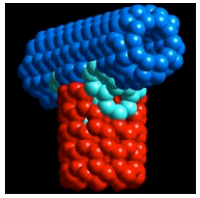
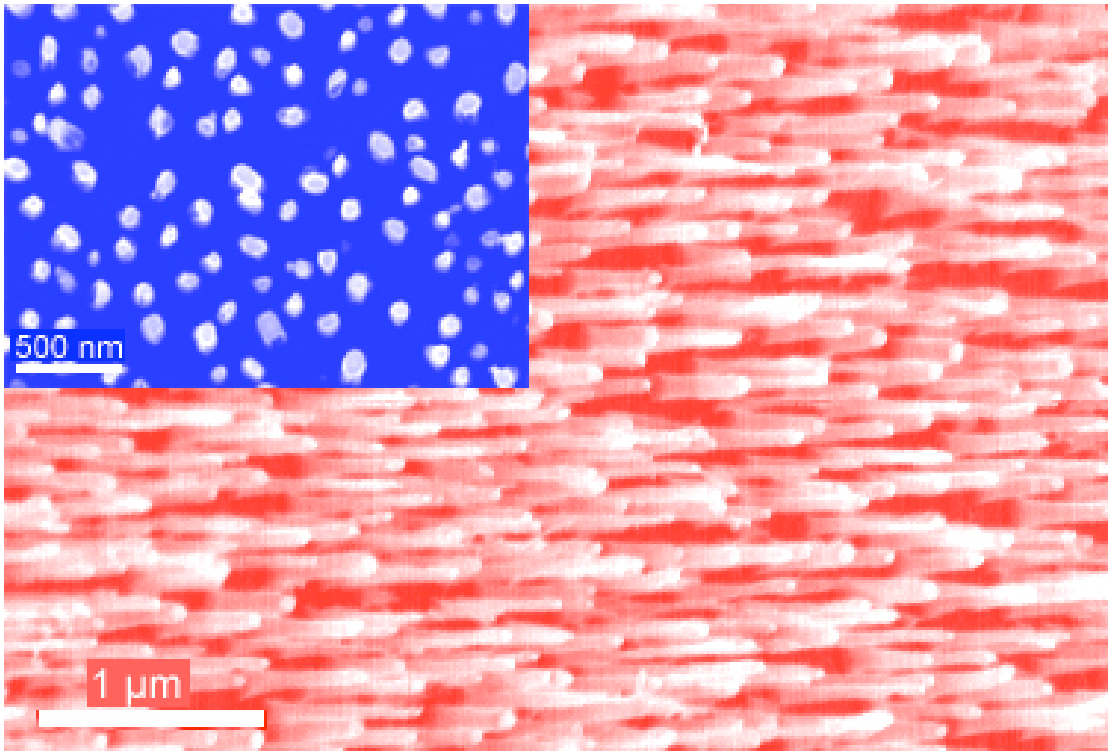
Review of Bio/Chemical Sensor Needs for NASA

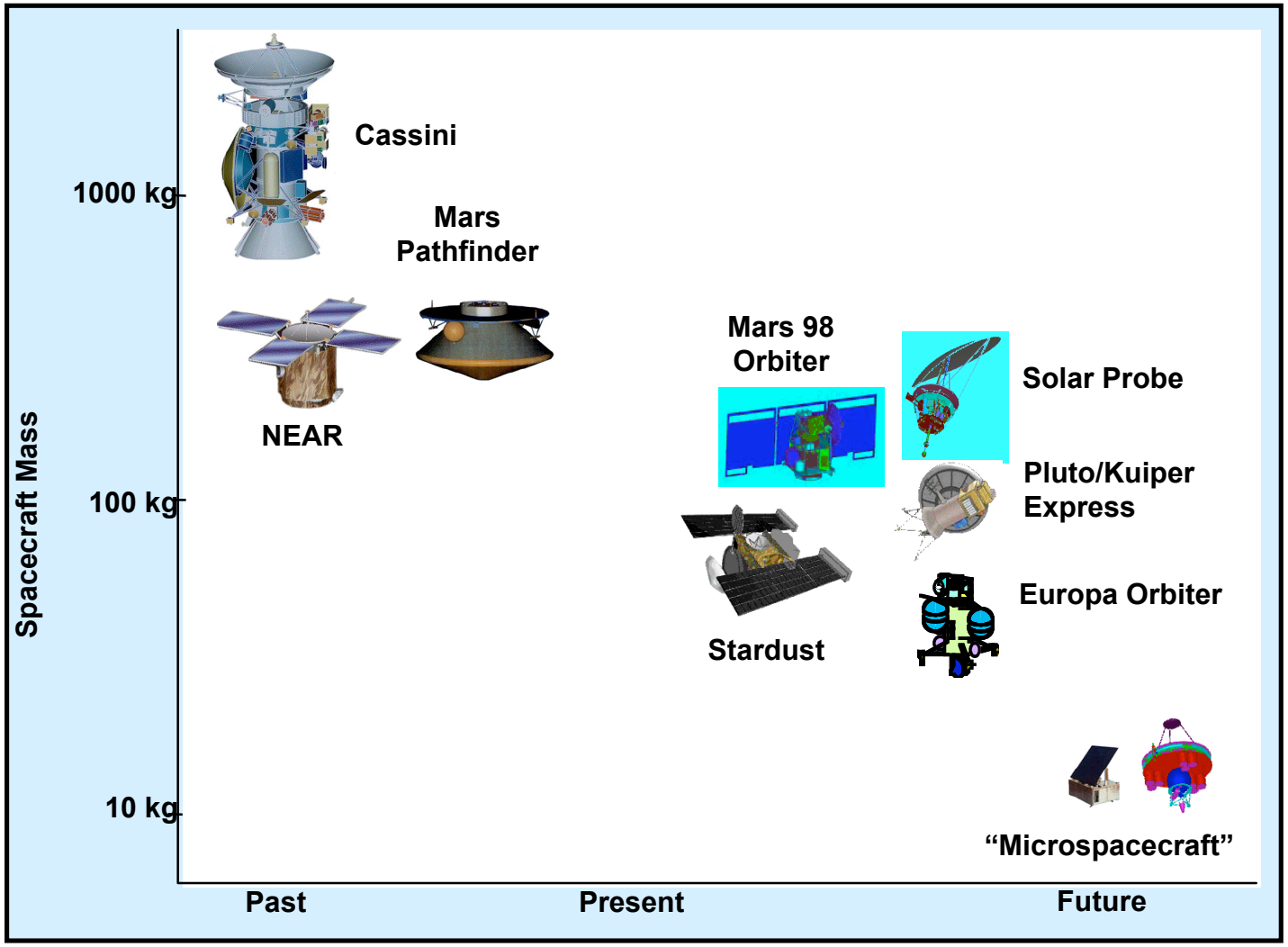




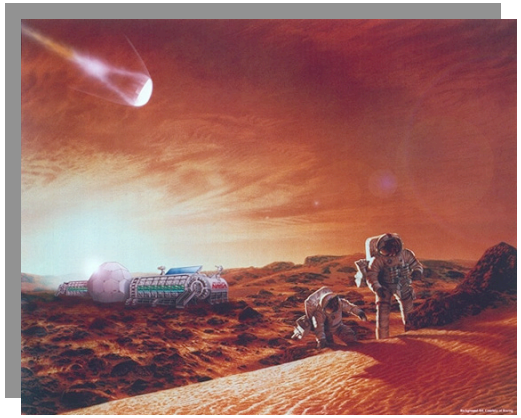
Harry Partridge
Manager, Bio-Nanotechnology
IT Strategic Research
CICT Program

