Tailor-made Nanomaterials

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MIT/Stanford/UC Berkeley Nanotechnology Forum

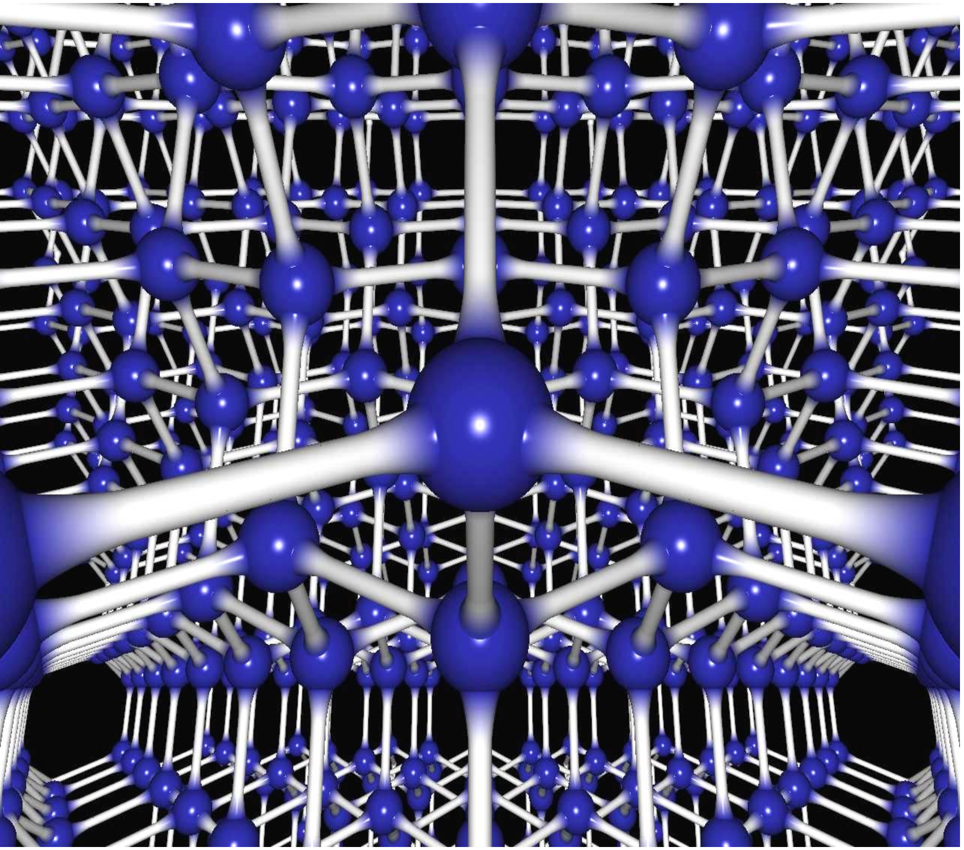
1/29/04

California Dreamin'

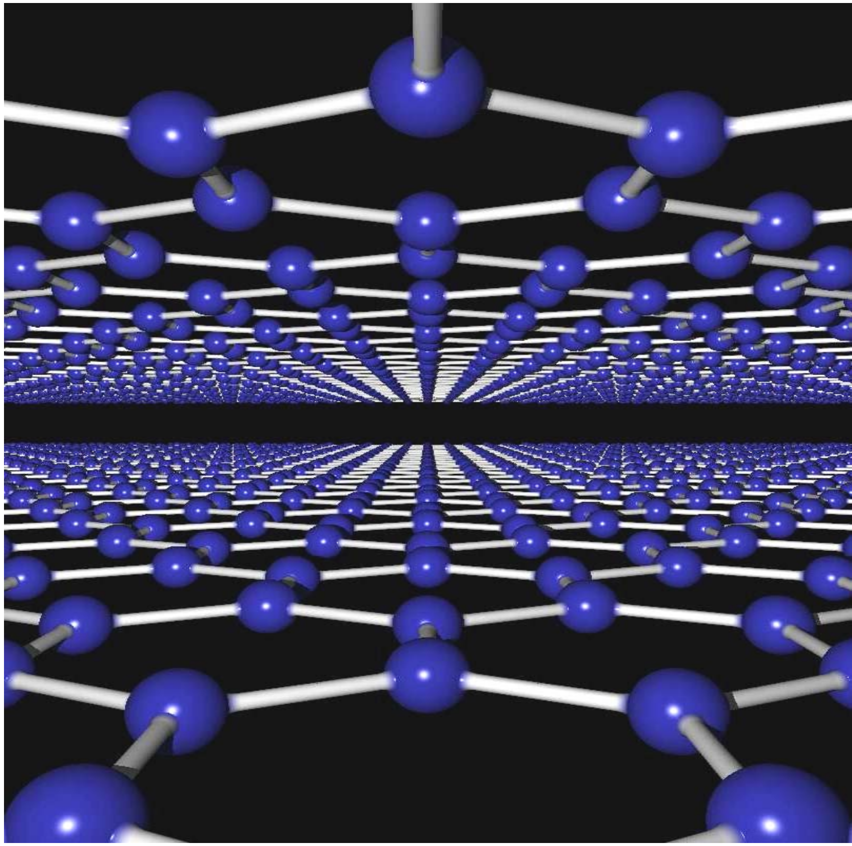
Wish list for "next-generation materials":

- Highest possible strength for composite applications
- Resistant to high temperature/harsh chemical environment
- Electronically useful as fast molecular-scale transistor
- Fully tunable semiconducting bandgap (zero to 5eV)
- Ultra-low-power quantum charge detection capability (sensors)
- Compatible with conventional Si technology (CMOS integration)
- Can be functionalized for chemical/bio/medical-applications
- Ultra-high thermal conductance
- Useful as high-speed MEMS/NEMS building block

