Ames Research Center

Nano-Electronics and Bio-Electronics

Deepak Srivastava
NASA Ames Research Center
MS T27A-1 and MS 229-3
Moffett Field, CA 94034-1000

deepak@nas.nasa.gov, (650) 604-3486

http://www.ipt.arc.nasa.gov
http://www.nas.nasa.gov/~deepak/home.html

Ames Research Center

Why Nanotechnology at NASA?

- Advanced miniaturization, a key thrust area to enable new science and exploration missions
  - Ultrasmall sensors, power sources, communication, navigation, and propulsion systems with very low mass, volume and power consumption are needed

- Revolutions in electronics and computing will allow reconfigurable, autonomous, "thinking" spacecraft

- Nanotechnology presents a whole new spectrum of opportunities to build device components and systems for entirely new space architectures
  - Networks of ultrasmall probes on planetary surfaces
  - Micro-rovers that drive, hop, fly, and burrow
  - Collection of microspacecraft making a variety of measurements

Ames Research Center

NASA Ames Nanotechnology Program

- Started in FY 97, currently about 25 FTEs on site working on nanotechnology research: additional 15 FTEs involved in simulation, process modeling, and computational chemistry

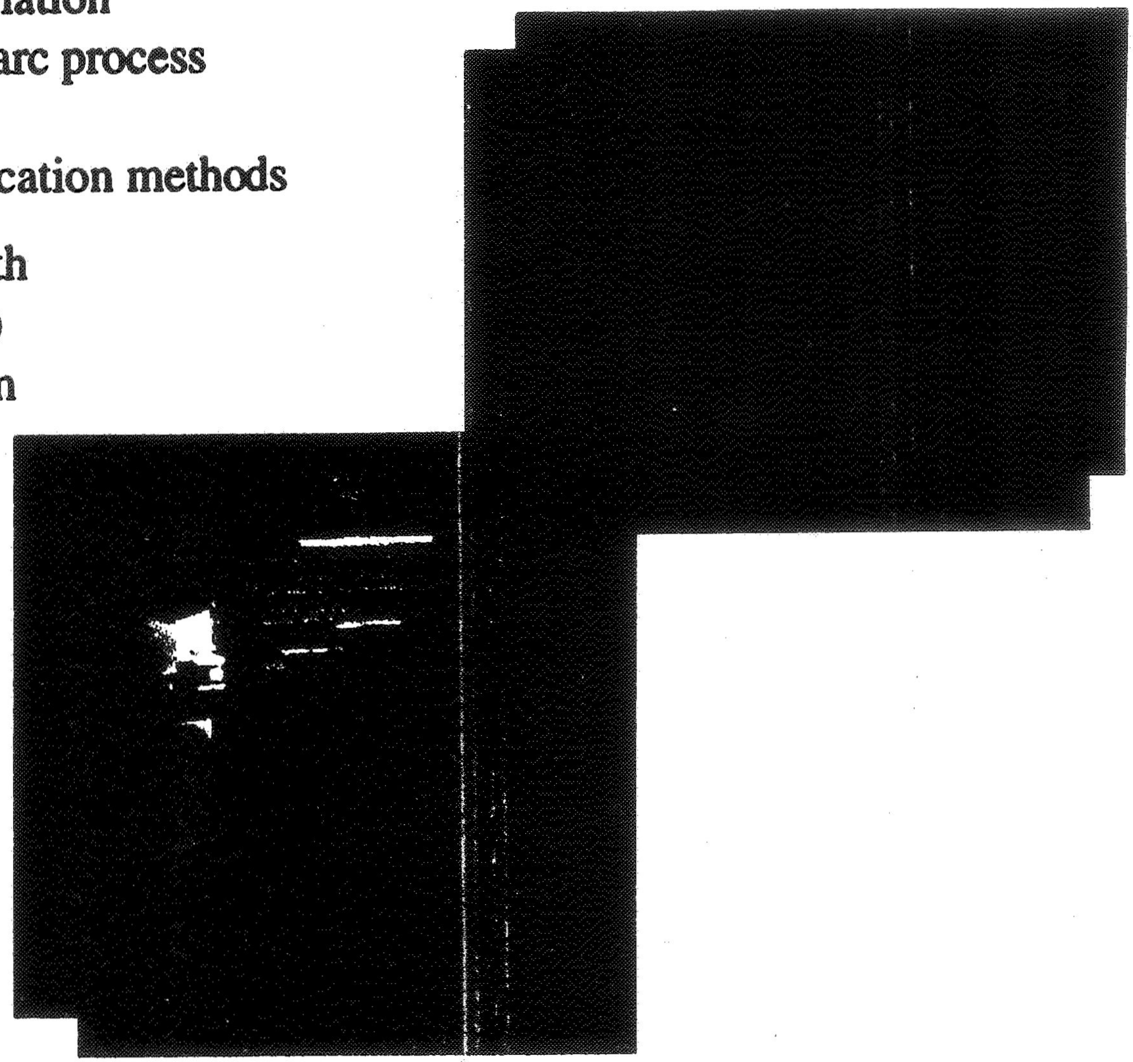
- Research focus ranges from carbon and protein nanotubes, quantum device physics, quantum computing, data storage to optoelectronics, DNA electronics, Bio-Sensors, Bacteriorhodopsin based Data-Storage

- Largest carbon nanotube effort in the Federal government and also one of the largest in the world
  - About ~60 refereed publications in the field
  - Over 100 talks in National/Intemational Meetings
  - Two Feynmann Awards

Ames Research Center

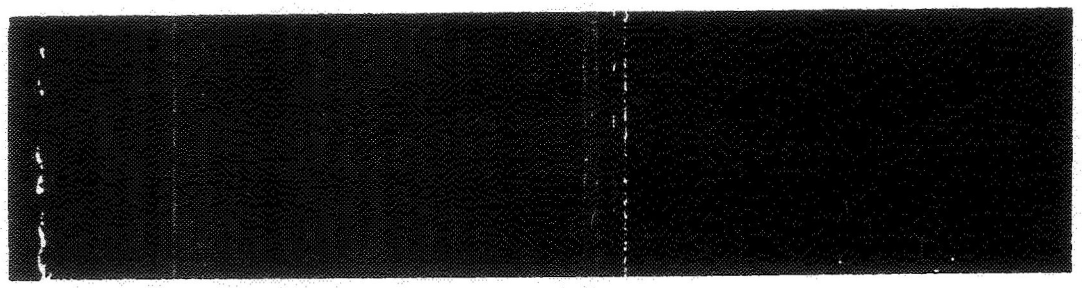
CNT Synthesis

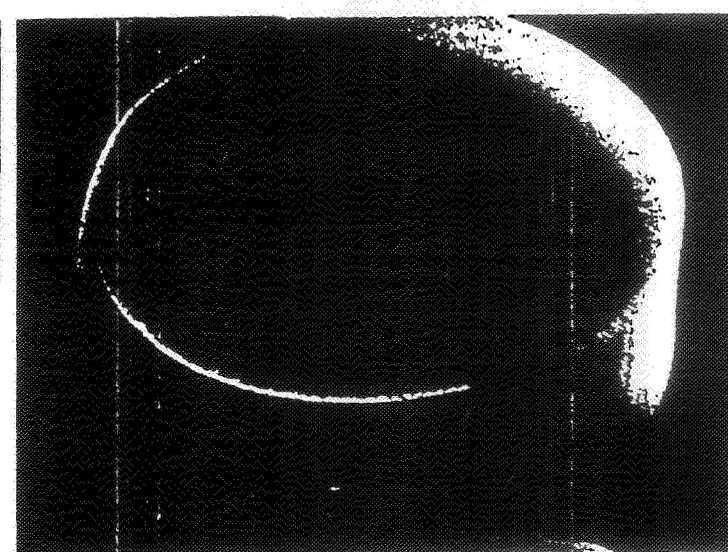
- CNT has been grown by laser ablation (pioneering at Rice) and carbon arc process (NEC, Japan) - early 90s.
  - SWNT, high purity, purification methods
- CVD is ideal for patterned growth (electronics, sensor applications)
  - Well known technique from microelectronics
  - Hydrocarbon feedstock
  -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

