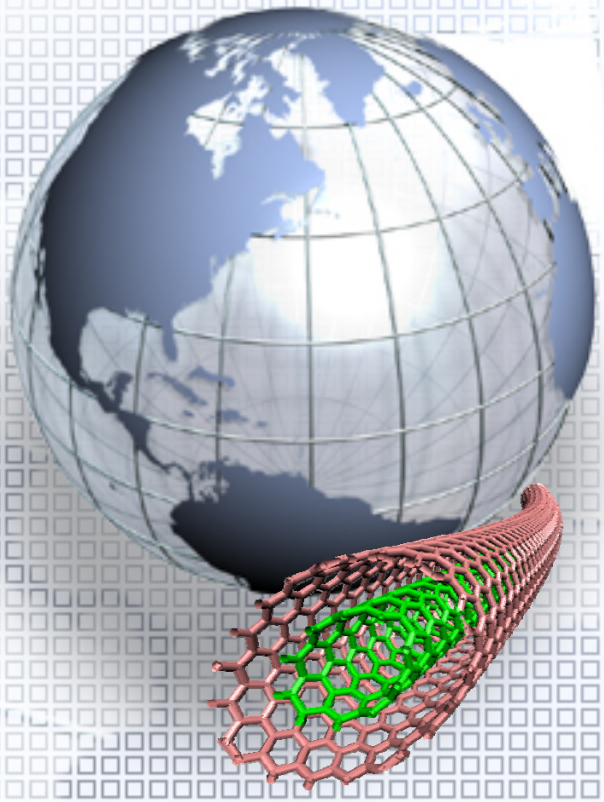
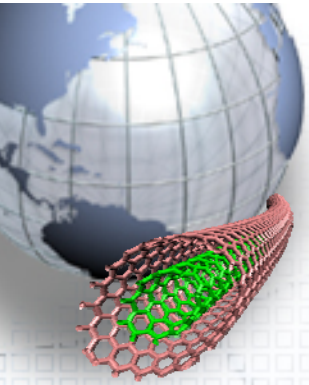


# Carbon Nanotube Based Nonvolatile Mechanical NanoRAM (MNRAM)

**Tienchong Chang**

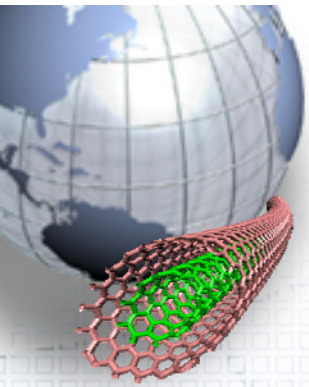
Shanghai Institute of Applied Mathematics and Mechanics



# MNRAM

MNRAM: Mechanical NanoRAM

Nano RAM whose Elements are switched between ON and OFF states via mechanical deformation.



# Expected Memory Market

(unit: billion US$)

| | MRAM | FRAM | Holo-graphic memory | Ovonic unified memory | Molecular memory | **Nanotube memory** | MEMS memory | Polymer memory | orthers | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 2004年 | 2 | 95 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 97 |
| 2008年 | 3,843 | 1,283 | 3,287 | 1,144 | 1,408 | **1,921** | 2,120 | 1,359 | 1,550 | 17,915 |
| 2011年 | 12,929 | 4,547 | 6,913 | 4,836 | 7,177 | **8,852** | 6,451 | 7,879 | 6,129 | 65,712 |

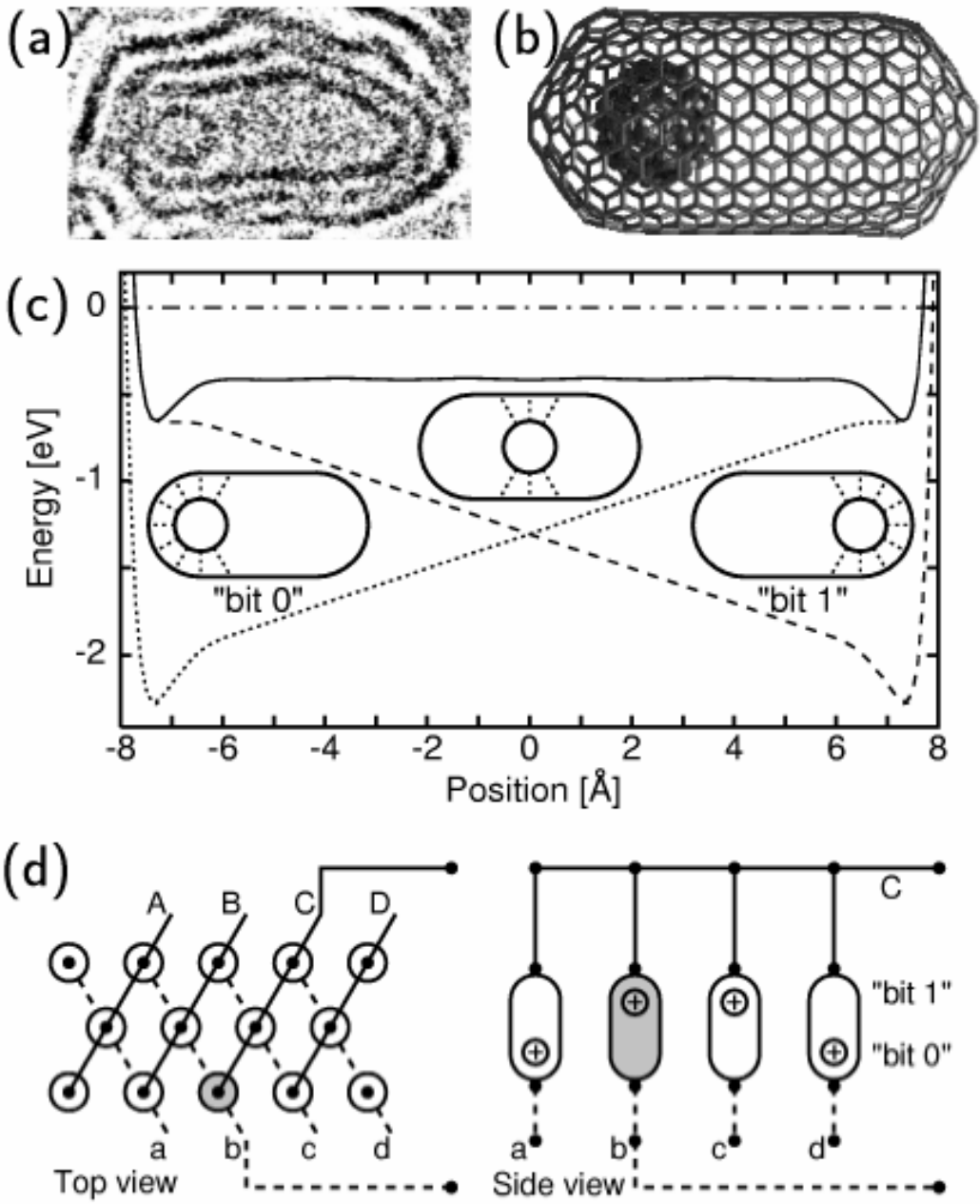
Data from the report of research firm NanoMarket LC.