Naturally Occurring Carbon Networks

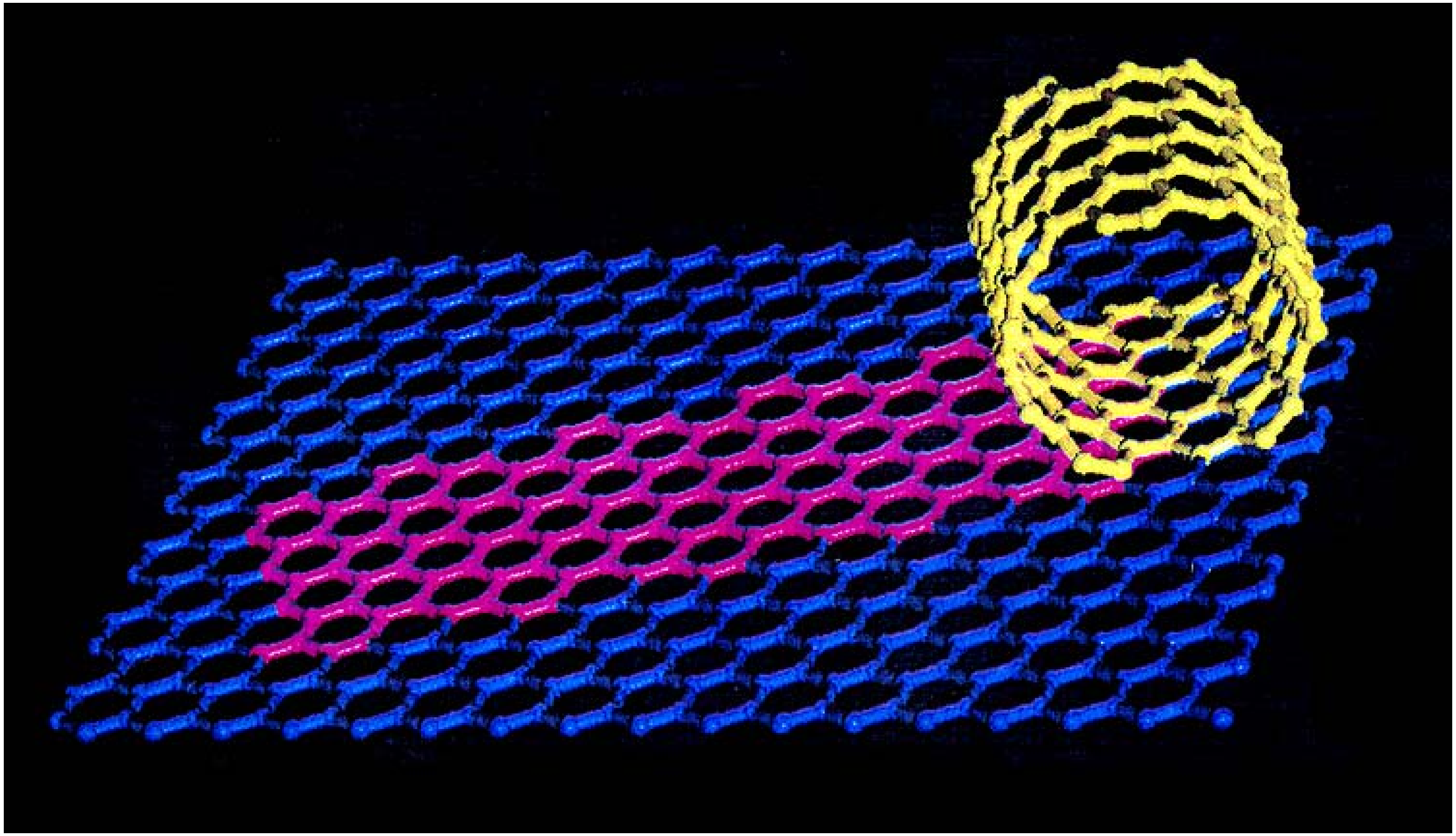


Diamond
Bond length = 1.54Å

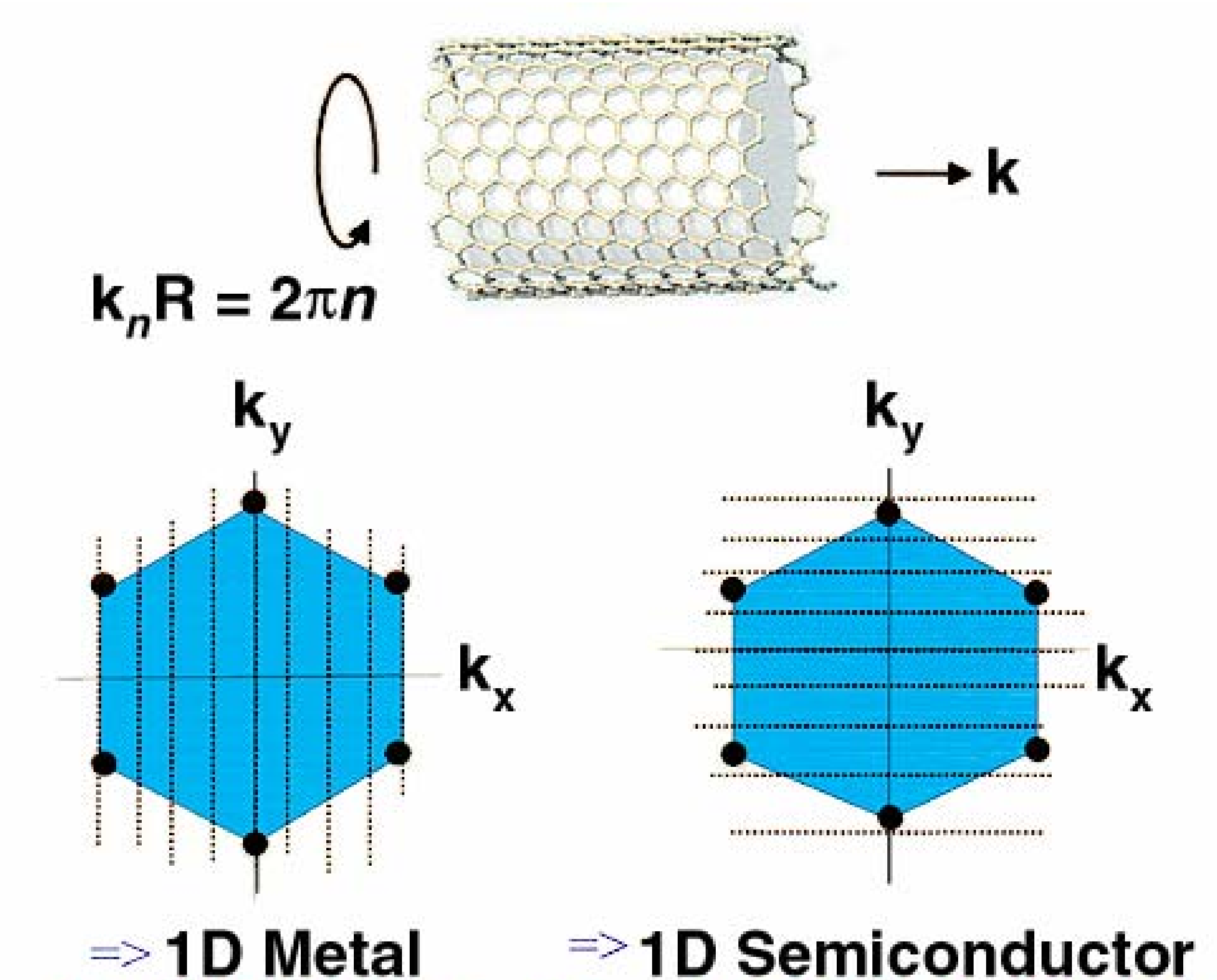


Graphite
In-plane bond length = 1.42Å
Out-of-plane bond length = 3.4Å

