DEFENCE R&D DÉFENSE

Marching Towards Smallness

Presented by S. Désilets, P. Laou and F. Wong

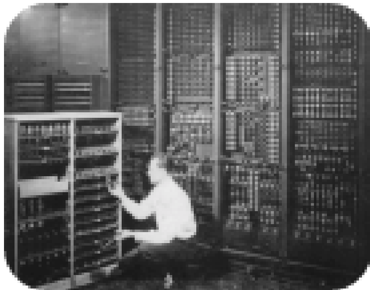
Potentially Disruptive Technologies Symposium

14-15 April 2003

Defence Research and Development Canada
Recherche et développement pour la défense Canada

Canada

Marching Towards Smallness



1940's 10^3 ops, 1000 sq. ft.

1980's 10^5 ops, 10 sq. ft.

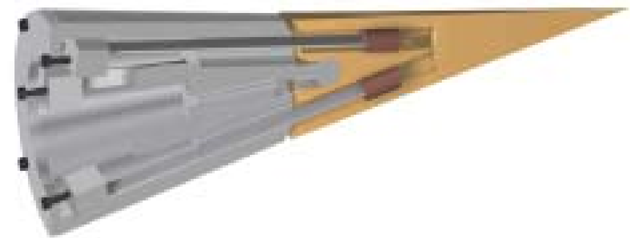
1990's 10^7 ops, 1 sq. ft.

2000's 10^9 ops, 0.1 sq. ft.

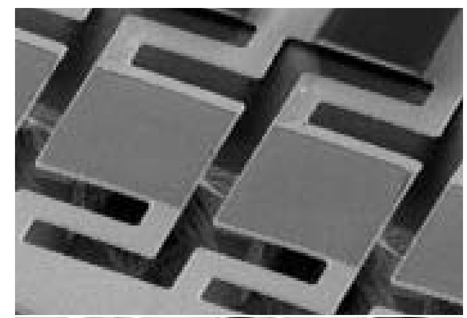
Emergence of miniaturized electronics and computers has radically altered military equipment design and capability.

Outline

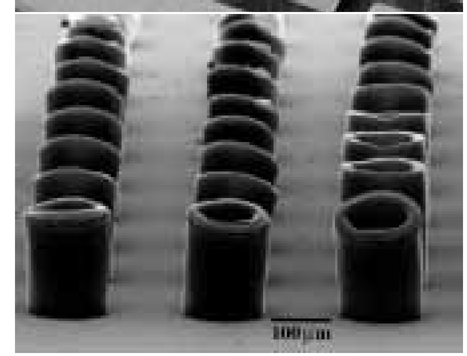
- How small is small?
- Adaptive Aerostructures
  (F. Wong)



- Micro-electromechanical Systems
  (P. Laou)

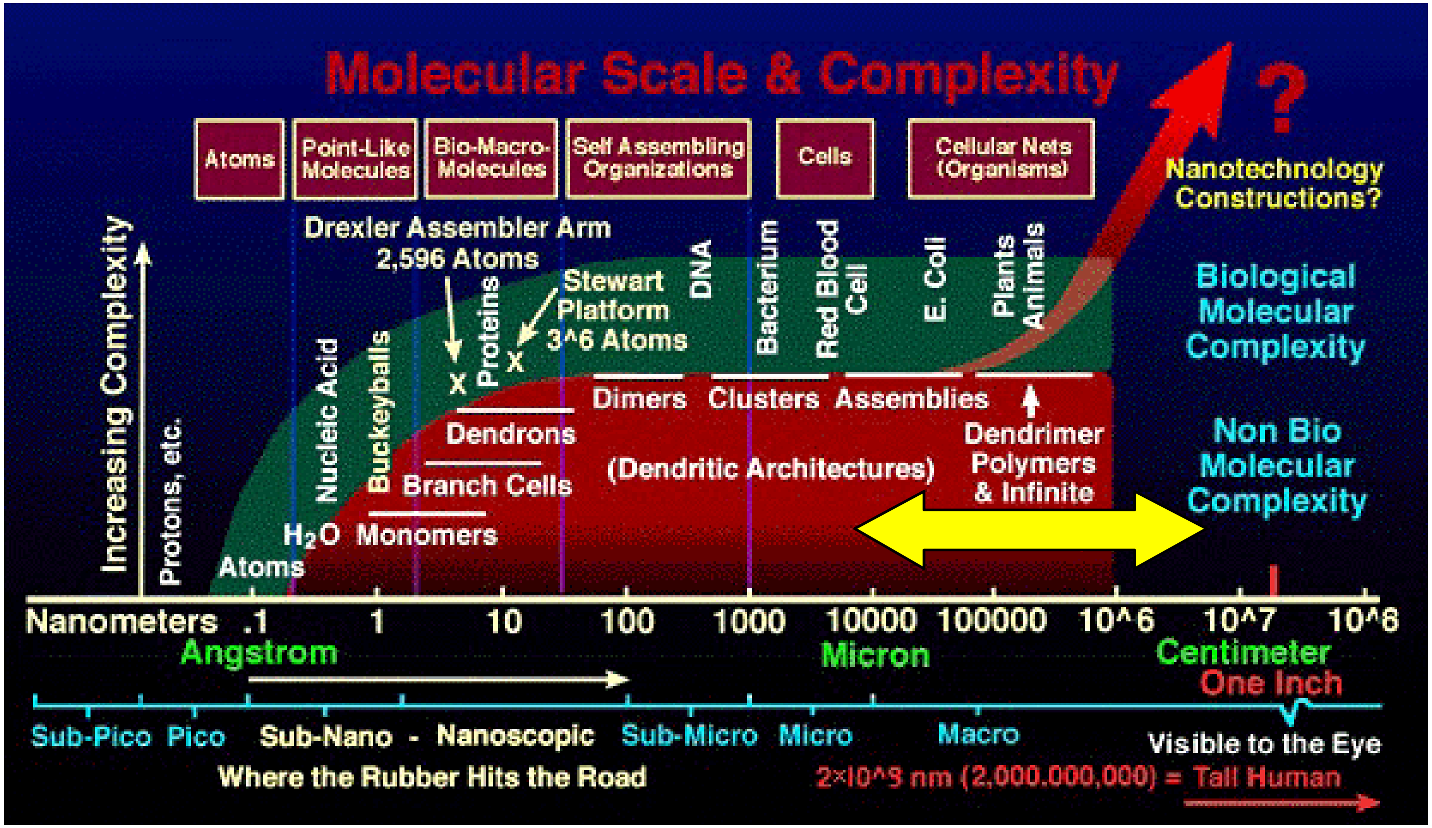


- Nanomaterials
  (S. Désilets)