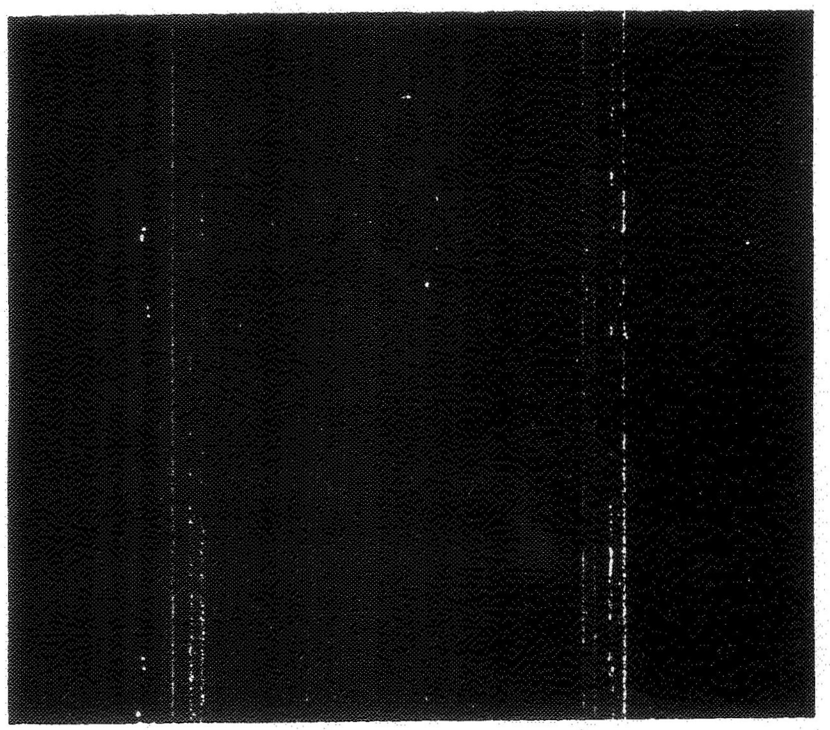


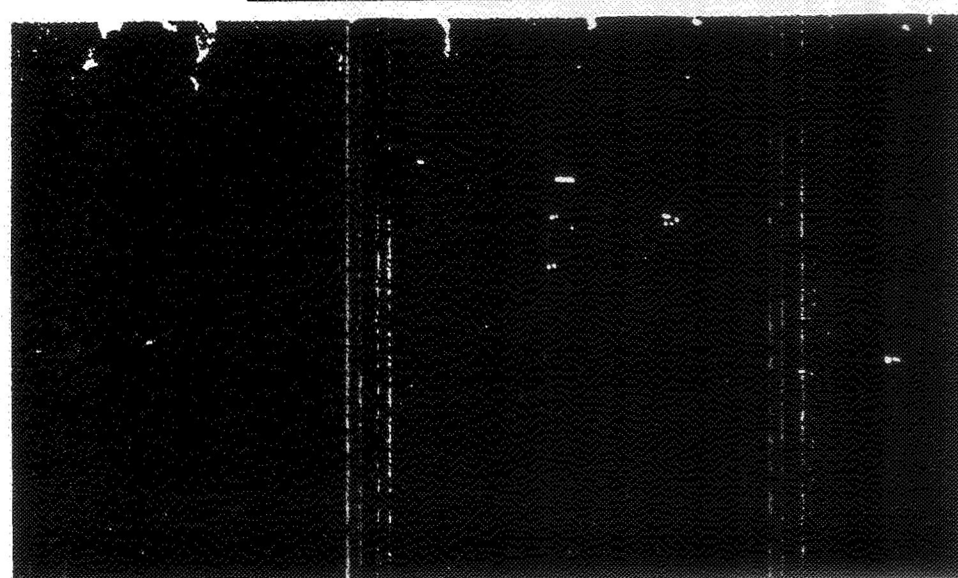
Ames Research Center

Carbon Nanotubes at Ames





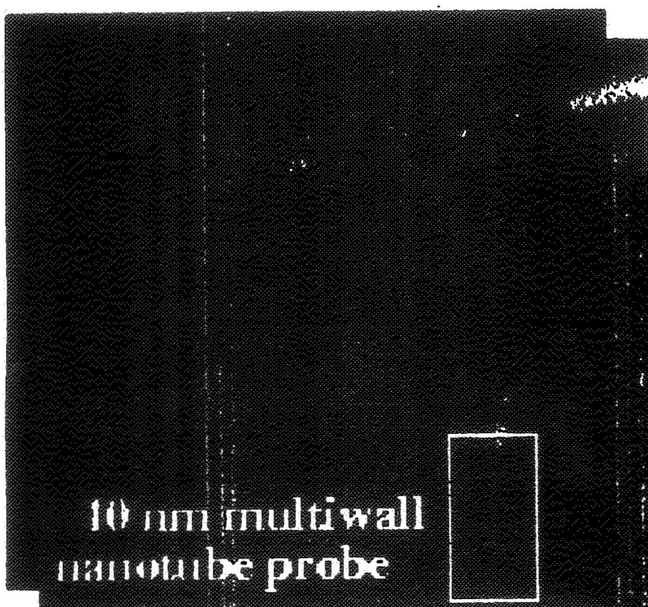




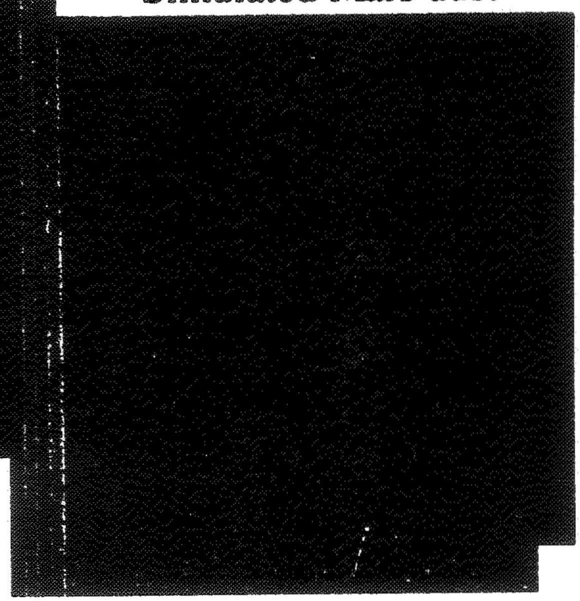
CNT in Microscopy

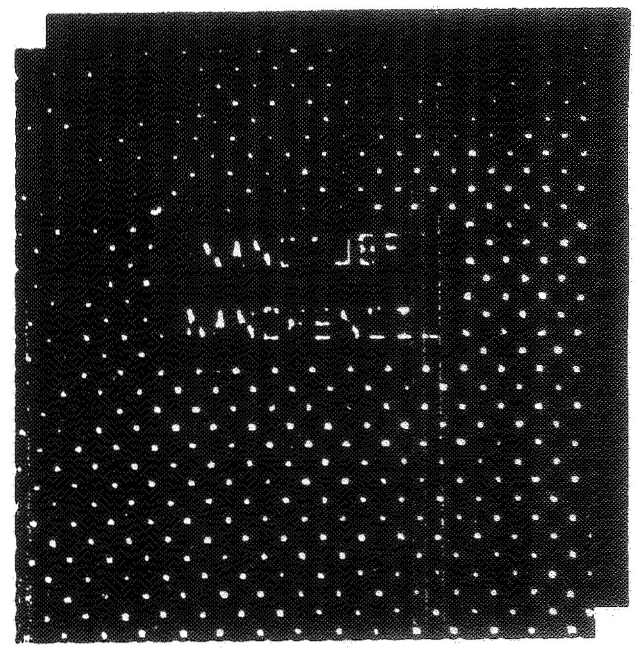
Atomic Force Microscopy is a powerful technique for imaging, nanomanipulation, as platform for sensor work, nanolithography...

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

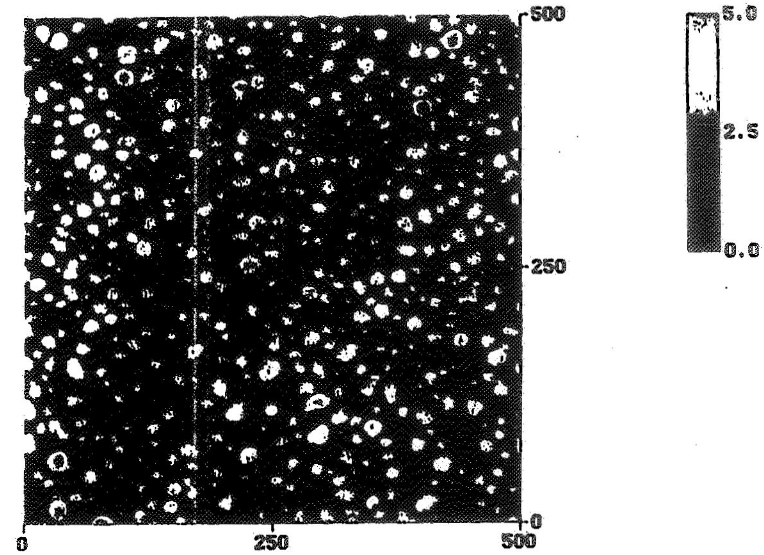


Simulated Mars dust

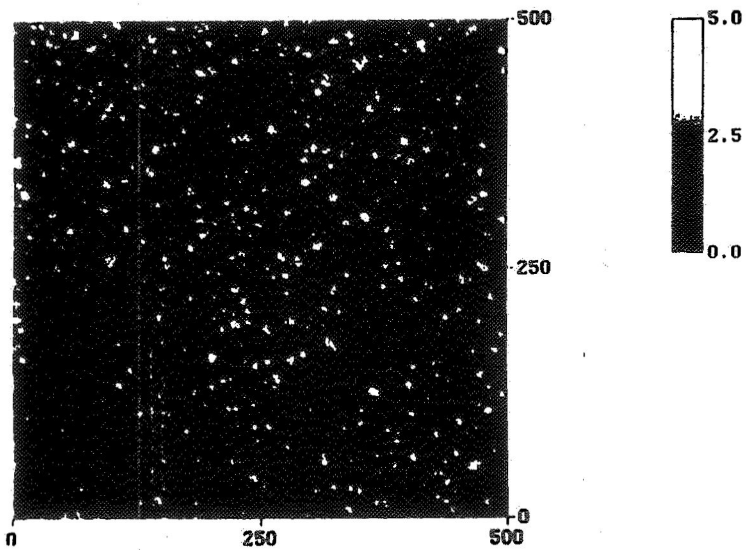




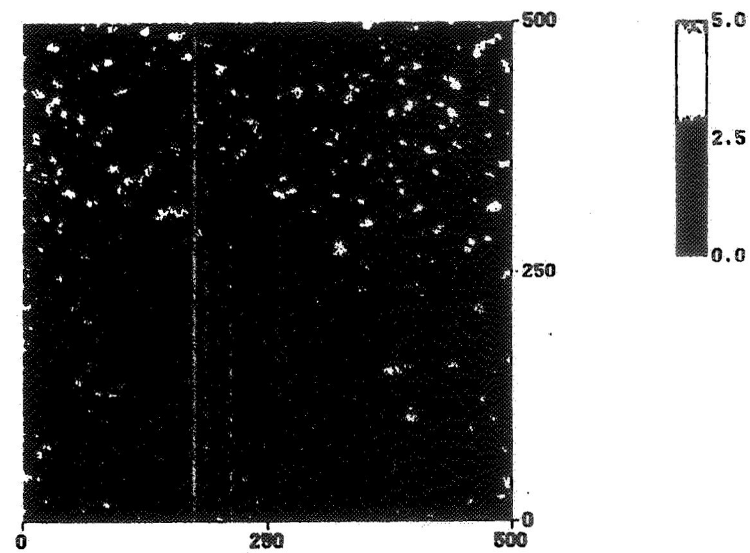
AFM Imaging with Single Wall Nanotube Tips