Conceptual Nanotube: Cylinder Rolled from Graphite Strip



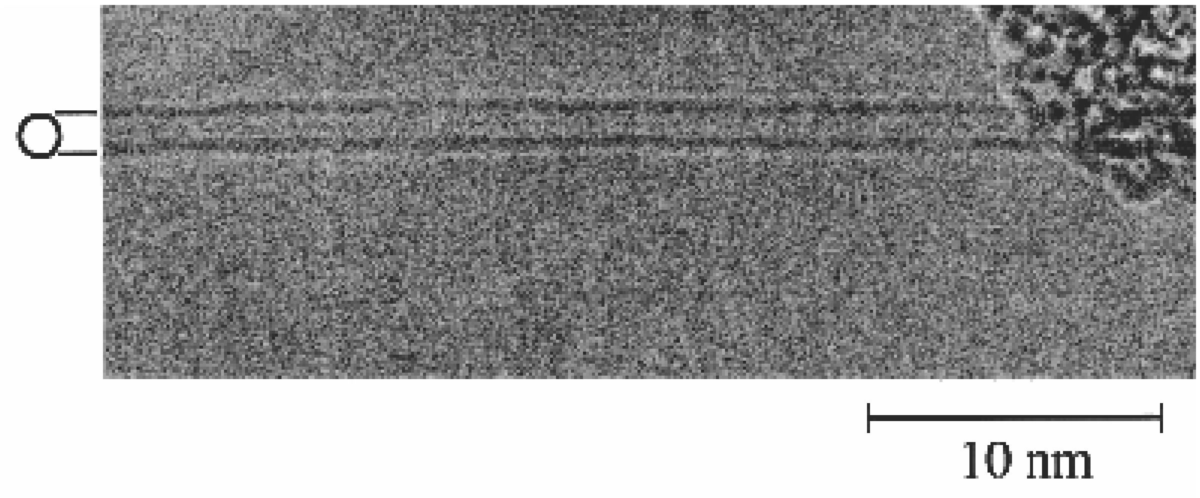
Carbon Nanotubes: Electronic Properties



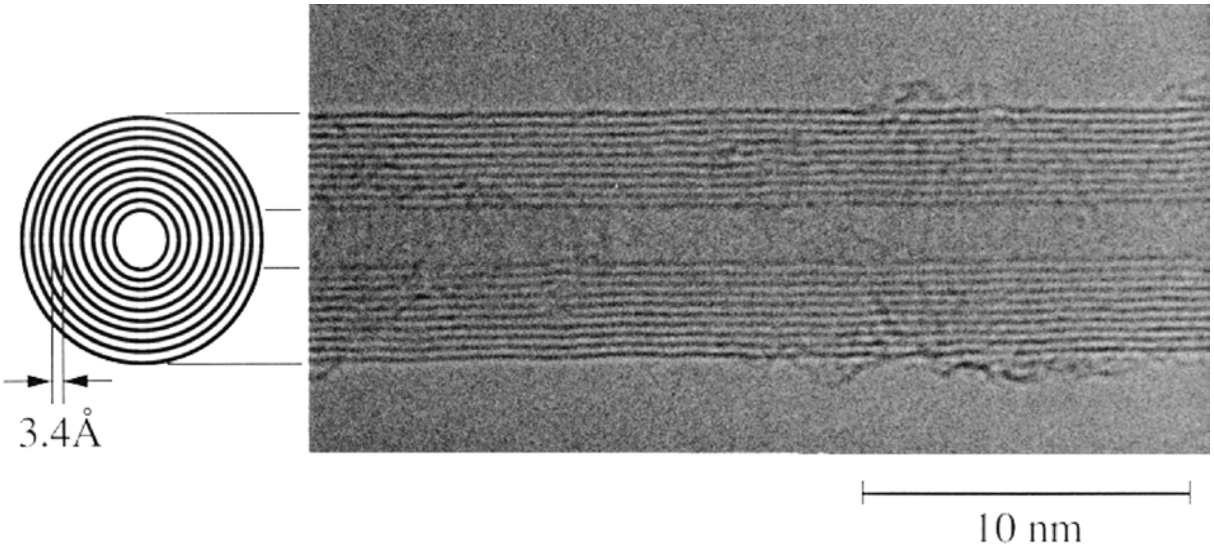
Two 1D Subbands *Eg = (dE/dk)Δk ~ 0.5 eV*

