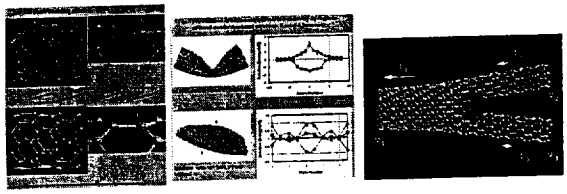
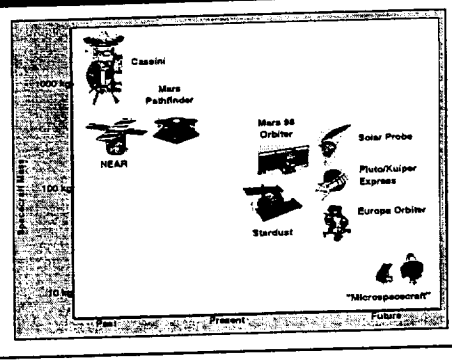
Nano-Bio Technology based Materials and Devices For Healthcare

Deepak Srivastava
Computational Nanotechnology at CSC/NAS
NASA Ames Research Center
Moffett Field, CA 95014



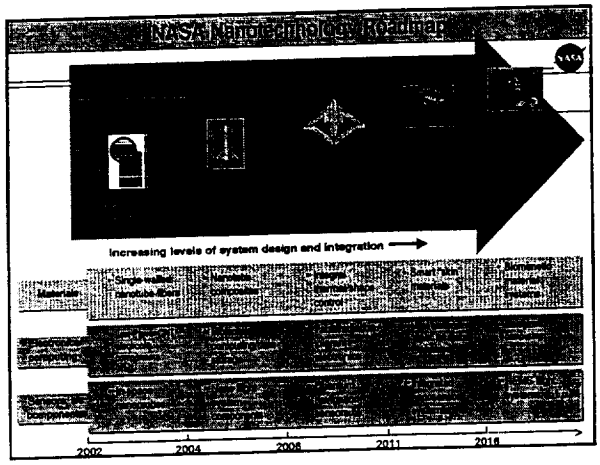
NASA's Own Moore's Law



Why Nanotechnology at NASA?

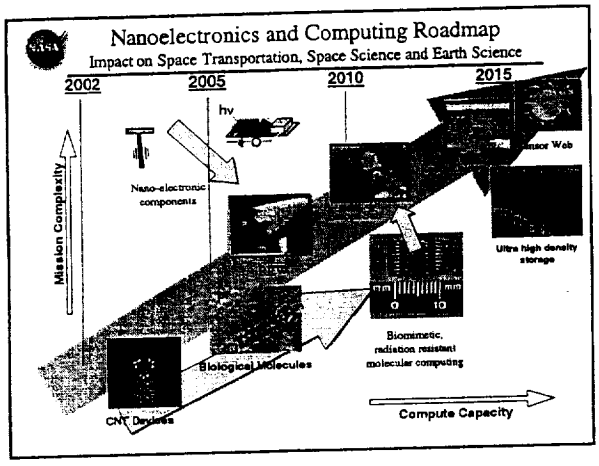
- Networks of ultrasmall probes on planetary surfaces
- Micro-rovers that drive, hop, fly, and burrow
- Collection of microspacecraft making a variety of measurements

