Nanoenabled Directions for N/MEMS

MTO Symposium

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DARPA MTO

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A MTO Nanotechnology Vision

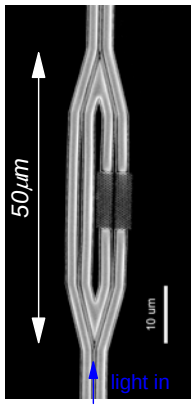
Nanotechnology Enabled Opportunities

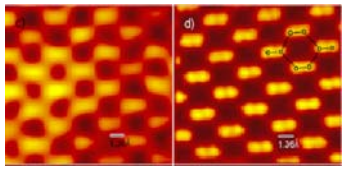
- **Chip-Scale Microfluidic Analyzers**
- **Nanosensors**
- **Nanowires for Sensors and Electronics**

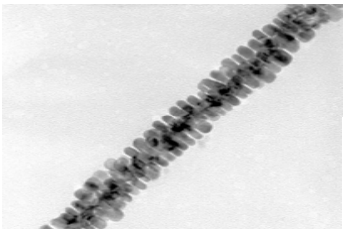
Nanotechnology and N/MEMS

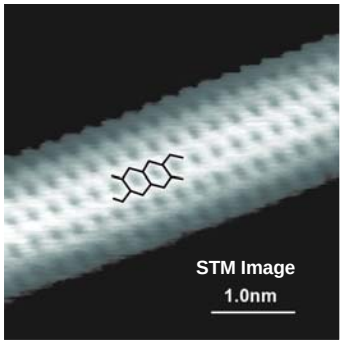
Two key themes:

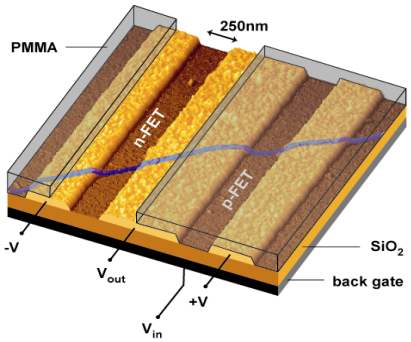
- **Nanotechnology enables new applications and drives performance**
- **Nanotechnology is emerging as a key aspect of integrated microsystems**

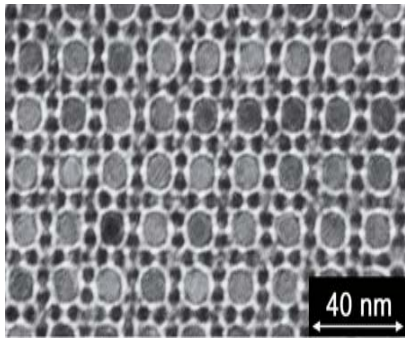


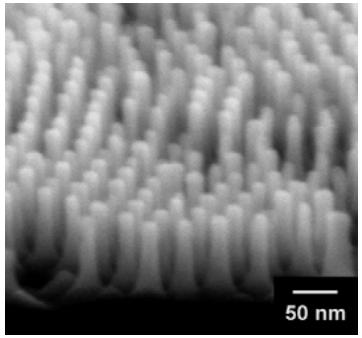


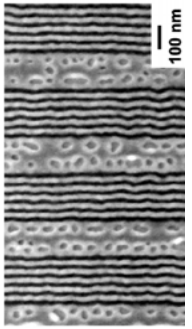


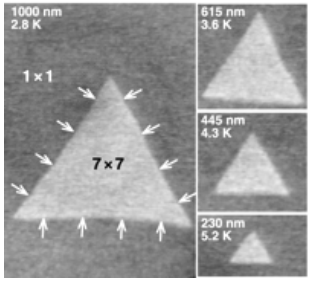


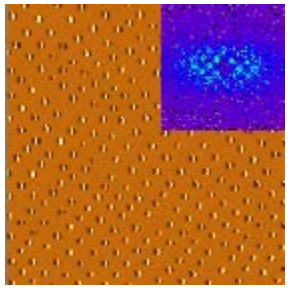


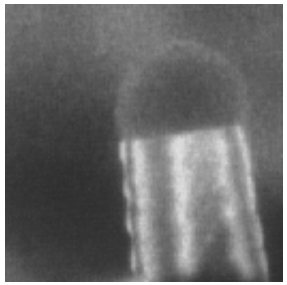


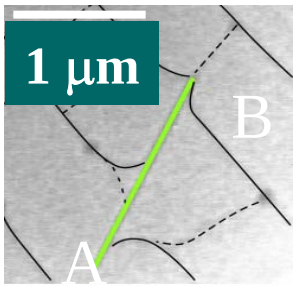


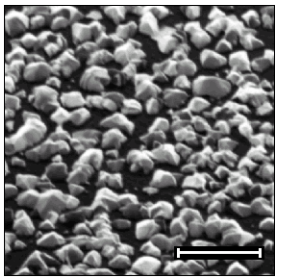


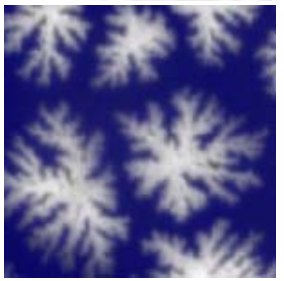






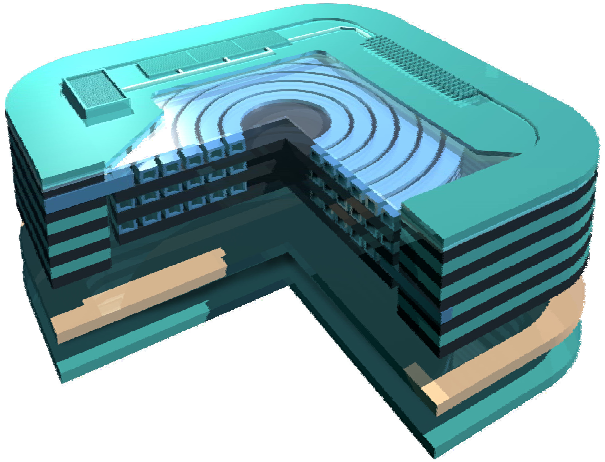






Images courtesy of Philip Wong, Stanford University

N/MEMS Program Examples

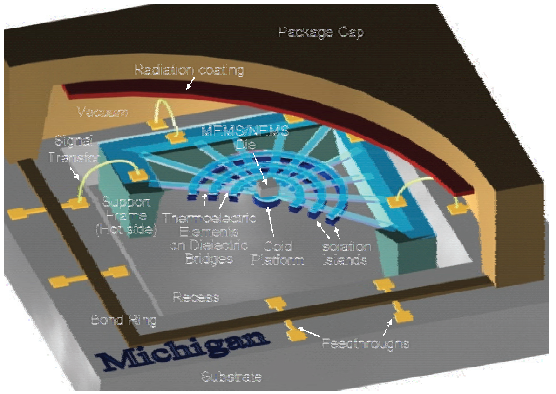


Micro Gas Analyzers

- CNT Preconcentrators
- Nanomechanical Sensors
- CNT Detectors
- Functionalized Chemiresistors

N/MEMS S&T Fundamentals

- CNT Sensors
- NEMS Biosensors
- Nanoresonators
- Reconfigurable Nanoelectronics