# Some Existing CNT MNRAMs

1. “Bucky Shuttle” Memory Devices

Kwon, Tomanek, Iijima

Phys Rev Lett, 82:1470, 1999

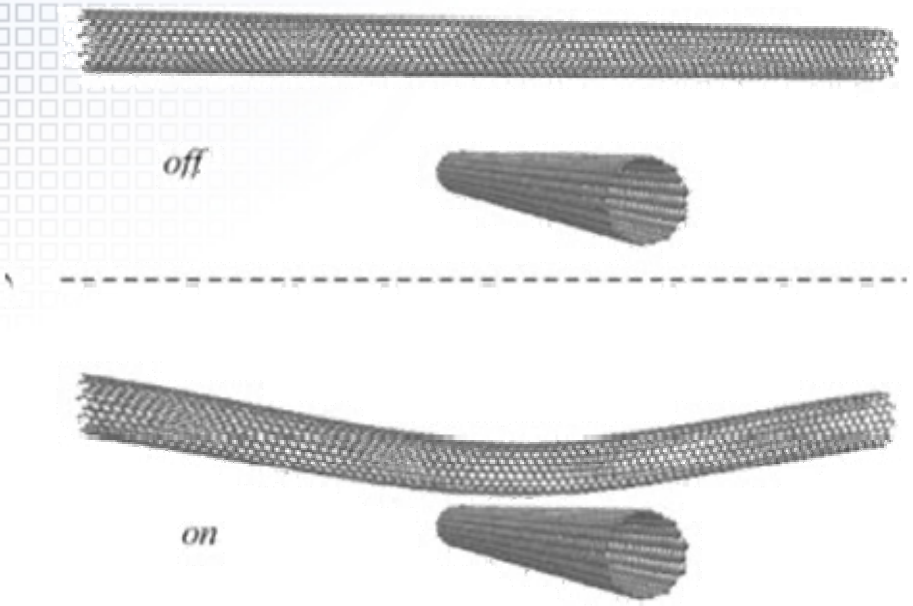


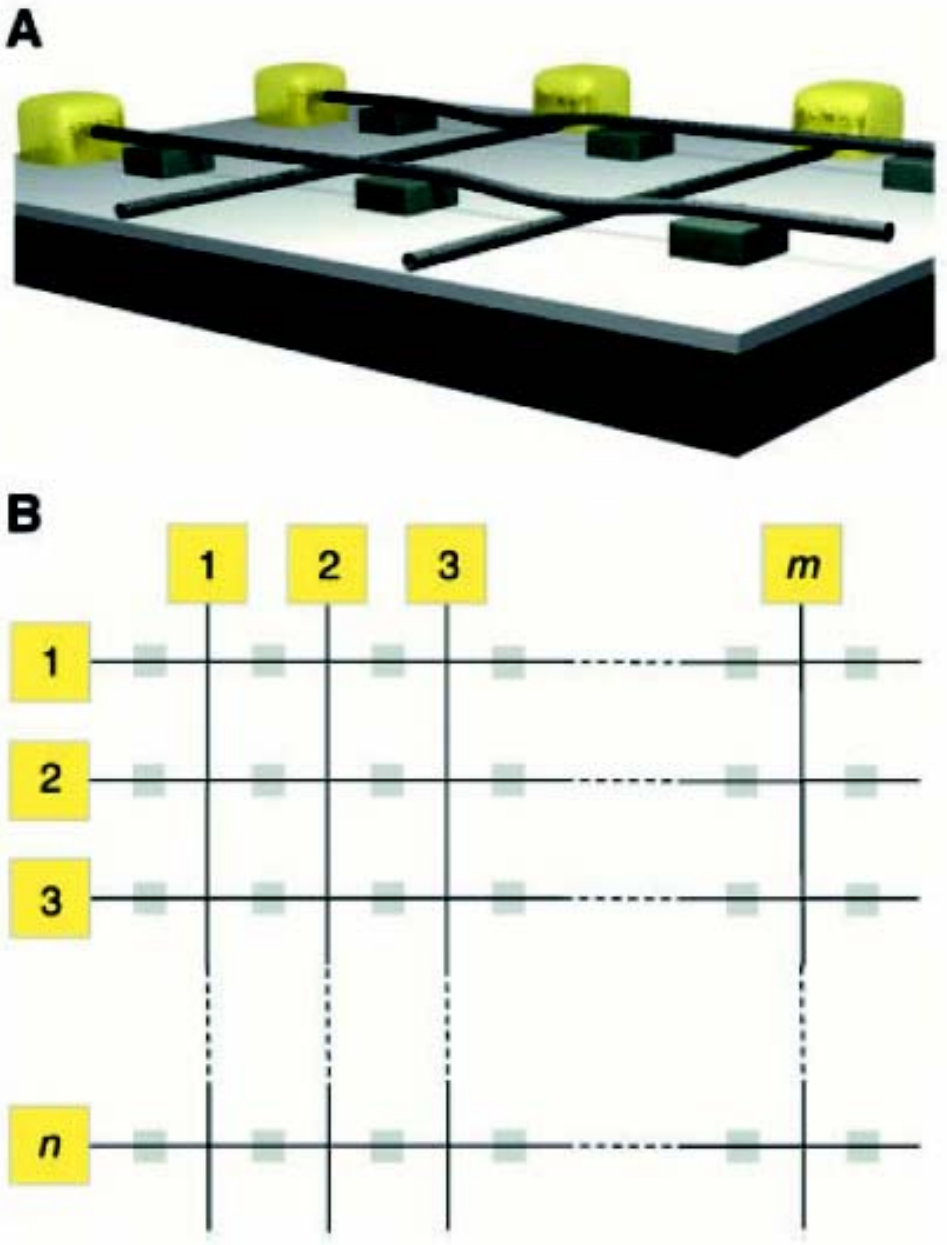
# Some Existing CNT MNRAMs

2. “Suspended Nanotube” NRAM

Rueckes, Kim, …, Lieber

Science, 289:94, 2000



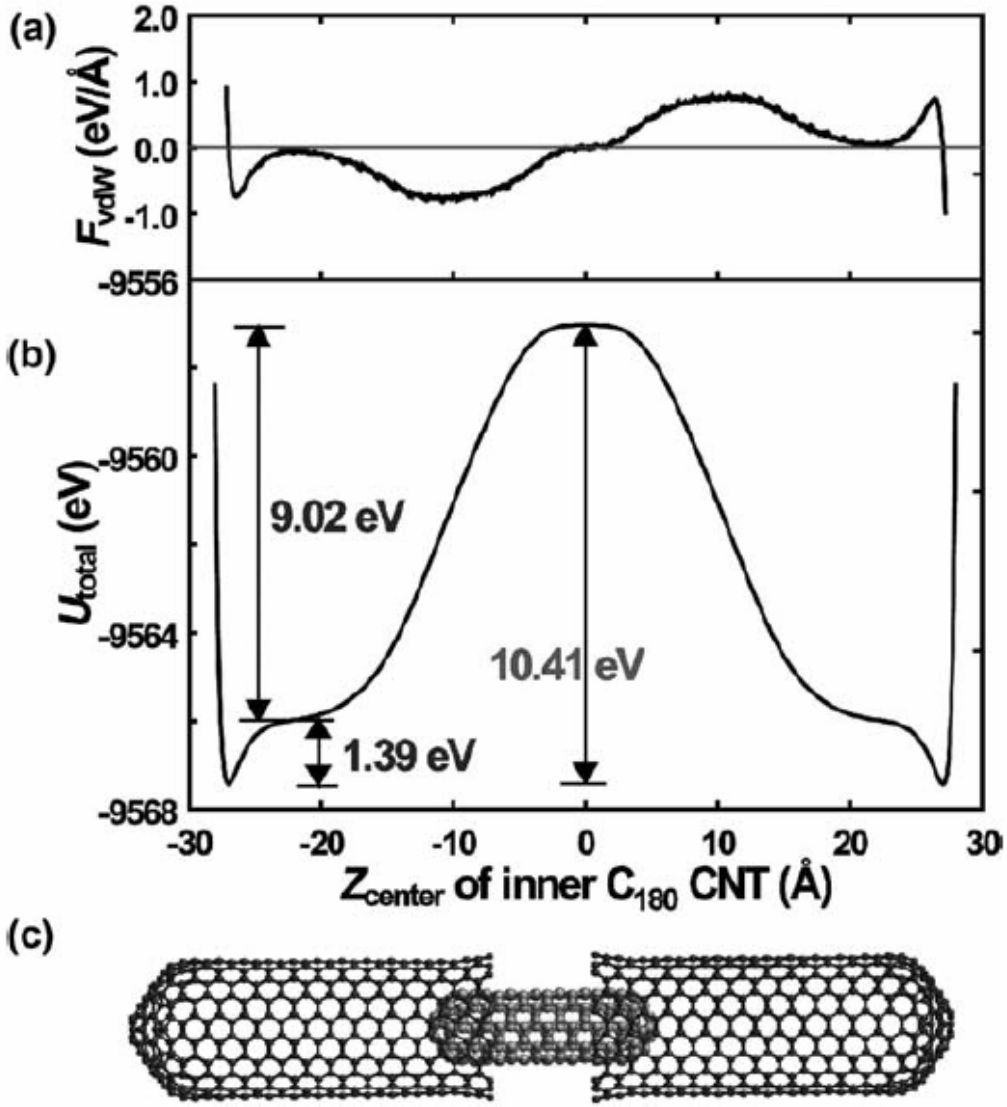



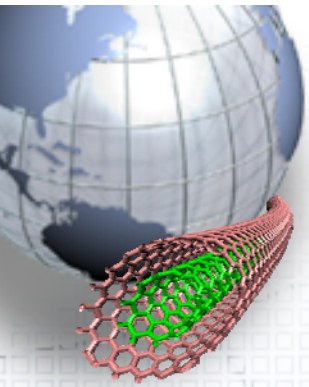
# Some Existing CNT MNRAMs

3. “Nanotube Shuttle” Memory

Kang, Hwang

Carbon, 42:3003, 2004





# Advantages and Difficulties

Advantages

High speed (~100GHZ)

High density (~100T/cm$^2$)

Low energy consumption

Difficulties

RAM structure is hard to be assembled.