- Summary

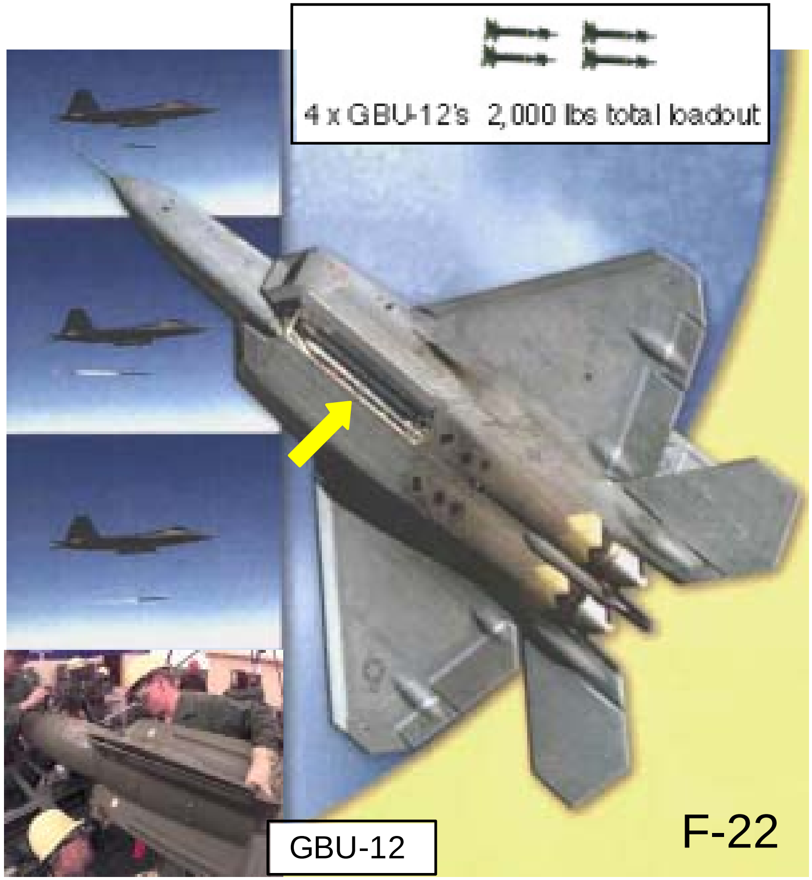
How Small is Small?



- Humans live and work in a macroscopic world.
- Devices need to be properly scaled to the phenomenon that they control or measure.

Adaptive Aerostructures

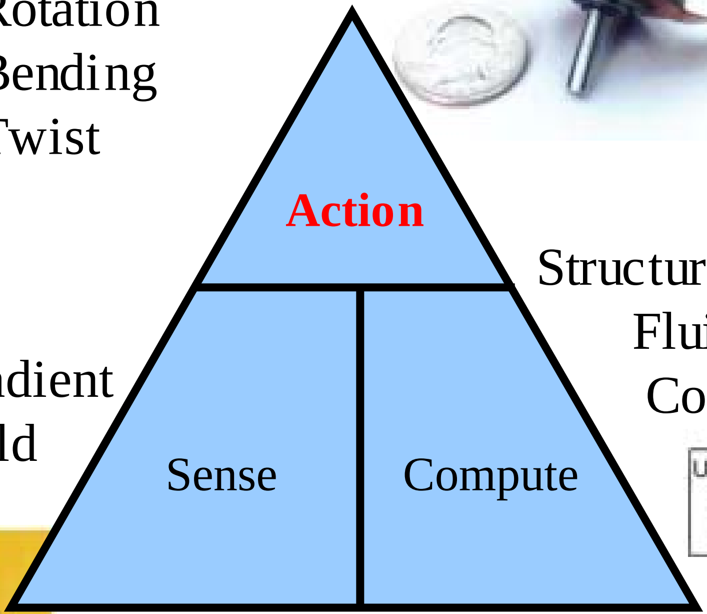
Benefits due to Miniaturization of Components



Reducing the volume occupied by a missile or bomb control actuation system using adaptive structures can dramatically increase the number of weapons that can be carried.

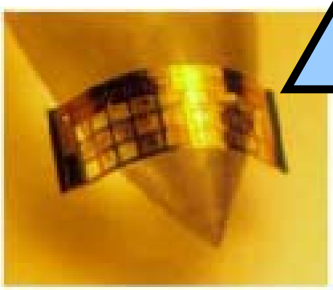
Enabling Technologies

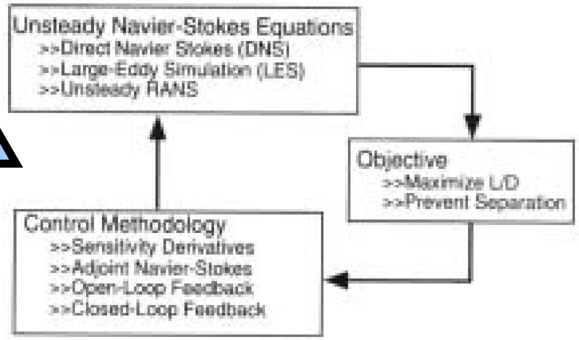
Linear Displacement
Rotation
Bending
Twist