Micro Cryogenic Coolers

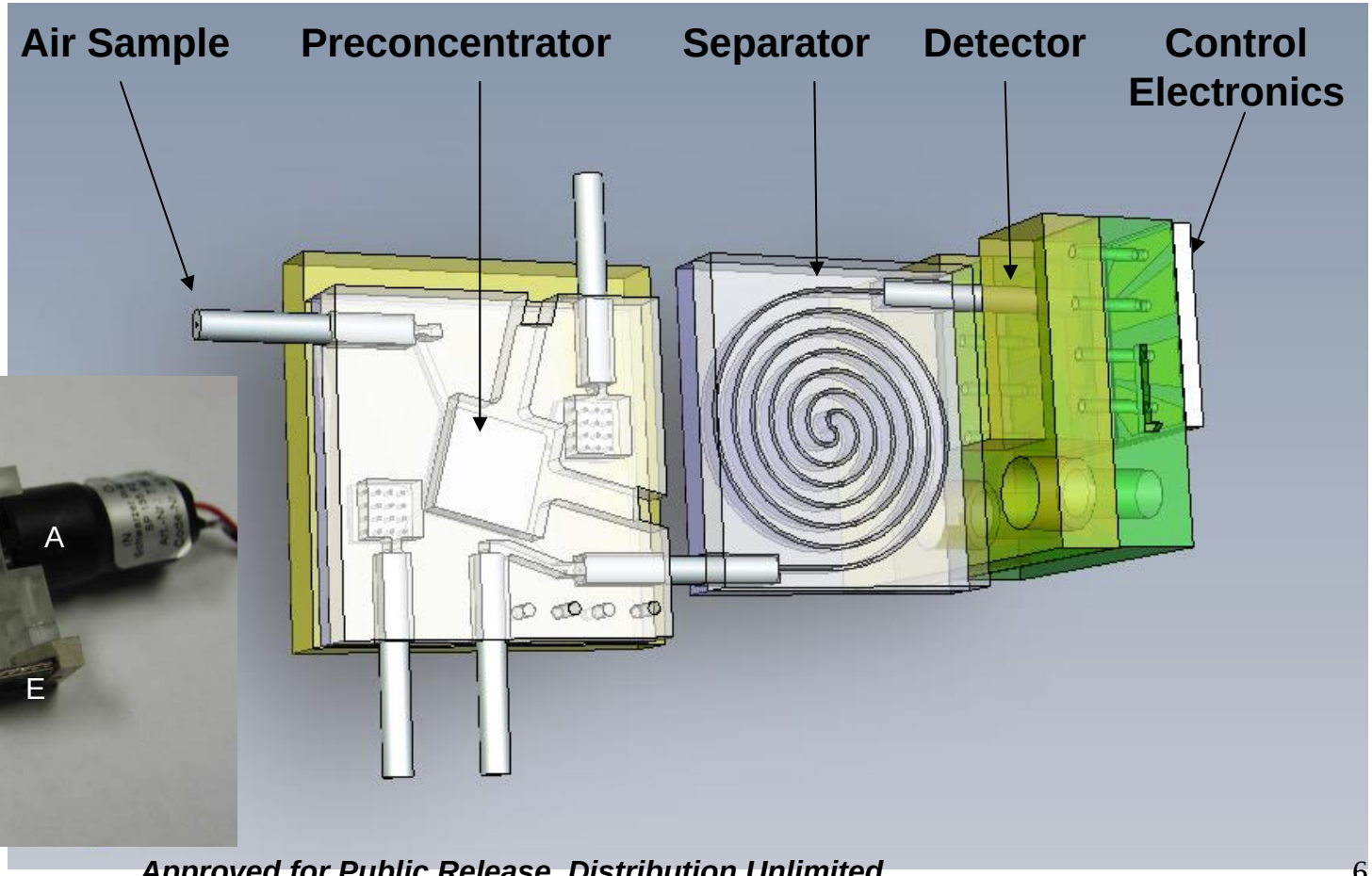
- Thermal nanostructures
- Nanoenabled cryogenic cooling

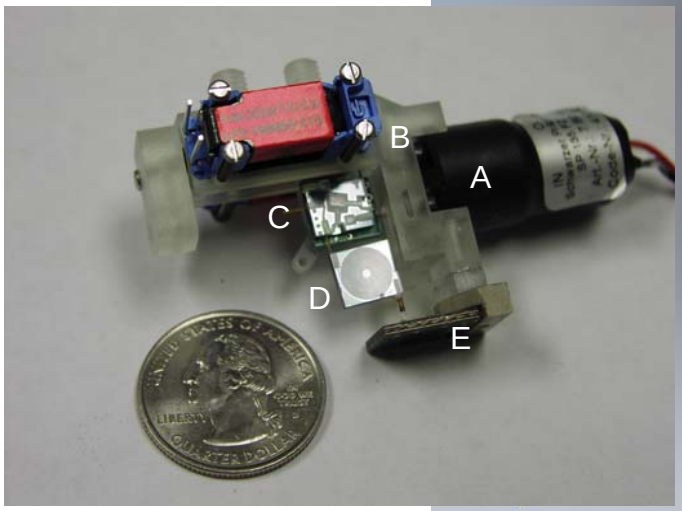
Chip-Scale Gas Analyzers Program

- ***Objective***:
  Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.

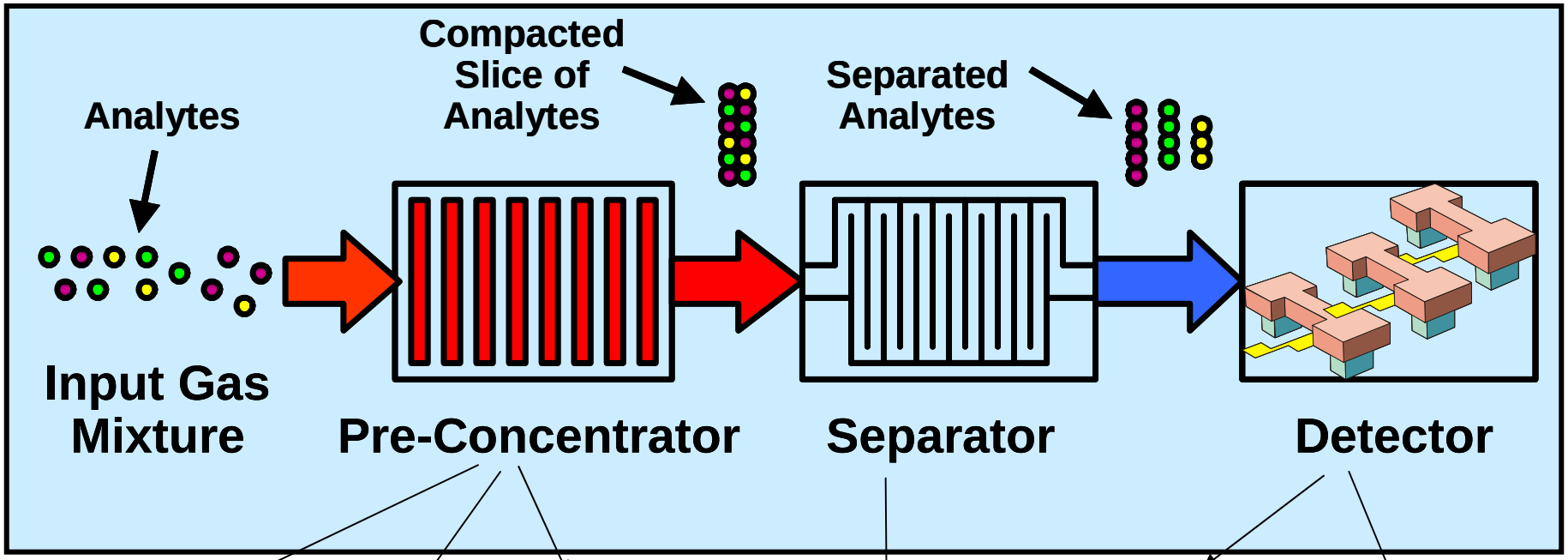
Sugar Cube – Size Instrument

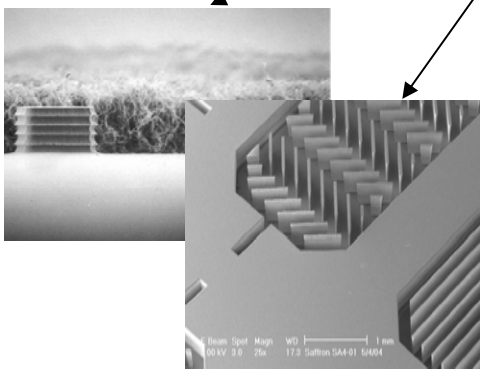
- ***Objective***:
  Enable remote detection of chemical agents via tiny, ultra-low power, fast, high sensitivity, chip-scale gas analyzers with low incidence of false positives.