Nanotube Morphologies

Single-wall:



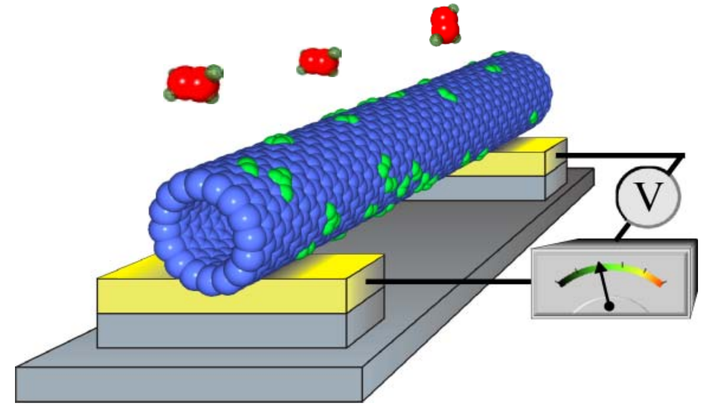
Multi-wall:

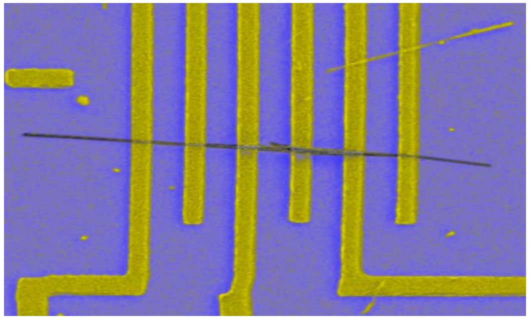


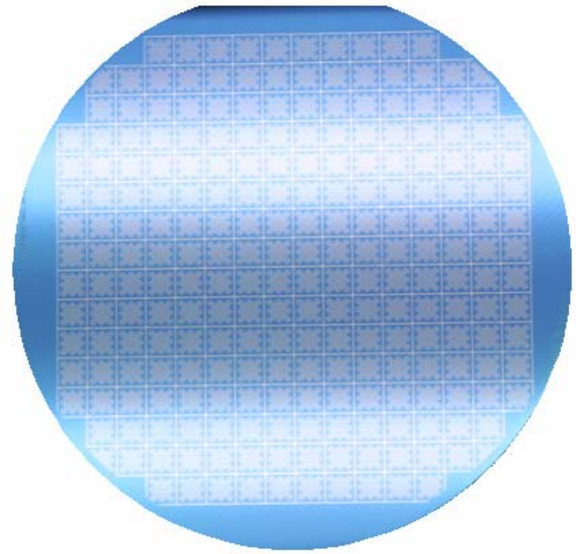
From Concept to Product

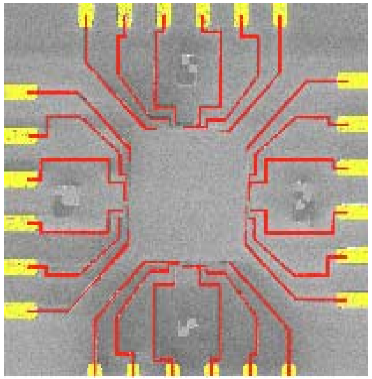
Chemical Sensor

- **Analyte specific**
- **Extremely low power**
- **Large scale manufacturability**
- **Robust, fault tolerant**