Structural Dynamics
Fluid Dynamics
Control Theory

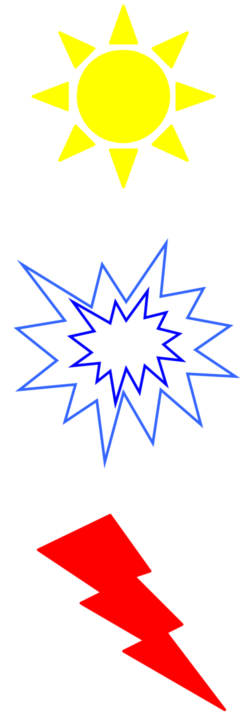
Velocity Gradient
Pressure Field

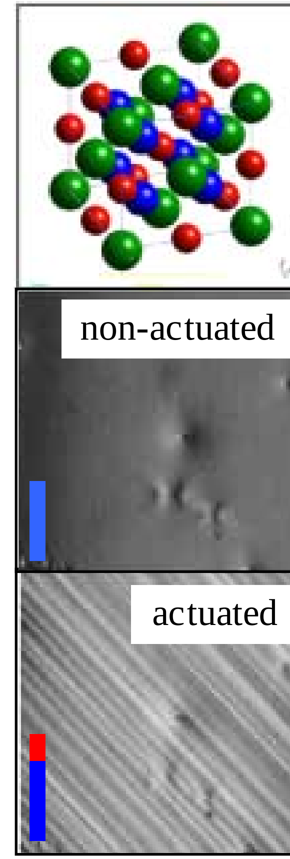




Functional Materials

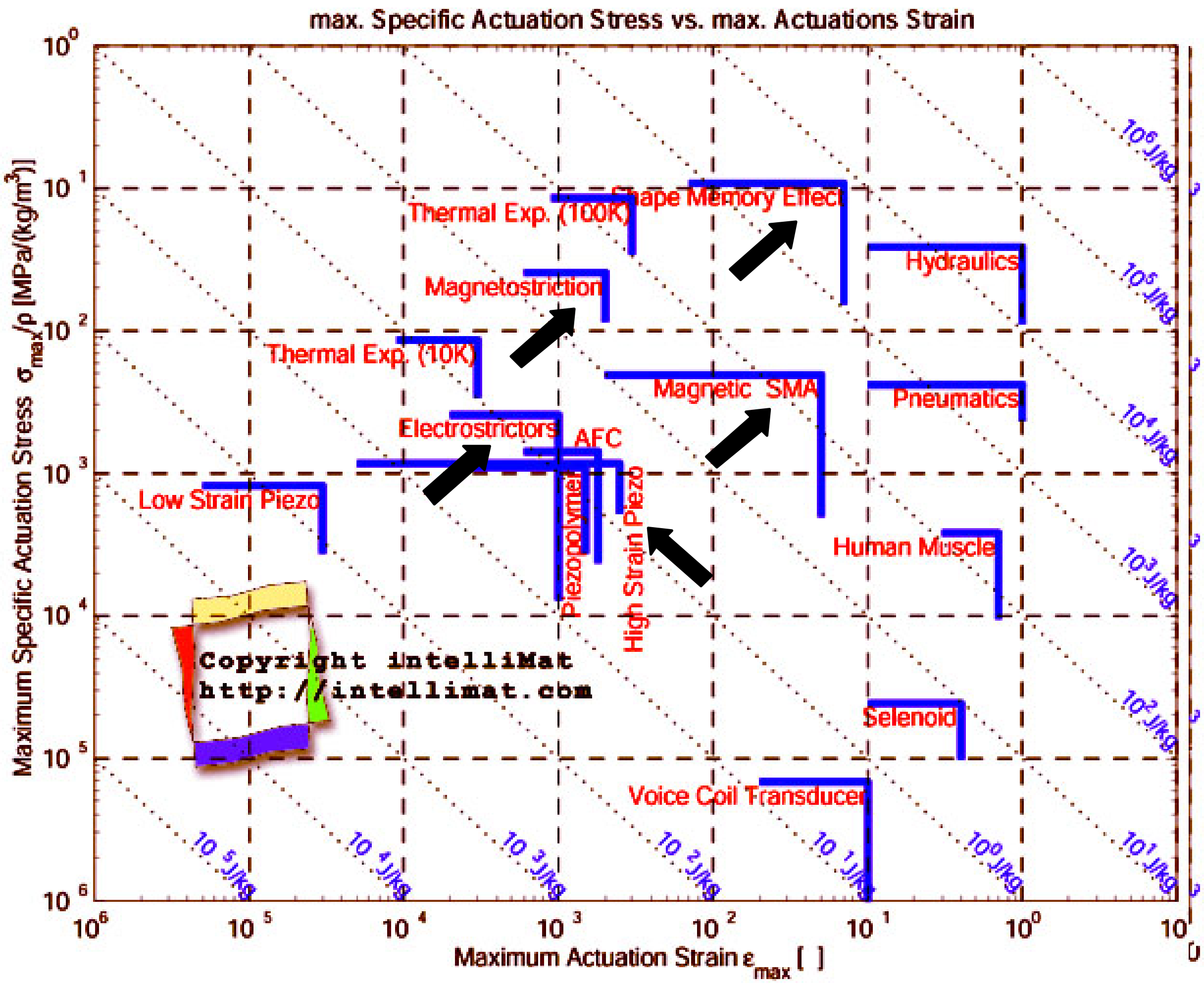
- Shape Memory Alloys
  - thermal
  - magnetic
- Magnetostrictive Materials
- Piezoelectrics
- Electrostrictive Polymers





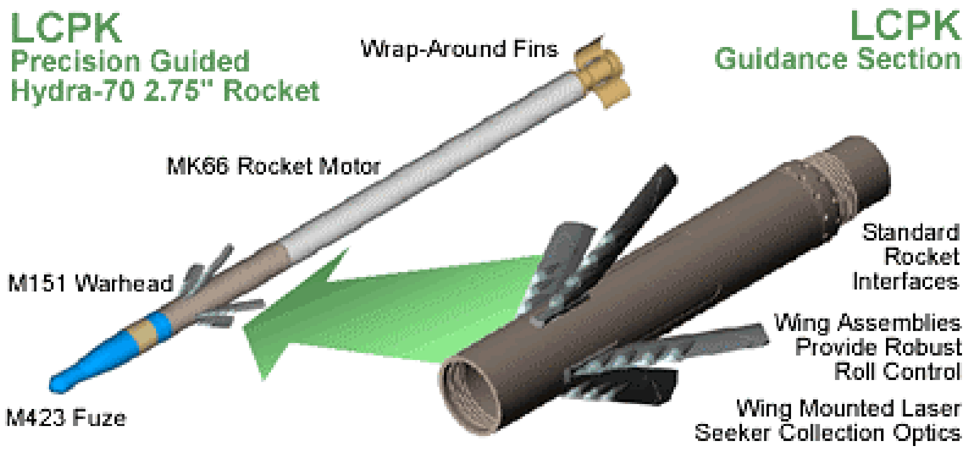
- Major advantage of functional materials is that they are activated by a flow of electricity.

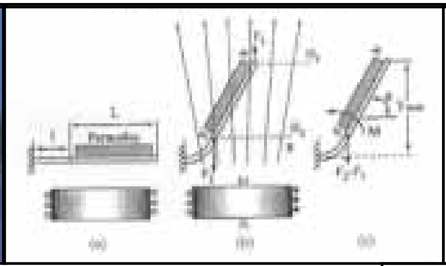
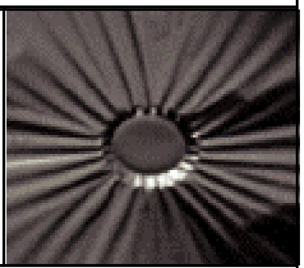
Force Generation



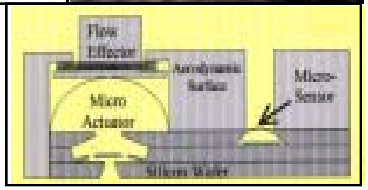
Application to Missiles

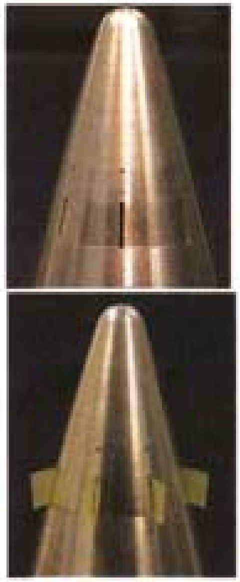
classic



MSMA	Magnetic Field	SMA
		

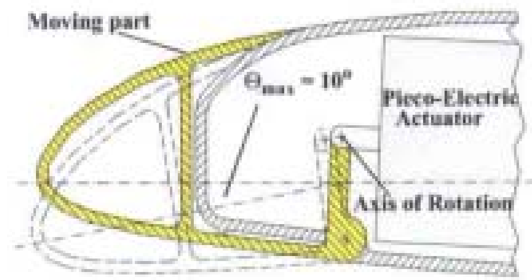
Pneumatically-driven co-located
micro-actuator and sensor