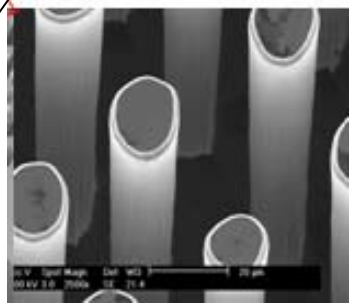


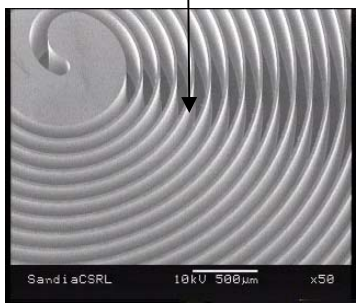


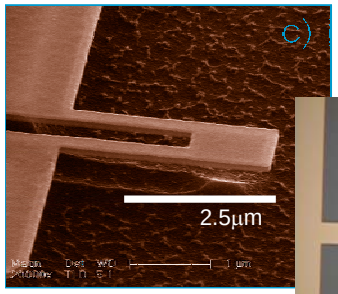
Integrated N/MEMS Components

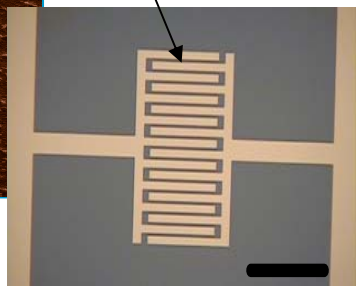










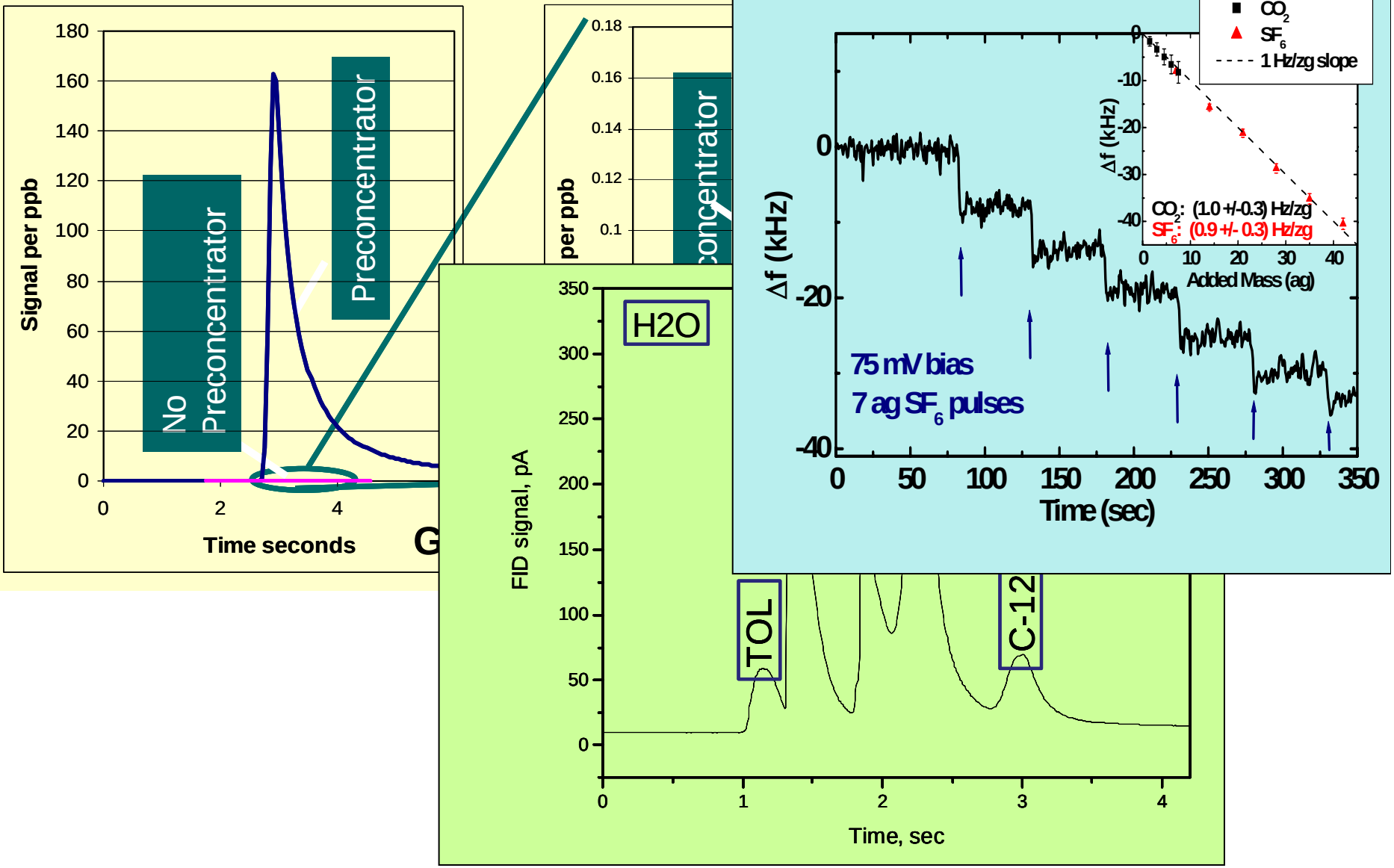


- Very high effective surface area
- Chemical functionalization

- DRIE
- Chemical polishing

- Low proff-mass
- Chemical functionalization

Enhancement of Performance



Nanotechnology Benefit

Nanotechnology Lessons Learned:

- **Nanotechnology and MEMS (a terrific combination!)**

  Size: 40,500 cm^3 → 20,000X → 2 cm^3

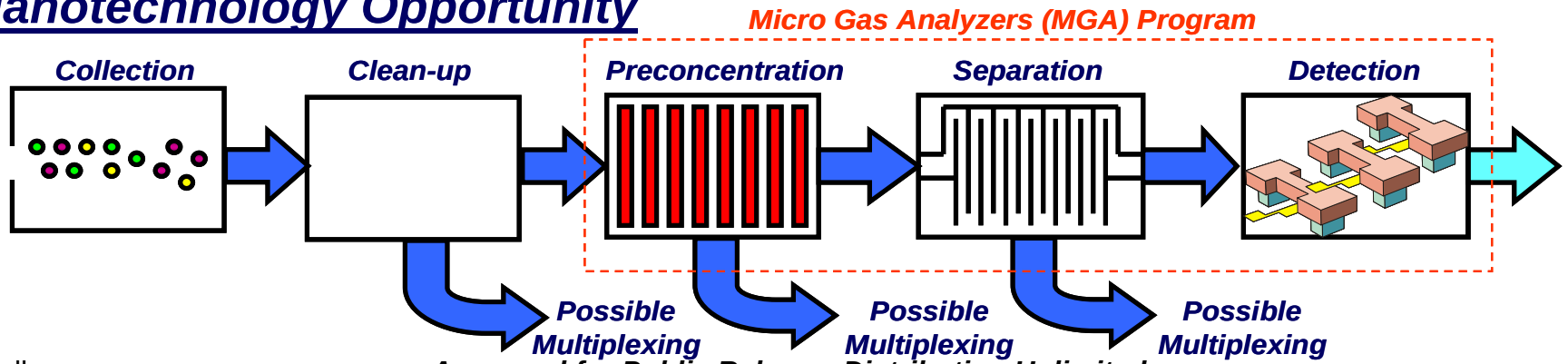
- **Nanotechnology enables systems with unprecedented performance:**