NASA Nanotechnology Roadmap



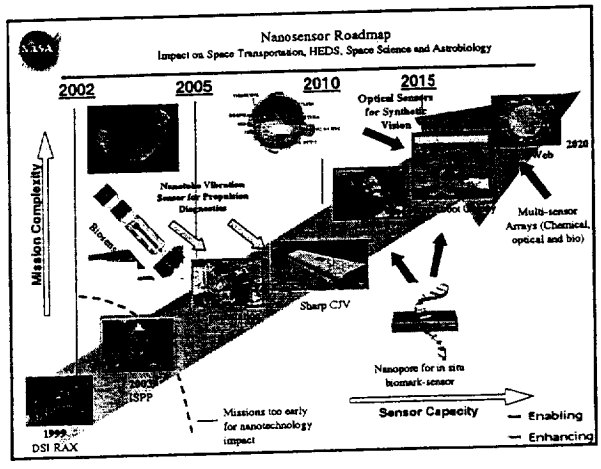
Nanoelectronics and Computing Roadmap

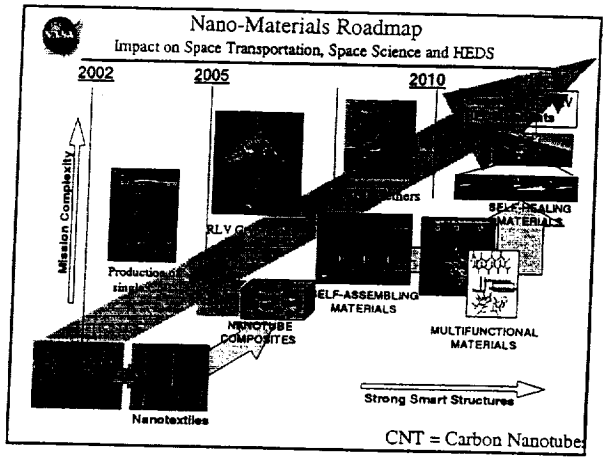
Impact on Space Transportation, Space Science and Earth Science

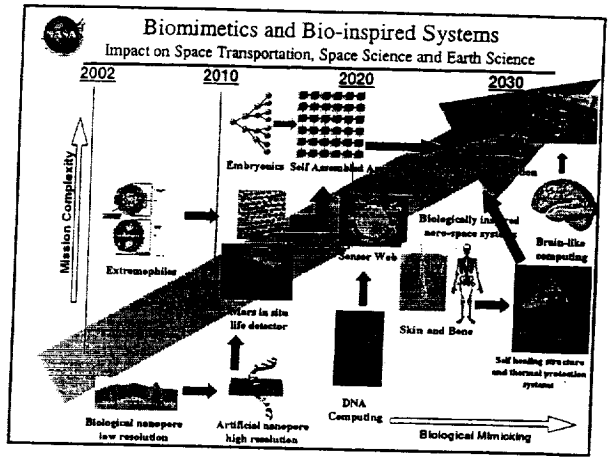


Nanosensor Roadmap

Impact on Space Transportation, HEDS, Space Science and Astrobiology

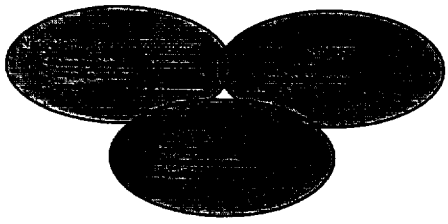






NASA Nanotechnology Program Content

- Nanotechnology Program Elements
  - Nanoelectronics and Computing
  - Sensors
  - Structural Materials



[illegible]

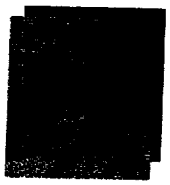
- **Diagnostics, Sensing and Imaging**
  Nanotubes, Fullerenes, Nanoparticles, Nanowires, Quantum Dots
  Nanodevices for fast Genomics and Proteomics
- **Drug Delivery**
  Encapsulating Materials, Nanoporous Systems
- **Nano-Surgery/Manipulation**
  Molecular Machines, Nano-controlled Energy Deposition
- **Novel Materials/Concepts**
  Dendric Neurons (CNT) for sensing and processing
  Nanomaterials with bio-mimetic functionality
- **Technology and Materials for Drug Design**
  Nano-Bio interface for drug design

Carbon Nanotube

CNT is a tubular form of carbon with diameter as small as 1 nm.
Length: few nm to microns.

CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.



CNT can be metallic or semiconducting, depending on chirality.