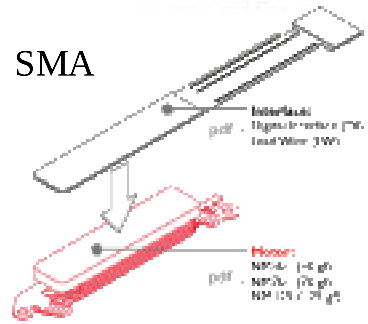


Application to Unmanned Aerial Vehicle

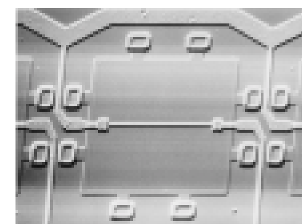
Piezoceramic

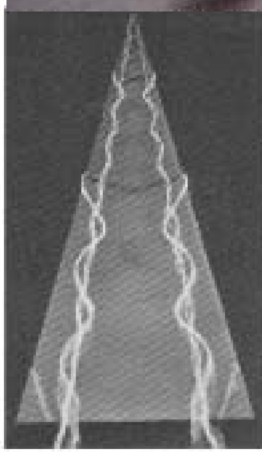


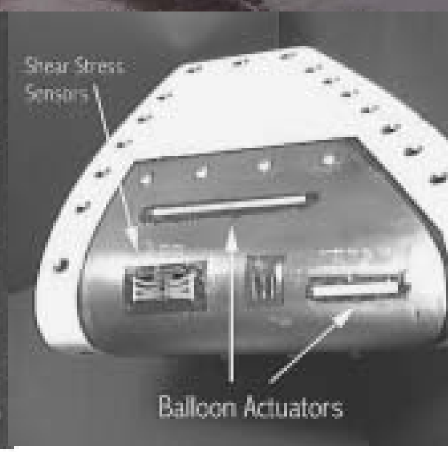
SMA

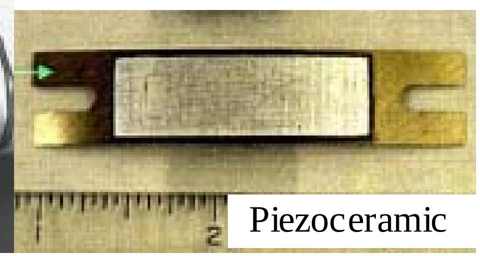


MEMS flow sensor

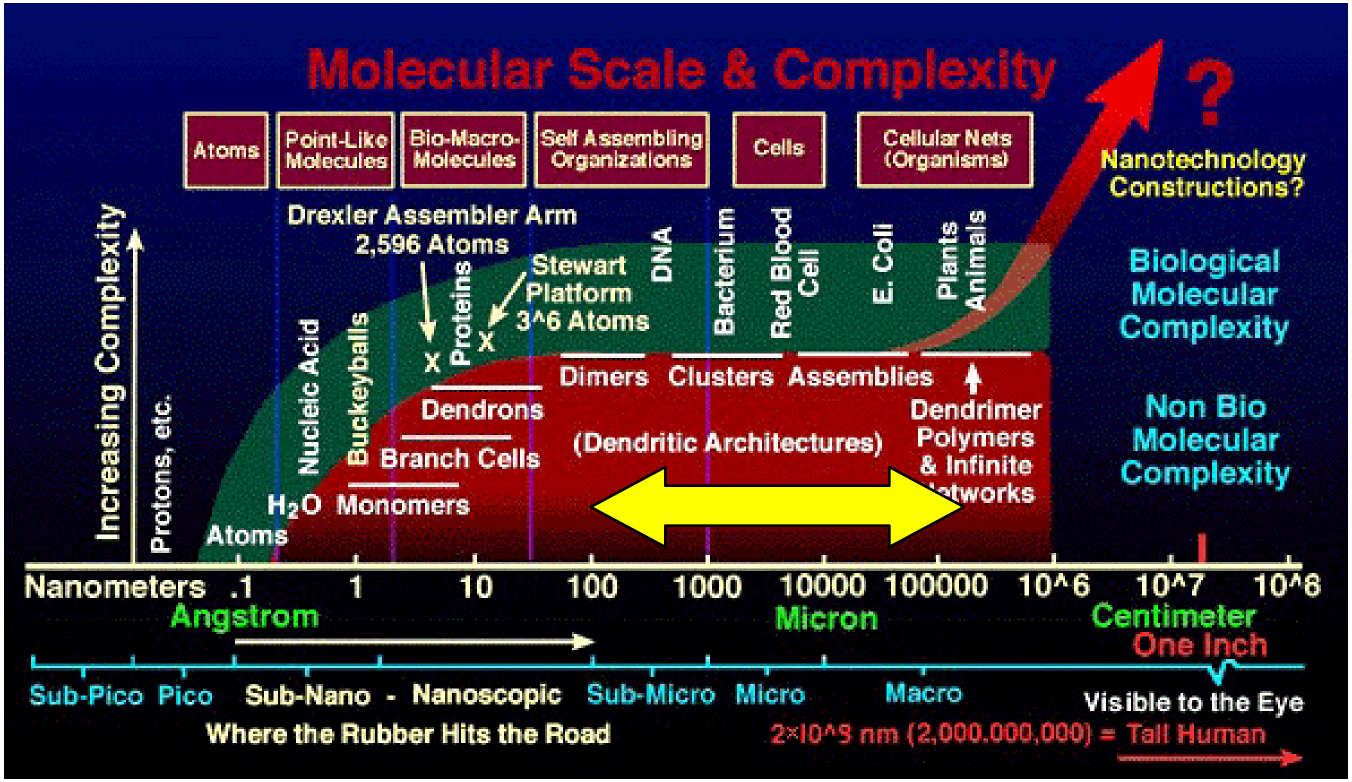








Micro-Electromechanical Systems



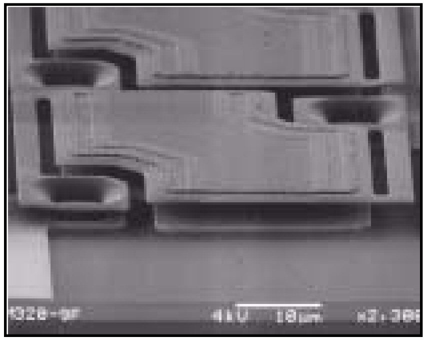
- Benefits of MEMS Technology
  - Compact, low power consumption
  - Additional functionalities

Definition of MEMS

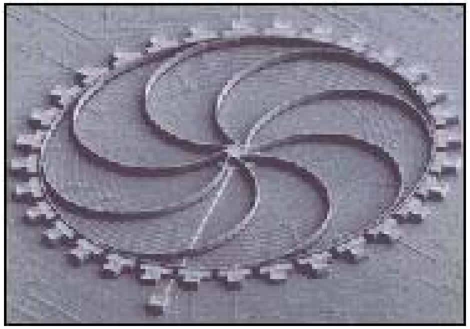
- A highly miniaturized device or an array of devices combining electrical and mechanical components that is fabricated using integrated circuit (IC) batch processing techniques and semiconductor micromachining
- A MEMS device may be a sensor (S), an actuator (A), or a combination of sensors and actuators (SA)