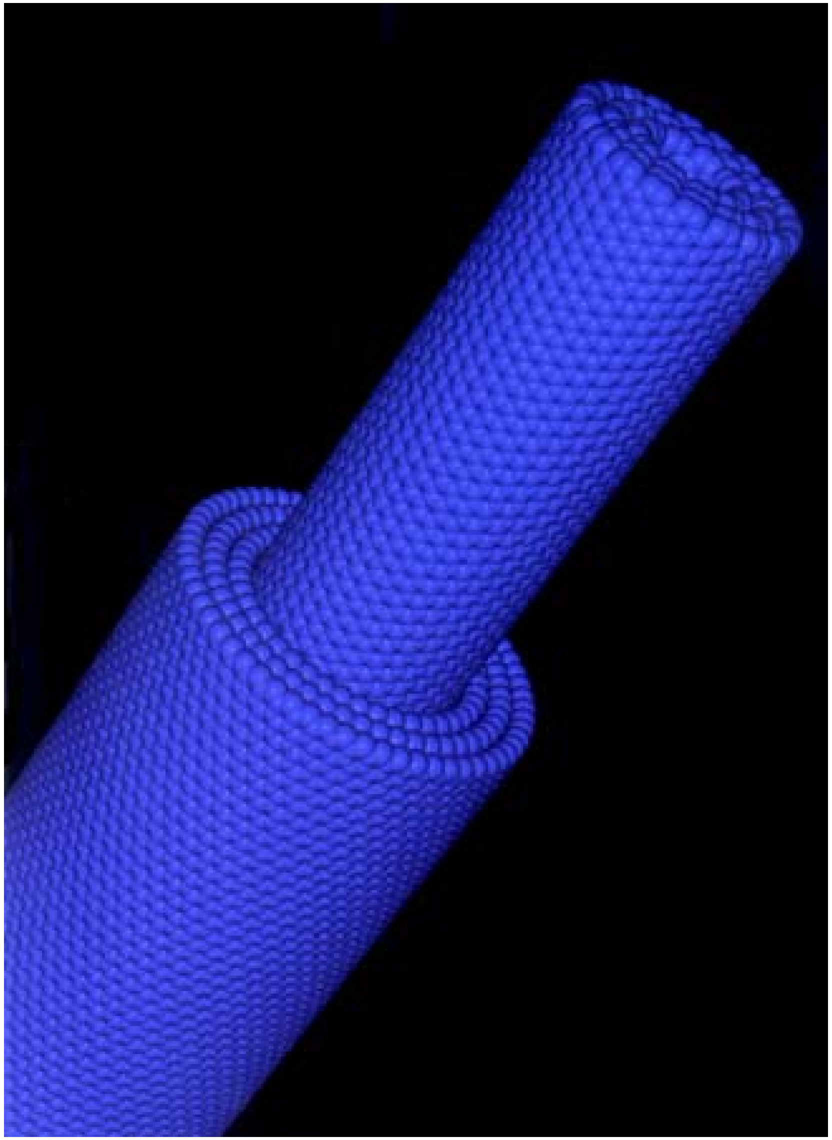


Mechanical Properties: Axial Young's Modulus

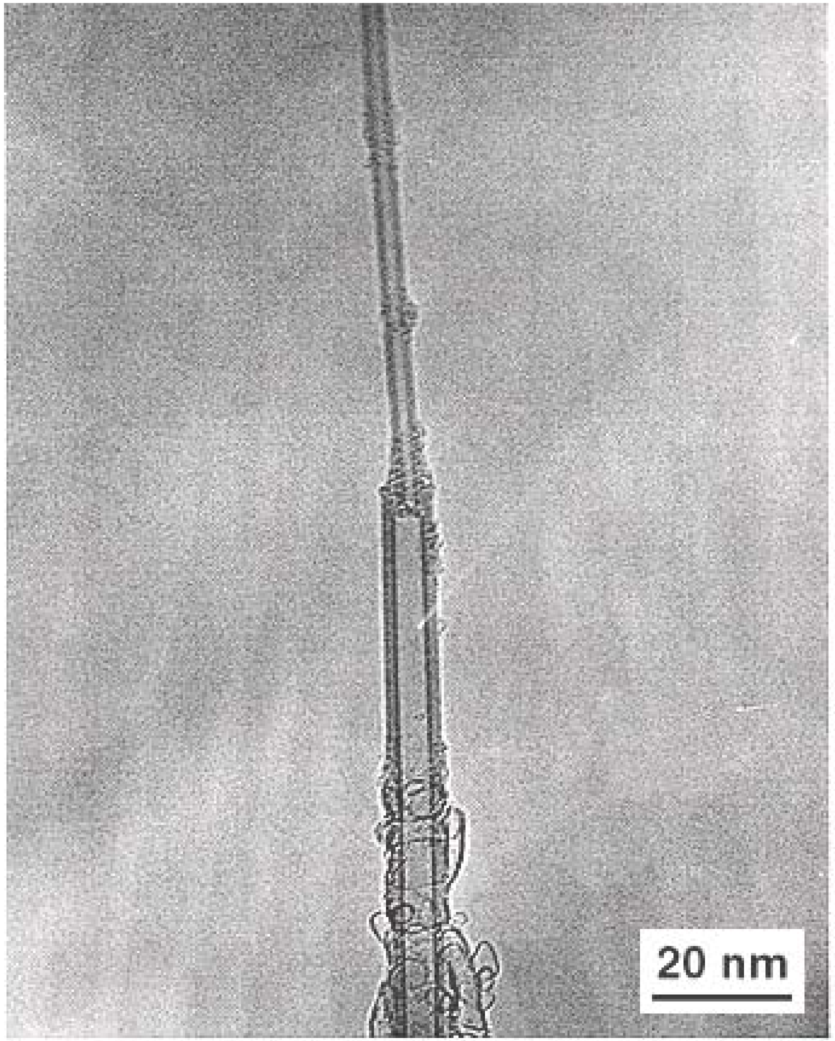
Material	Y(GPa)
Copper Wire	110
Steel Wire	200
Iridium Wire	520
$Bi_2Sr_2Ca_1Cu_2O_x$ whisker	20
$Bi_2Sr_2Ca_1Cu_3O_x$ whisker	30
Carbon Fiber	200-800
Carbon Nanotube (multiwall)	1260 *
Carbon Nanotube (singlewall)	1210 *

* World Record

Telescopically extended nanotube



Nanoscale Linear Bearing



9 walls = 4 (core) + 5 (housing)