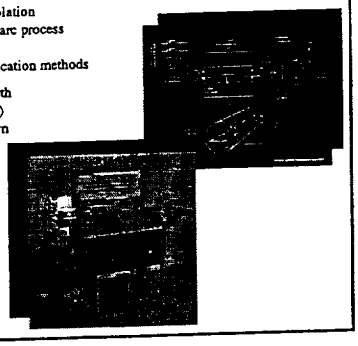
Acknowledgement

Experimental Work:

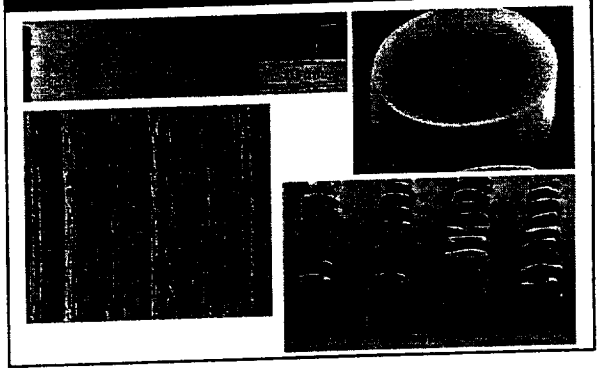
- Meyya Meyyappan (Program Director)
- Viktor Stolc (Genomics/Nanopore)
- Jonathan Trent (Protein Nanotubes)
- Jie Han (Bio-Sensors)
- Jun Li (Bio-Sensors)

CNT Synthesis

- CNT has been grown by laser ablation (pioneering at Rice) and carbon arc process (NEC, Japan) - early 90s.
  - SWNT, high purity, purification methods
- CVD is ideal for patterned growth (electronics, sensor applications)
  - Well known technique from microelectronics
  - Hydrocarbon feedstock
  - Growth needs catalyst (transition metal)
  - Multiwall tubes at 500-800° deg. C.
  - Numerous parameters influence CNT growth

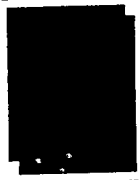


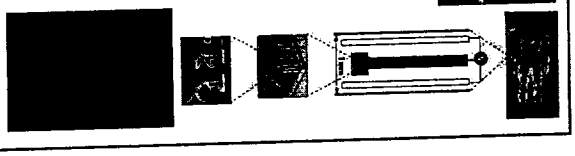
Carbon Nanotubes at Ames



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





QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

Solid-state nanopores for DNA sequencing:

the fastest method for sequencing nucleic acids

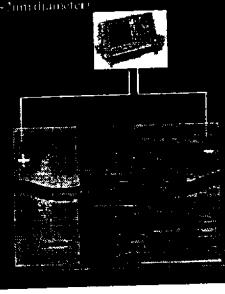
1 subunit/microsecond = 1 human genome in 2hrs

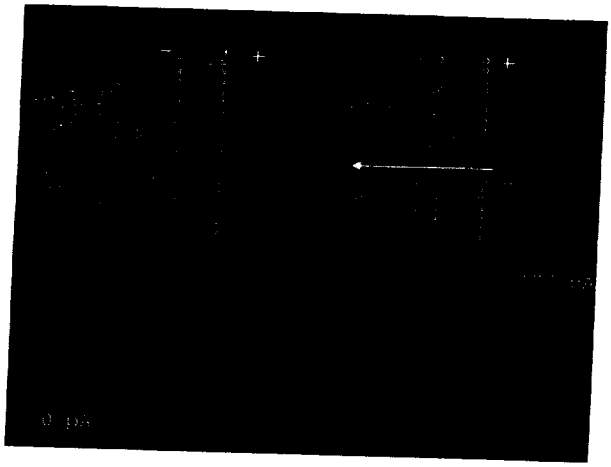
HGP: 13 years /single genome/ $3 billion