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

NASA's Own Moore's Law

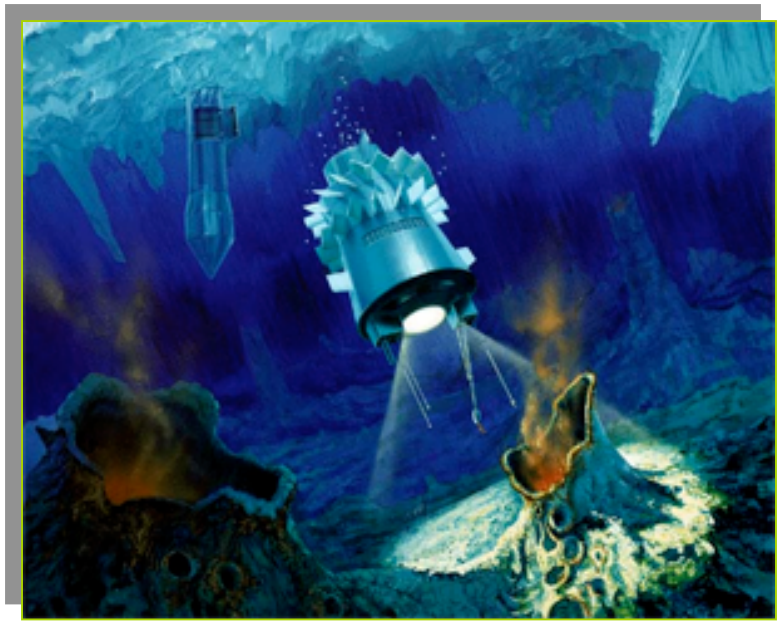


Impact of Nanotechnology on NASA Missions

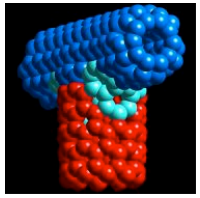


- **New and Powerful computing technologies**
  - Onboard computing systems for future autonomous intelligent vehicles; powerful, compact, low power consumption, radiation hard
  - High performance computing (Tera- and Peta-flops)
    - processing satellite data
    - integrated space vehicle design tools
    - climate modeling

- **Smart, compact devices and sensors**
  - Ultimate sensitivity to analytes
  - Discrimination against varying and unknown backgrounds
  - Ultrasmall probes for harsh environments
  - Advanced miniaturization of all systems
- **Microspacecraft/Micro-Nanorovers**
  - "Thinking" Spacecraft with nanoelectronics/nanosensors
  - Size reduction through multifunctional, smart nanomaterials



NASA Nanotechnology Investments



Nanoelectronics and Computing

- Molecular electronics & photonics
- Computing architecture
- Assembly

Sensors and Spacecraft Components

- Life detection
- Crew health & safety
- Vehicle health

Nanomaterials and Structures

- Composites
- Multifunctional materials
- Self healing

- Emphasis on 'bio-inspired' approach
- Guidance from modeling and simulation

NASA's Vision

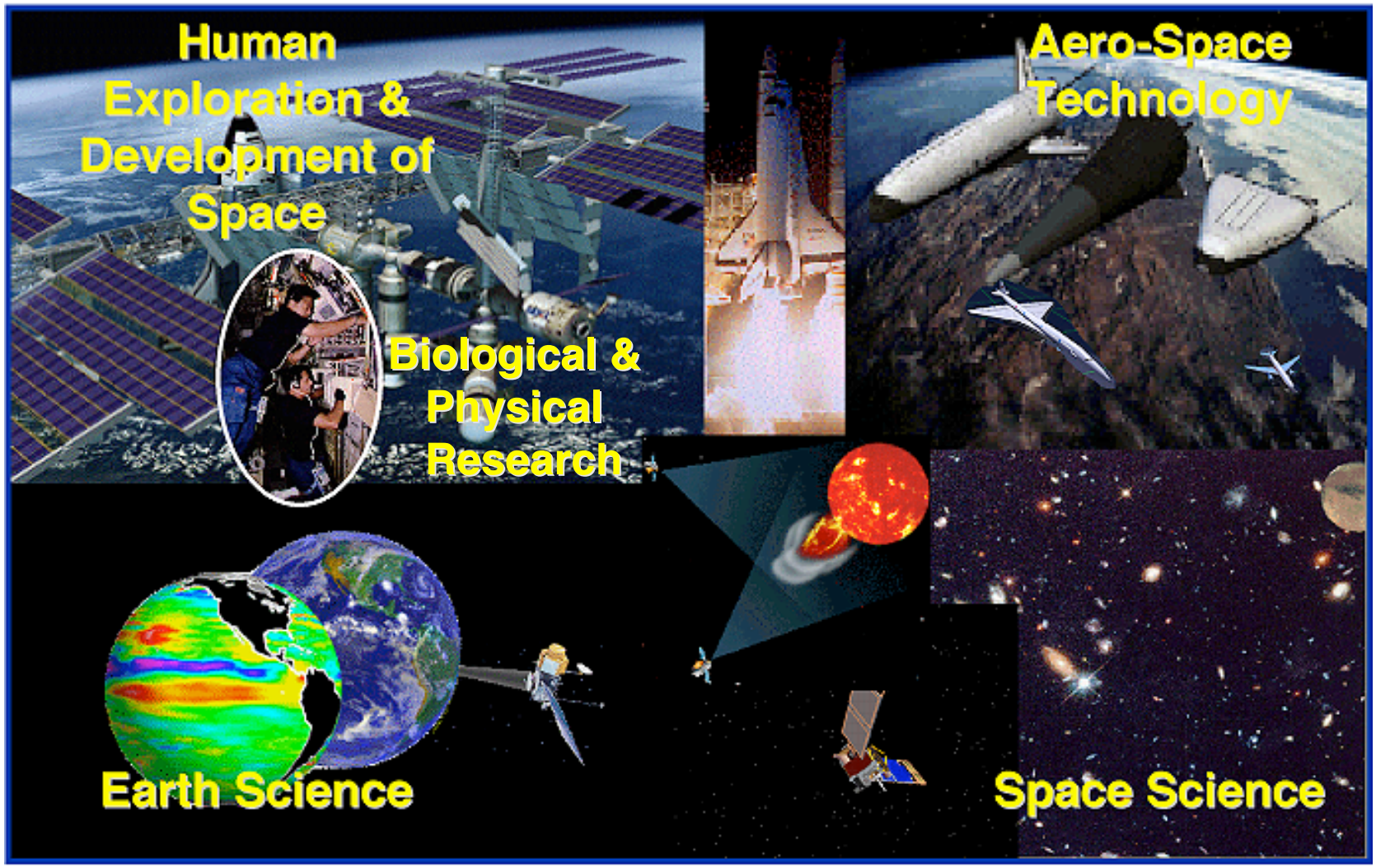
To improve life here,
To extend life to there,
To find life beyond.

