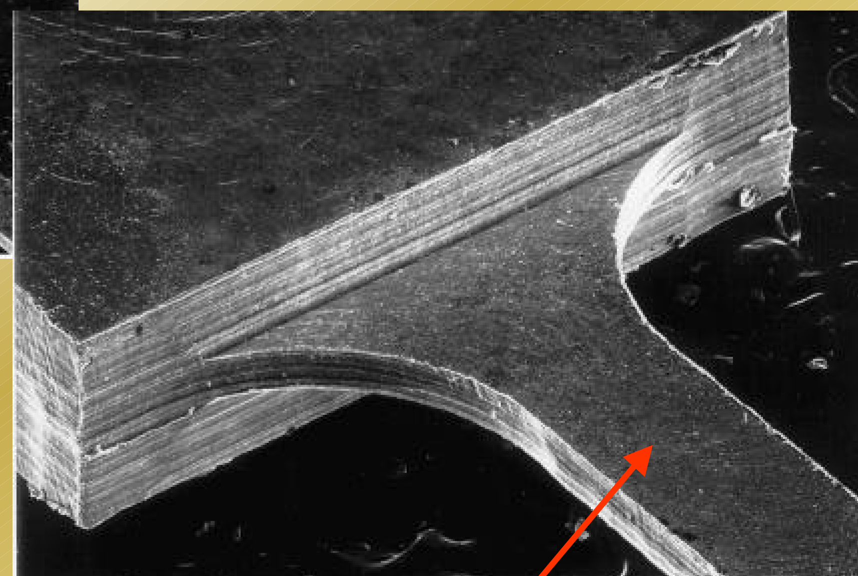
Web dimensions 400 μm by 92 μm

Frame: 10 mm square

Micro-mechanical machining of Force Transducer







Design goals:
Maximum Load : ~40 mN
Maximum Torque: 1.5 mN-m
Resolution: ~10 mN/15 nN-m