2 nm thick Au on Mica

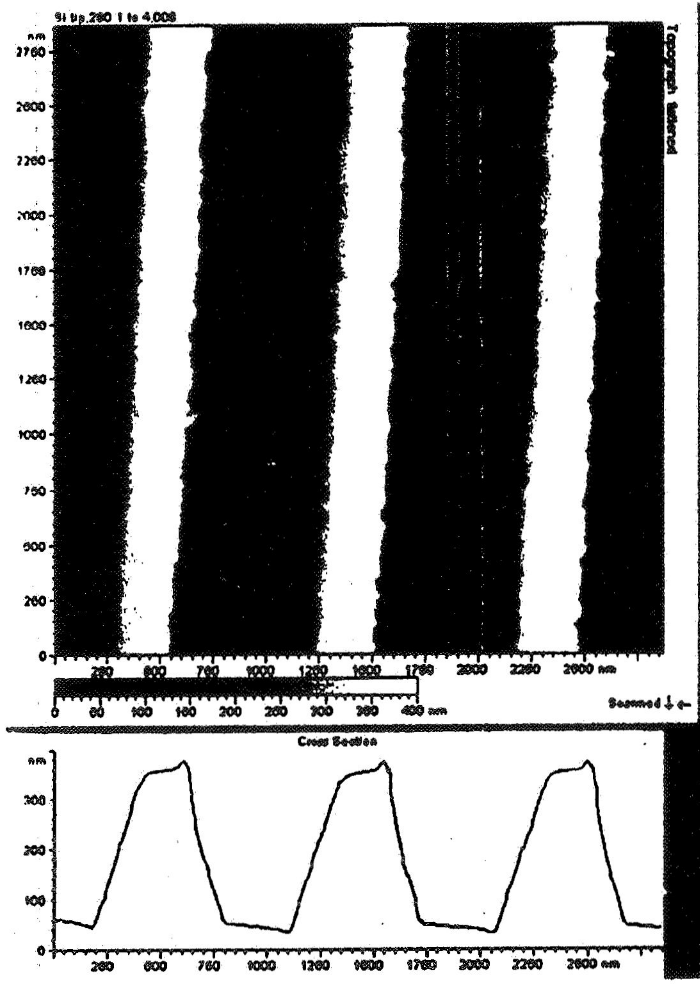


5 nm thick Ir on Mica

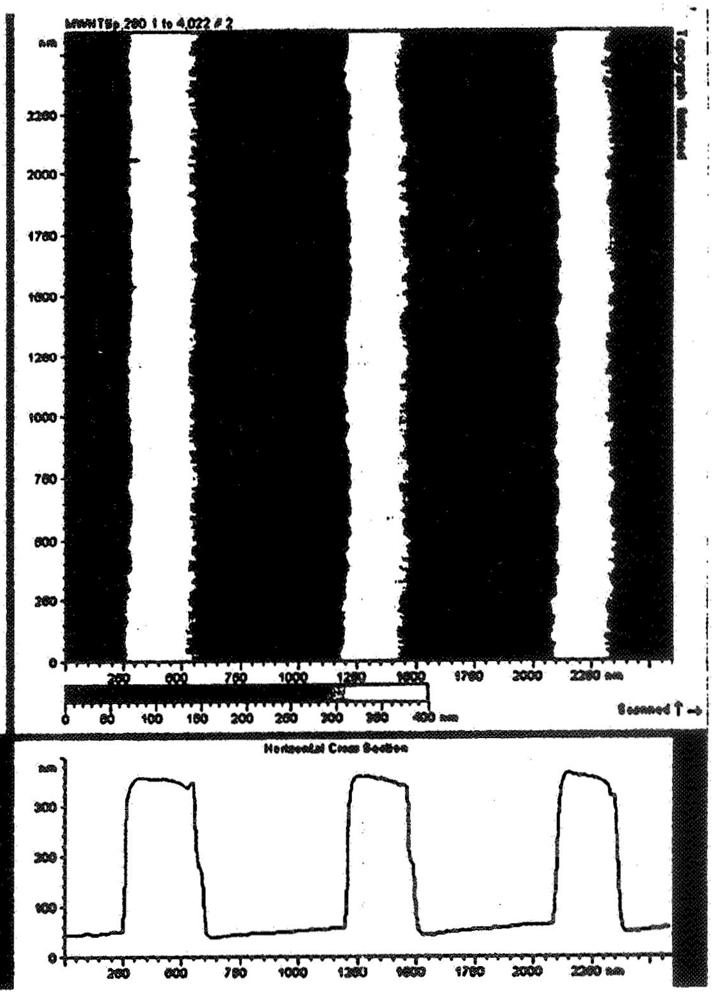


Si_3N_4 on Silicon substrate

280 nm Line/Space Array of Polymeric Resist on silicon Substrate



Silicon Tip

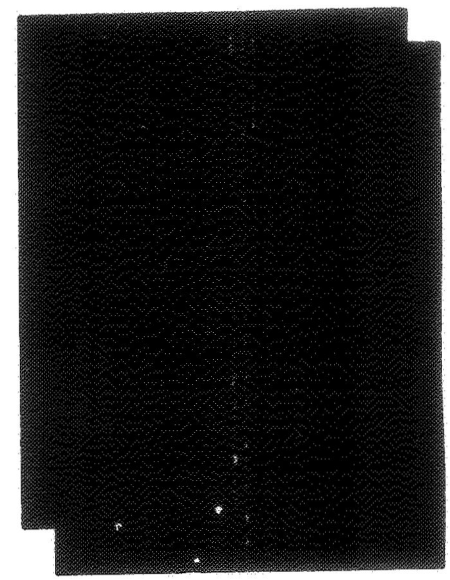


Multi-Walled Carbon
Nanotube Tip

Ames Research Center

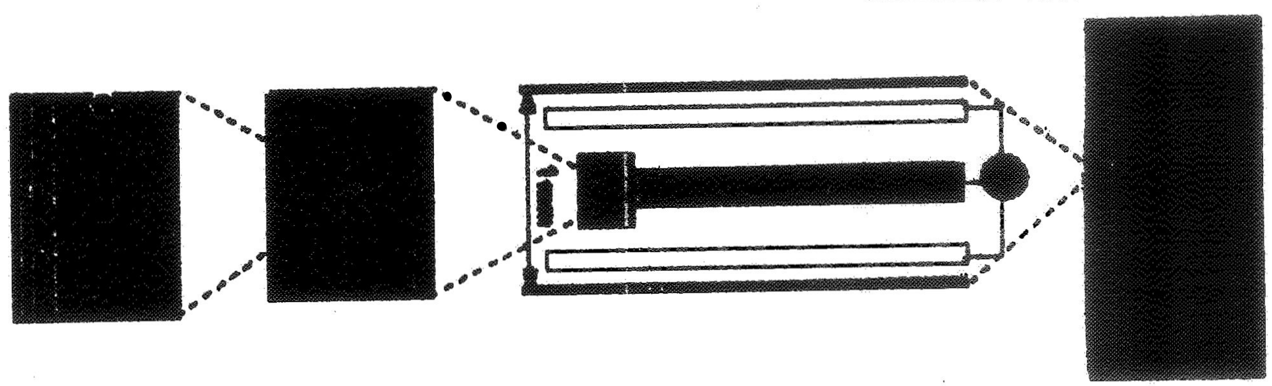
CNT Based Biosensors

- 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

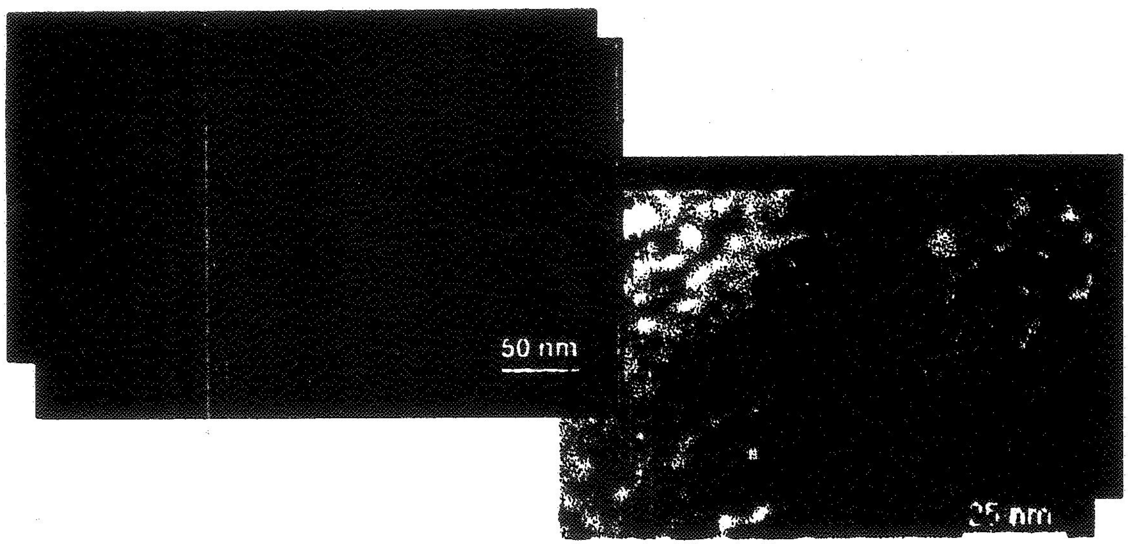


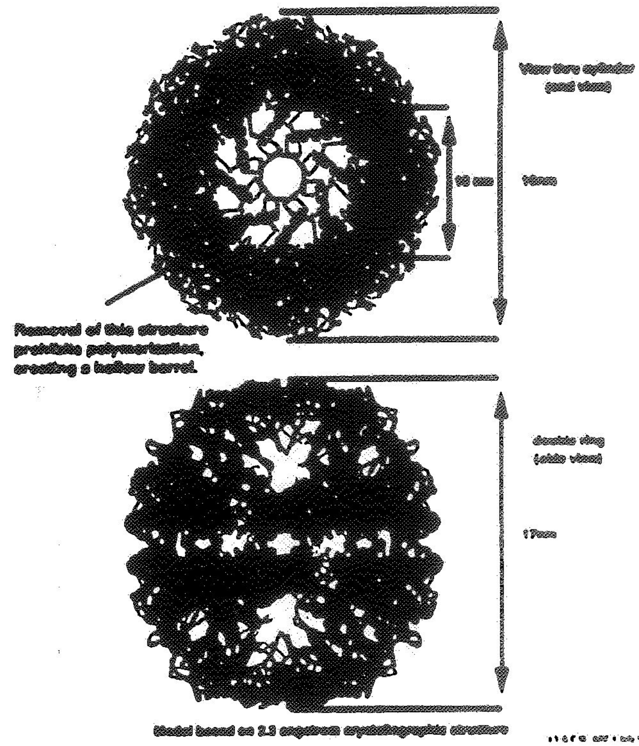
Ames Research Center

Protein Nanotubes

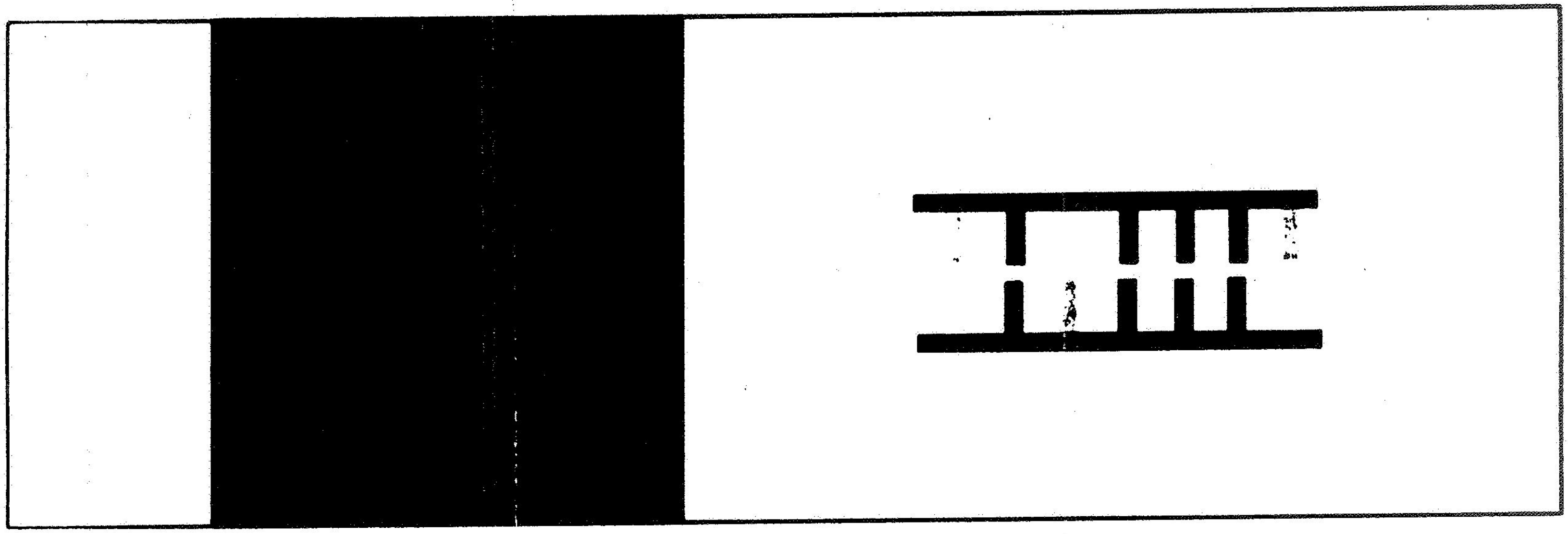
- Heat shock protein (HSP 60) in organisms living at high temperatures ("extremophiles") is of interest in astrobiology

- 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.





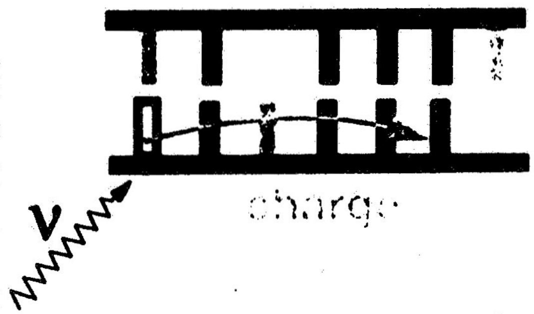
IMPORTANCE



- Conductivity of DNA has been controversial for decades.
- Electron transfer experiments (biochemistry) / Possible connection to cancer
- Transport experiments (physics)
- DNA Electronics (Device / Lithography)

ELECTRON TRANSFER EXPERIMENTS

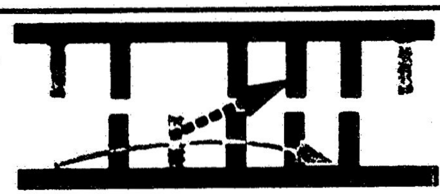
- Oxidative damage of DNA has been linked to cancer.
- How effective is long range electron transfer in causing oxidative damage?



* Fluorescent analog of a base pair

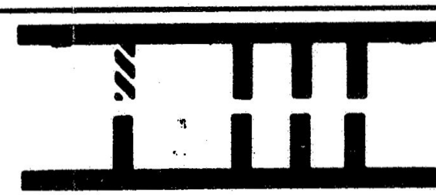
* Intercalator

- Estimates of electron transfer rates span <u>two</u> orders of magnitude.



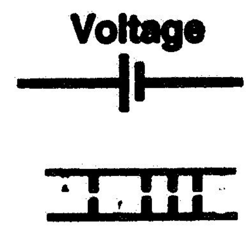
Intrastrand & Interstrand

Significant dependence on intervening sequence

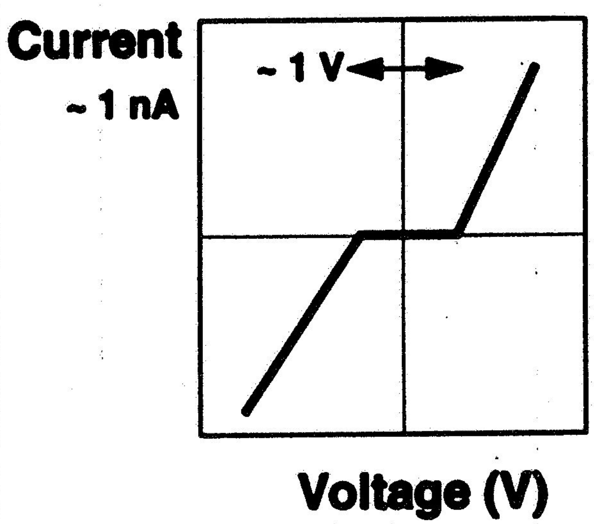


Significant dependence on base pair mismatches.

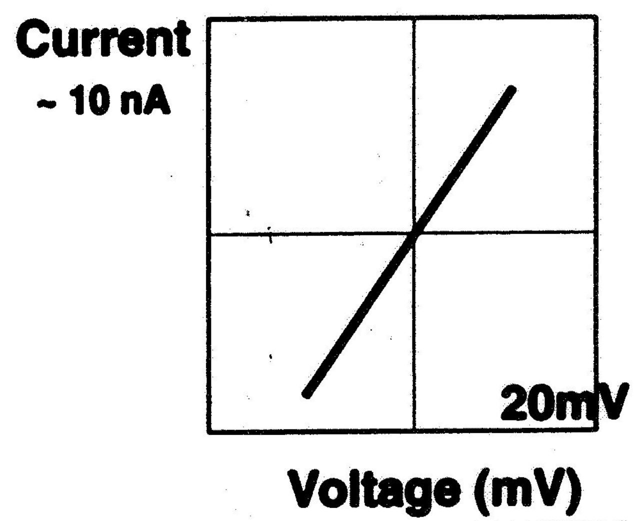
TRANSPORT EXPERIMENTS



Porath et. al, Nature (2000)   INSULATING



Fink et. al, Science (1999)   NO GAP!