  Sensitivity: 1 ppb → 1,000X → < 1 ppt

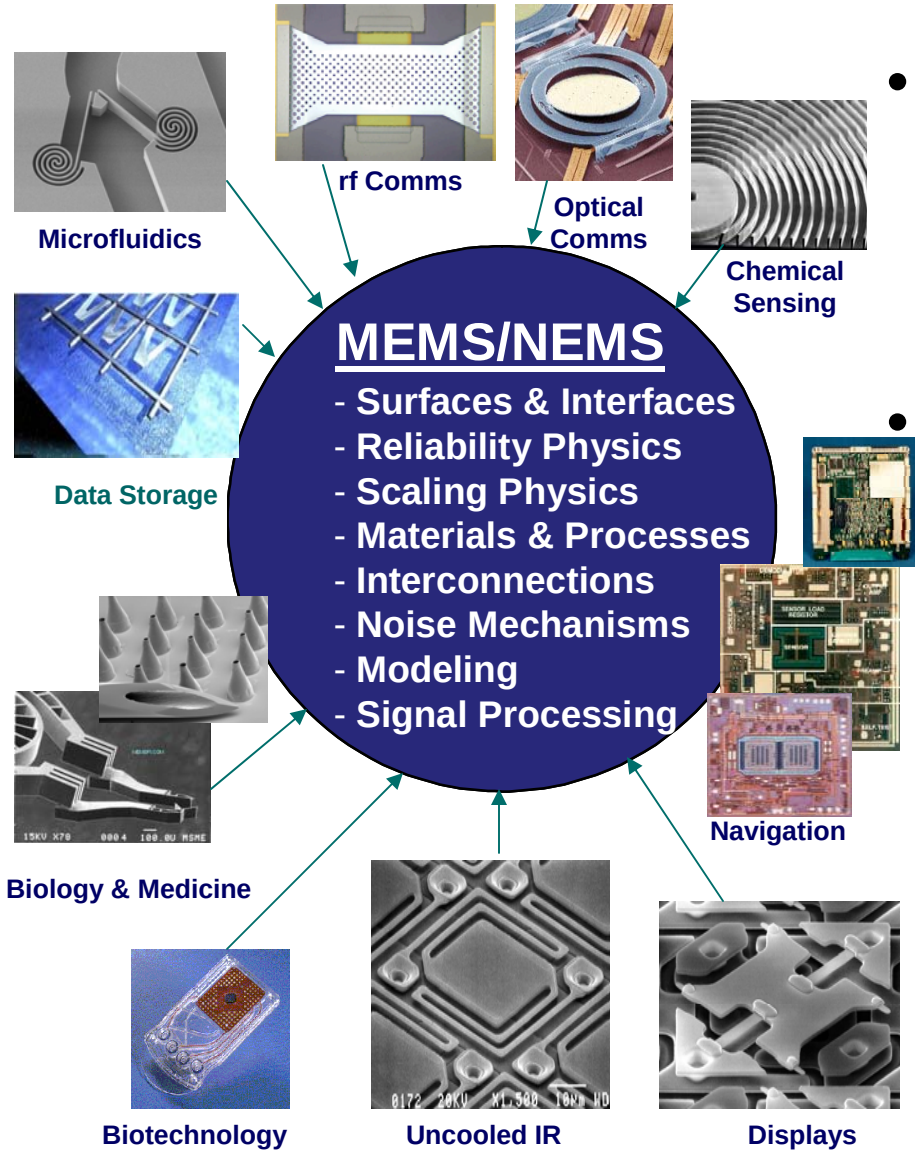
  Analysis time: 15 min → 225X → 4 s

  Energy per analysis: 10^4 J → 10,000X → 1 J

Nanotechnology Opportunity



N/MEMS S&T Fundamentals



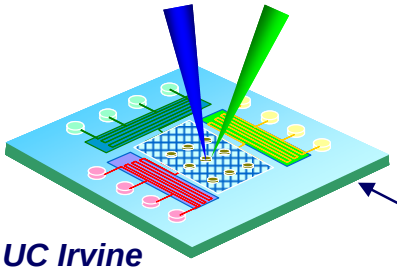
- **Goal:**
  - **Support basic research of importance to DoD in N/MEMS**
- **Technical Challenges**
  - **Failure Mechanisms and physics**
  - **New materials and processes**
  - **Scaling laws in multiple domains**
  - **Interfaces and interconnects between the macro-micro-nano worlds.**

N/MEMS S&T Fundamentals

MEMS/NEMS

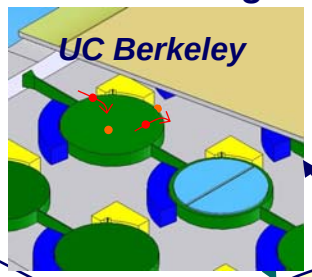
- Surfaces
- Interfaces
- Reliability
- Scaling
- Materials
- Fabrication
- Modeling
- Nanostructures

Microfluidic Processors

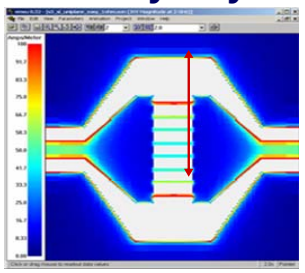


UC Irvine

RF Scaling



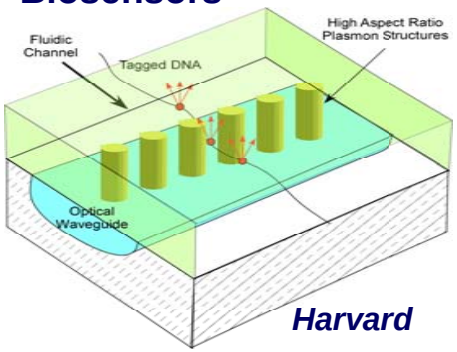
Reliability Physics



UC San Diego

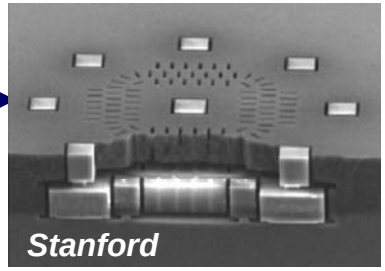
Non-lithographic Fabrication

Biosensors

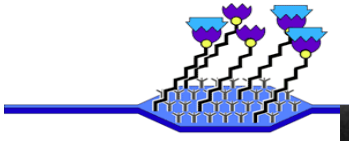


Harvard

Materials Interfaces

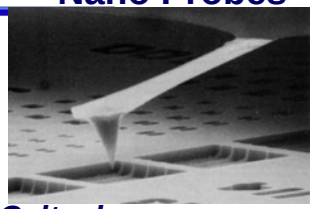


Functionalized Surfaces



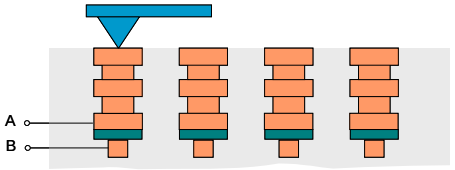
Cornell

Nano Probes



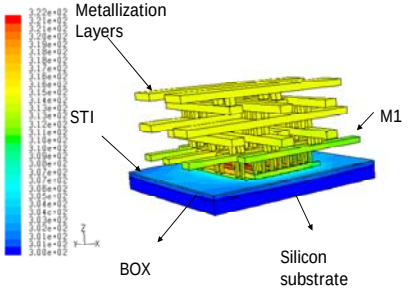
Caltech

Self-Configuring ICs



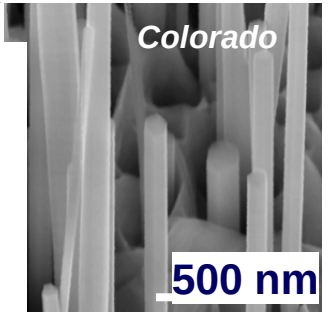
Carnegie Mellon

Multi-Physics Modeling



Illinois

Nanowire Sensors



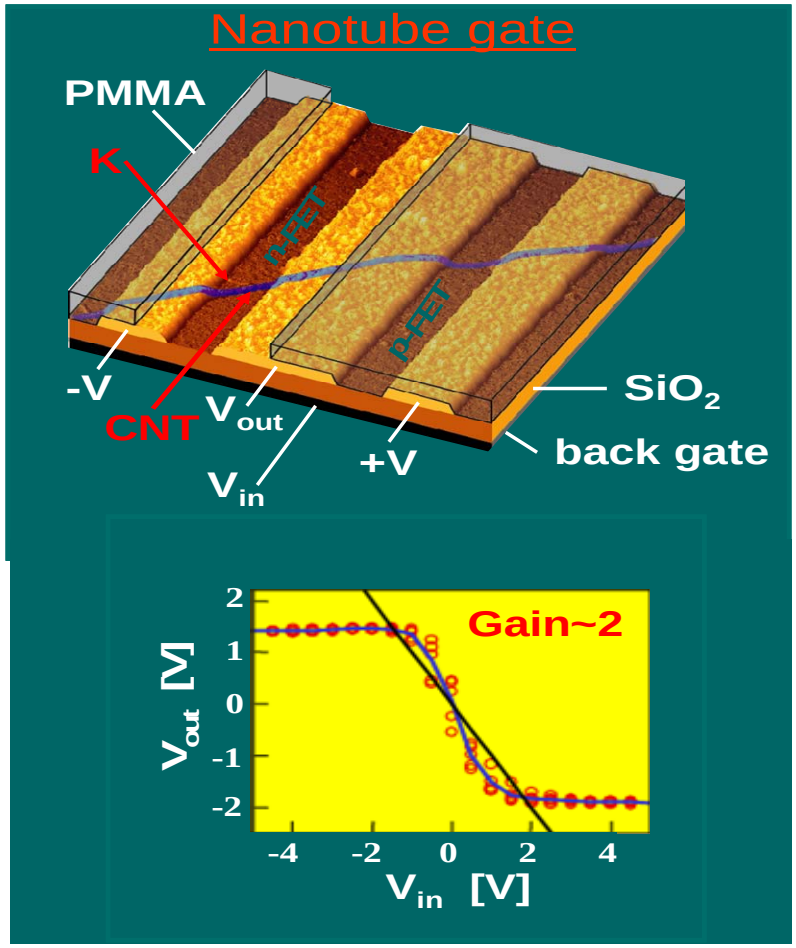
Nanotechnology Vision

Six Nanoenabled Opportunities

1. **Nanoenabled Electronics**
2. **Nanoenabled Informatics**
3. **Nanoenabled Biotechnology**
4. **Nanoenabled Plasmonics and Photonics**
5. **Nanoenabled Sensors**
6. **Nanoenabled Energy**