Frame:
10 mm square

Pad size:
2mm square

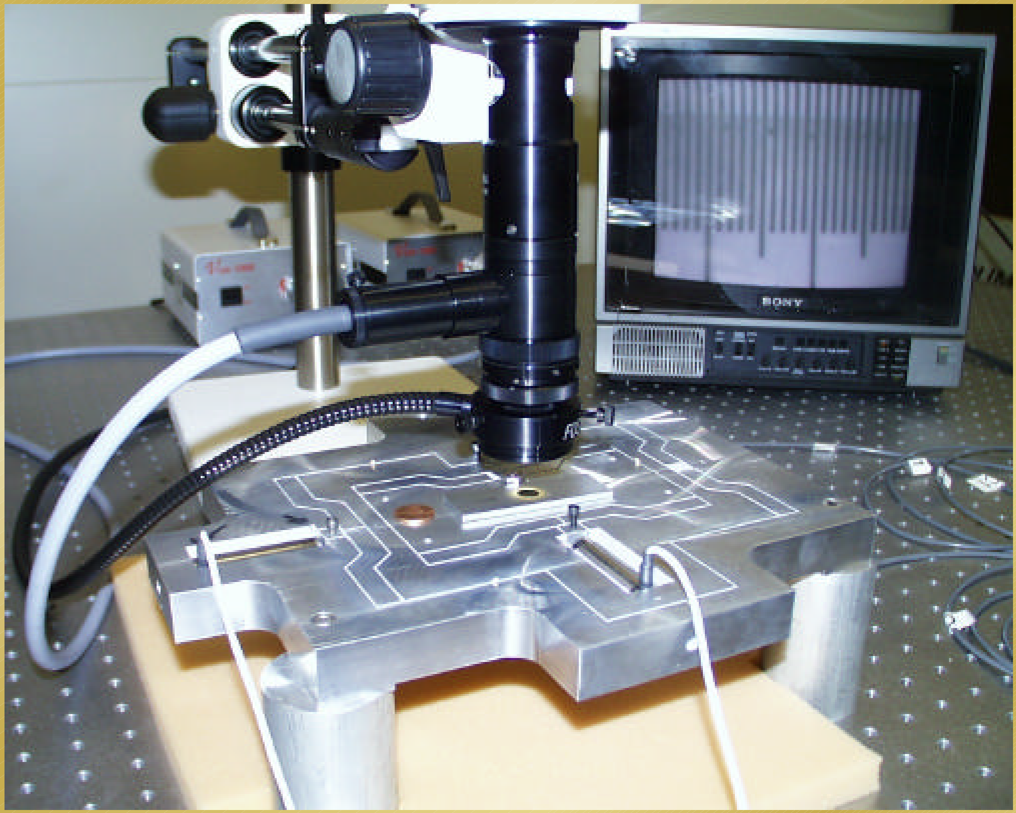
Web dimensions
400 mm by 92 mm

Meso/Micro Assembly and Packaging

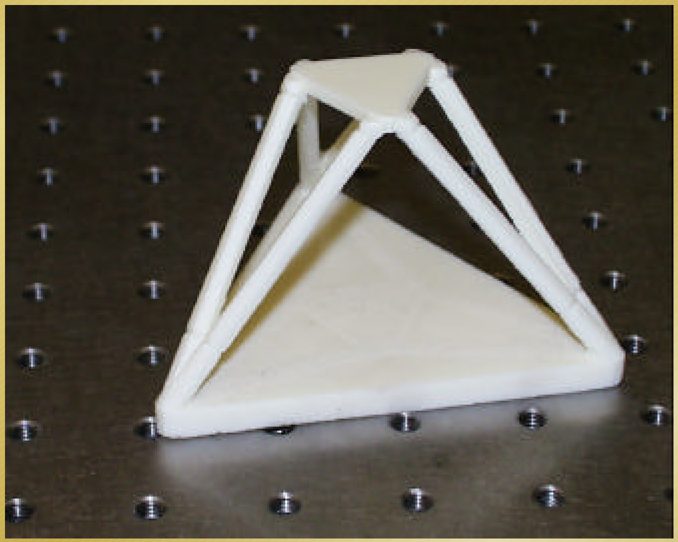
- NIST can provide
  - Information exchange
  - Sensors (measurement technology) for microrobotics and microstages
  - Chemical and materials data
  - Performance measures and testing methods
  - Proactive role in creating interim de facto standards to help US industry, eventually being the catalyst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

Stage Motion Performance Tests

- X-Y Axes Cross Talk
- Angular Error Measurements
- Stage Linearity
- Mechanical Coupling Transmission Ratio



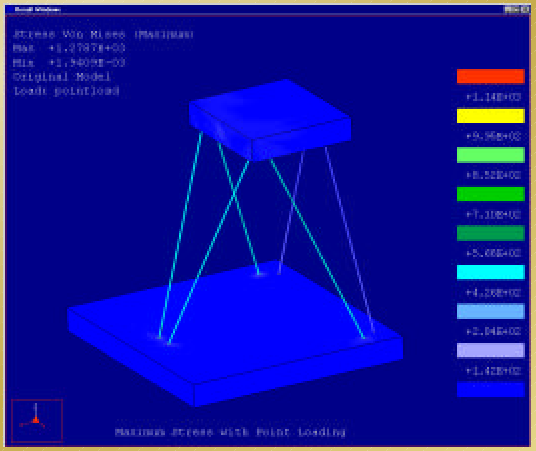
MicroDevices - Performance Measures

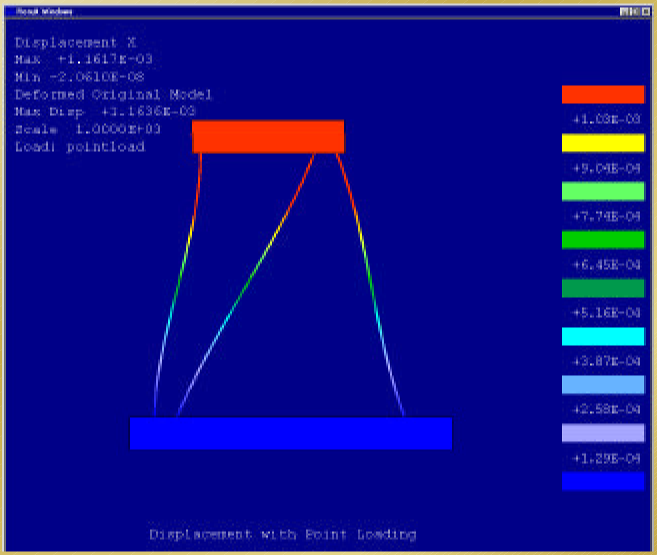


6 Degree of Freedom

Microstage Prototype

Advanced Performance Measures and Design Tools





How we *manufacture* now

- Chemical milling, surface and bulk etching
- Reactive ion etching
- Lithography
- Crystal growth
- Classical mechanical manufacturing at small scales (milling, grinding, stamping, plating, polishing, EDM, etc.)
- Thick and thin film deposition
- Robotics, machine tools, automated process control
- and others...