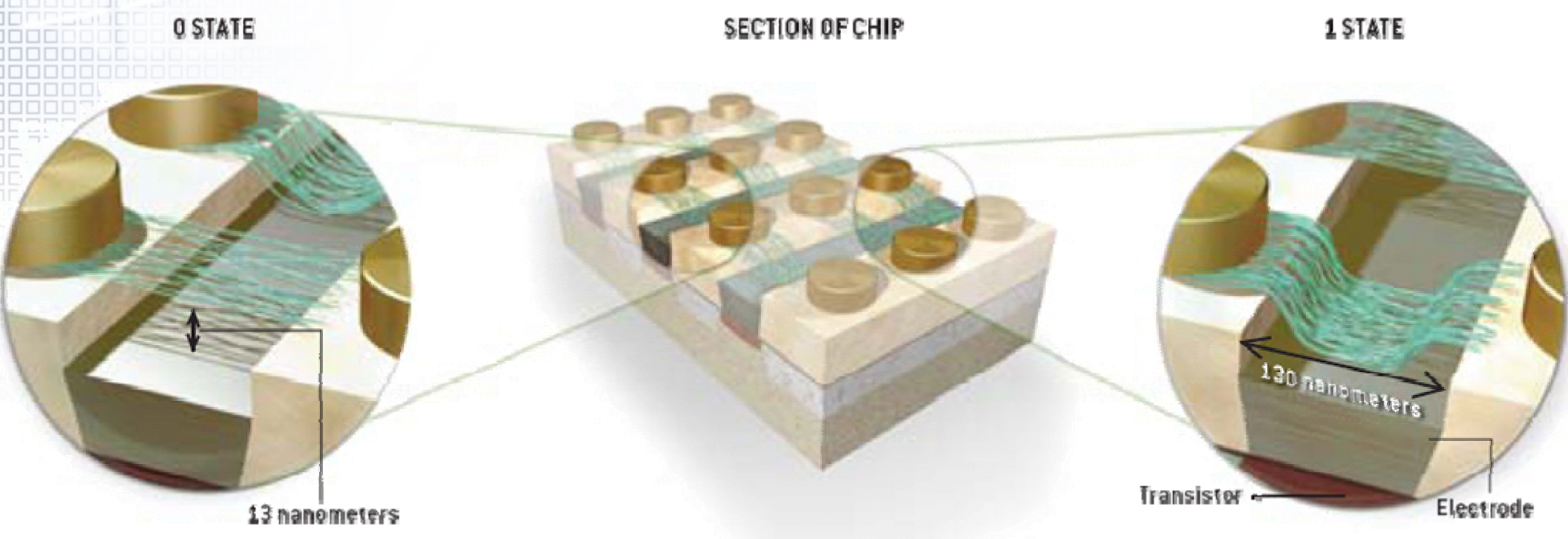
# NRAM by NanTero

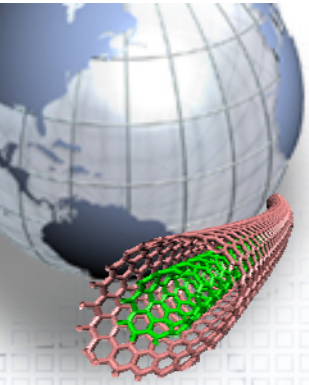
A variant of “Suspended Nanotube” Memory

Cooperated with ASML, LSI

A new structure that is easier to be manufactured than the original design.

The density is lowered about 100 times.





# Reports on NanTero

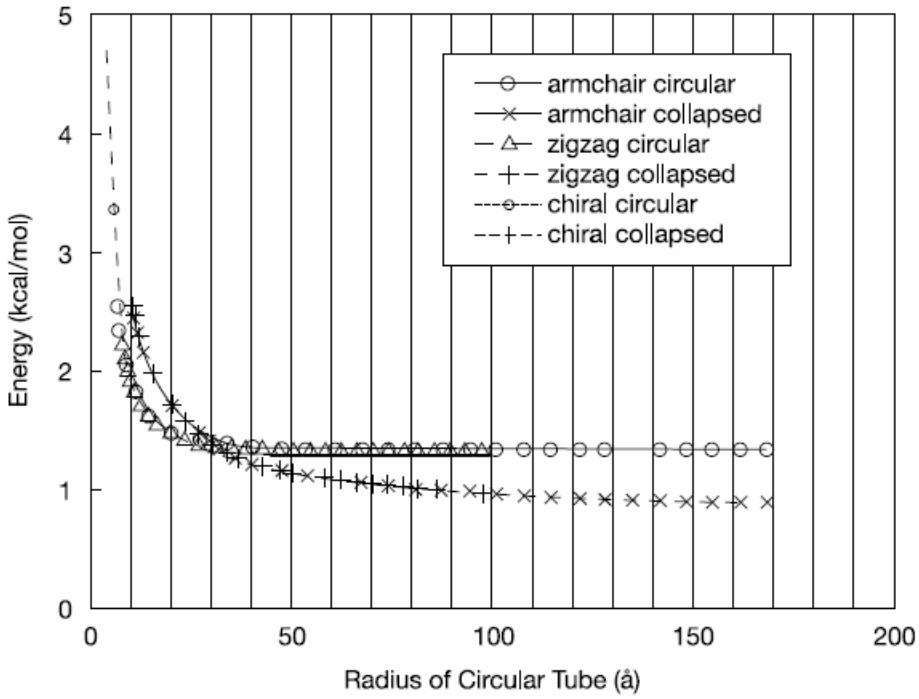
"10 Emerging Technologies," MIT Technology Review, May 2005, p. 47.
"The Coming Chip Revolution," BusinessWeek, April 18, 2005, p. 90.
"Patents Aplenty Surfacing for Startups, Corporations," Boston Business Journal, March 28, 2005.
"From Lab to Fab," Fast Company, March 2005.
"Nanotubes in the Clean Room," **Scientific American**, February 2005, page 82.
"Nanoengineered Memory Solutions," Solid State Technology, January 2005, page 24.
"Best of Small Tech Winners Named," Small Times, November 15, 2004.
"UNH Builds Invisible Tools: Grant Promotes Nanotechnology," Concord Monitor, November 14, 2004.
"The 2004 Scientific American 50 Award: Business Leaders", **Scientific American**, November 11, 2004.
"Memories may mark early beachhead for nanotech", Silicon Strategies, November 5, 2004.
"Nantero to debut carbon nanotube memory in 2005", Silicon Strategies, November 4, 2004.
"Nanotechnology: Genesis of Semiconductor's Future", Semiconductor International, November 1 2004.
"10 Tech Companies for the Next 10 Years", IEEE Spectrum, November 2004."
"Small Ideas for a Big Market," Electronic Business, November 1, 2004.
Carbon Nanotube-Based Radiation Hard Nonvolatile RAM Project, **$4.5M**, CASE Southwest Missouri State University and Nantero, Inc.,"Nanotech: Universe in a Grain of Sand," Businessweek, October 11, 2004, page 138.
"School Trio Lands **$12.6M** Nanomanufacturing Grant", Mass High Tech, Sept 27, 2004.
"Nano-Made in Massachusetts?", Boston Business Journal, July 26, 2004, page 1.
Nanotubes in Space," Mass High Tech, July 26, 2004, page 1.
"Nantero Strikes Deal with BAE Systems," Small Times, July 19 2004.
"Nanotech Memory Chips Might Soon Be a Reality," New York Times, June 7, 2004.
"Tiny tubes a big deal at LSI", Oregonian, June 7, 2004.