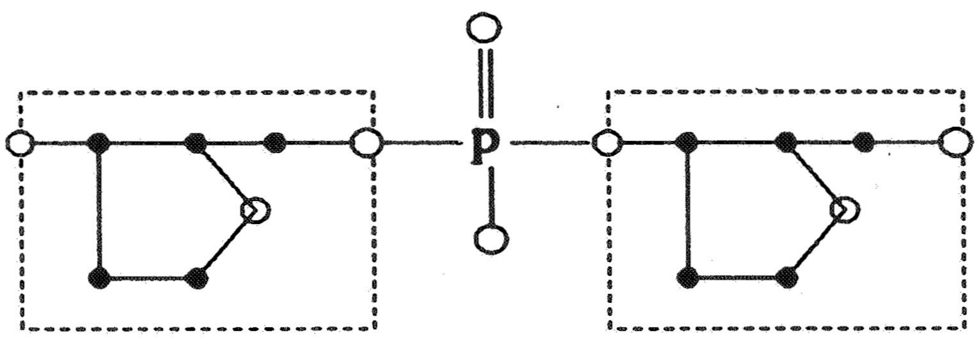


[redacted]

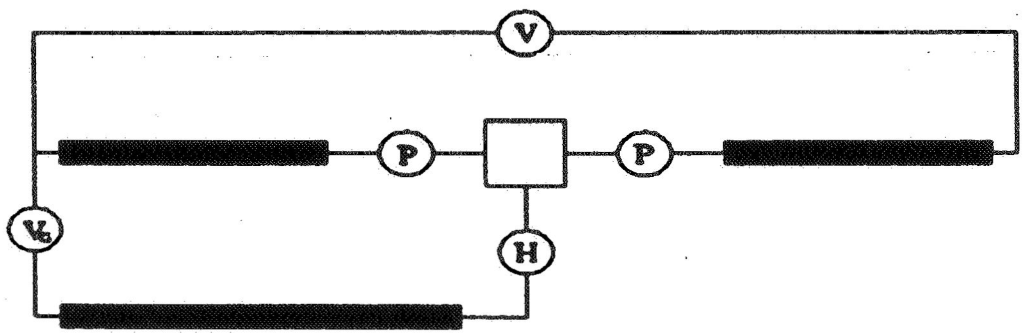
Based on Phosphate bridges acting as tunnel junctions and H acting as capacitive element.

DNA coated with metals can act as interconnects

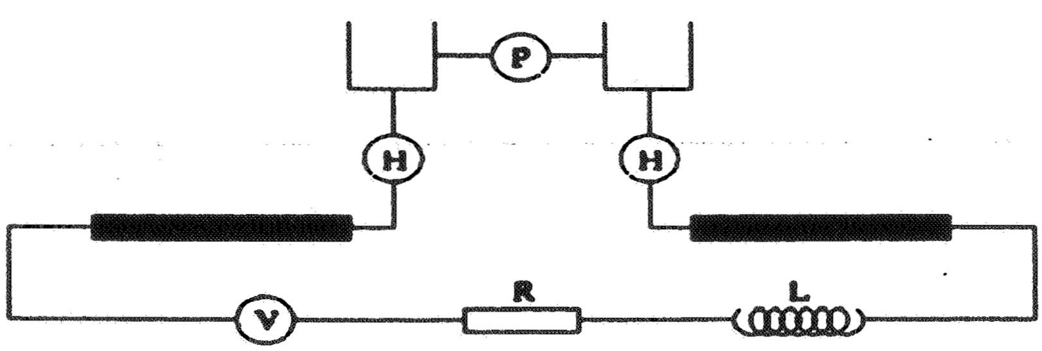
DNA has self–assembly properties



DNA Junctions



Single Electron Transistor



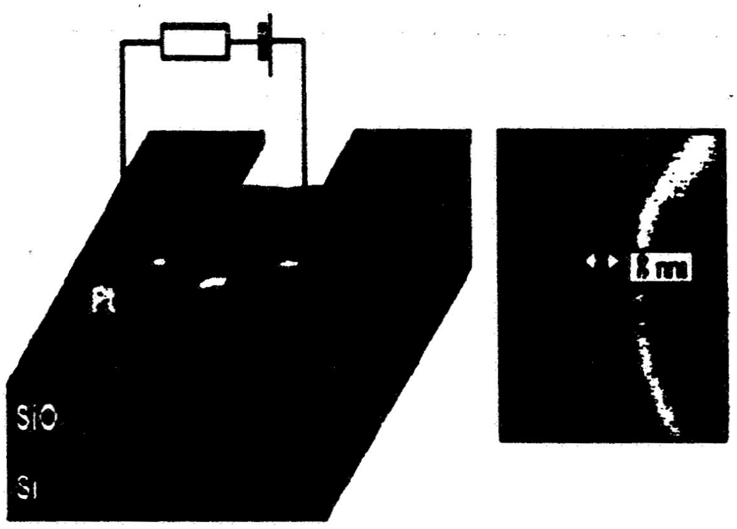
Quantum Bit

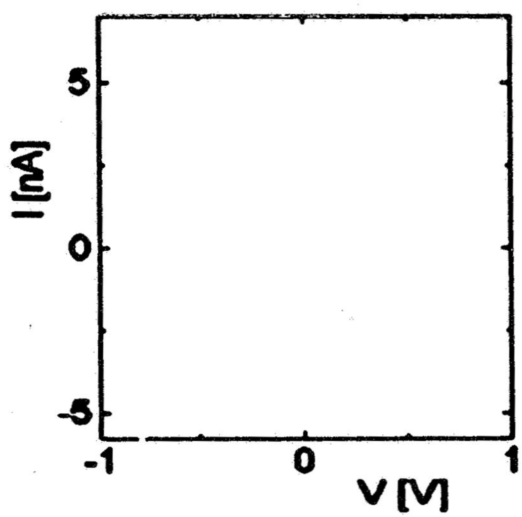
DNA as Electronics Elements:

about DNA as metal or semiconductor ?

Indirect measurements in the beginning led to this controversy?

Transport measurements on single DNA molecules **C. Dekker (Delft)**
Nature, 2000

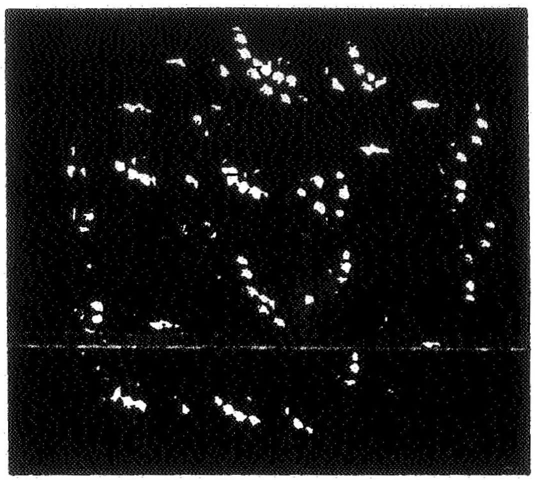




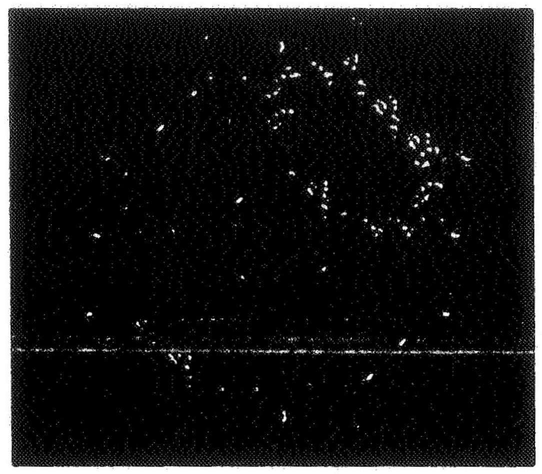
A 10.4 nm long, double–stranded poly(G)–poly(C) DNA molecule
Metal nanoelectrodes that are separated by 8 nm

Metal coated DNA serve as conductor.

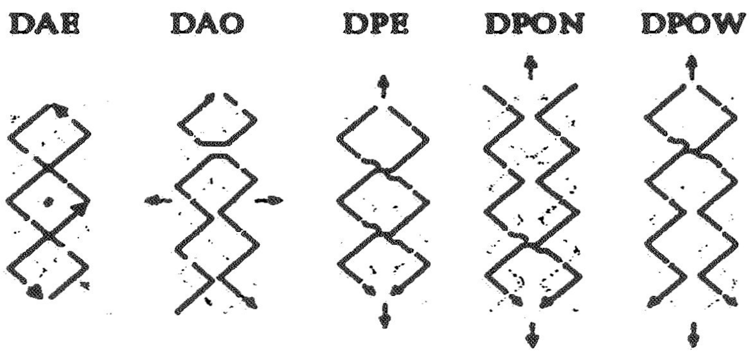
Example: [redacted] (NYU)



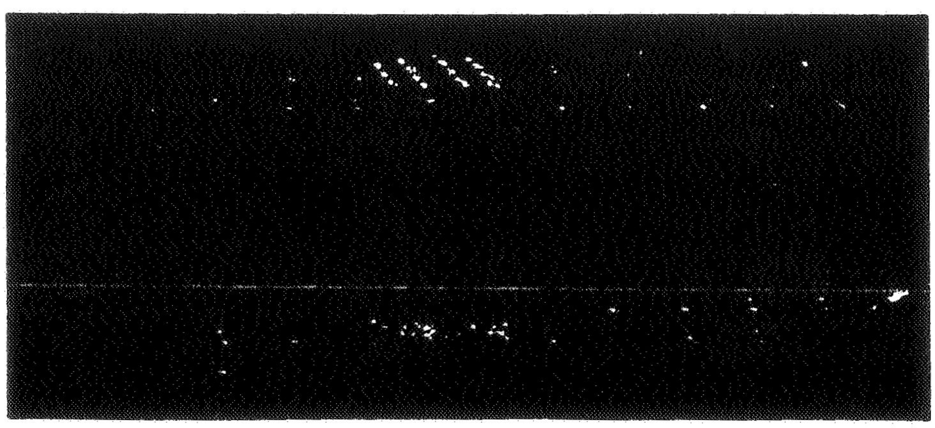
Cube



Truncated Octahedron



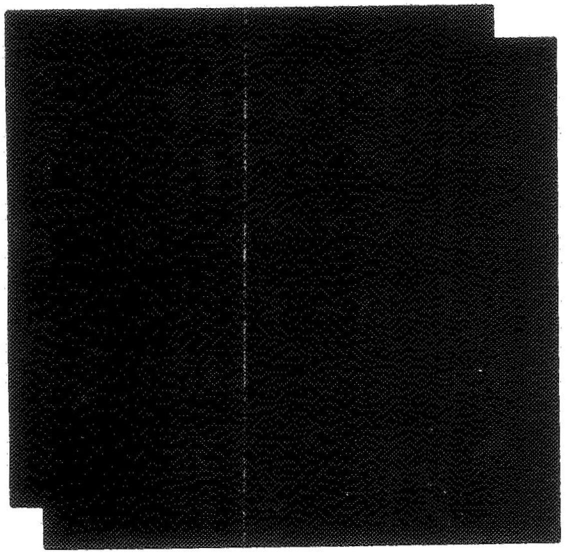
Double Cross–Over Molecules



DNA Nano–mechanical Device

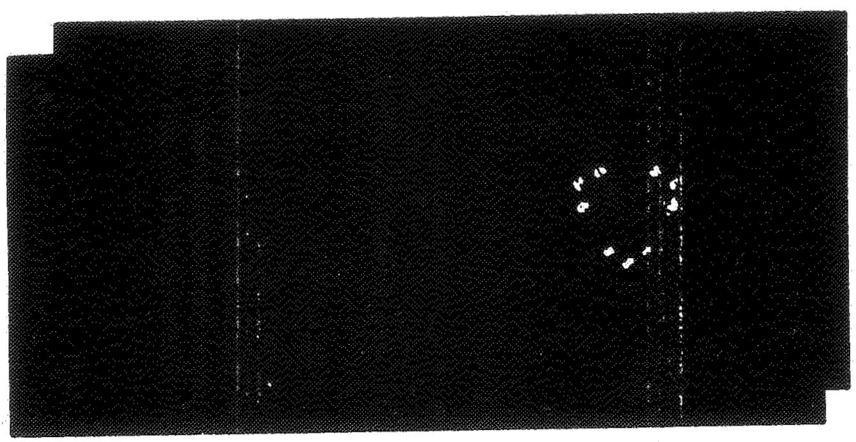
Ames Research Center

Computational Nanotechnology

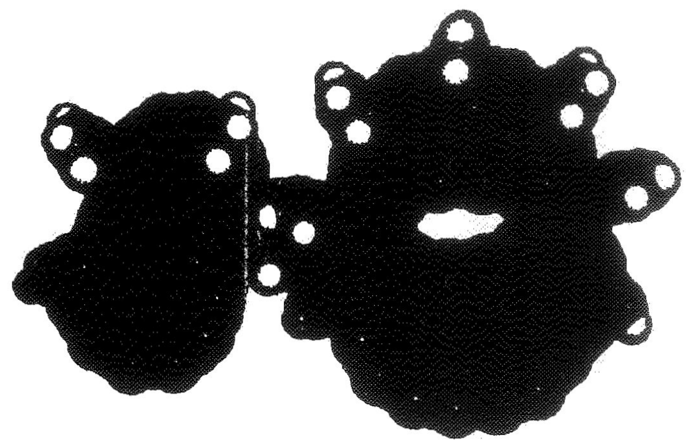


CNT Molecular Network

- Large scale computer simulations based on ab initio methods enable understanding nanotube characteristics and serve as design tool
  - Evaluation of mechanical properties
  - Evaluation of electronic properties
  - Electron transport in CNT devices
  - Functionalization of the nanotubes
  - Design of electrical and mechanical devices
  - Evaluation of storage potential (H_2, Li)