How will we *manufacture* at the nanoscale?

- Laser and focused ion beam material removal and deposition
- Manipulation and imaging with electron microscopes, scanning tunneling electron microscopes, and atomic force microscopes
- Self assembly

……..but, at some point we have to interface to the macro world: this is a significant technological barrier to adopting nanotechnology to commercial uses.

MEL Strategic Program: Nano Manufacturing

MEL Program Goal

To provide the measurements and standards needed by industry to measure, manipulate, and manufacture *nano-discrete part products*.

Nano-Discrete Part Product

a product having critical part features with dimensions of <= 100 nm
either a single discrete part or an assembly of discrete parts

Industry Need

"A flexible, enabling measurement and standards infrastructure to support the rapid commercialization of new nanotechnology-based discoveries and innovations"

Metrology and Standards Needs

•ability to measure the mechanical and dimensional parameters of nanostructures
•measurement systems with atomic-scale accuracy for length and mass
•new standards for materials, data and tools to assure the quality of the nano-based commercial products.

Manufacturing Needs

•new processes and manufacturing systems for producing nanostructures
•models of basic processes
•manipulation tools (Meso to Nano scale)
•assembly and packaging technologies

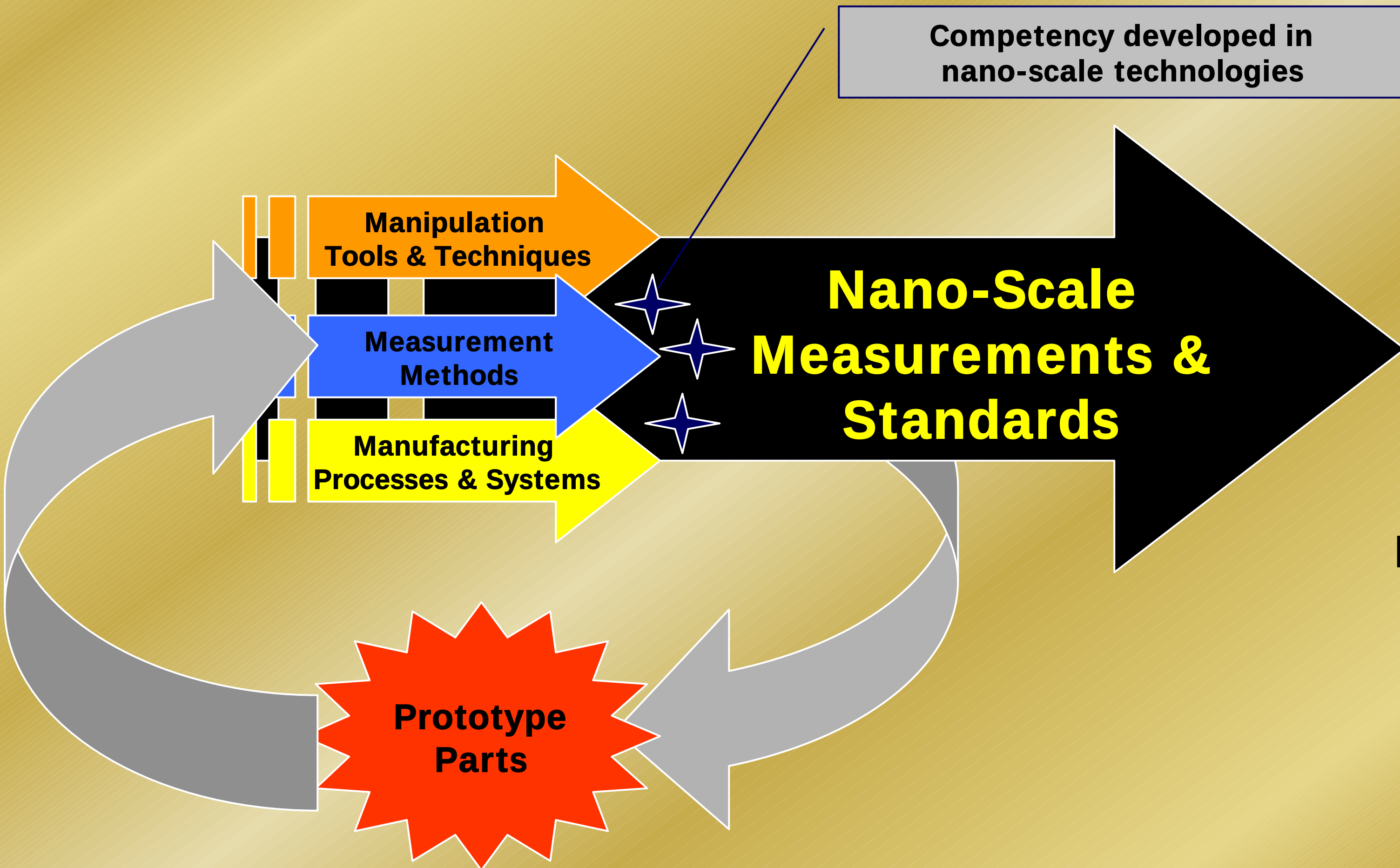
Measure Manipulate and Manufacture

Measure
the mechanical properties of product features with accuracy at the sub-atomic scale (e.g. dimensional accuracy better than 0.1 nm)

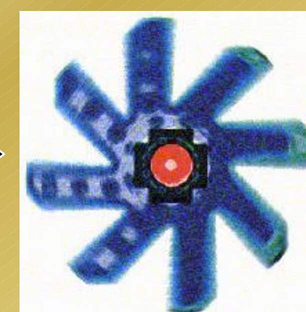
Manipulate
tools that can grasp, position and assemble to sub-nanometer accuracy

Manufacture
the fundamental manufacturing, production and assembly processes of material removal, addition, reshaping and transformation for producing large lot sizes of nano-molecular discrete parts at and below the nanometer level

Program Technical Approach



Prototypes of
Multi-functional Nano-Discrete Parts



Nano-Discrete
Part Products
for Industry

Strategic Approach

Long-term Lab-wide Program

- Parallel Technical Efforts (Measure, Manipulate & Manufacture)
- Produce prototypes of nano-scale discrete parts (Lab on chip)