Nanoenabled Electronics

Nanowire Electronics



Key Challenges

- Controlled Growth
- Selective Placement
- Interconnections

Self-Configuring Electronics

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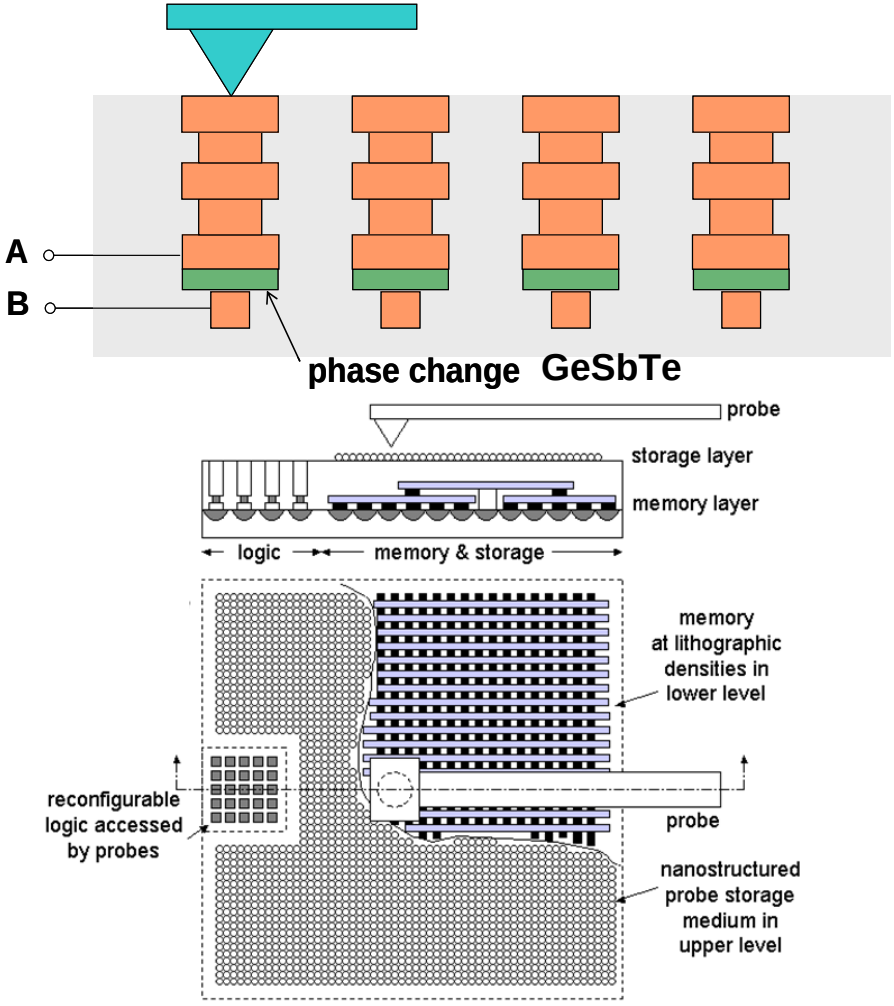

T. Schlesinger, DARPA
N/MEMS S&TFundamentals, CMU.

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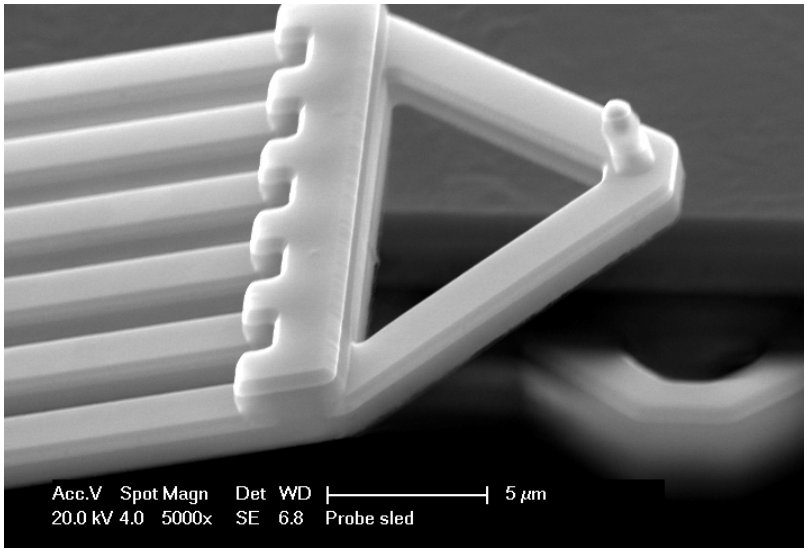
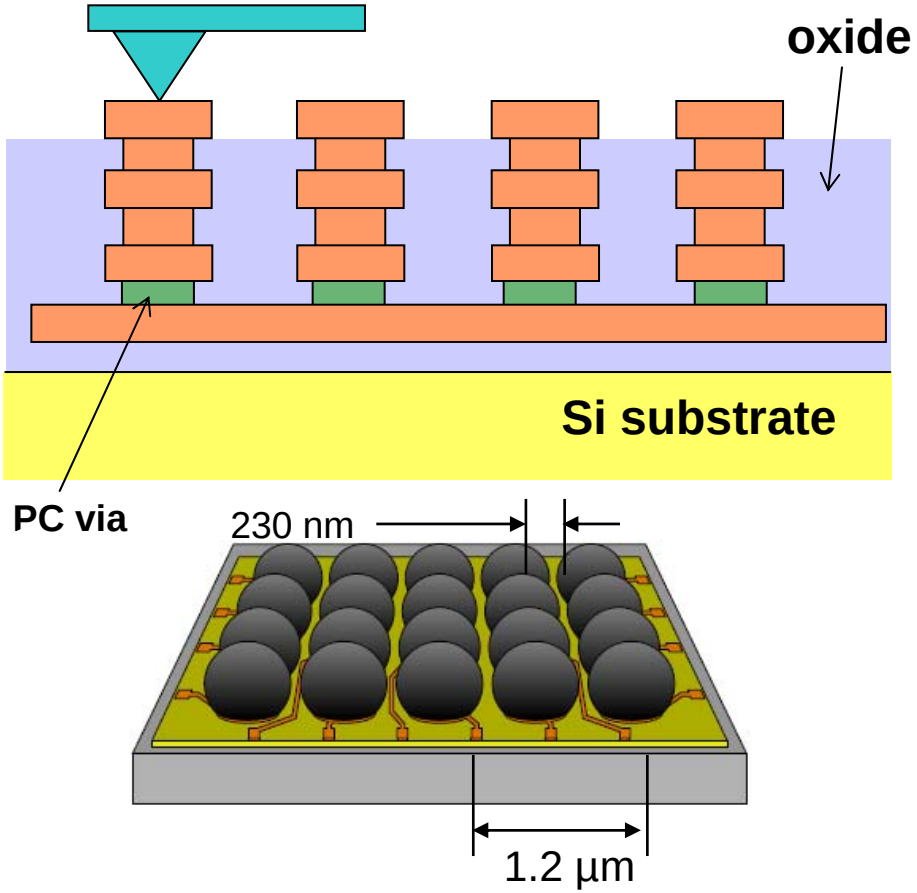
Self-Configuring ICs

- NEMS Thermal Actuators
- Designed-in stress gradient
- 3 µm post, 230 nm tip area