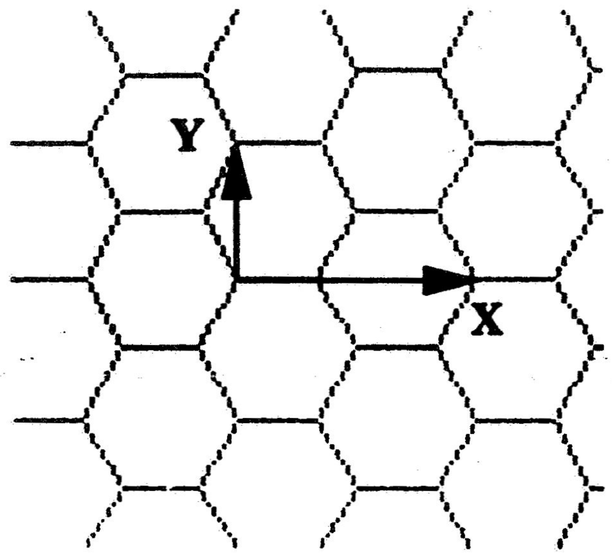


CNT "T" and "Y" Junctions

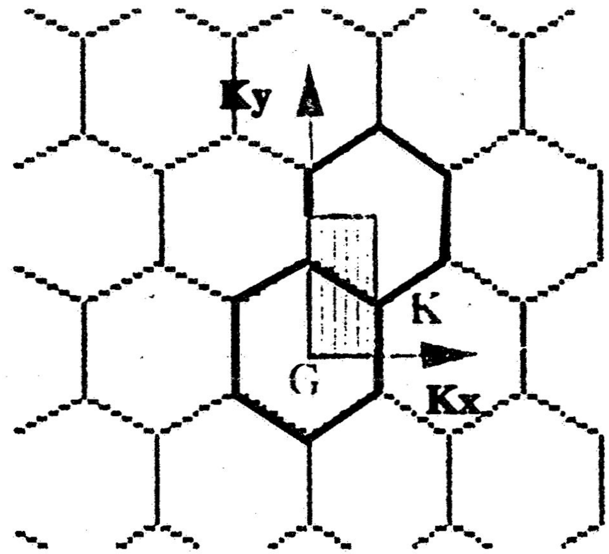


www.nas.nasa.gov/~deepak/home.html

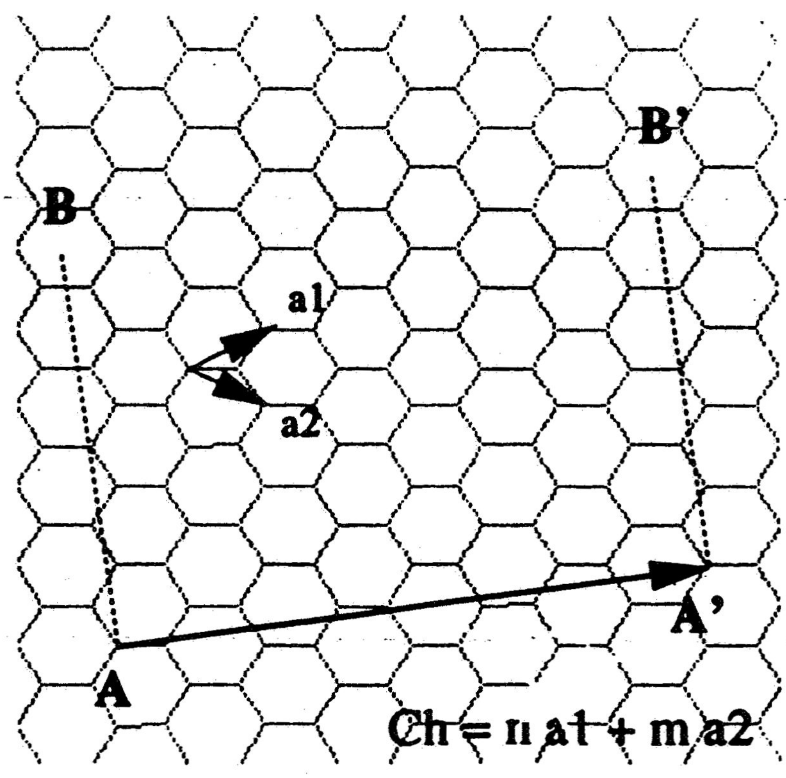
Carbon Nanotube Electronics Band Structure (basics)



Hexagonal Lattice of a Graphene Sheet – (2xunit cell)



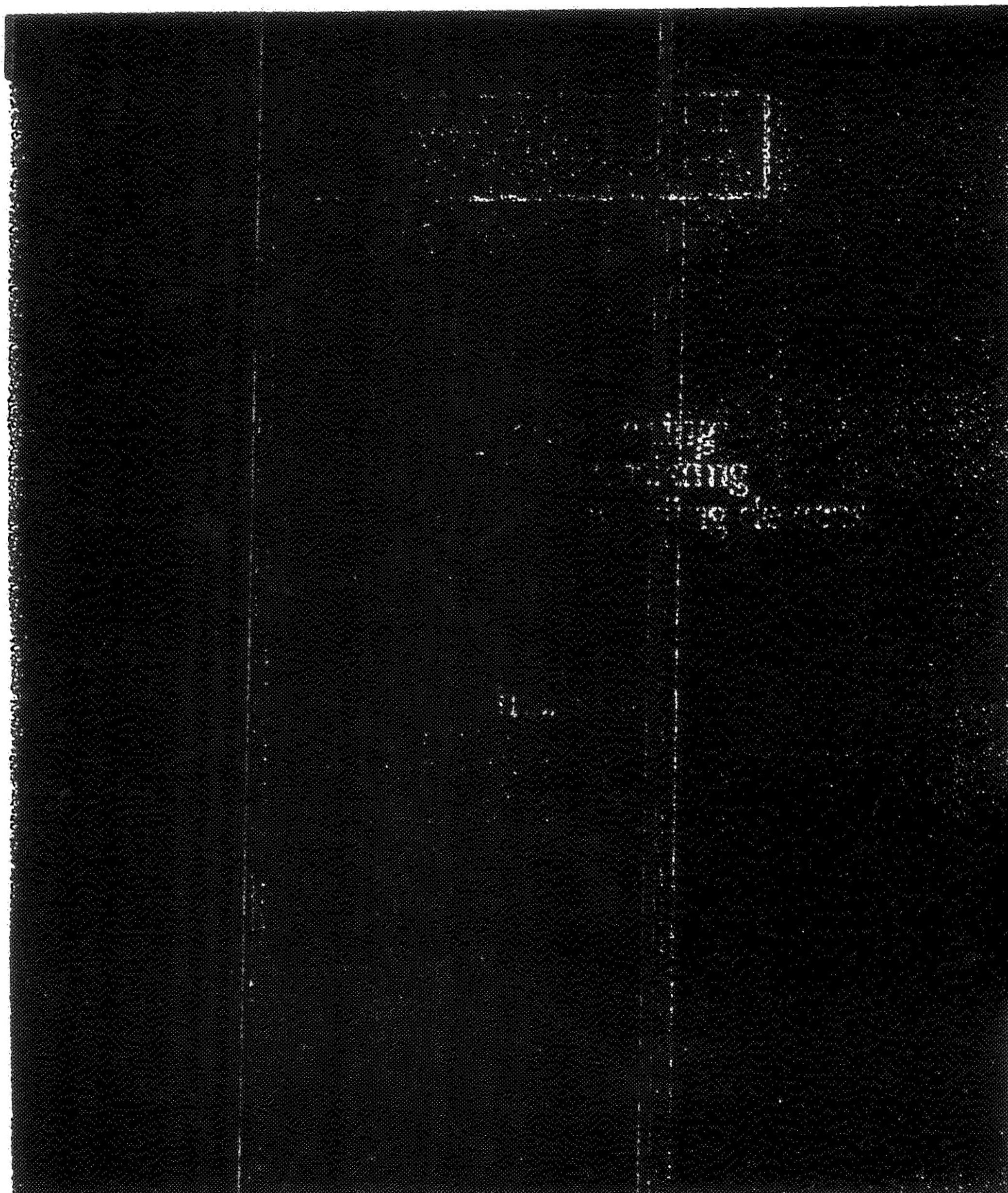
First Brillouin zone for an arm–chair tube.

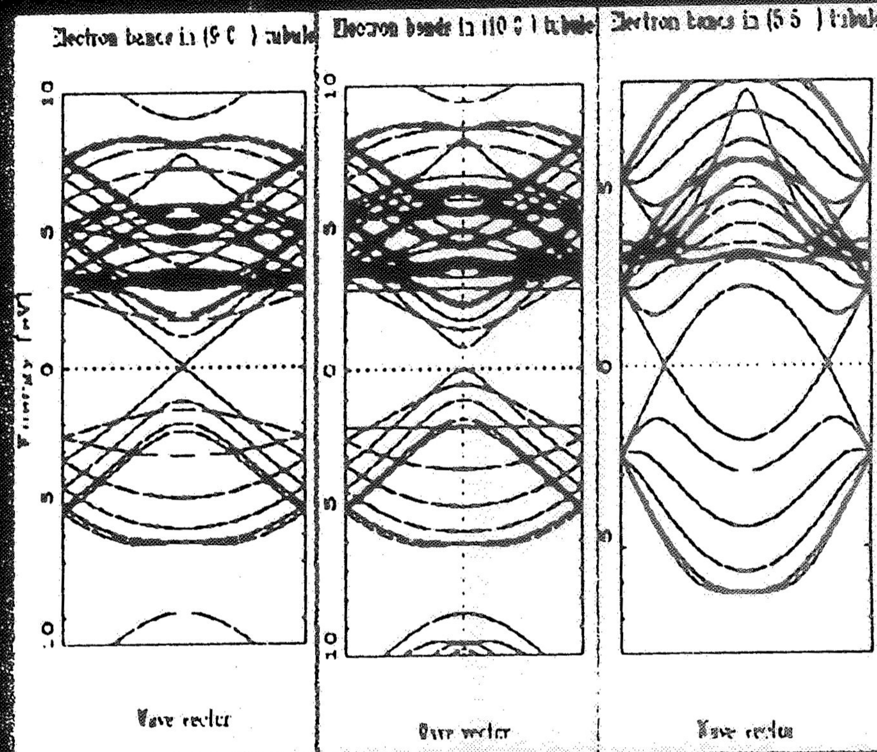


$Ch = n\,a1 + m\,a2$ (chiral vector)

Ames Research Center

Computational Nanotechnology





Carbon based Electronics

3-terminal CNT Heterojunctions

VOLUME 79, NUMBER 22 PHYSICAL REVIEW LETTERS 1 DECEMBER 1997

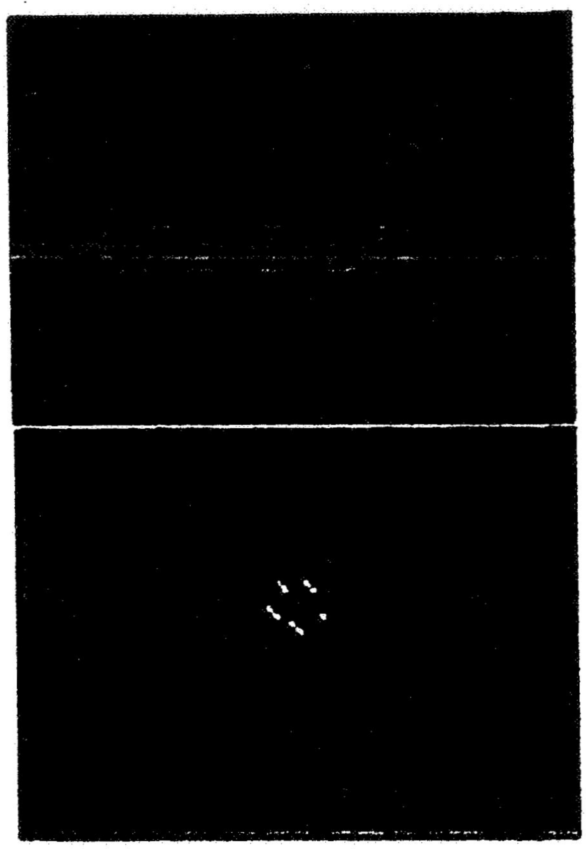


FIG. 1(color). (a) Fully relaxed (5,5)-(10,0)-(5,5) tube (T1). The turquoise colored balls denote the atoms forming the heptagons. The structure contains six heptagons and no pentagons. (b) Fully relaxed (9,0)-(10,0)-(9,0) tube (T2). The turquoise colored balls denote the atoms forming the heptagons. Pentagons are denoted by white balls. The structure contains eight heptagons and two pentagons.