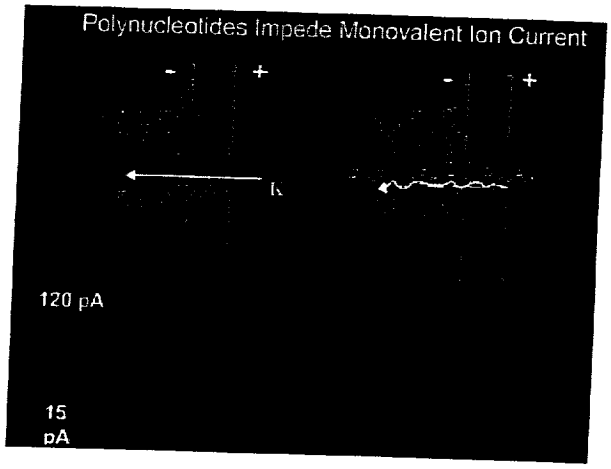
DNA Sequencing with nanopores

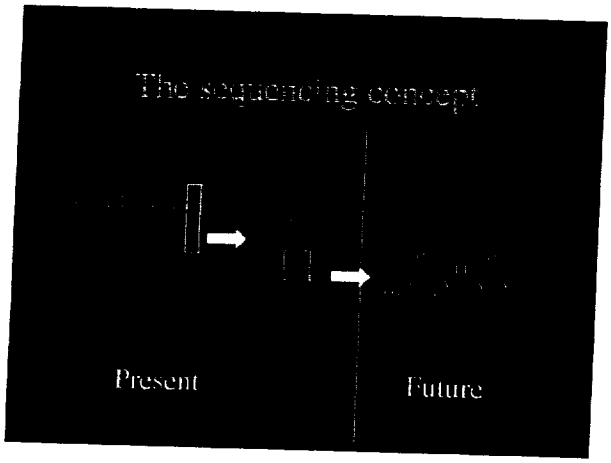
The Concept

- Nanopore in membrane
- DNA in buffer
- Voltage clamp
- Measure current









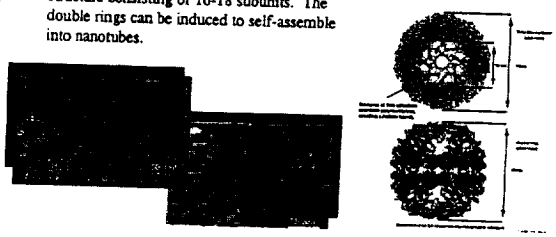
Impact/Applications:

Rapid extraction of genetic information to enable:

1. *In-situ* detection of DNA, RNA, or protein on other planets.
2. Identification of the genetic basis of phenotypic variation among all organisms on Earth.
3. Personalized molecular medicine
   1 subunit/microsecond = 1 human genome in 2hr.

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.



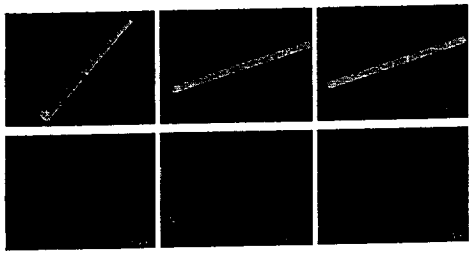
Computational Nanotechnology for New Materials and Devices

- **Multi-Functional Materials for Biomimetics**
  - Nanostructured Skin Effect
  - Nanoporous Materials with Controlled Pores
- **Biomimetic/Revolutionary Concepts**
  - Evolutionary Computing and Sensing
  - Self-Healing Materials
- **Drug Design and Target/Drug Interactions**
  - Fullerene based drugs for HIV, ALS
- **Bio-Molecular Machines**

Computer Simulations: Characterization and Discovery of New Materials/Devices!

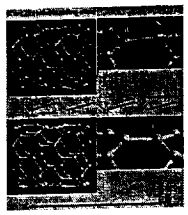
Nanomechanics Examples: Nanotubes

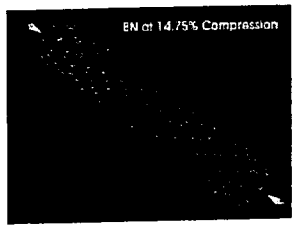
- High value of Young's Modulus (1.2 -1.3 T Pa for SWNTs)
- Elastic limit up to 10-15% strain



Computer Simulations: Characterization of New Materials!

New Prediction: Anisotropic Plastic Collapse

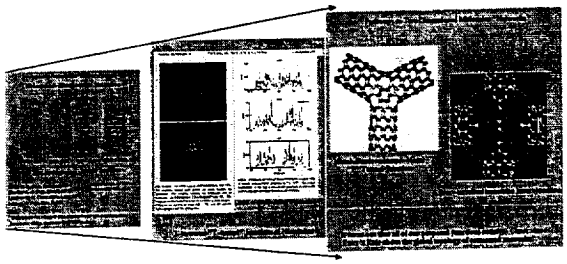




Nanostructured skin effect !