NASA's Mission

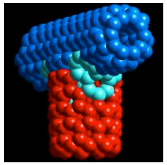
To understand and protect our home planet
To explore the Universe and search for life
To inspire the next generation of explorers

…as only NASA can.

NASA's Strategic Enterprises

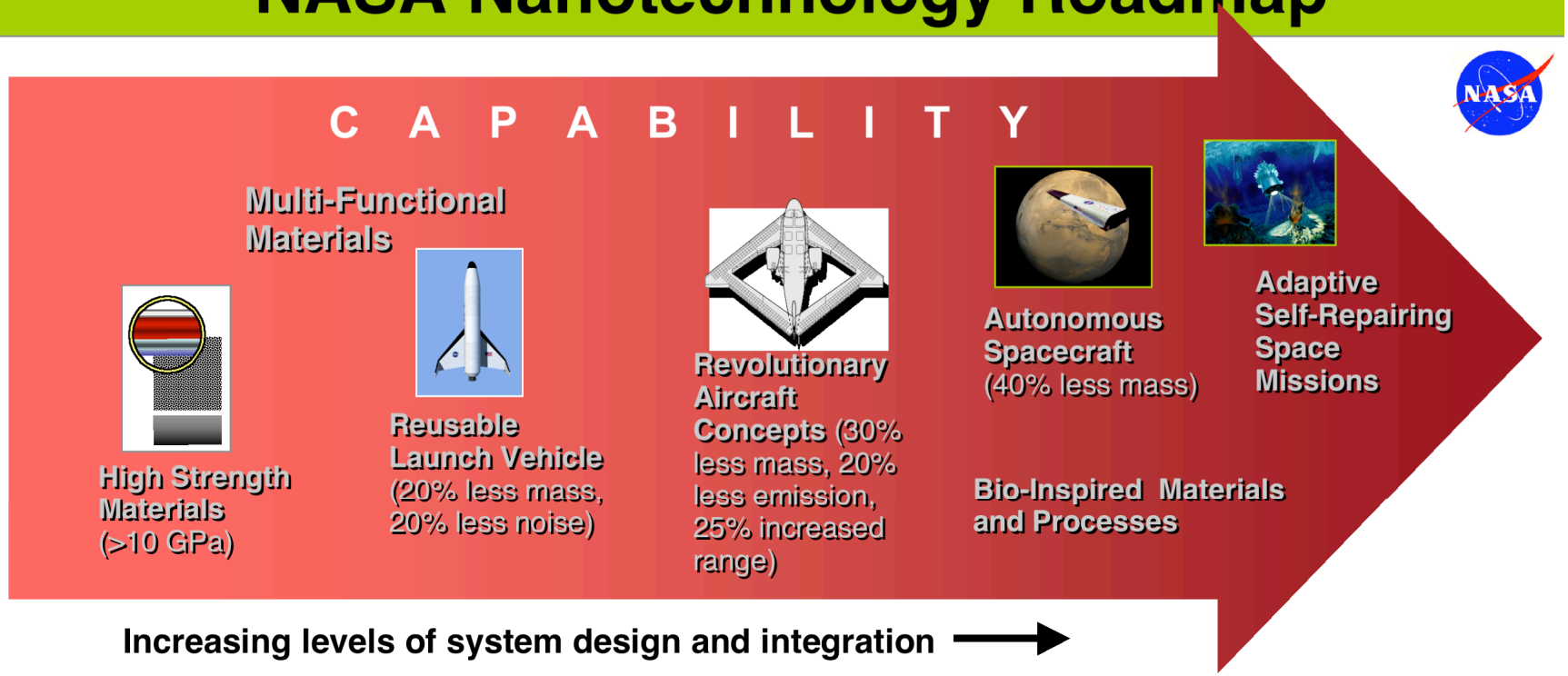


NASA's Investments in Nano



- NASA Ames Center for Nanotechnology, started in 1996, is the largest in-house R & D in Federal Government; consists of 50 scientists and engineers working on various aspects of experimental and computational nanotechnology fields.
- NASA Ames has strong collaboration with the academia
  - undergraduate student research program
  - high school student research program
- Programs at JPL (Sensors), Langley (Nano materials), Glenn (Energy storage), and JSC (CNT composites)
- NASA's university-based Nano-Institutes
  - Four institutes, $3 M/year/institute for 5 + optional 3 years
    1. Purdue University and Partners (Nanoelectronics and computing)
    2. UCLA (Bio/Nano/IT Fusion)
    3. Princeton and Partners (Nanostructured materials)
    4. Texas A & M, Partners
- Recent spin-off: Integrated Nanosystems, Inc.

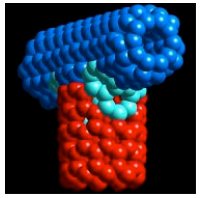
NASA Nanotechnology Roadmap



Increasing levels of system design and integration →

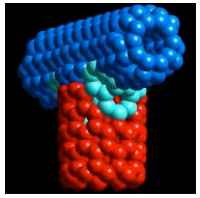
	2002	2004	2006	2011	2016 →
Materials	• Single-walled nanotube fibers	• Nanotube composites	• Integral thermal/shape control	• Smart "skin" materials	• Biomimetic material systems
Electronics/ computing	• Low-Power CNT electronic components	• Molecular computing/data storage	• Fault/radiation tolerant electronics	• Nano electronic "brain" for space Exploration	• Biological computing
Sensors, s/c components	• In-space nanoprobes	• Nano flight system components	• Quantum navigation sensors	• Integrated nanosensor systems	• NEMS flight systems @ 1 μW

NASA Ames Nanotechnology Research Focus

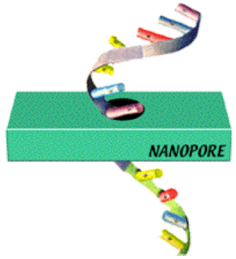


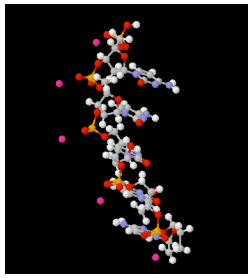
* **Carbon Nanotubes**
  - Growth (CVD, PECVD)
  - Characterization
  - AFM tips
    - Metrology
    - Imaging of Mars Analog
    - Imaging Bio samples
  - Electrode development
  - Biosensor (cancer diagnostics)
  - Chemical sensor
  - Logic Circuits
  - Chemical functionalization
  - Gas Absorption
  - Device Fabrication
* **Molecular Electronics**
  - Synthesis of organic molecules
  - Characterization
  - Device fabrication
* **Inorganic Nanowires**
* **Protein Nanotubes**
  - Synthesis
  - Purification
  - Application Development
* **Genomics**
  - Nanopores in gene sequencing
  - Genechips development
* **Computational Nanotechnology**
  - CNT - Mechanical, thermal properties
  - CNT - Electronic properties
  - CNT based devices: physics, design
  - CNT based composites, BN nanotubes
  - CNT based sensors
  - DNA transport
  - Transport in nanopores
  - Nanowires: transport, thermoelectric effect
  - Transport: molecular electronics
  - Protein nanotube chemistry
* **Quantum Computing**
* **Computational Quantum Electronics**
  - Noneq. Green's Function based Device Simulator
* **Computational Optoelectronics**
* **Computational Process Modeling**