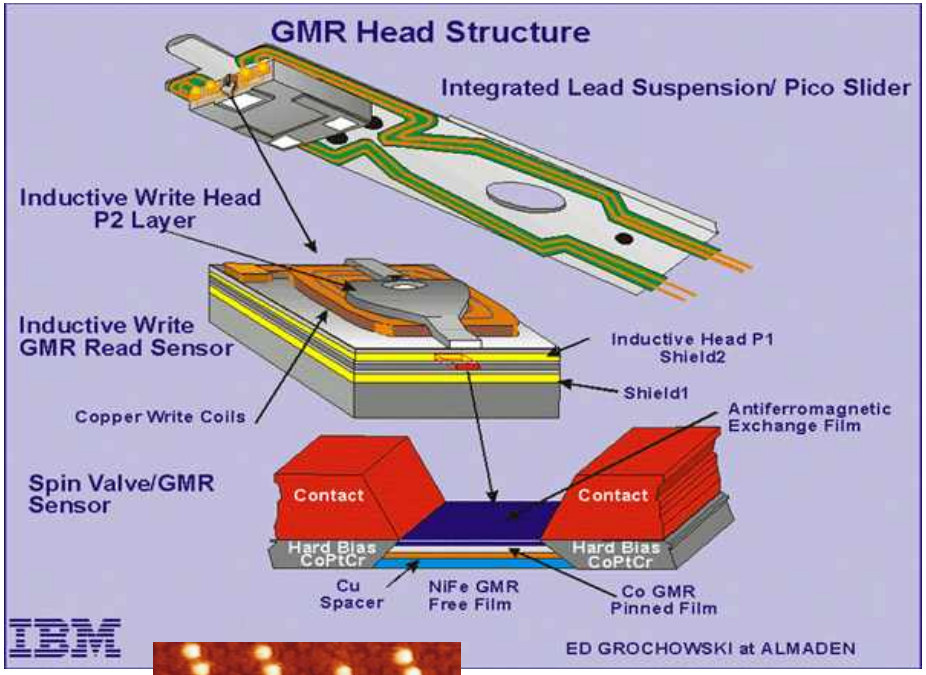


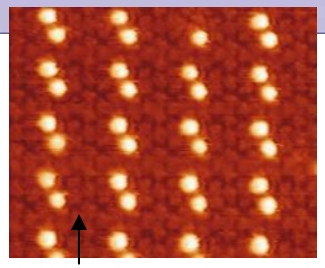
Imagine… Dynamically changing the basic function of an electronic chip according to current need.

Nanoenabled Informatics

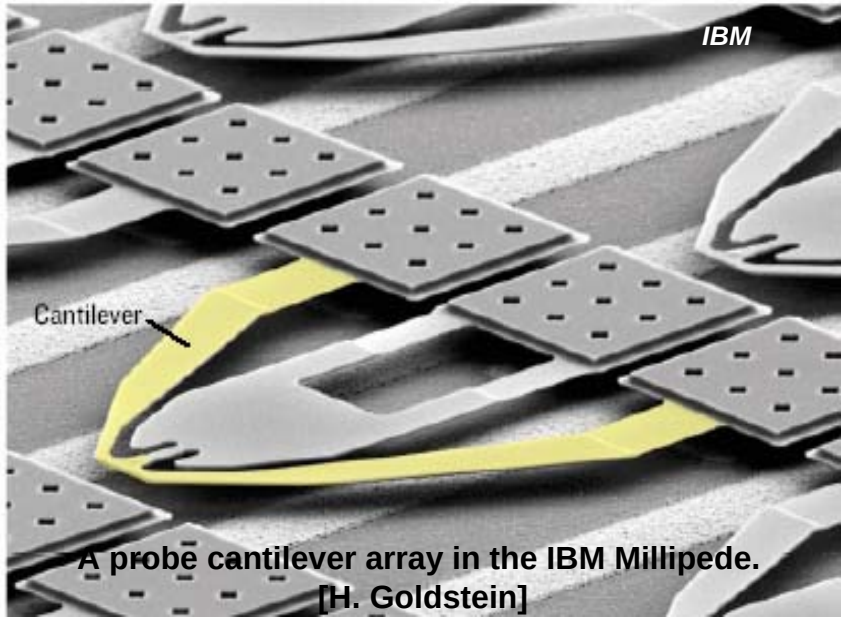
Storage Media

Feature size reductions dramatically increase the capacity of storage media. Nanotechnology enables future optical and magnetic storage.





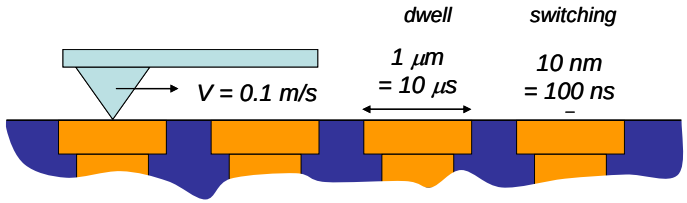
Nanomechanical Memory



A probe cantilever array in the IBM Millipede. [H. Goldstein]

Key Aspects

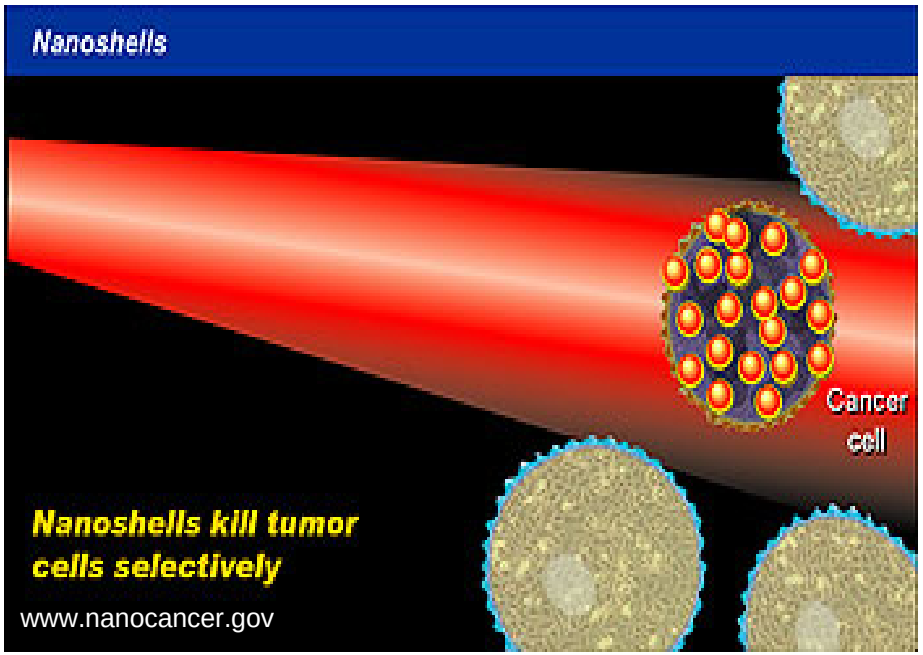
- MEMS probes used for media read/write
- 3 Tbits/inch2 demonstrated



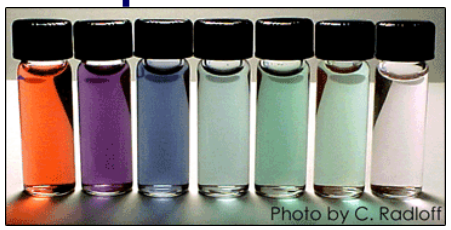
Nanoenabled Biotechnology

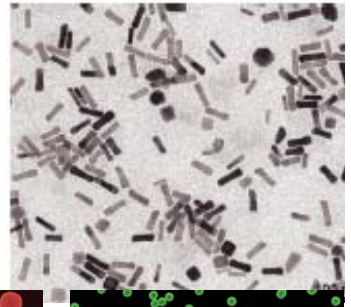
Medical Therapeutics / Drug Delivery

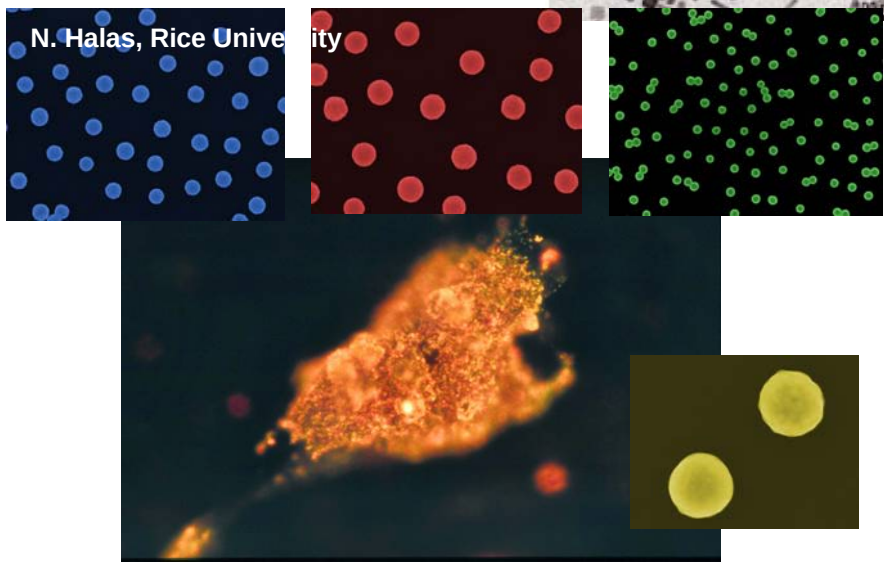
Therapeutic nanoparticles can be targeted to specific biological sites.