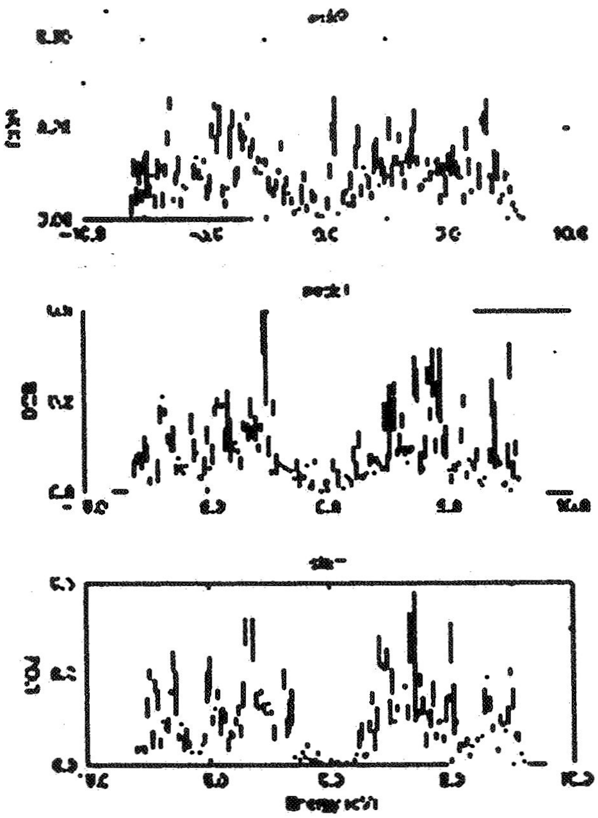
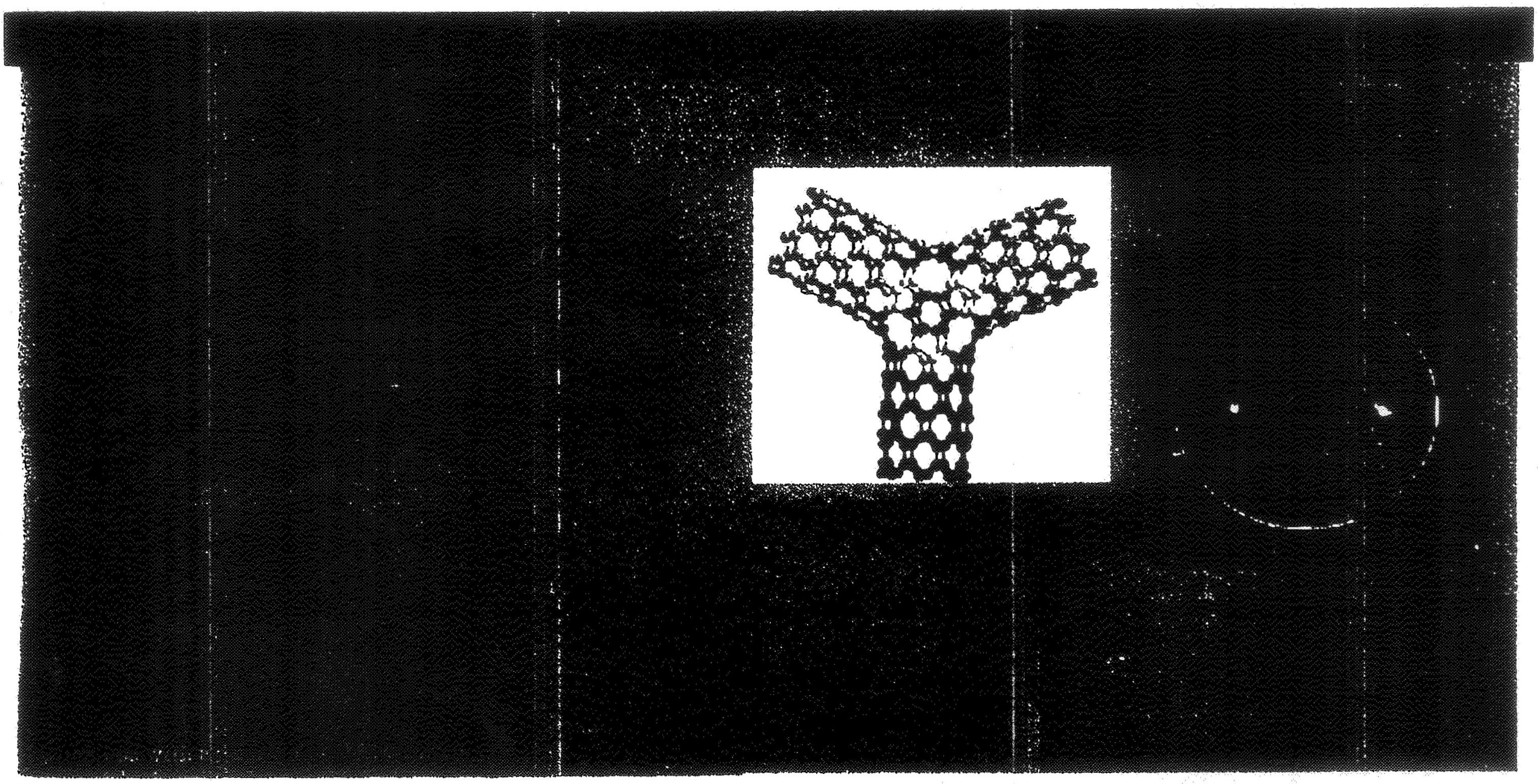


FIG. 3. LDOS for the relaxed (9,0)-(10,0)-(9,0) structure (T2) at various cross sections indicated in Fig. 1(b). The larger contribution in the gap is due to the presence of two extra pairs of heptagon-pentagon defects at the junction.

LDOS of (10,0)–(9,0) "T–junction"

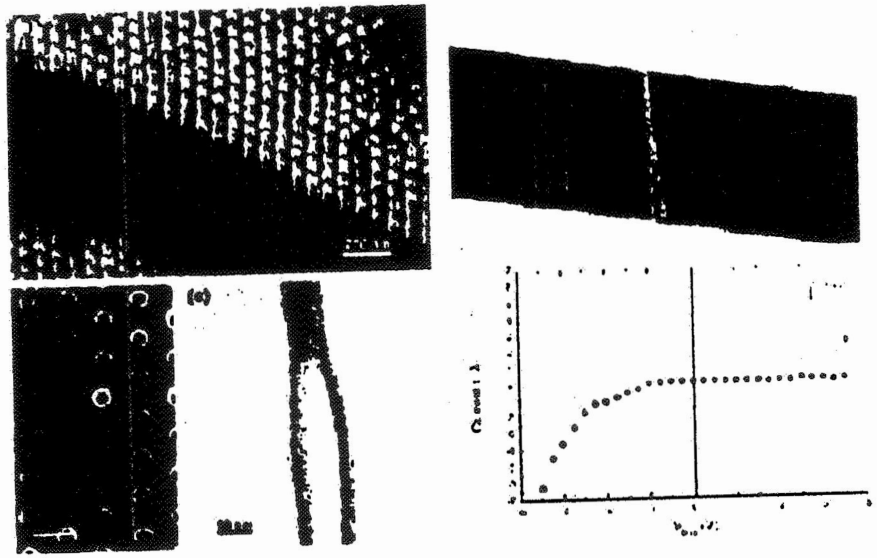
3-terminal "T-tunnel" CNT Heterojunctions for Molecular Electronics Applications

Computational Nanotechnology

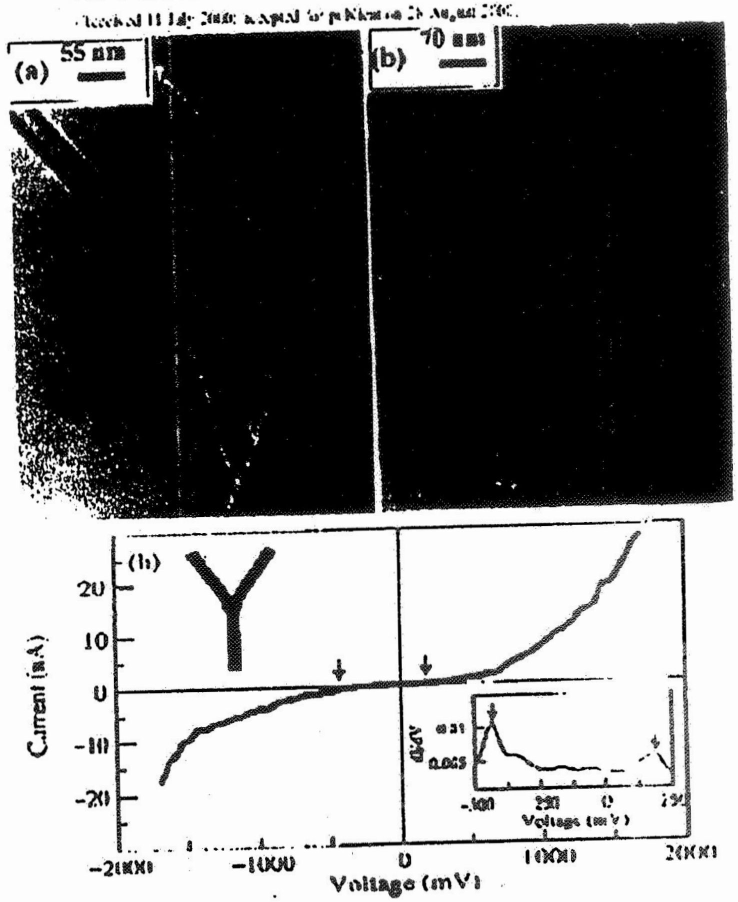


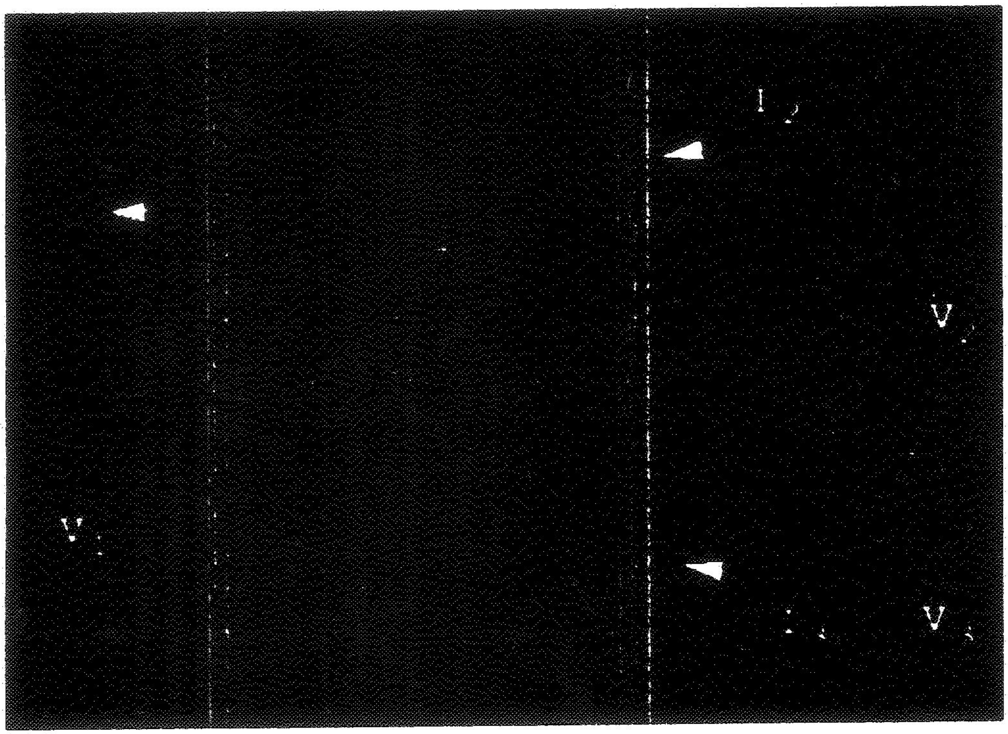
Multi-wall Y-junction Carbon Nanotubes

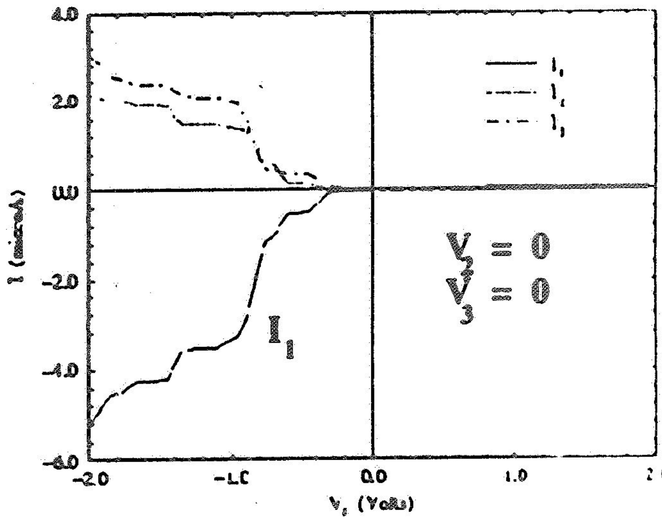
Electronic Transport in Y-Junction Carbon Nanotubes