- Develop competency in critical nano-scale technologies

Collaborative Research Projects

- Built from existing programs & capabilities
- Include NIST Laboratories (BFRL, PL, EEEL, CSTL, MSEL, etc.)
- Identify new opportunities (Industry & Other Gov't Agencies)

Distributed Research Facility

- Leverage equipment and resources
- Develop experimental manufacturing capability
- Provide online data and information

Nano-Manufacturing Research Facility

Characteristics

- geographically distributed
- involves multiple organizations
- real & virtual processes and equipment
- built on NAMT infrastructure
- remote access to
  - Lab Equipment
  - Tools
  - Data

Platform to

- test new measurement methods
- build prototype parts
- experiment with manipulation tools
- prove-out manufacturing processes
- demonstrate program results

Acknowledgements

- MEL Exploratory Project Team listed on the opening slide
- Our colleagues in ATP, CSTL, EEEL, MSEL, PL, BFRL and MEL at NIST to numerous to mention whom participated and contributed to our findings.
- DARPA/NIST workshop:
  - Kevin Lyons, former DARPA Program Manager (currently at NIST)
- NIST/NSF workshop organizers:
  - Dr. Robert Hocken, Director of the Center for Precision Metrology at the University of North Carolina, Charlotte
  - Dr. Ming C. Leu, Program Director of NSF’s Manufacturing Processes and Equipment program
  - Dr. John Evans, Chief of the Intelligent Systems Division, MEL, NIST
  - Dr. E. Clayton Teague, Chief of the Automated Production Technology Division, MEL, NIST
- Companies/Laboratories we visited, including, but not limited to: Remmele Engineering, Honeywell, Hutchinson Technology, Professional Instruments, MicroFab Technologies, M-DOT, Sandia Microelectronics Laboratory, UC Berkley, NIST Boulder Optoelectronics Division, Fanuc Berkley Research Center, Adept Technology, Johns Hopkins / Applied Physics Lab, Potomac Photonics, Intuitive Surgical, Inc.

For more information:

- Information posted on our website:
  - Final Report on Micro-Meso Scale Manufacturing Exploratory Project
  - Workshop proceedings:
    - Manufacturing Technology for Integrated Nano- to Millimeter (In2m) Sized Systems, March 1999
    - Manufacturing Three-Dimensional Components and Devices at the Meso and Micro Scales, May 1999

http://www.isd.mel.nist.gov/meso_micro/