Enabling MEMS Devices

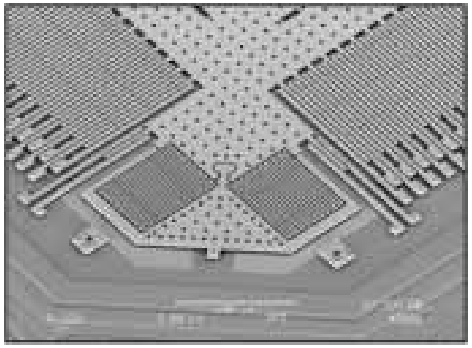
- Infrared Imager (S)
- Inertial Measurement Unit (S)
  - Accelerometer
  - Gyros
- Air Velocity (S)
- Pressure (S)
- Chemical Species (S)
- Micromotor (A)
- Micromirror (A)



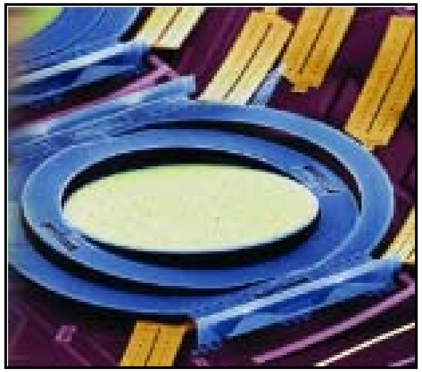
Microbolometer, INO/DRDC



Vibration ring for gyros



Accelerometer, Analog Device



Micromirror/optical switch, Lucent

Comparison of Infrared Imager Characteristics

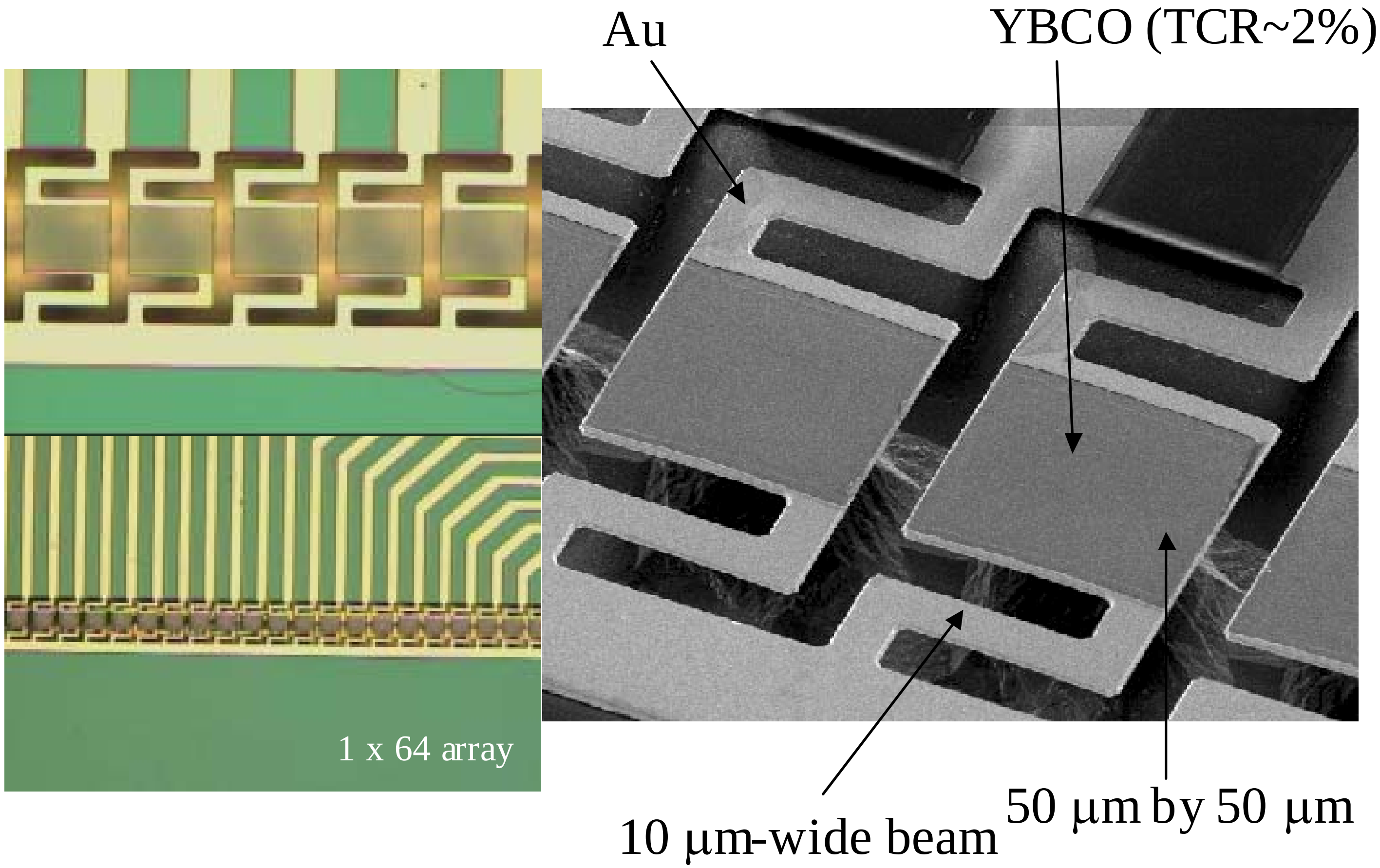
Cooled Imager

- Photon detectors – radiation to electron-hole pairs
- Narrow bandgap materials (MCT, InSb)
- Cryogenic or single/multi-stage thermo electric cooling (TEC)
- More sensitive ($D^* > 10^{10}$ cm-$Hz^{1/2}$/W at 10 μm)
- Imagers usually bulky, heavy, high power consumption

Uncooled Imager

- Thermal detectors – heating effect-physical parameter change (electrical resistance, capacitance, etc.)
- Room temperature operation – may need a single stage TEC for temperature stabilization
- Imagers more compact and low power consumption