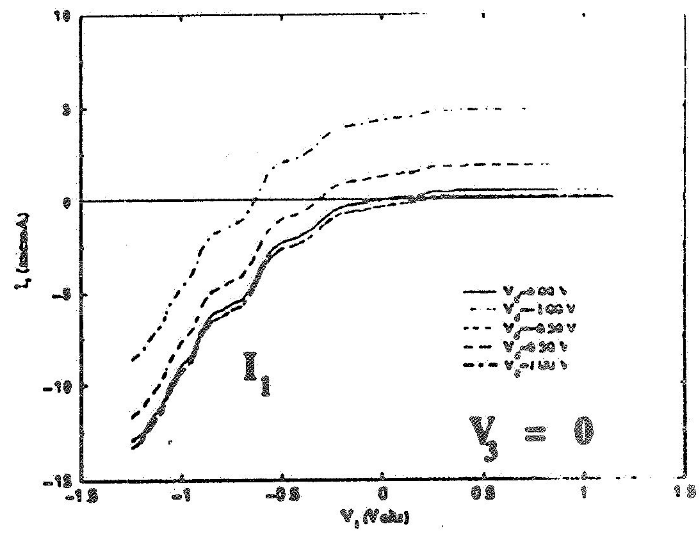


Y-junction carbon nanotubes



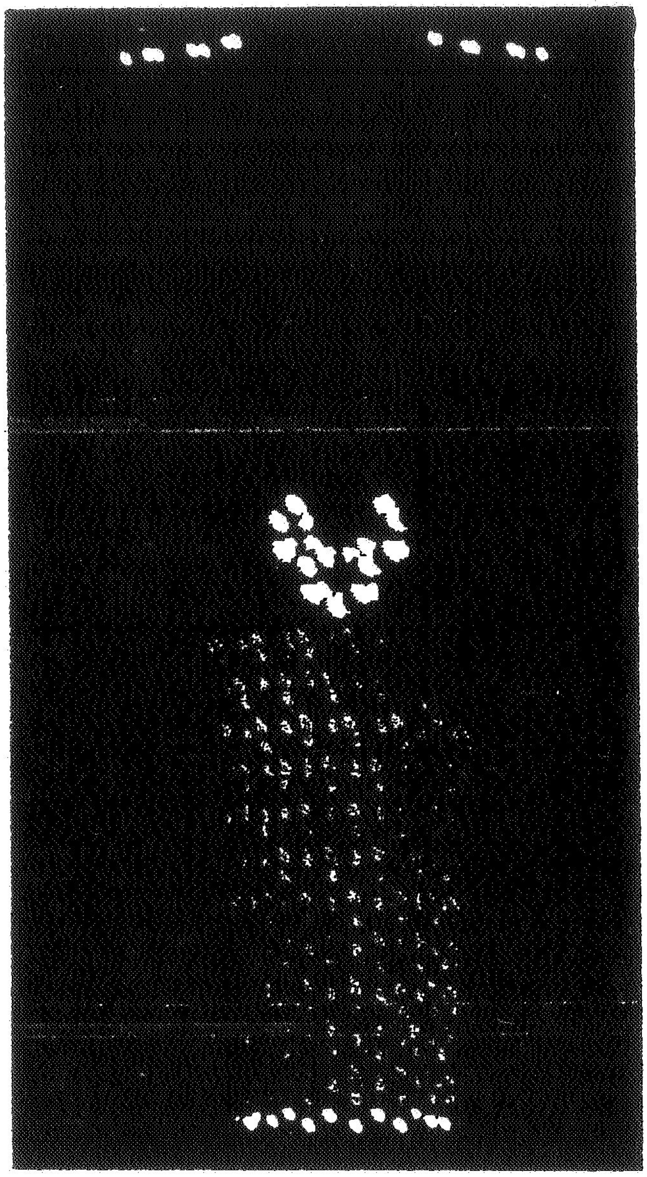


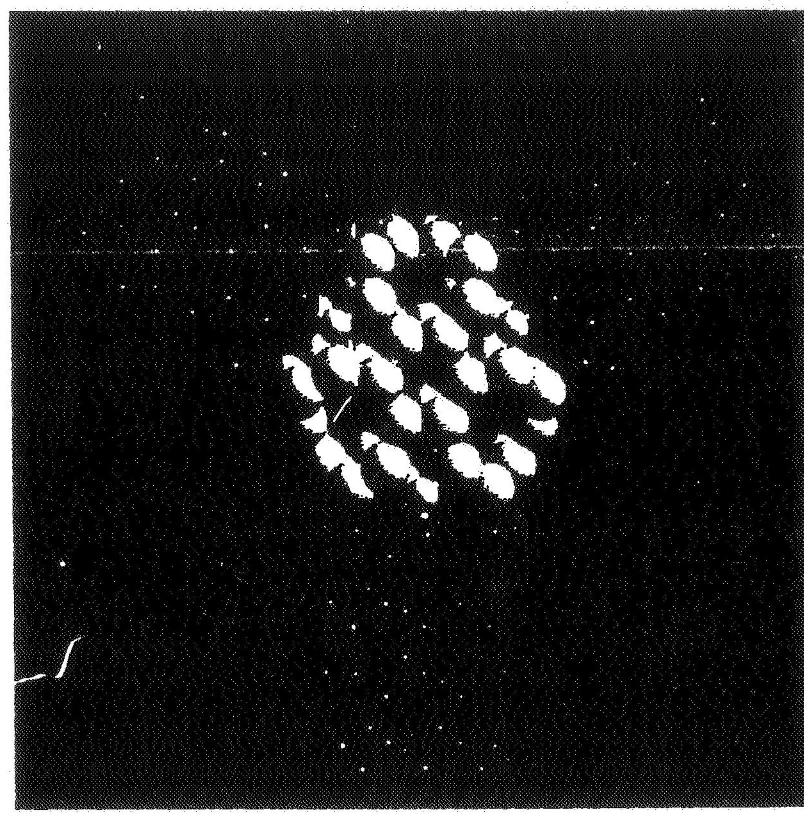




A Andriotis, M. Menon, D. Srivastava and, L. Chernozatonski, submitted, Phys. Rev. Lett. (2001)

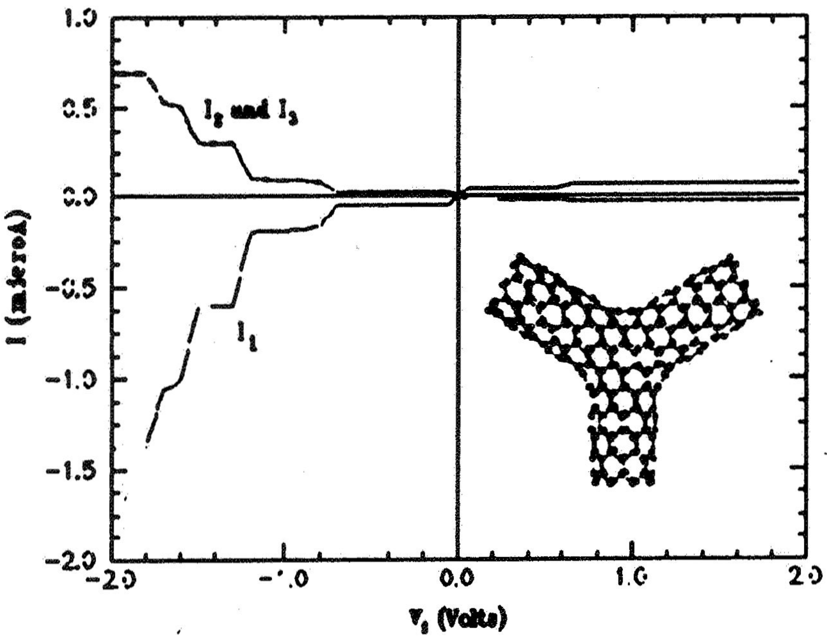
Semiconducting Y–junction Nanotubes with Different Angles