Cumings & Zettl, *Science*

No observable wear after many cycles

Constant restoring force

Δt (100nm) = 1nsec

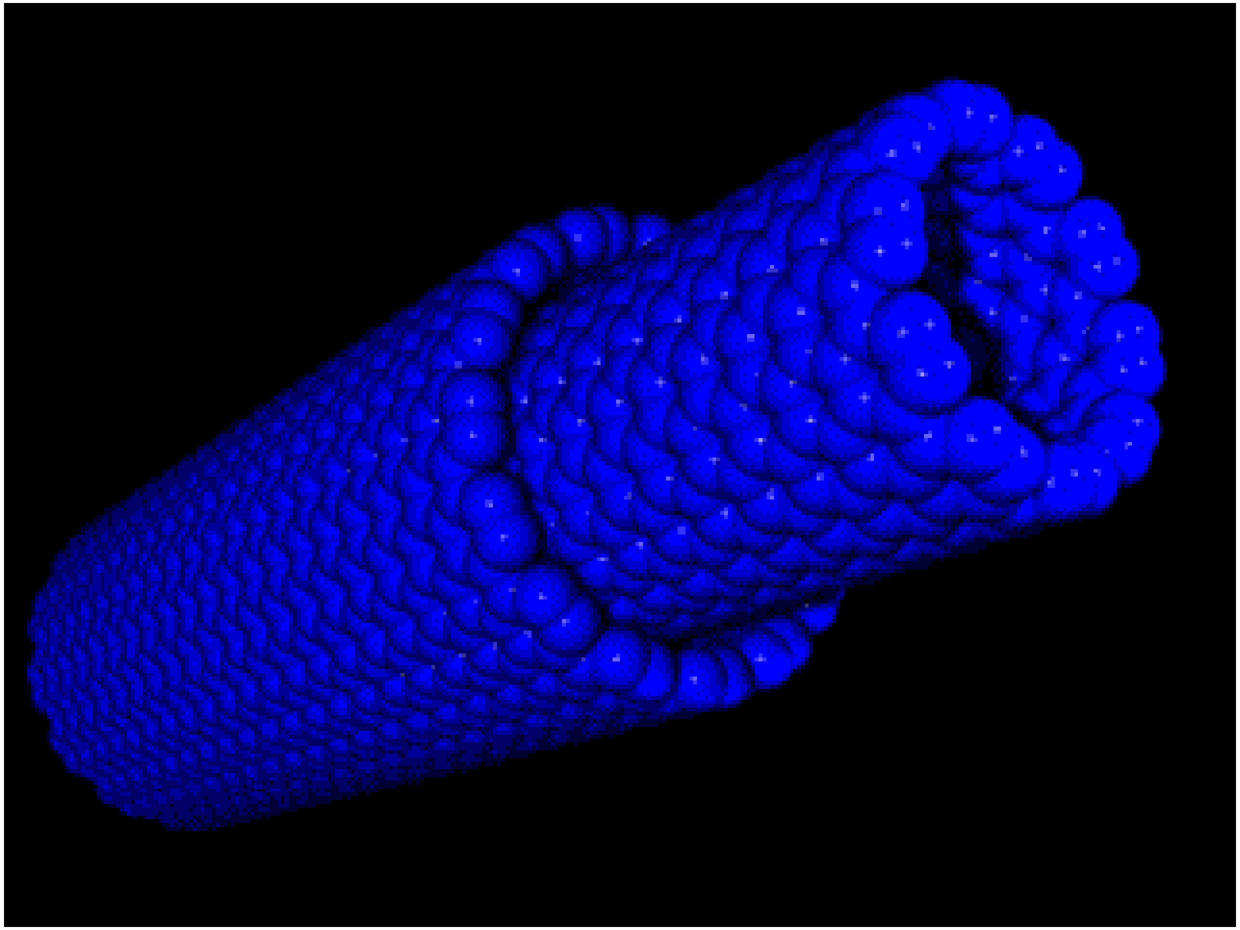
Extremely low friction

$F_{static} < 2.3 \times 10^{-14}$ N/atom

$F_{dynamic} < 1.5 \times 10^{-14}$ N/atom

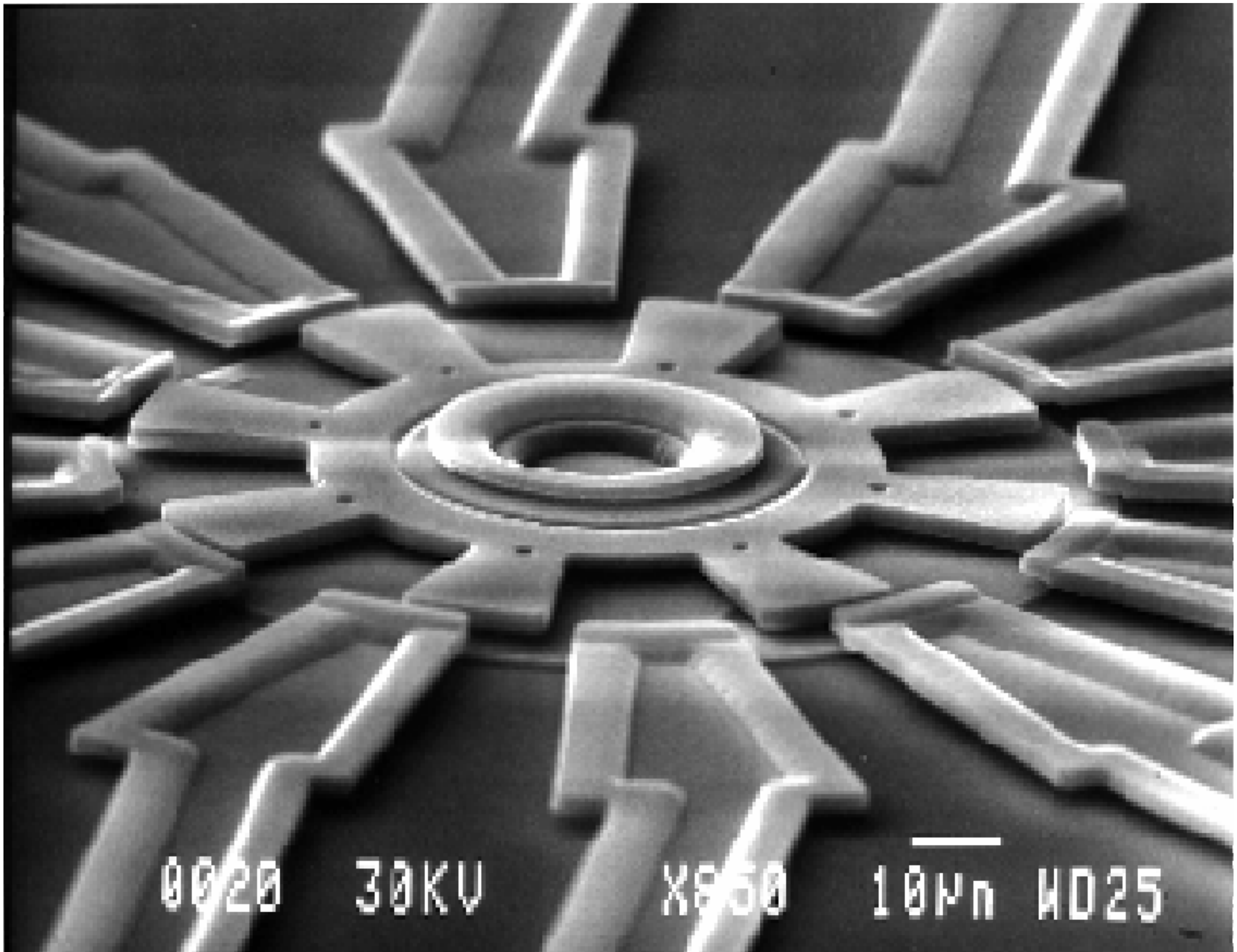
NOTE: MEMS friction 1000x larger!