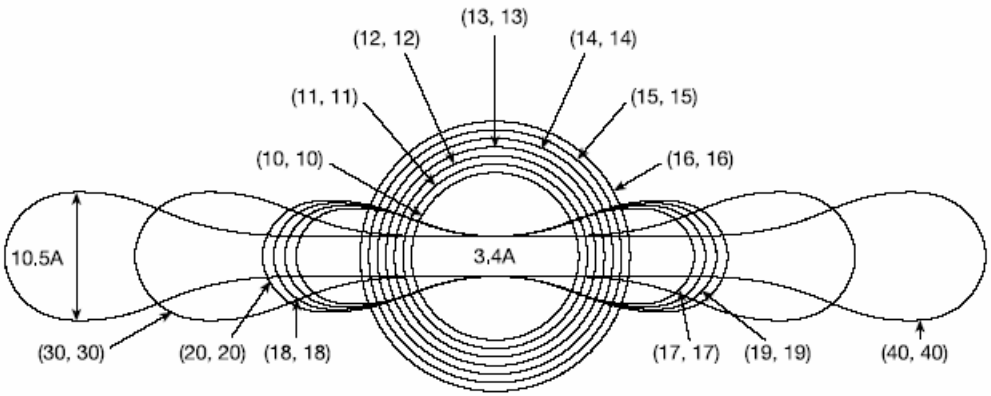
# Structural Bistability of SWCNTs

Gao, Cargin, Goddard

Nanotechnology, 9:184, 1998

SWNTs with radius between 2nm and 6 nm poses two stable structures: circular form and collapsed form