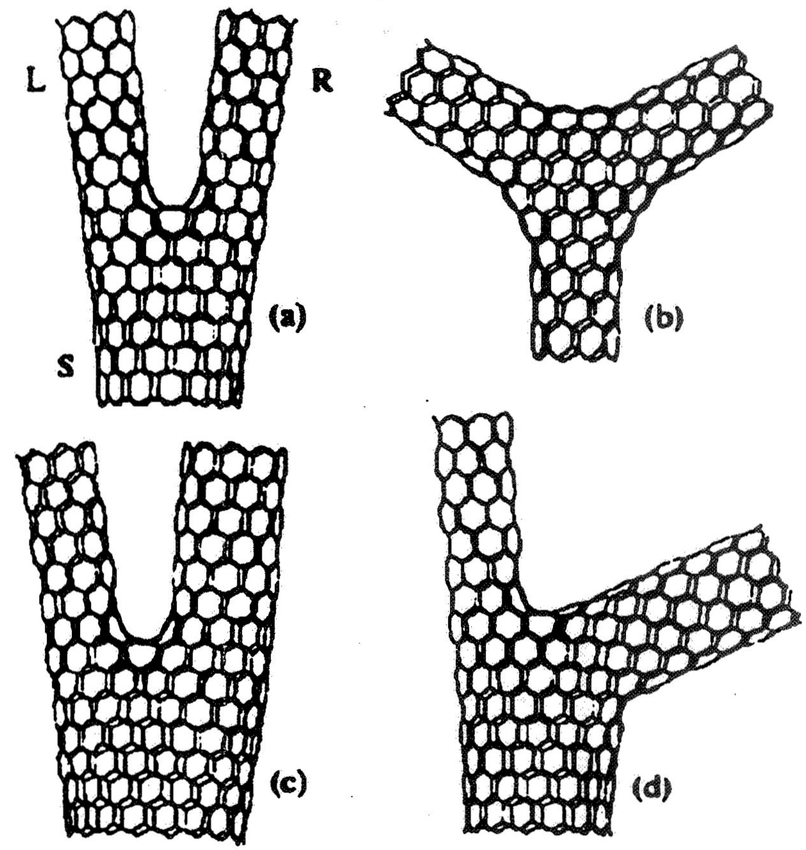




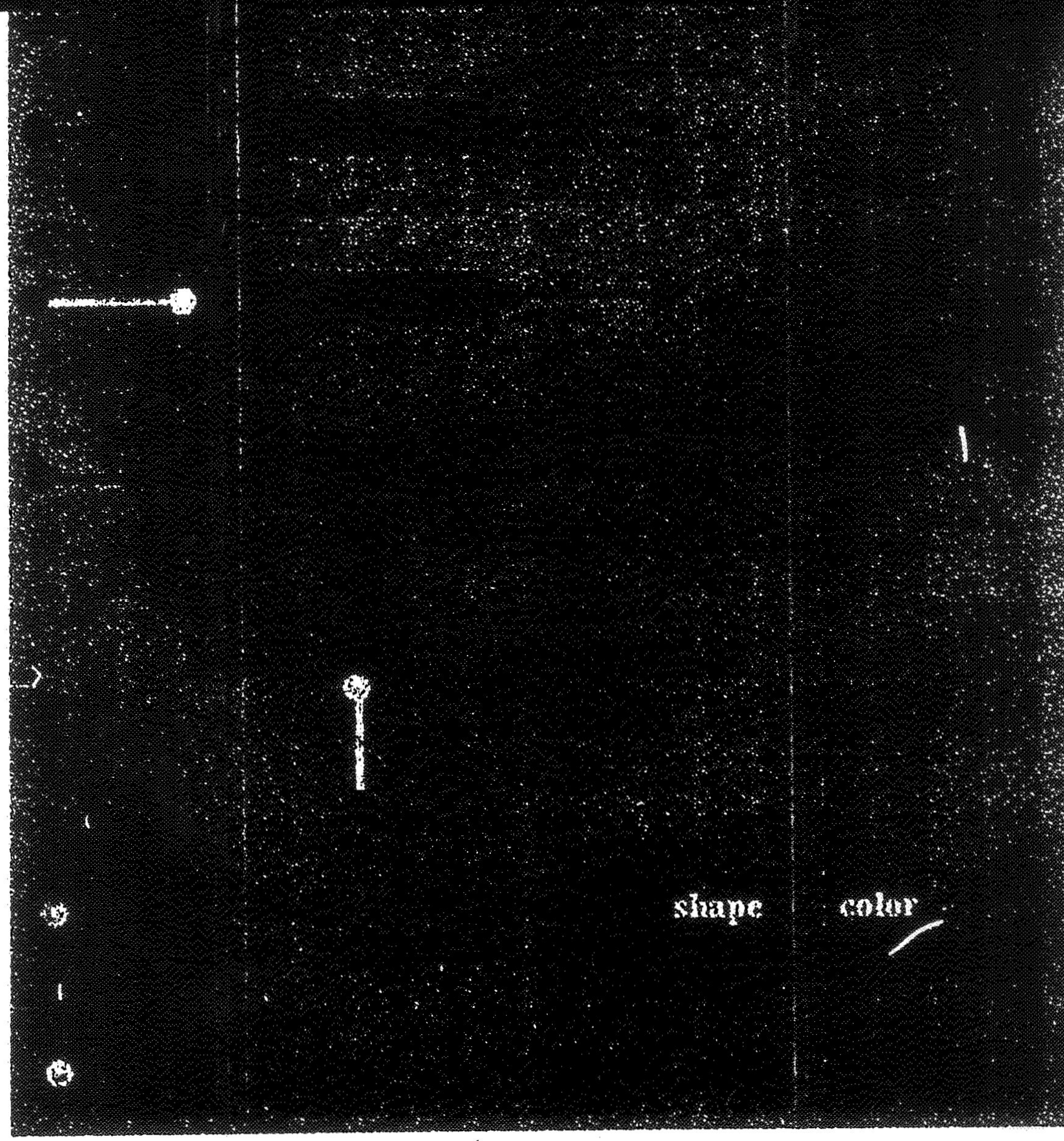
NASA

Ballistic R

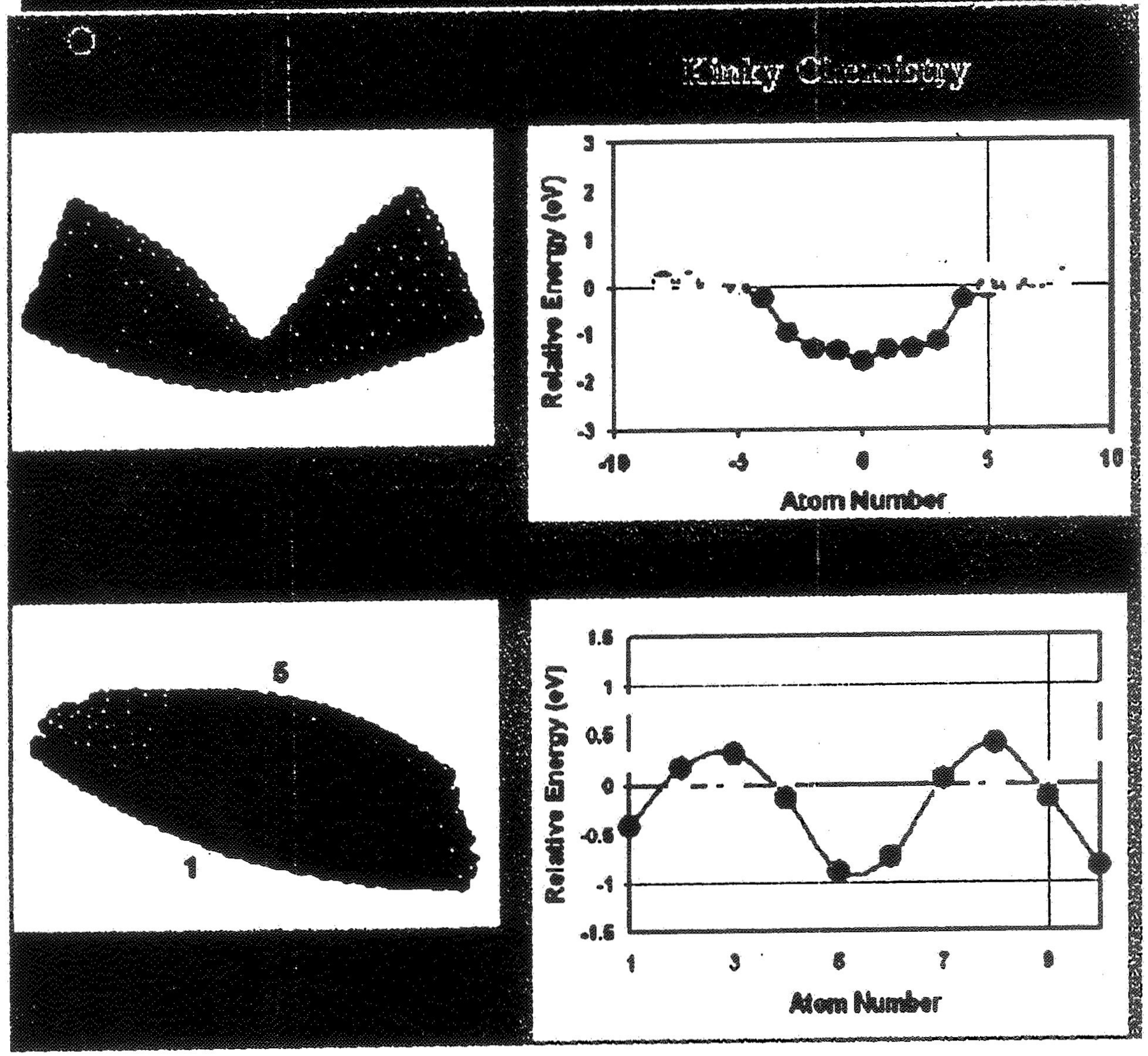




A Andriotis, M. Menon, D. Srivastava and L. Chernozatonski, submitted, Appl. Phys. Lett. (2001)

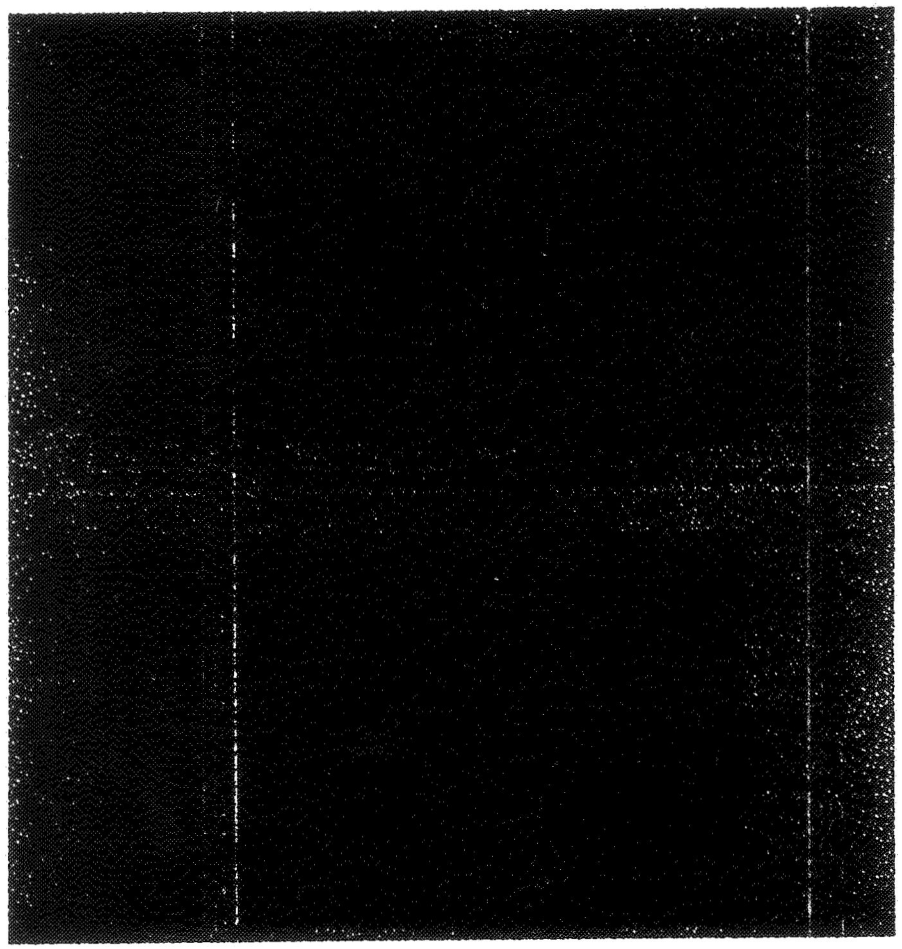

shape
color

Kinky Chemistry



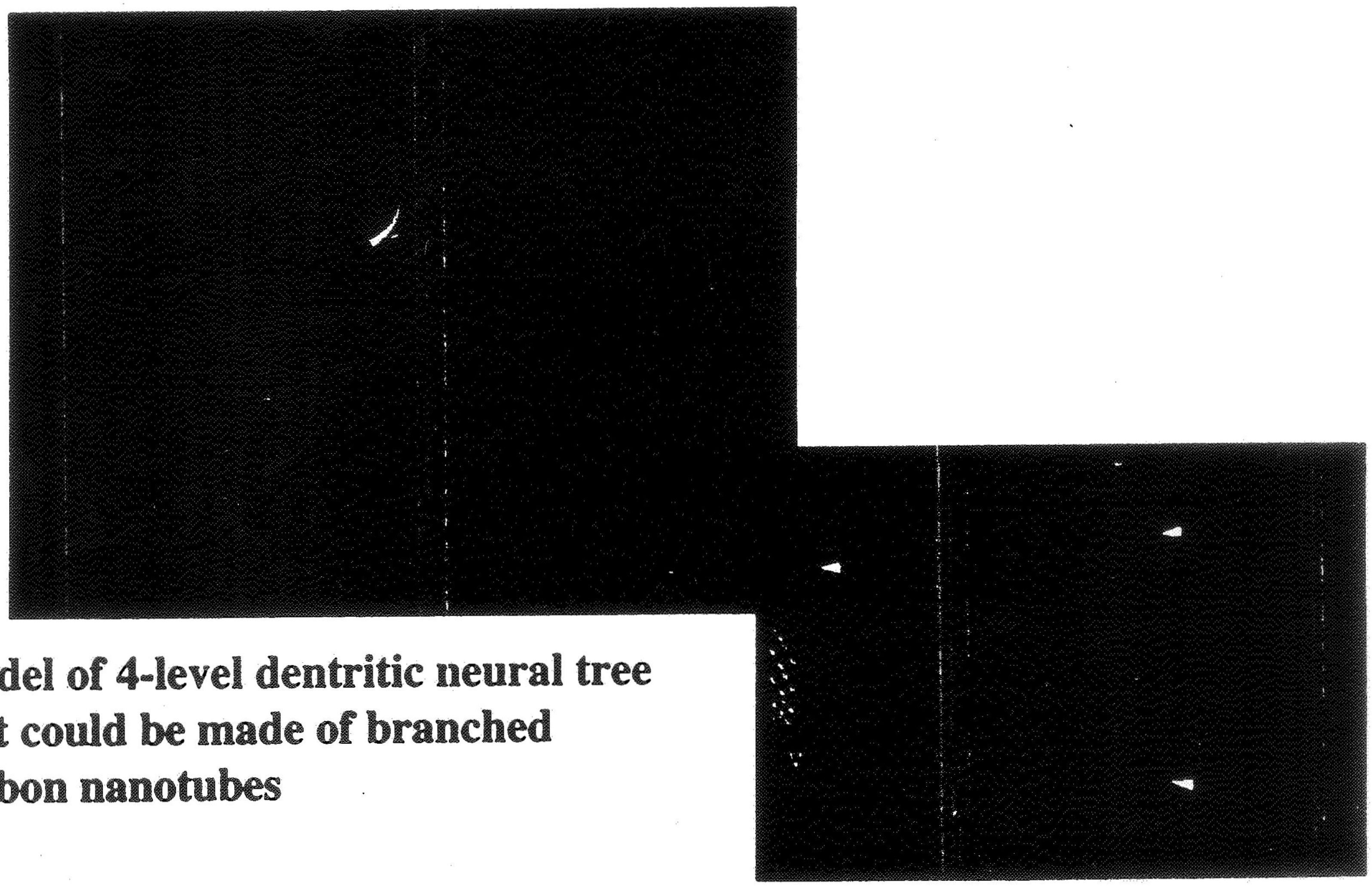
Binding Energy

D. Srivastava, J. D. Schall, D. W. Brenner, K. D. Ausman, M. Feng And R. Ruoff, J. Phys. Chem. Vol. 103, 4330 (1999).



D. Srivastava, J. D. Schall, D. W. Brenner, K. D. Ausman, M. Feng
And R. Ruoff, J. Phys. Chem. Vol. 103, 4330 (1999).

Bio-mimetic Dendritic Neurons: Carbon Nanotube



Model of 4-level dentritic neural tree
that could be made of branched
carbon nanotubes

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