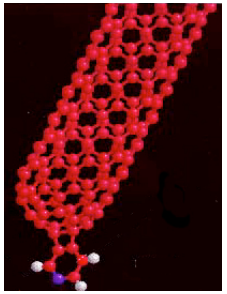
Nearer Term Technology Infusion Targets



- **Space Science Applications**
  - High Resolution imaging of Mars surface samples (MECA instrument*)
  - X-Ray Chemical/Mineral surface analysis(XRF & XRD) of solar system objects*
  - Cosmochemical sensing of solar system atmospheres
  - Nanoelectronics/ radiation hardened devices
  - Quantum dot infrared photodetector focal plane arrays
  - Mars dust sizing and Life detection technology – DNA Nanopore Project*
- **Earth Science Applications (Airborne only at this point)**
  - Advanced sensing of atmospheric volatiles from aircraft platforms
- **Biological and Physical Research Applications**
  - Use of Ground-based ANCT genomics lab for Early ISS biological flight sample analysis
  - Nanosensors for monitoring of biologically important for use on Bioexplorer/mini free flyer satellites
  - Carbon nanotube scanning probes for high resolution imaging of biological samples
  - Nanopore-based gene variation detection

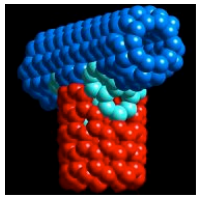






* Experiments submitted as candidates for Mars '09 MSL via January '03 RFI

Space* and Earth Science Needs** where Nanotechnology can Contribute

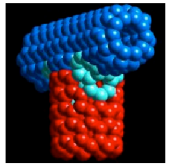


- **Greatly increased science measurement capability - less mass and power requirements for electronics and sensors. Lightweight (<Kg), high resolution mass spectrometers highly desirable**
- **Cosmochemistry: Volatiles: (H_2O, NH_3, CH_4 , SO_2 , ,CO_2, H_2S , SO_2); H, He, O, C, N S and their isotopes & noble gases and their isotopes.**
- **Surfaces: Sample gathering and analysis with attendant requirements for new surface science instruments, INCLUDING organic chemistry and Biological measurements.**
- **Inner planets: Extreme temperature capability (hot & cold); corrosion-resistant and pressure tolerant for Venus.**
- **Outer Planets and their moons - Radiation hardened, shielding and reliability.**

*Based on study of National Research Council Prepublication "New Frontiers in the Solar System, July 8, 2002. Emerging nanotechnology timing fits well with NF progam needs for later missions,e.g., Jupiter multiprobe

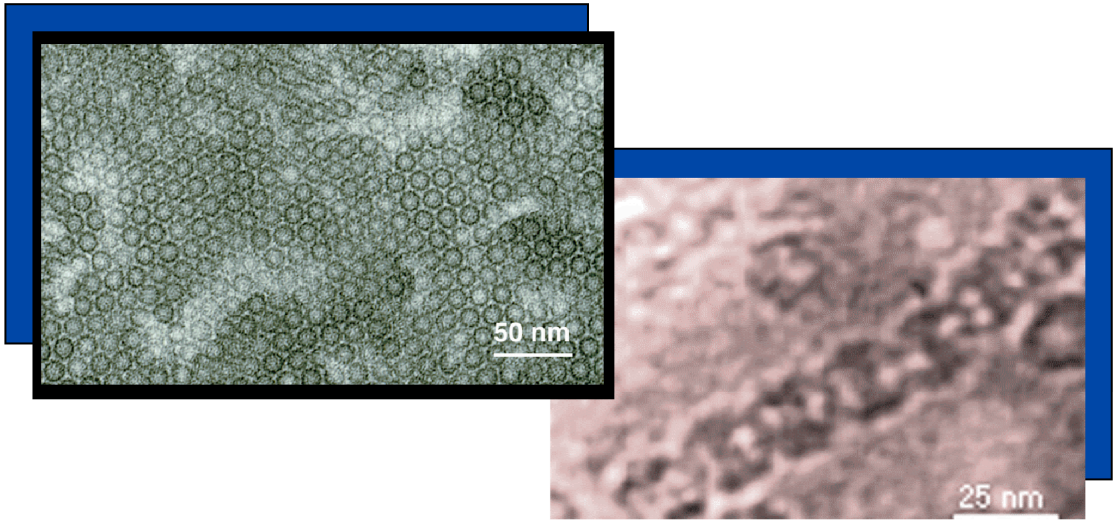
**Volatiles listed in blue are of interest to Earth Science/SG programs, as is NO_2 INTEX-NA Intercontinental Chemical Transport Experiment - North America

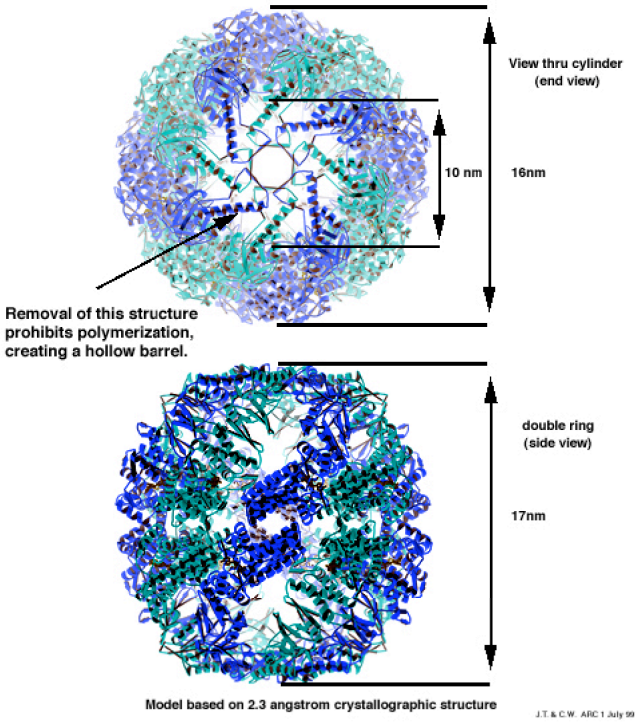
Protein Nanotubes



- Heat shock protein (HSP 60) in organisms living at high temperatures ("extremophiles") is of interest in astrobiology

- HSP 60 can be purified from cells as a double-ring structure consisting of 16-18 subunits. The double rings can be induced to self-assemble into nanotubes.