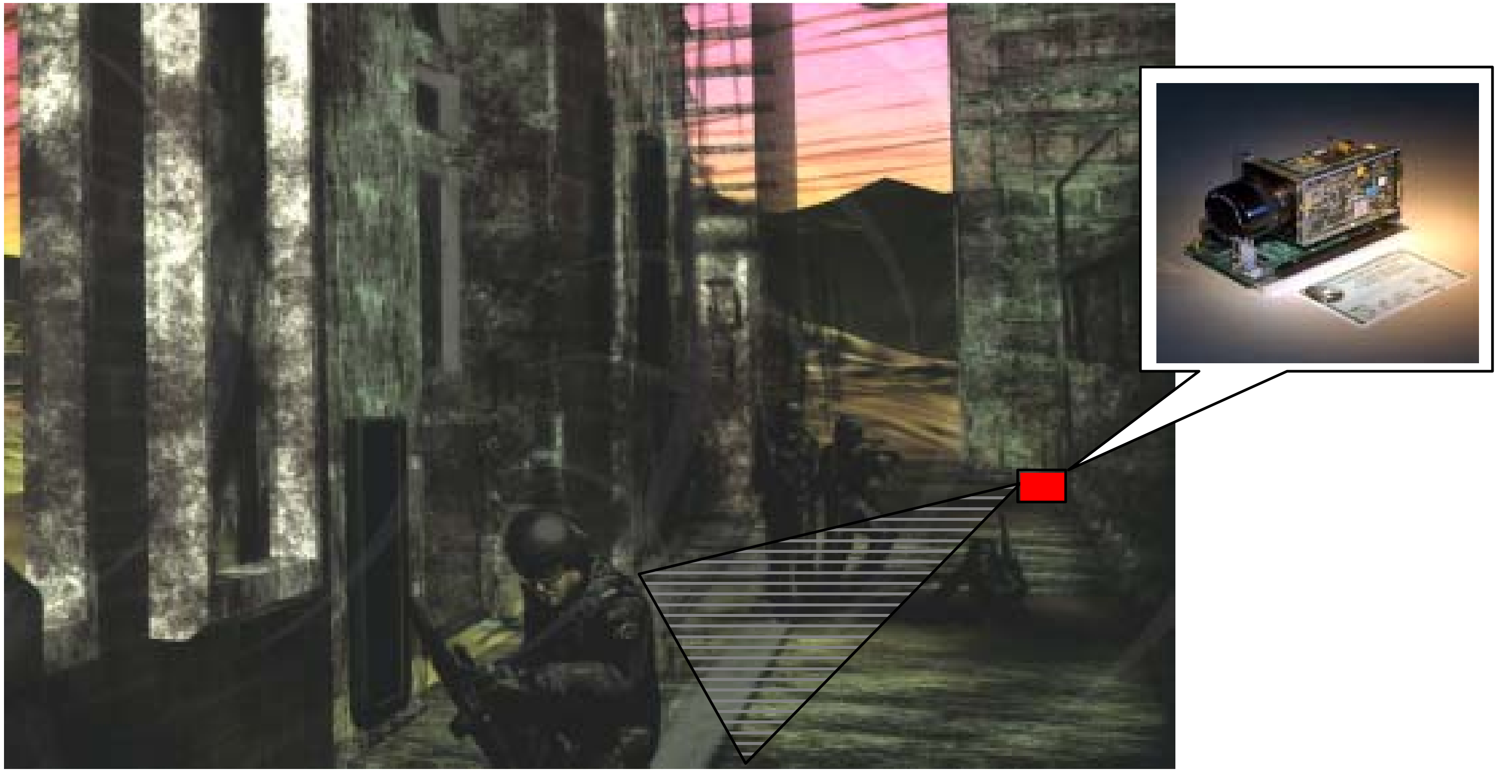
Uncooled Bolometric Infrared Imager



• Suspended pixel to reduce thermal conductivity

Autonomous Surveillance System

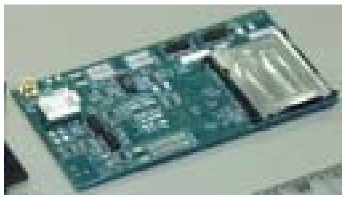
- Image to classify and count
- Location, distance and velocity



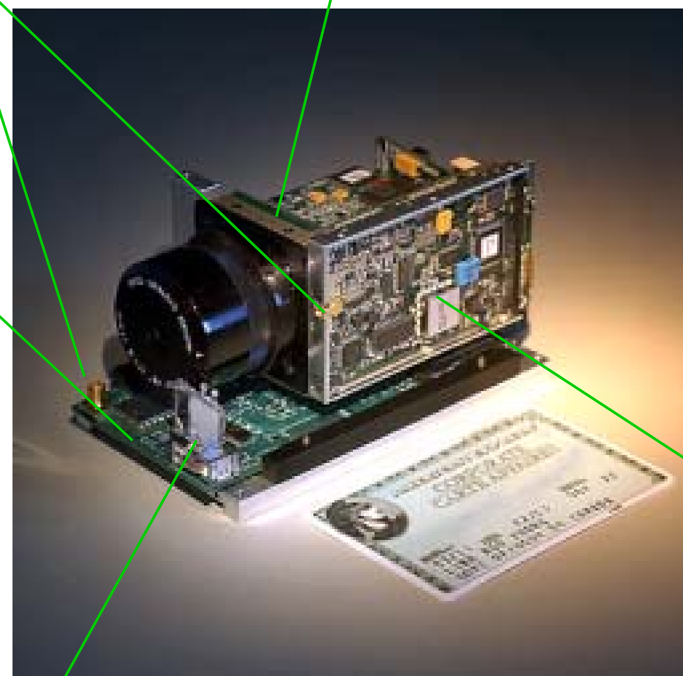
Autonomous Microsystem for Ground Observation (AMIGO)

Patch antennas for GPS and transceiver

Uncooled infrared camera



Customized PCB
- Microprocessor
- Infrared motion sensor
- GPS/SmartMedia
- Electronic compass
- Memory
- Motor (optional) control



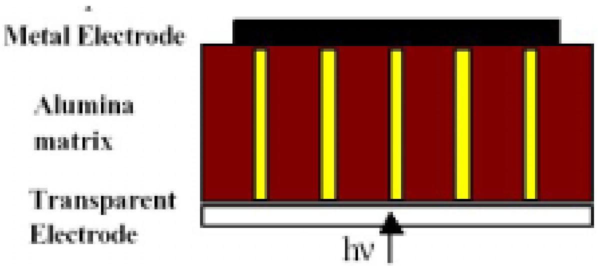
operator

Transceiver

Infrared motion sensor

Potential Sensors combining MEMS and Nanotechnology

- Infrared Sensors
- Gas Sensors
- Temperature Sensors



University of California

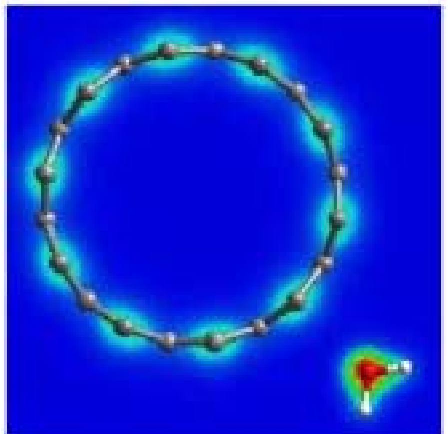
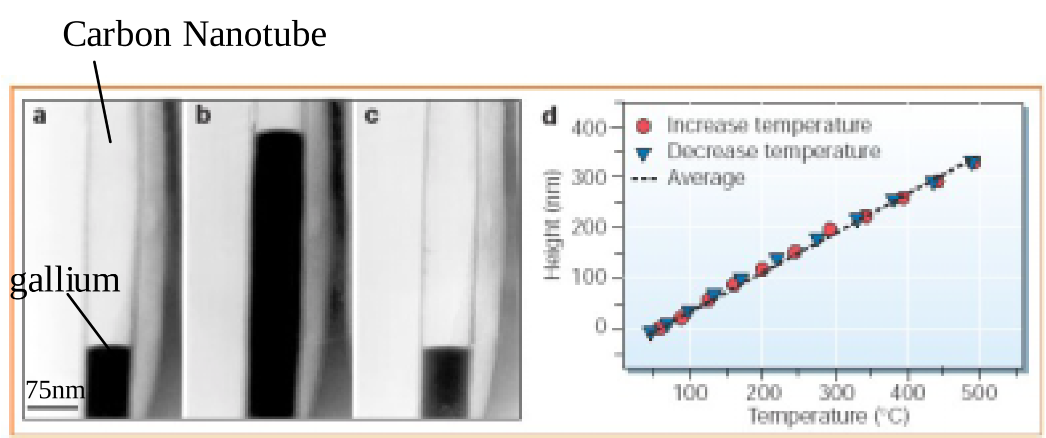