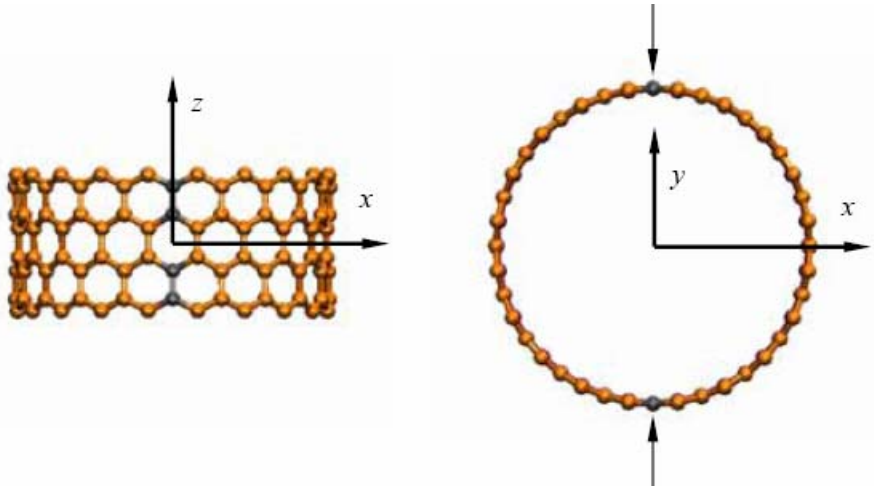



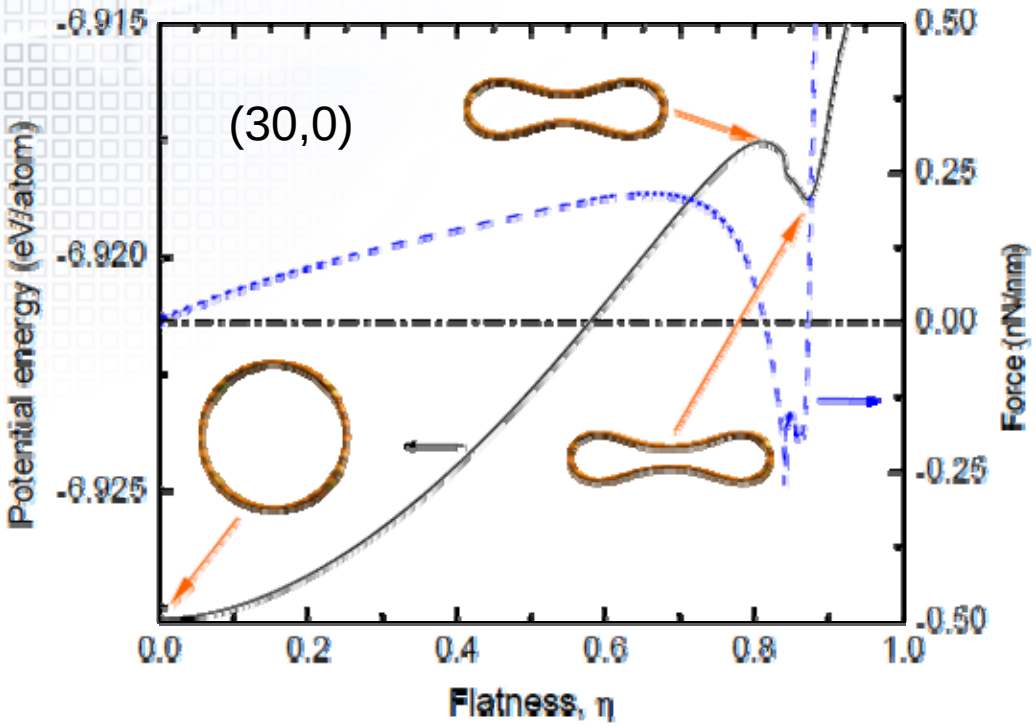
# Transition between two states

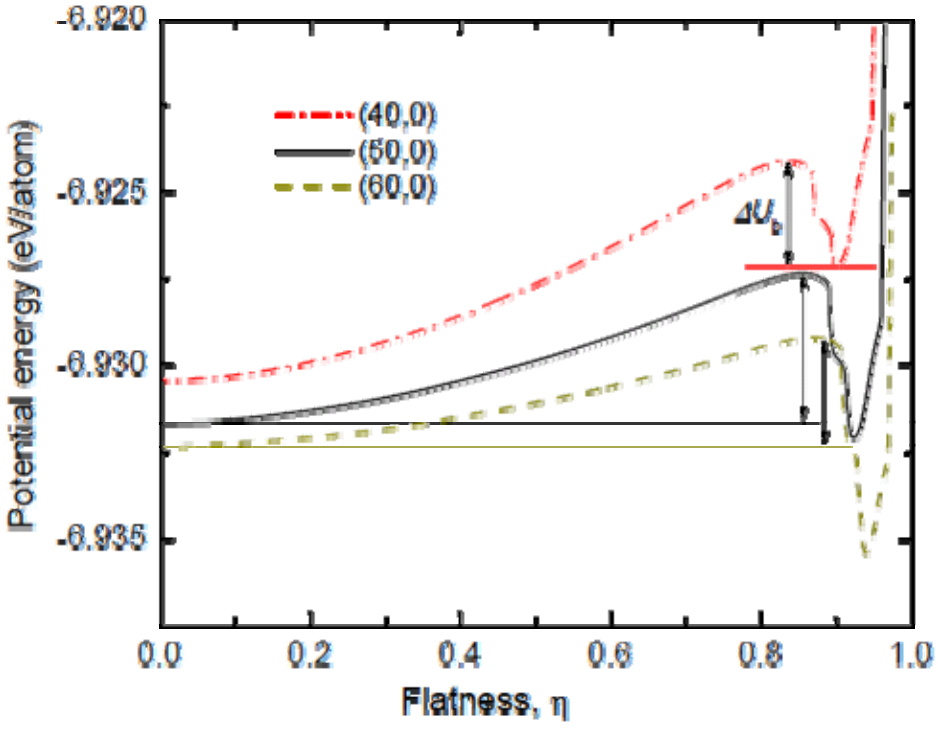
MD simulation

Chang, Guo

Acta Mech Sinica, 2005



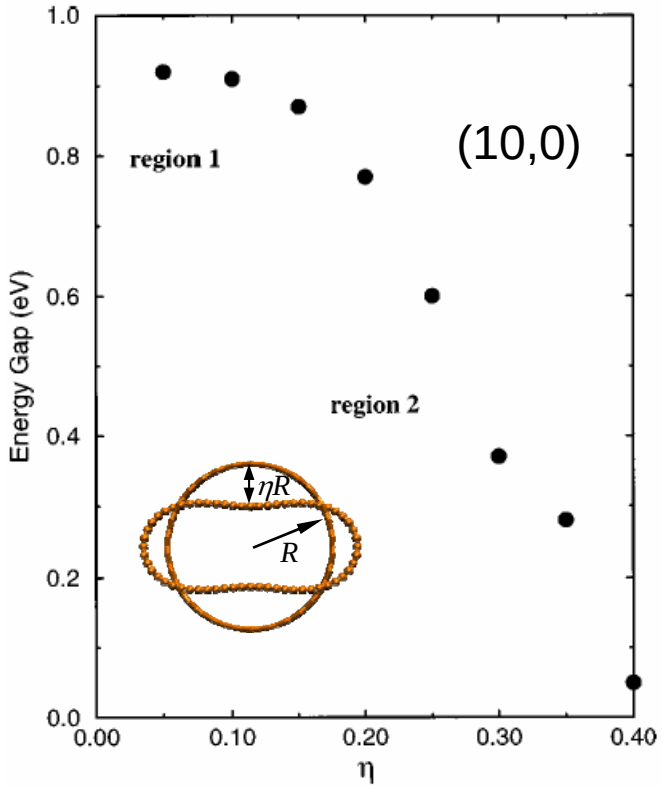



# Structure Dependent Conductance

Mario, Mazzoni, Chacham

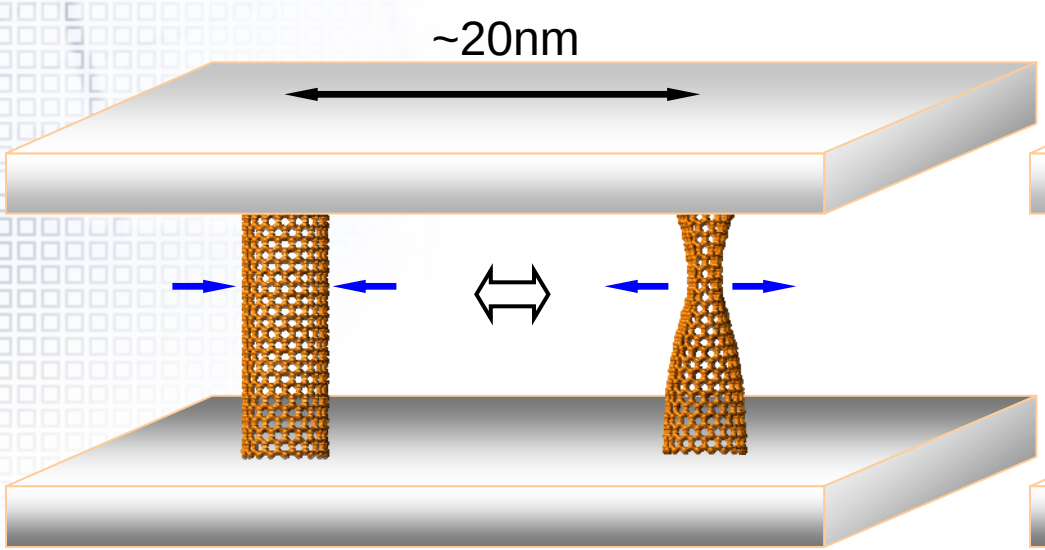