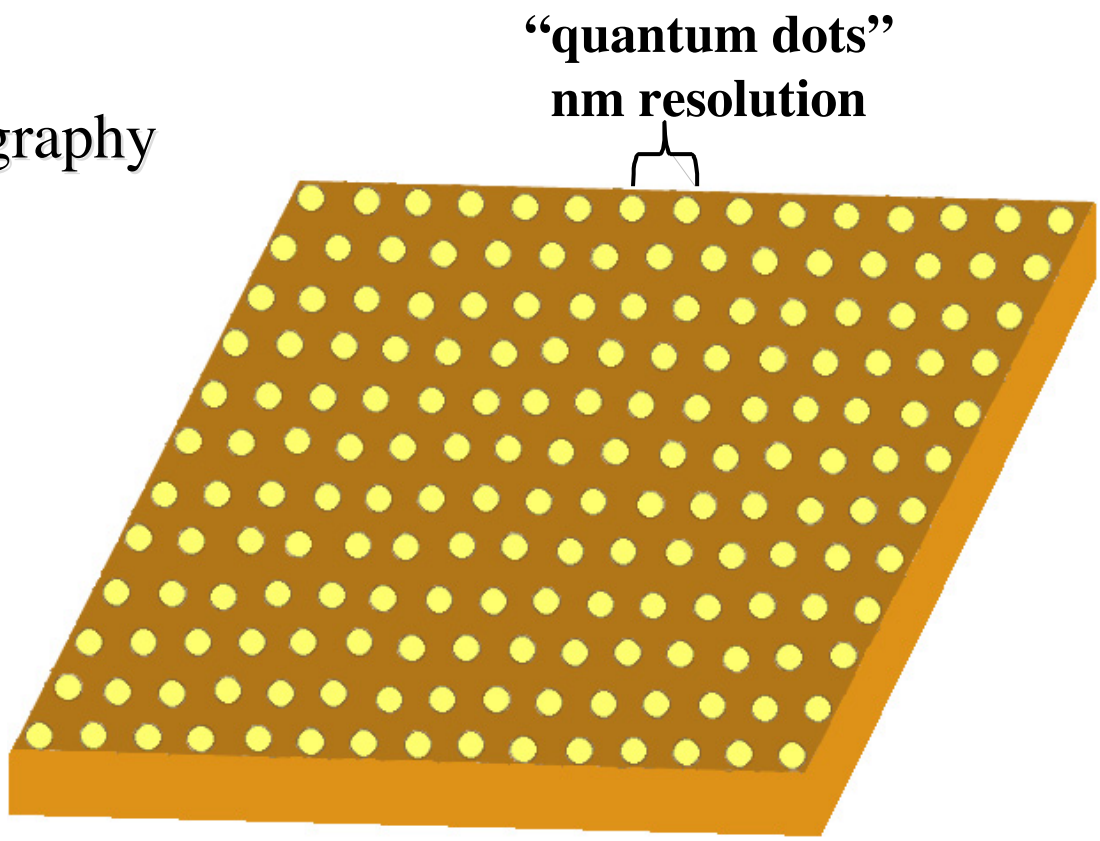




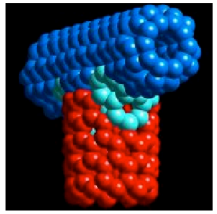
Extremophile Proteins for Nano-scale Substrate Patterning

Nano-scale engineering for high resolution lithography

Future: Bio-based lithography
- Batch self-assembly
- Evolving
- Inexpensive

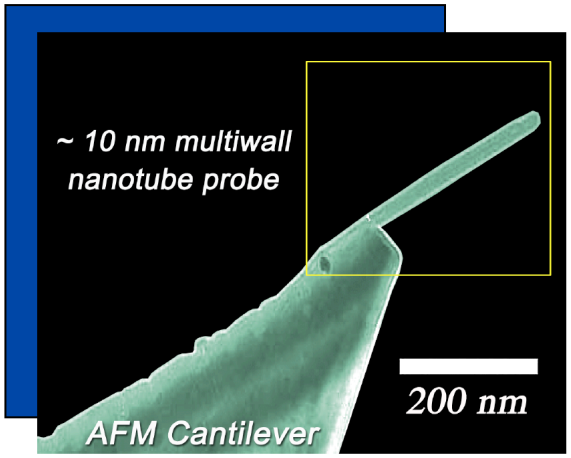


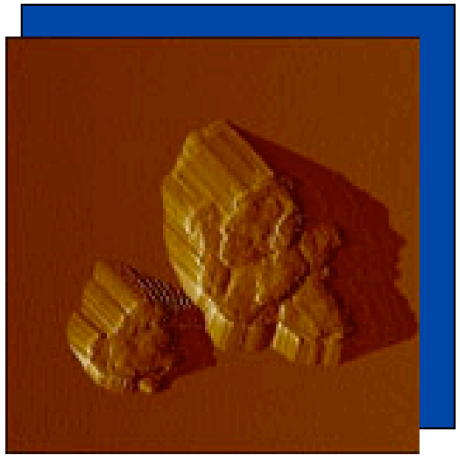
CNT in Microscopy



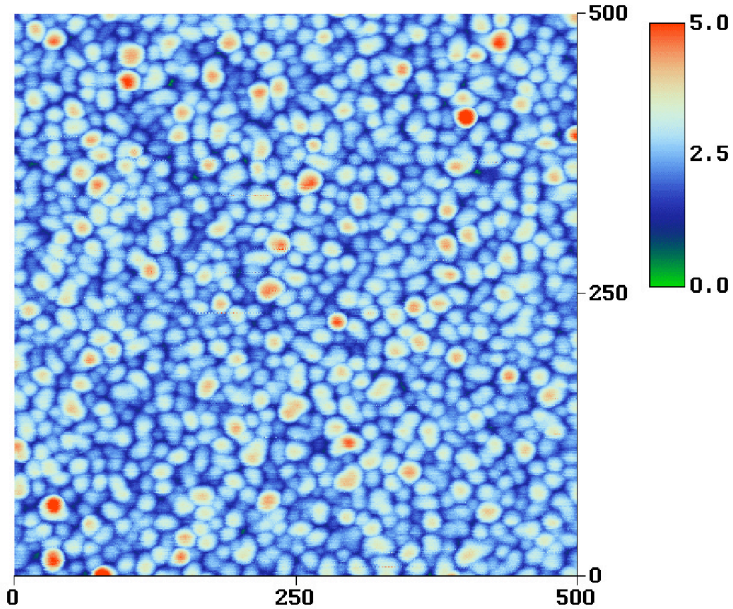
Atomic Force Microscopy is a powerful technique for imaging, nanomanipulation, as platform for sensor work, nanolithography...

Conventional silicon or tungsten tips wear out quickly. CNT tip is robust, offers amazing resolution.