Proposed Nanotube Rotational Bearing

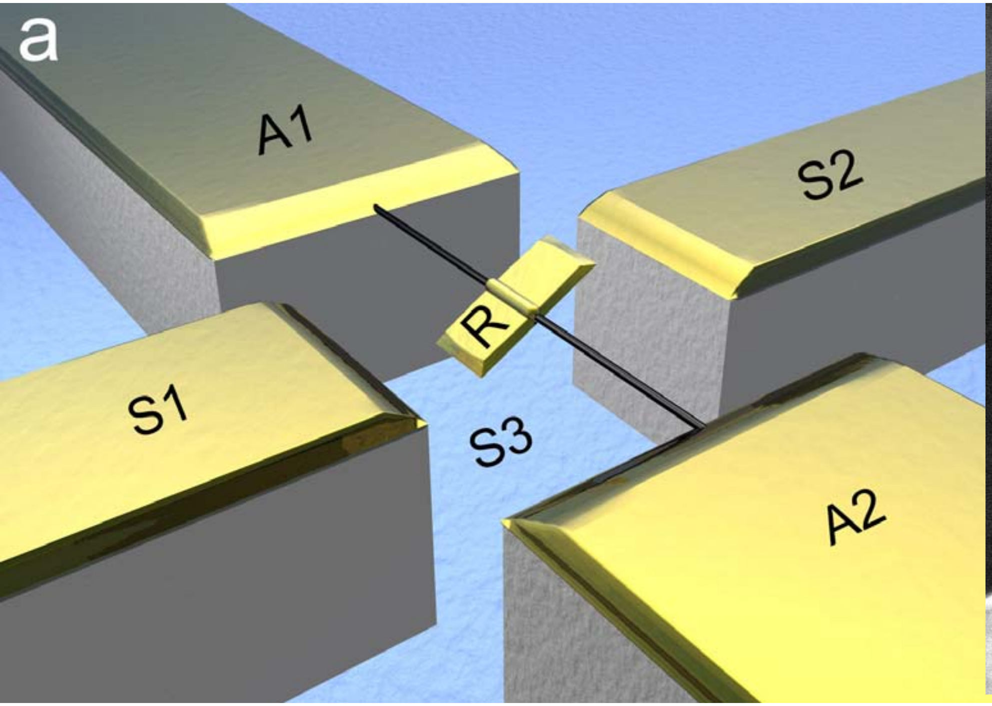


MEMS Rotational Motor

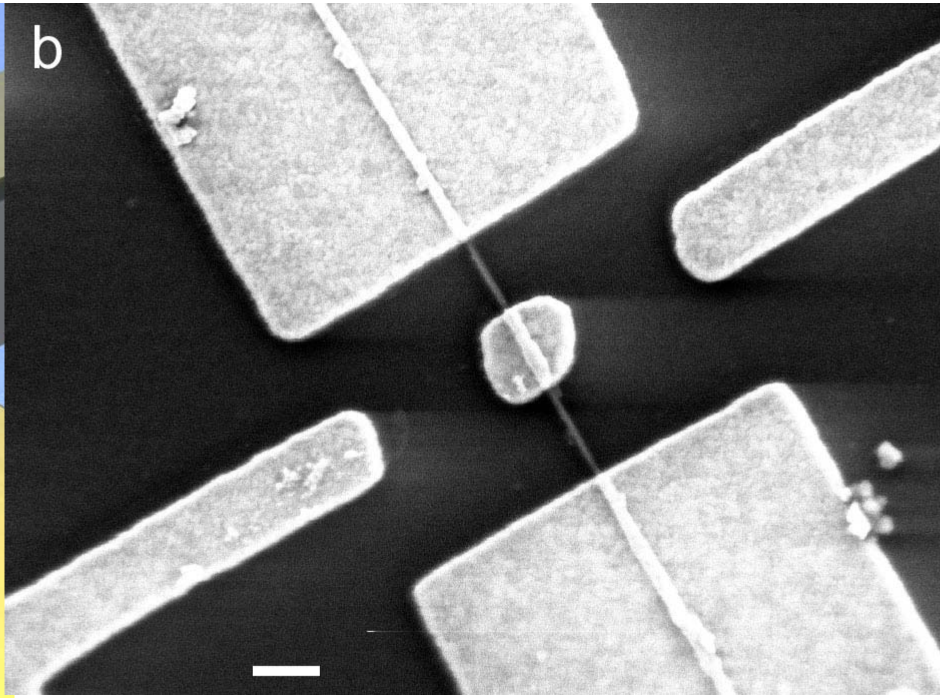
L.S. Fan, Y.C. Tai, R. S. Muller Sensors and Actuators 20, 41 (1989)



Nanotube-based Electric Nanomotor



a) Schematic motor layout. R: nanotube-suspended metal plate rotor
A1, A2: anchors; S1,S2,S3: stators