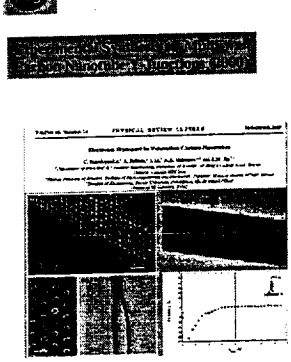
Computer Simulations Generating new IP !

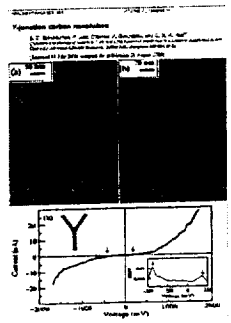
Nanotube Junctions for Devices



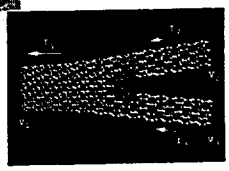
M. Menon and D. Srivastava, Phys. Rev. Lett. Vol. 74, 4453 (1997)
M. Menon and D. Srivastava, J. Mat. Res. Vol 13, 2357 (1998)

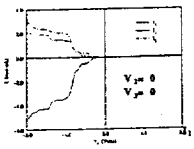
Multiwall Y-Junction Carbon Nanotubes





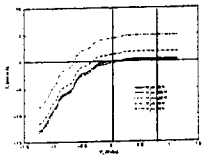
Rectification and Analog Logic Devices





V2	V3	OR	XOR
0	0	0	0
0	1	1	1
1	0	1	1
1	1	1	0

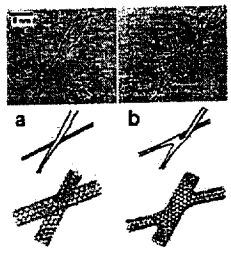
OR XOR

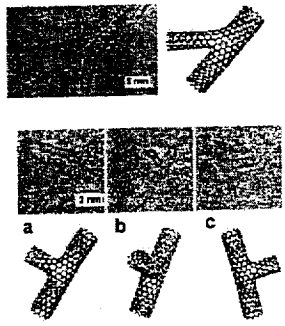


V_1

Andriotis, Menon, Srivastava, Chernozatonskii, Phys. Rev. Lett. (2001)

Single Wall Carbon Nanotube Junctions: Welding





Terrones et. al., Phys. Rev. Lett.
12 August (2002)

Our Approach to CB Neural Signal Processing/Sensing in Biological Systems

Ceral Sensory System (inter-neuron) of a cricket

Biomimetic Dendritic Neurons: Carbon Nanotubes

A 4-level dentritic neural tree: 14 branched carbon nanotube junctions

D. Srivastava et. al., Comp. in Science and Engineering, IEEE, APS (2001)

Biomimetic Dendritic Neurons: Carbon Nanotubes

Biological Dendritic Neural Tree	Carbon Nanotube: Dendritic Tree
• One dimensional cable theory + Hodgkin-Huxley model for action-potential based information flow	• Electronic, acoustic, thermal, and chemical signal transmission and information processing
• Information processing is coded in (a) branching at the junctions, and (b) time-series sequencing of the signal spikes	• Information processing can be based on (a) branching + switching at the junctions, and (b) time series sequencing of signal-spikes
• Input – output – control: is based on (a) structural details of the branches and junctions, and (b) via chemical environment	• Input – output – control: can be based on (a) structural details, (b) chemical environment, and (c) physical contacts at the ends?
• Short and long term memory is part of the structure: evolutionary in nature	• Short and long term memory can be part of structure by defect and chemical adsorbate placements: design for specific purpose/functionality

D. Srivastava et. al., Comp. in Science and Engineering, IEEE, APS (2001)

Acknowledgement

External Collaborators:

- Prof. K. Cho (Stanford University)
- Prof. Don Brenner (NC State University)
- Dr. Madhu Menon (University of Kentucky)
- Dr. Antonis Andriotis (Crete, Greece)
- Dr. Uri Sagman (CSixty, USA)