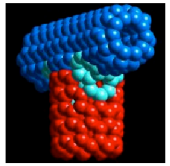
Simulated Mars dust



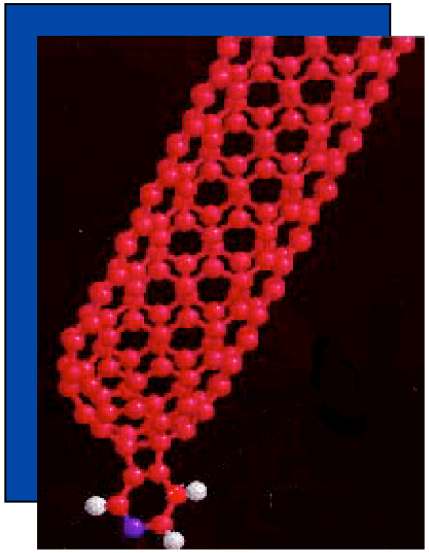
2 nm thick Au on Mica

NASA Ames Research Center
Ramsey Stevens, Lance Delzeit, Cattien Nguyen

CNT Based Biosensors

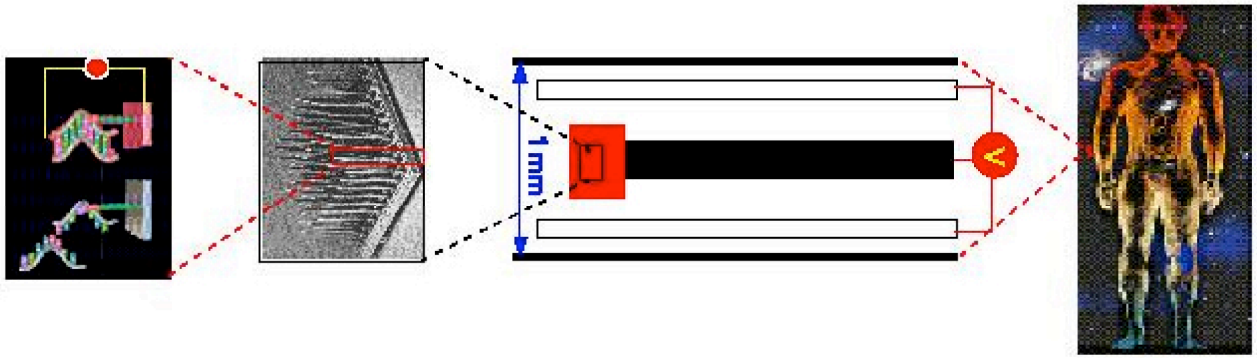


- Our interest is to develop sensors for astrobiology to study origins of life. CNT, though inert, can be functionalized at the tip with a probe molecule. Current study uses AFM as an experimental platform.

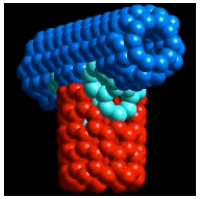


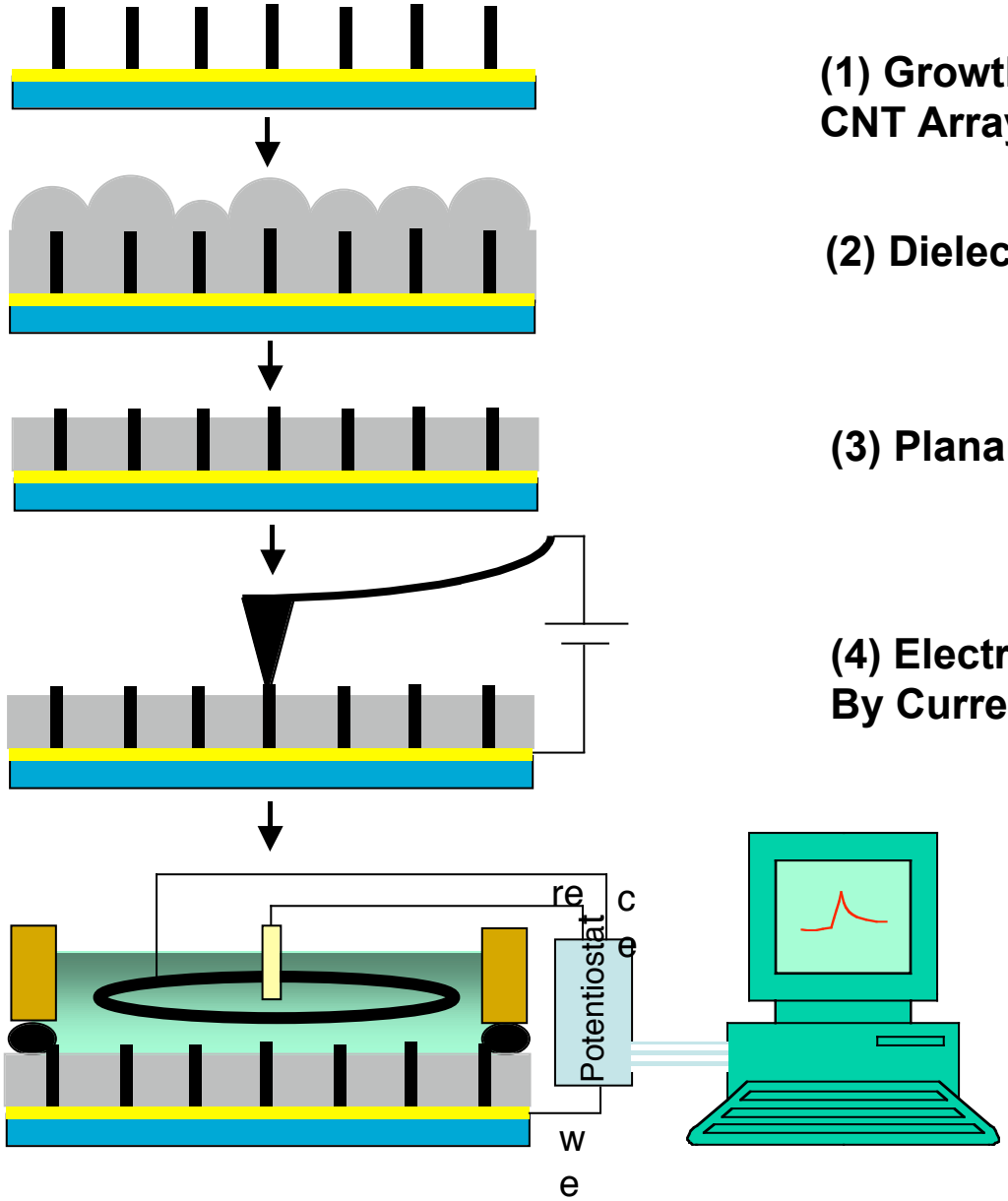
- The technology is also being used in collaboration with NCI to develop sensors for cancer diagnostics
  - Identified probe molecule that will serve as signature of leukemia cells, to be attached to CNT
  - Current flow due to hybridization will be through CNT electrode to an IC chip.
  - Prototype biosensors catheter development

- **High specificity**
- **Direct, fast response**
- **High sensitivity**
- **Single molecule and cell signal capture and detection**