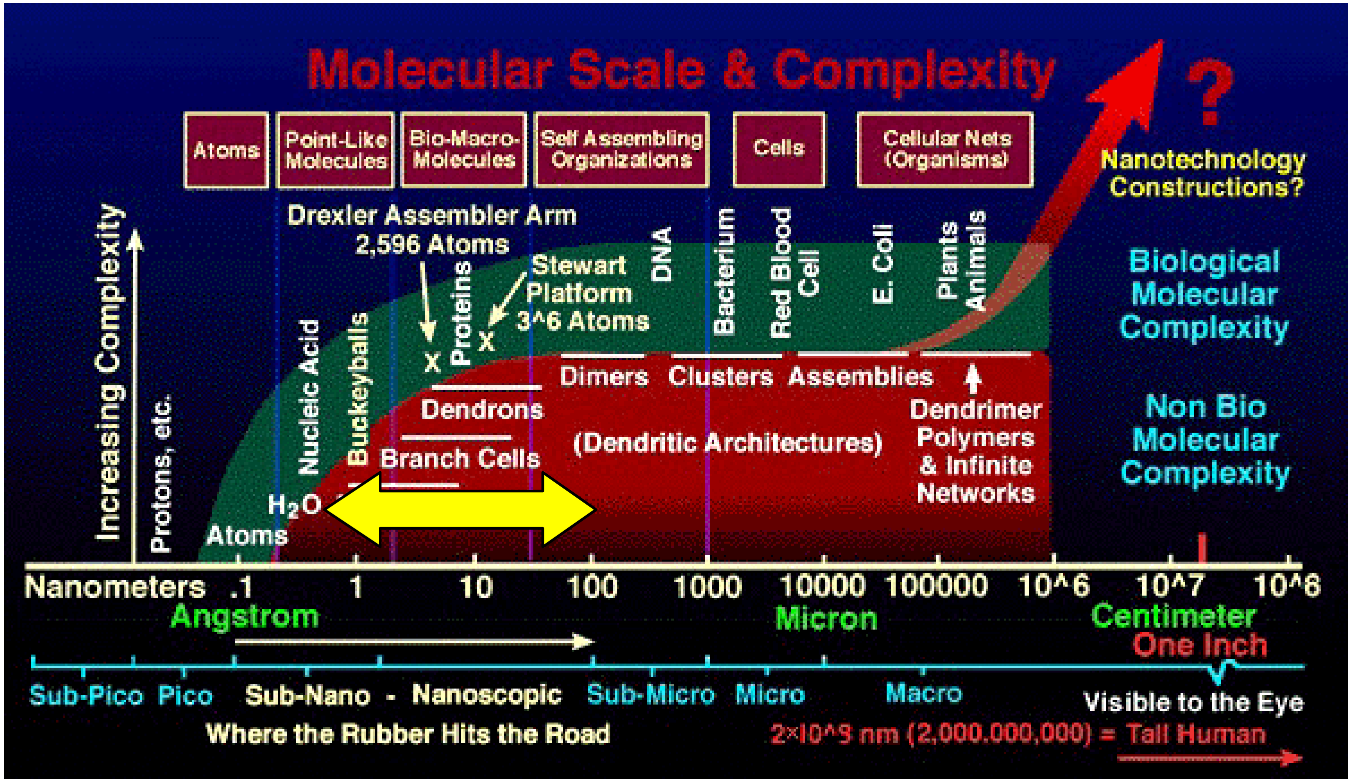
Fig.1 Geometric structure and total valence electron density (slice at (100) direction) of H_2O attach to a (10,0) tube. No significant overlap of the electron density is found between molecule and tube.

University of North Carolina



National Institute for materials Science, Japan

Nanotechnology



- New field where structures are created on the atomistic level.

Definition of Nanotechnology

- Fabrication, manipulation or self-assembly of atoms, molecules into structures with dimensions in 1-100 nanometer to create materials with new and superior properties.

Wide Field of Applications

- **Electronics**: computer/information/optoelectronics/sensors/magnetics
- **Materials**: nanocomposites/nanoparticle/coating
- **Medical**: drug delivery/biotechnology
- **Energy**: density, efficiency and conversion
- **Particles**: catalyst/environment

Why nano will change the properties of materials?

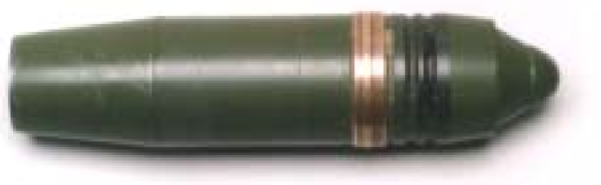
- Example: Smaller size means larger surface area

10 μm diameter
0.22 m^2/g

50 nm diameter
44 m^2/g

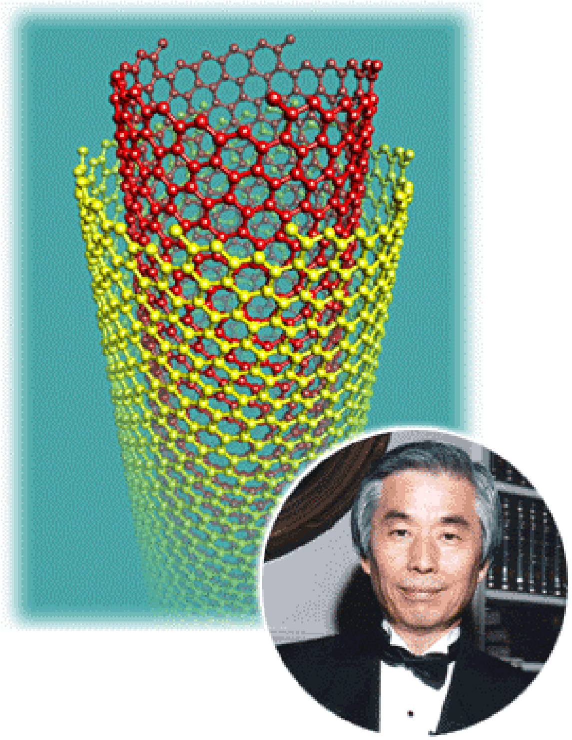
Nanoparticles in Energetic Materials

- Advanced propellants
  - Improved mechanical properties
  - Higher burn rate
- Polymer nanocomposites
  - Stronger materials
- Advanced explosives
  - Modified behaviour
  - Tailored energy release
- Metallic intermolecular composites
  - Very high energy output