Nanoparticles



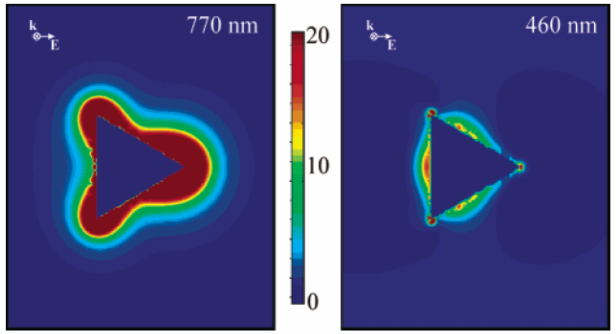


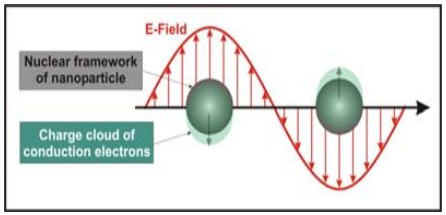


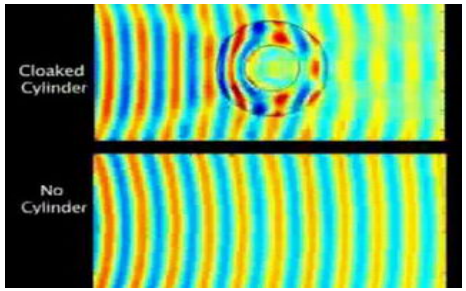
Imagine… Site specific targeting of nerves with therapeutic nanoparticles that enhance sensory perception.

Nanoenabled Plasmonics/Photonics

Plasmonics

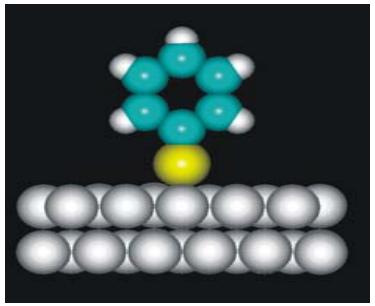






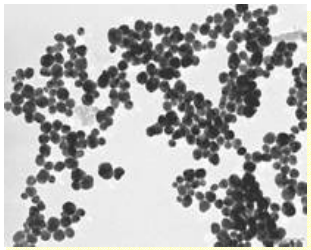
Key Challenges

- Control of EM-field Enhancement
- Materials properties

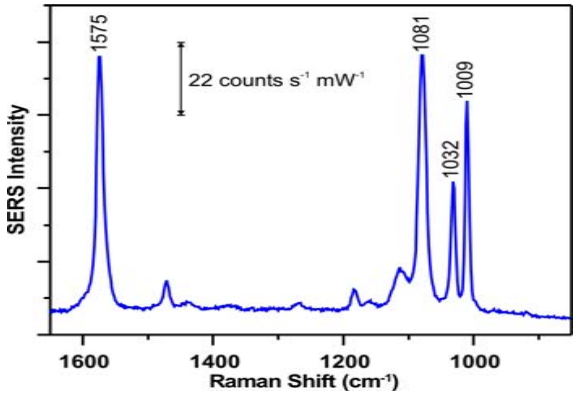


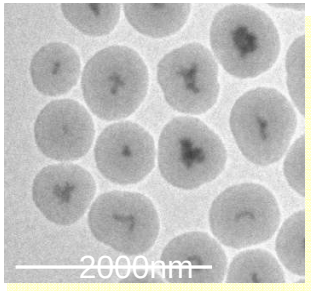
SERS Nanosensors

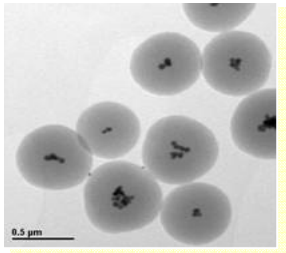
Basic physics and materials science associated with SERS nanoparticles as physical, chemical, and biological nanosensors



Spectral finger-printing
- **sub-ppt sensitivity**
- **P_D> 99.99%**
- **FAR < 1:10^9**
- **Fast response < 1 s**



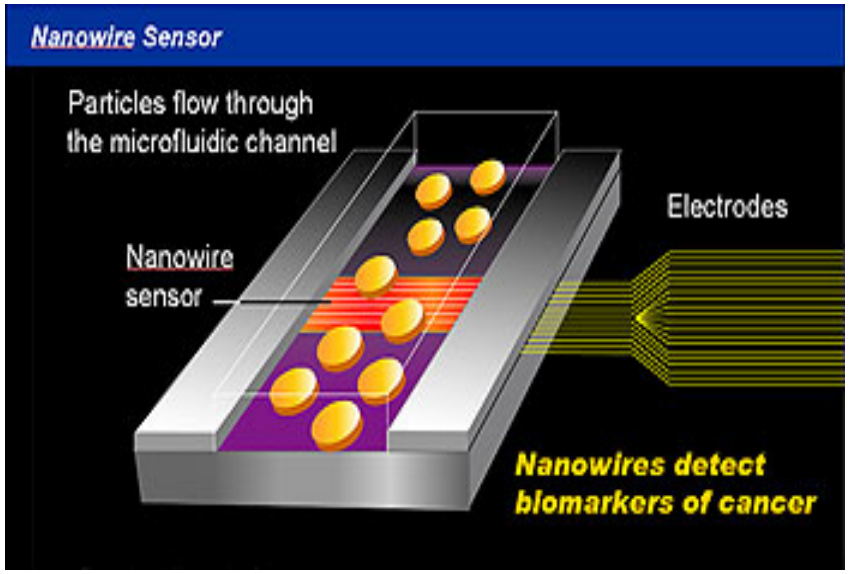




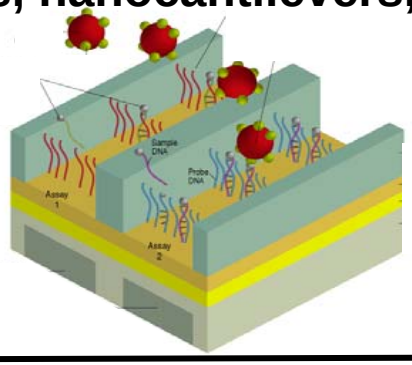
Imagine… Nanosensors with ppq sensitivities and no false alarms.

Nanoenabled Sensors

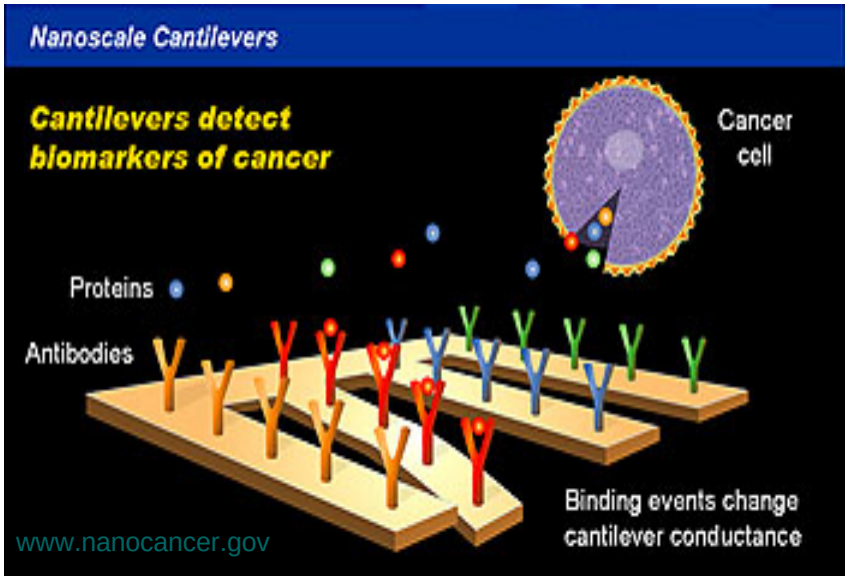
Nanowire Sensors



- **Nanowires, CNTs, nanocantilevers, nanoparticles, quantum dots, nanoporous, magnetic materials**