The Fabrication of CNT Nanoelectrode Array





(1) Growth of Vertically Aligned CNT Array

(2) Dielectric Encapsulation

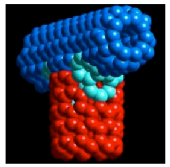
(3) Planarization

(4) Electrical Property Characterization By Current-sensing AFM

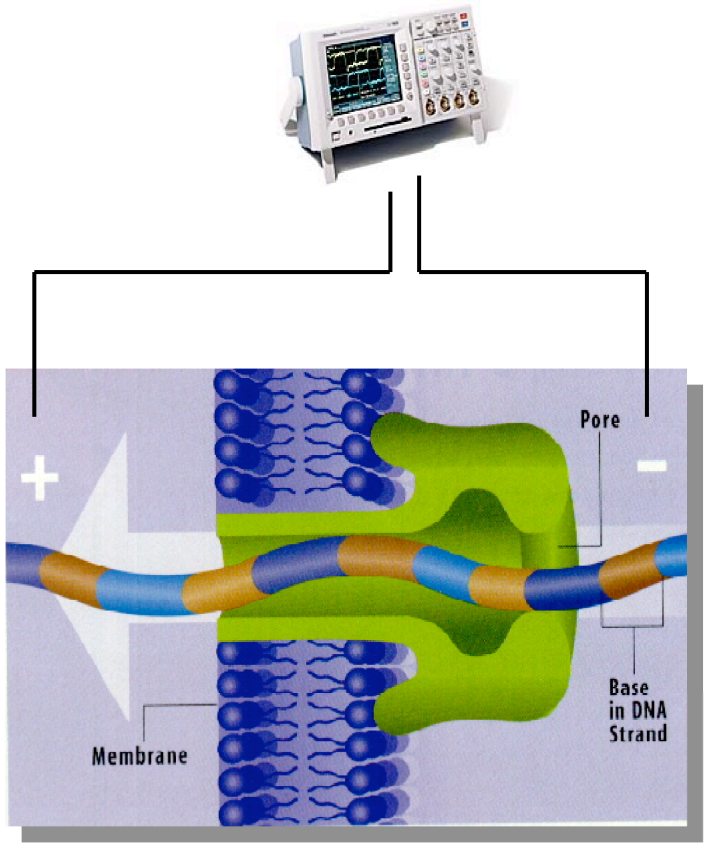
(5) Electrochemical Characterization

DNA Sequencing with Nanopores

The Concept

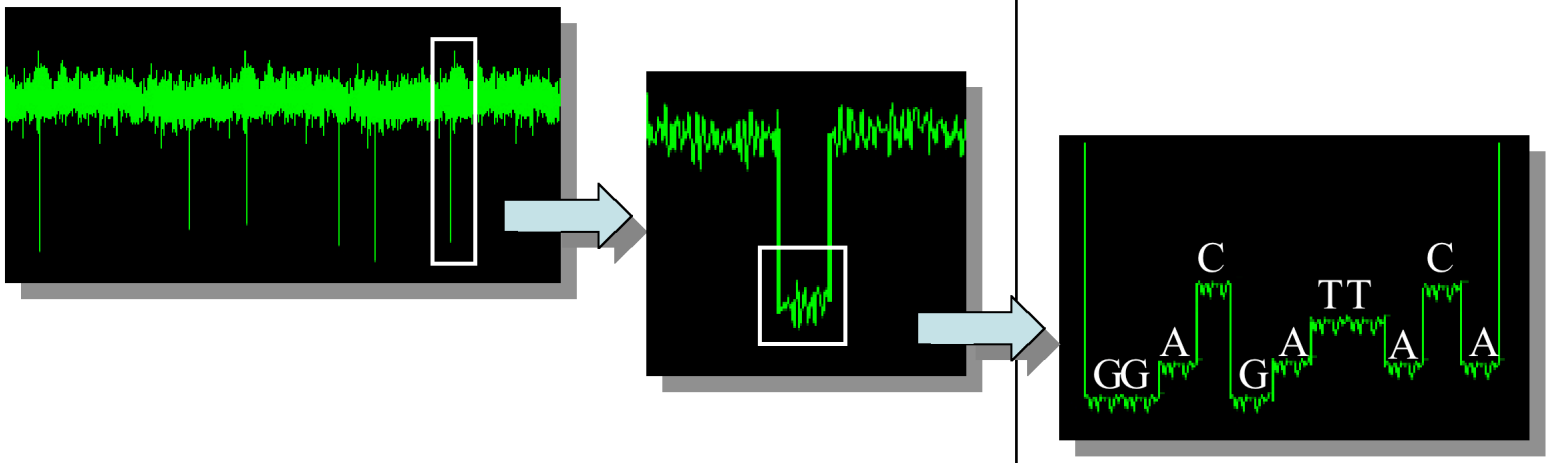


- Nanopore in membrane (~2nm diameter)
- DNA in buffer
- Voltage clamp
- Measure current