Appl Phys Lett, 76:1561, 2000

With an increase of the flatness, a semiconductor SWCNT becomes a conductor.

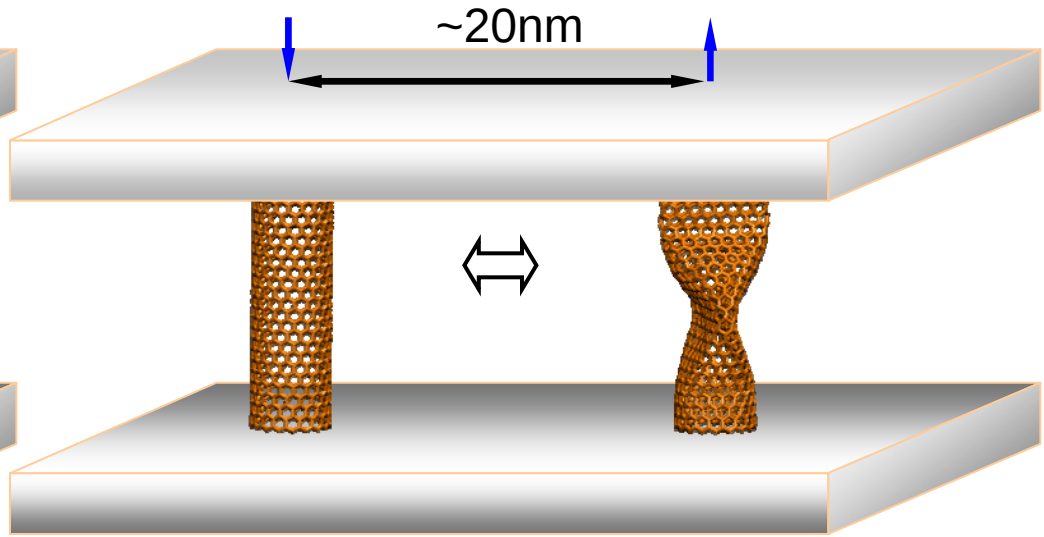


# Prototype Design of MNRAMs

Well defined ON and OFF states of SWCNTs with radius of about 4nm make them suitable to act as nanoswitches, such as nonvolatile MNRAM elements