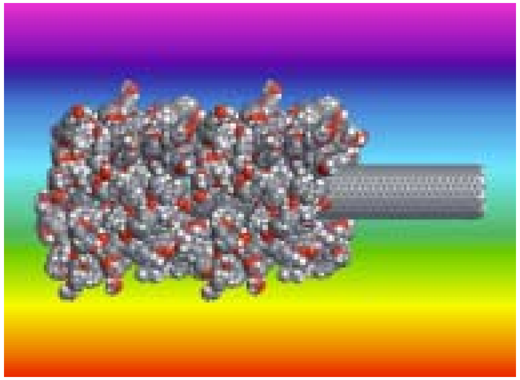
Carbon nanotubes

- Field Emission properties
- Fibers
- Molecular electronics
- Optoelectronics
- Advanced composite materials
- Energy devices

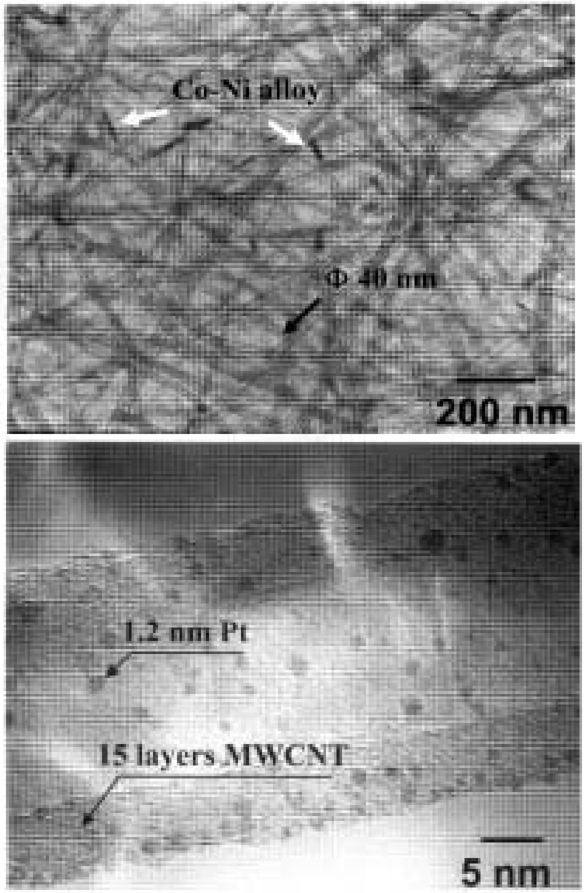


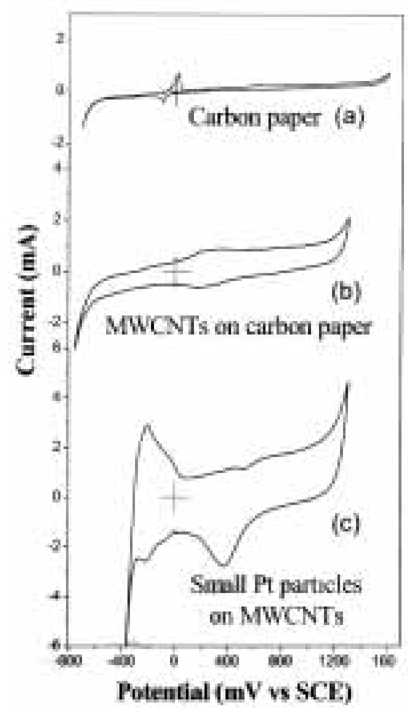
Composite Materials – Carbon Nanotubes

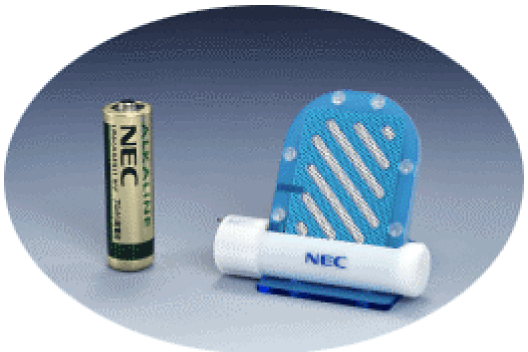
- Reinforced materials
- Lighter materials
- Conductive polymers
- Radar absorbing materials



Carbon Nanotubes(CNT) – Fuel cell Electrodes

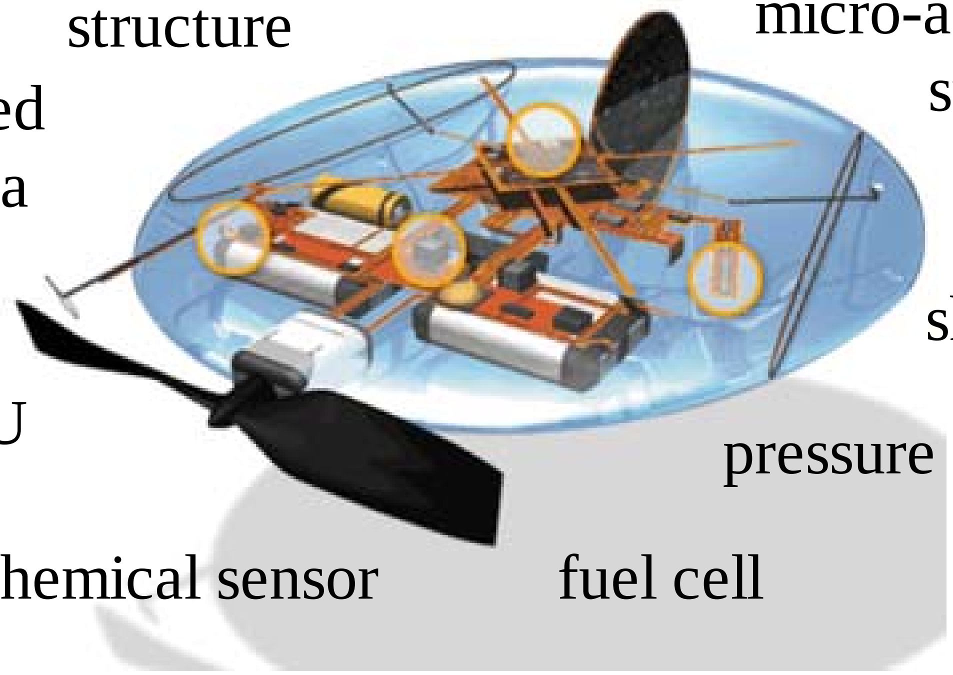






Pt nanoparticle deposited on CNT

Systems Integration of Miniaturization Technologies



Summary

- Miniaturization has and will allow the creation of new, more capable devices.
- Functional materials such as piezoceramics and shape memory materials play a key role in the design of adaptive aerostructures for use in missile and UAV flight control systems.
- Full integration of MEMs and IC technologies allows the creation of "microsystem-on-a-chip" with electro-opto-mechanical functionalities.
- Nanotechnology brings unprecedented freedom to design materials with specific properties and capabilities.
- The key to successful exploitation of these miniaturization technologies is the design of hardware from a systems perspective.