G. Church, D. Branton, J. Golovchenko, Harvard
D. Deamer, UC Santa Cruz

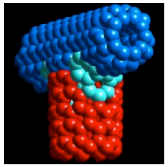
The Sequencing Concept



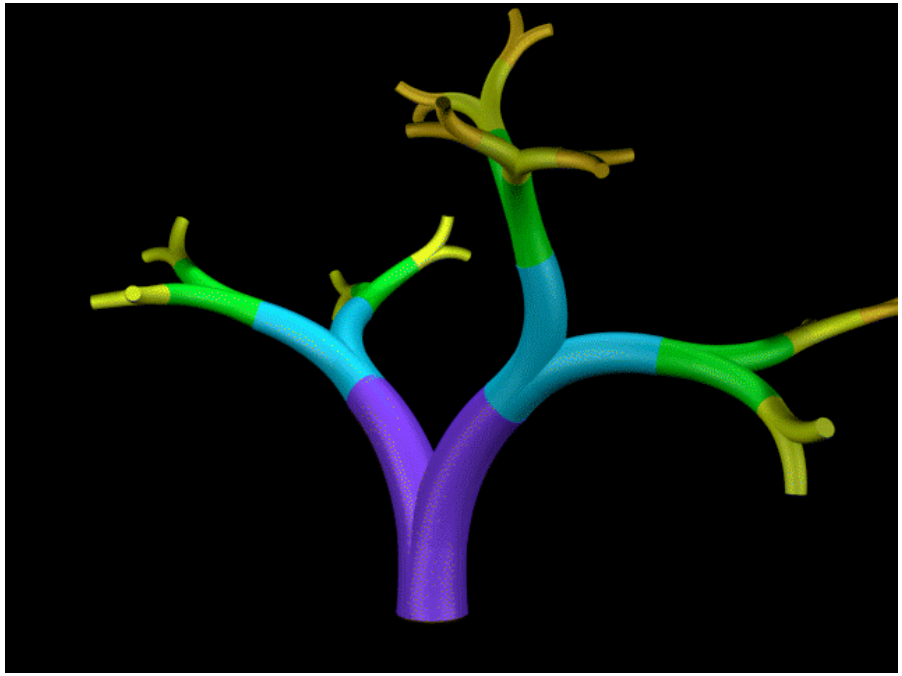
Present

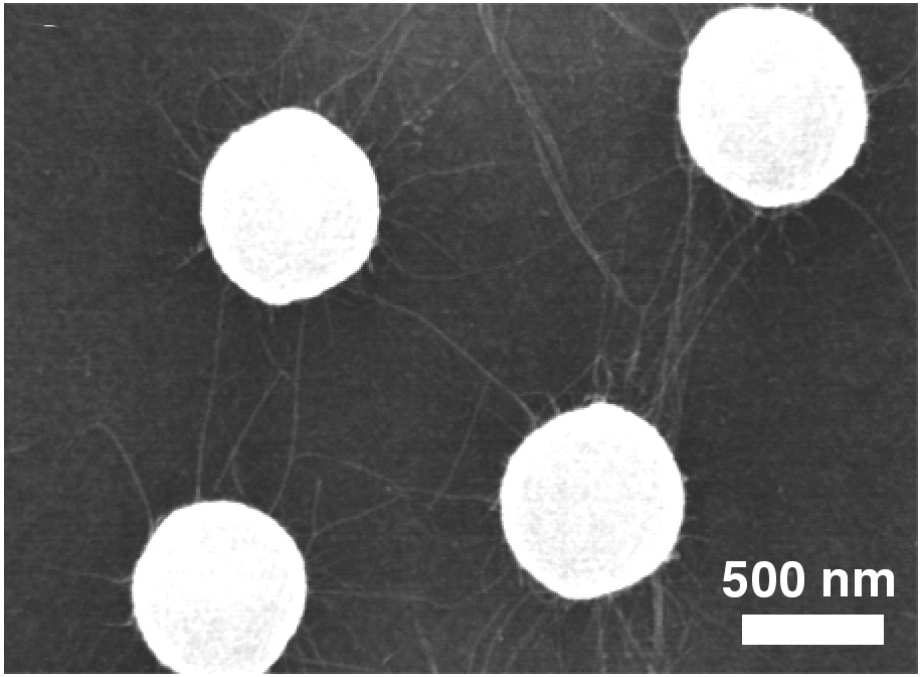
Future

Four-level CNT Dentritic Neural Tree



- Neural tree with 14 symmetric Y-junctions
- Branching and switching of signals at each junction similar to what happens in biological neural network
- Neural tree can be trained to perform complex switching and computing functions
- Not restricted to only electronic signals; possible to use acoustic, chemical or thermal signals





Code S Interest in Nano/Bio Technology Program

- Advanced nano-scale sensor and components development
  - Focal Planes
  - In-situ bio/chem. Sensors
  - THz Sources
  - RF Filters
  - Rad-hard Computing & Memories

Science Measurement Needs

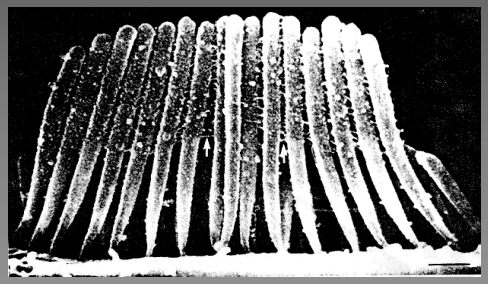
- In-Situ and orbital based locations
- Harsh Environments
- Long-duration monitoring

- In-Situ Signatures:
  - Physical
    - IR Spectroscopy
  - Biological
    - UV Fluorescent
    - Micro Fluidic
  - Chemical
    - Mass-spectroscopy
    - E-nose

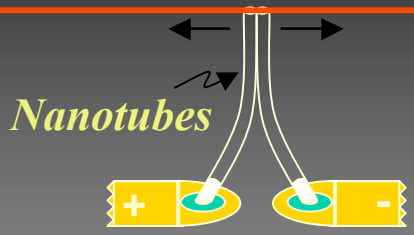
- Remote Sensing:
  - Thermal IR
  - Sub-mm Radiometer
  - Radar
  - Lidar

Order Carbon Nanotube Arrays

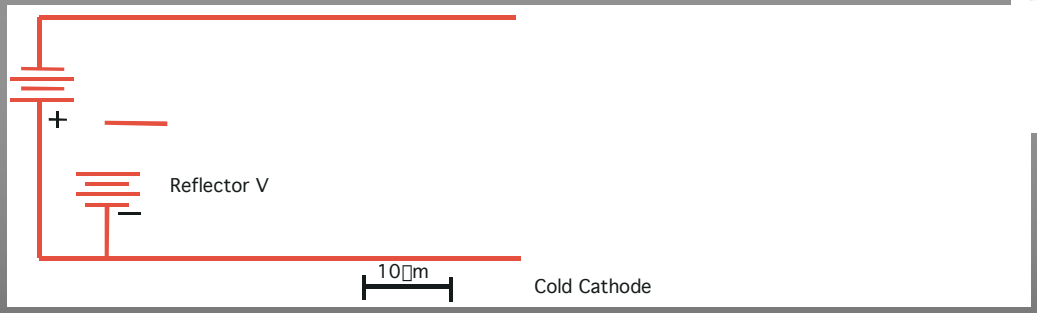
Nanotube based acoustic sensors using biomimetic detection principles



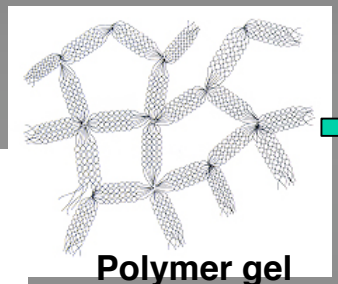
Stereocilia bundle protruding from an inner hair cell of a guinea pig cochlea. Scale bar 500 nm.

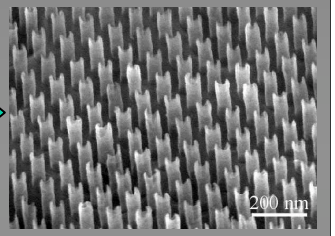


Nanotube bimorph actuator and force sensor

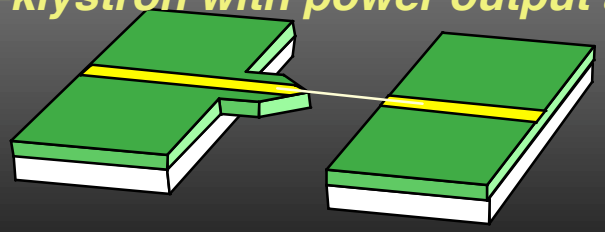


Monolithically fabricated vacuum-tube nano-klystron with power output at THz

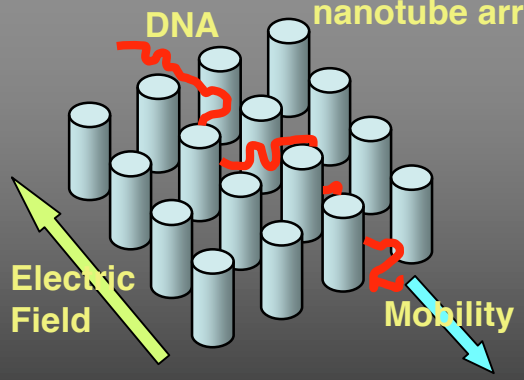




Carbon nanotube array



Nanotube tunable high-Q resonator



Nanotube-Based Electrophoresis System for Biomolecular Analysis