Radial Actuation



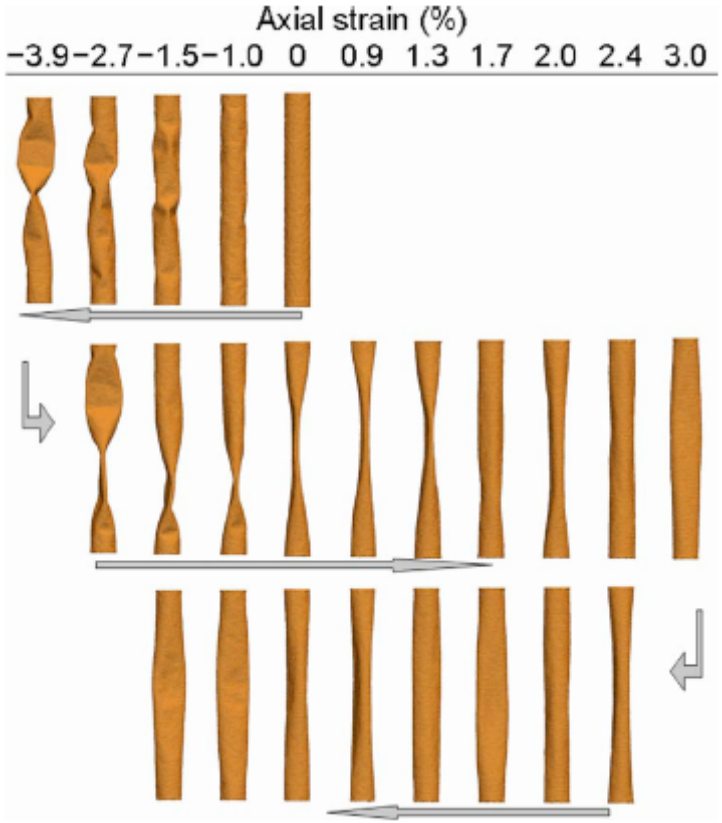

Axial Actuation

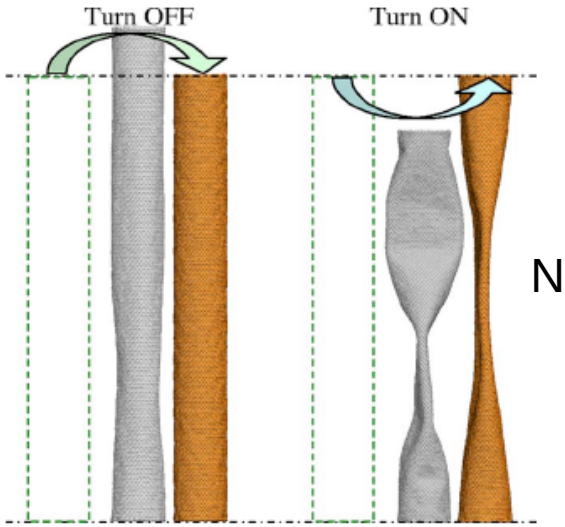
# An MD Simulation

Reversibility of the structural bistability of SWCNTs under axial strain

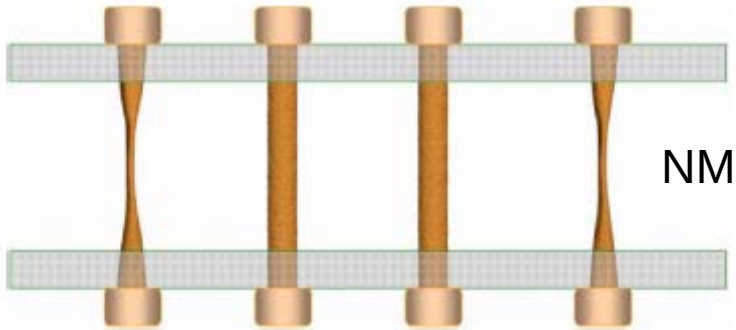
Chang, Hou, Guo

Appl Phys Lett, 88, 211906, 2006




Nanoswitch



NMRAM

# Advantages of Present Design

Besides aforementioned:

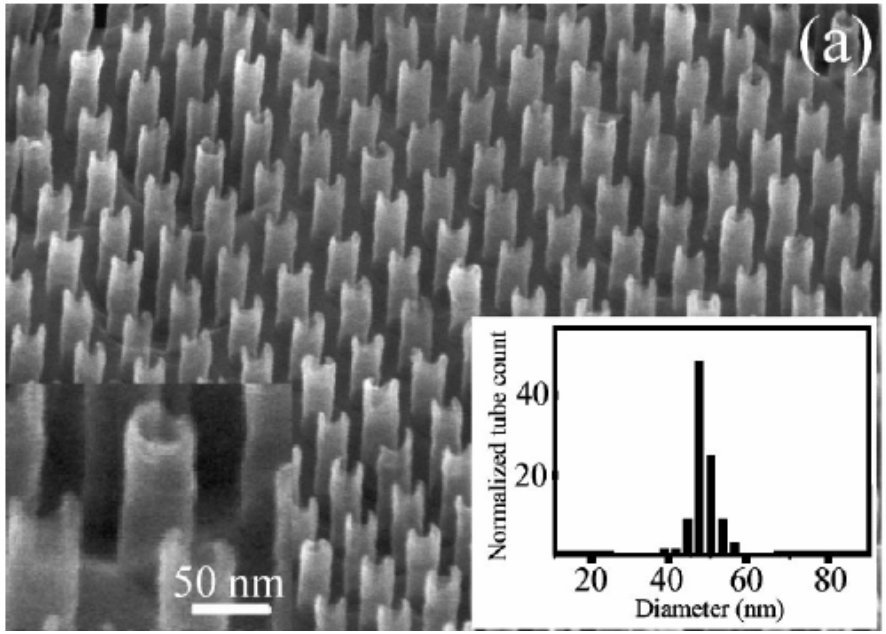
High speed (~100GHZ)

High density (~100T/cm$^2$)

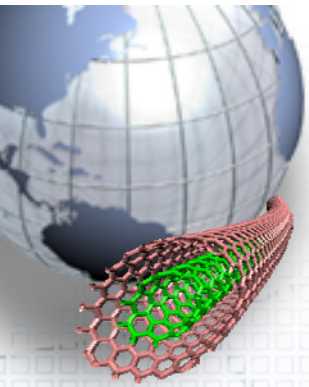
Low energy consumption

They also take:

Easier-assembled RAM structure (as the techniques for highly-ordered CNT arrays can be available).

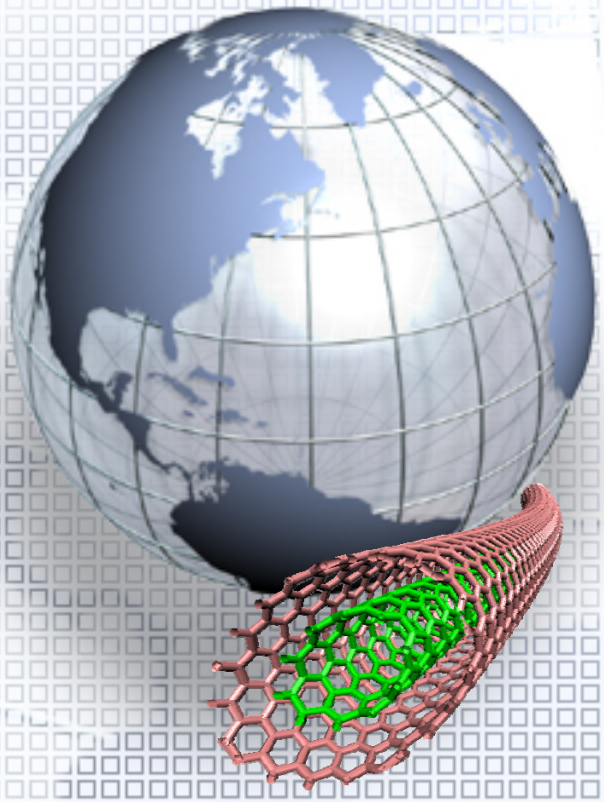



Li, Papadopoulos, Xu
Appl Phys Lett, 75:367, 1999



# Cooperation wanted

We are now looking for universities, companies and individuals who can perform experimental investigations on the electromechanical behavior of carbon nanotubes.



# Thanks!