200nm

b) SEM image of completed nanomotor

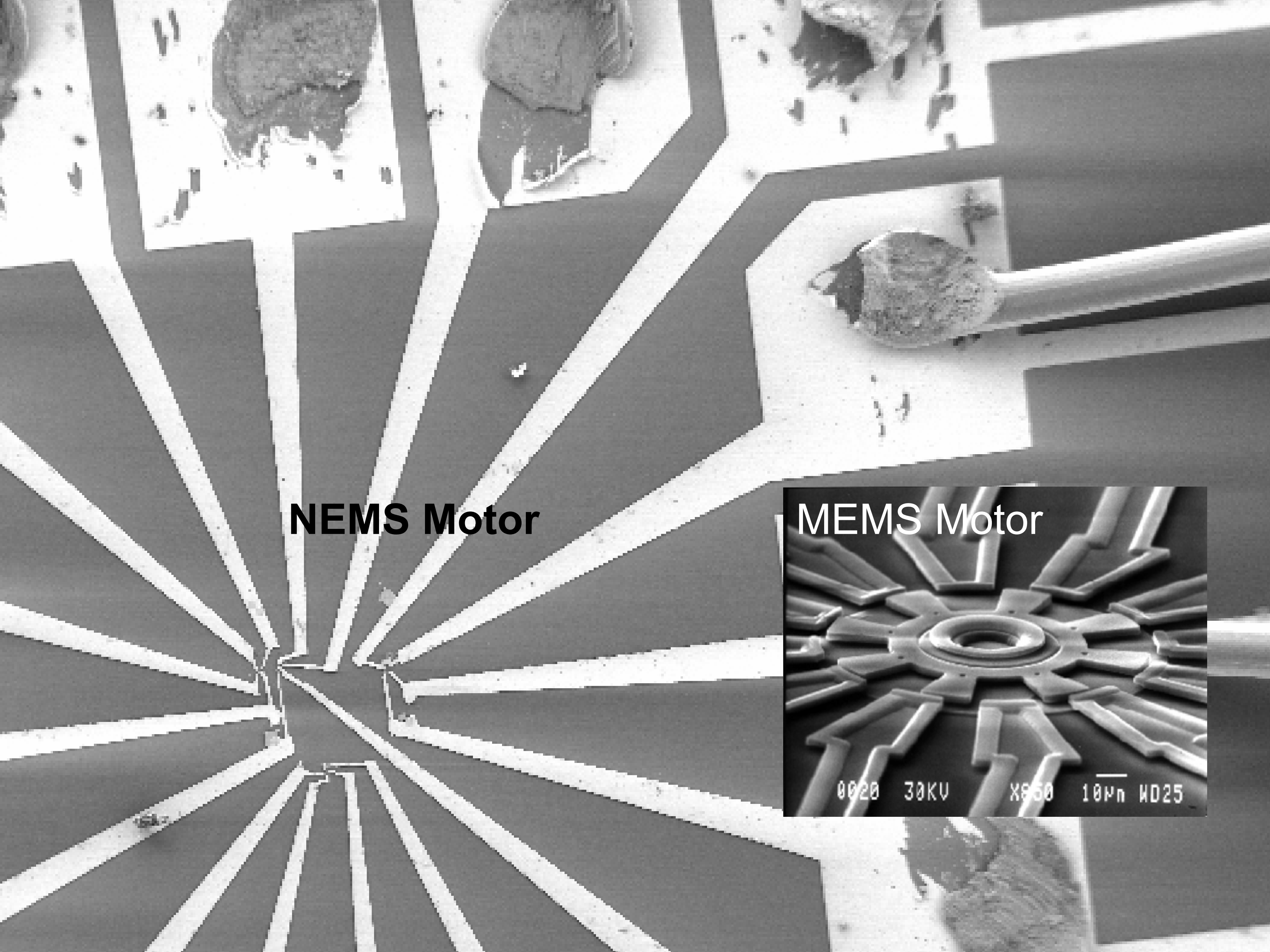
(Fennimore, Yuzvinsky, Zettl et al, *Nature* 2003)

Full Rotation

QuickTime™ and a MPEG-4 Video decompressor are needed to see this picture.

Simulation

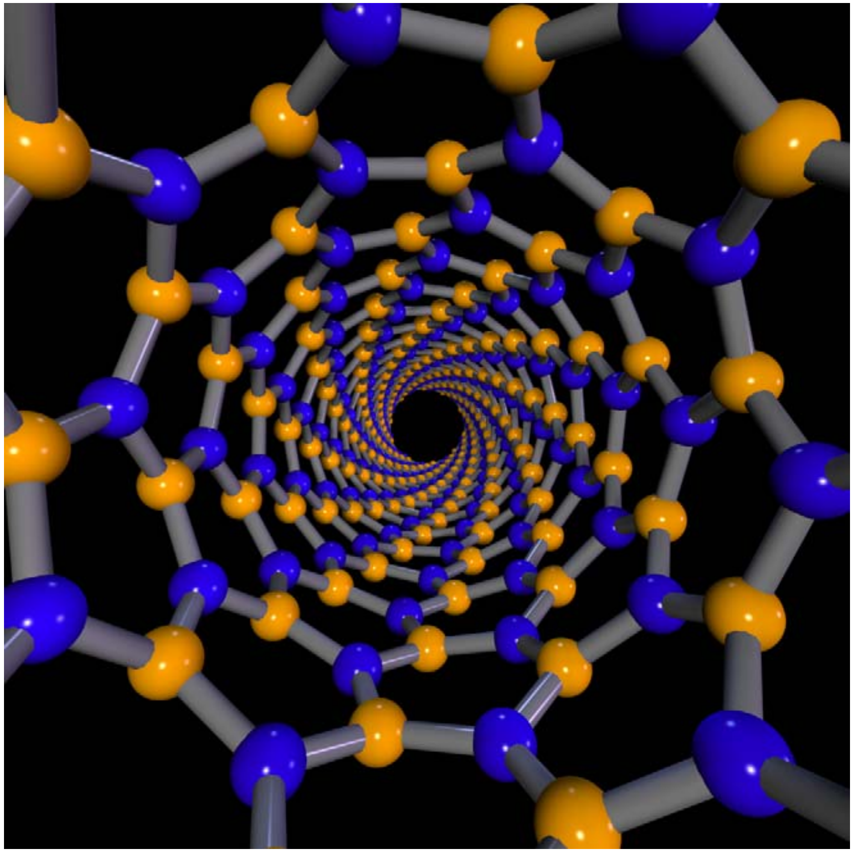
QuickTime™ and a MPEG-4 Video decompressor are needed to see this picture.


NEMS Motor
MEMS Motor
0020 30KV
10μm WD25

Boron Nitride Nanotubes

- Wide bandgap semiconductor (E_g ~ 5 eV)
- Bandgap can be tuned externally

Zettl, Cohen, Louie, et al., *Science*



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Achieved with one class of nanomaterial!