Nanomechanical Sensors

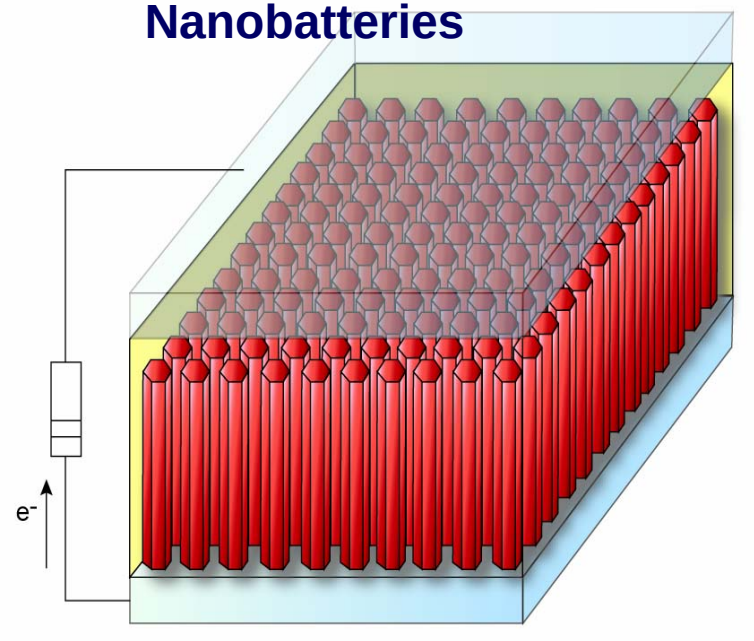


- **Application examples:**
  - **Gas sensing**
  - **Protein/DNA detection**
  - **Particle detection**
  - **Chemical detection**
  - **Signal amplification (e.g.SPR)**

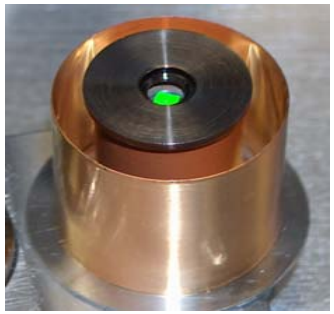
Imagine… Integrated multi-functional nanosensor modules capable of multiplexed bioanalysis and physical sensing.

Nanoenabled Energy

Nanobatteries

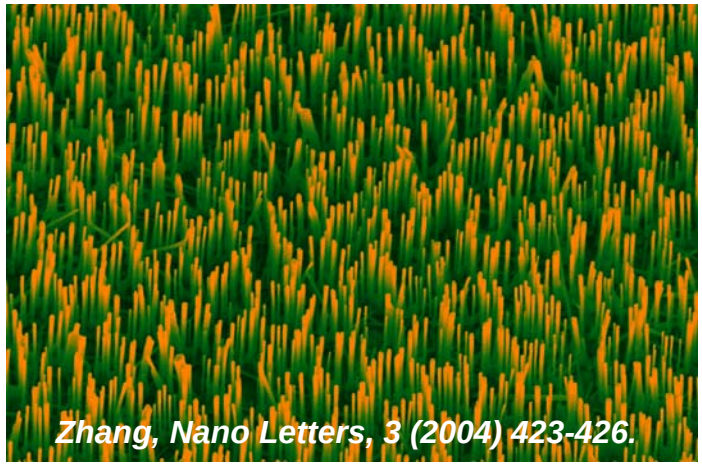


ZhangP. Yang, U.C. Berkeley

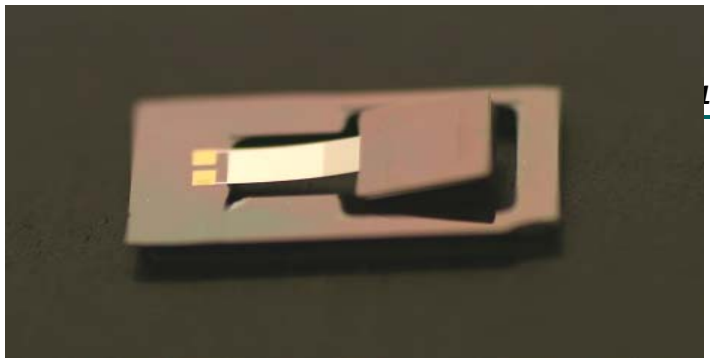


Sandia National Laboratories Thermo-photovoltaic Power Converter

Piezoelectric Energy Scavengers



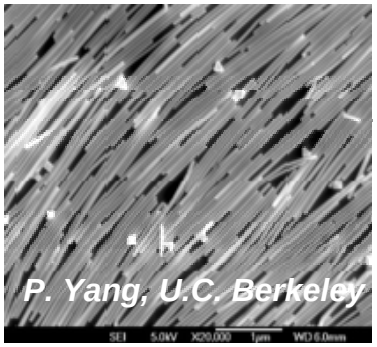
Zhang, Nano Letters, 3 (2004) 423-426.



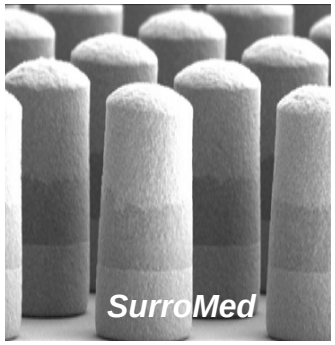
Cornell Prototype MEMS Continuous-Mode Piezo-Cantilever Beta converter

Imagine… Never having to replace a battery.

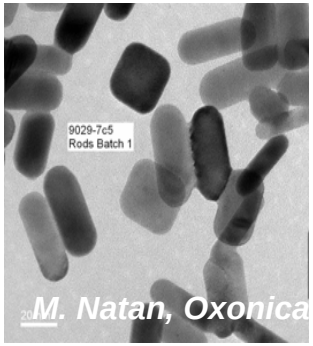
Nanowires for Sensors & Electronics

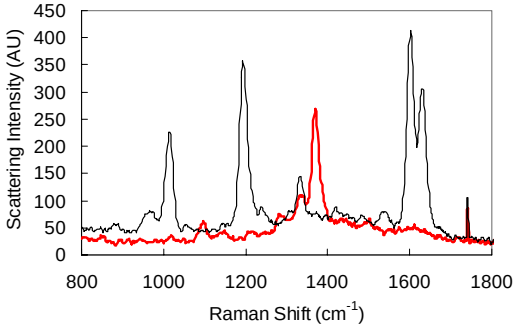


Ag nanowires for explosives detection

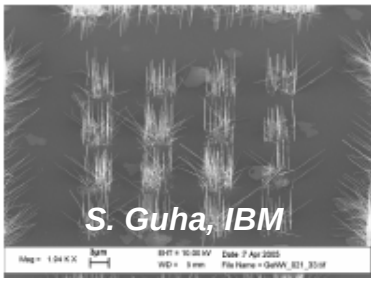


Encoded nanowires

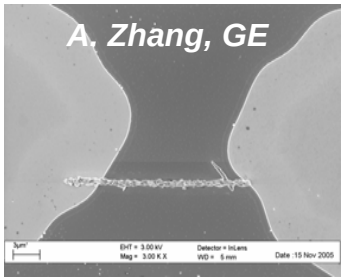




Au nanowires for multiplexed bioanalysis



Vertical selective growth of Ge nanowires for sensor and electronics applications



Assembled Co nanowire

- **Goal:**
  - **Develop new chemical, and biological nanosensors based on nanowires**
- **Applications**
  - **All types of sensing**
  - **Energy harvesting**
  - **Thermal management**
  - **New class of nanosensors for the detection of biochemical warfare agents.**

Lessons Learned

What are the opportunities for nanotechnology?

1. **Largest opportunities for nanotechnology are in enabling new systems**

2. **Look to nanotechnology to enable performance; not drive down cost.**

3. **Nanotechnology apps are best driven from top-down not bottom-up.**

4. **Multi-domain scaling is the key to performance-driven nanotechnology.**

5. **World competition is intense. Success in nanotechnology requires a vision, patience, and entrepreneurial spirit.**

Summary

Many, many new challenges remain (Challenge = Opportunity)

Microfluidic Analyzers

- Preparation (nanostructures)
- Preconcentration (nanochem)
- Nanoanalytics
- Nanodetectors (multiplexing)

SERS Nanosensors

- Enhancement Factor (EM)
- Substrates
- Geometries
- Porous nanoparticles

Nanowires

- Nanosensors
- Nanosolar cells
- Nanoenergy scavenging
- Thermal interfaces

dpolla @ darpa.mil