Billion-year Ultradense Memory

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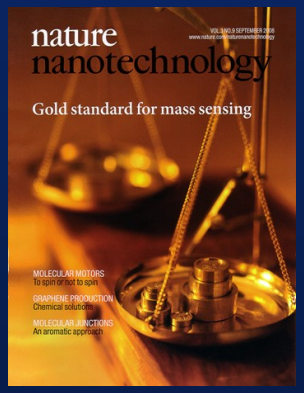
Zettl Group

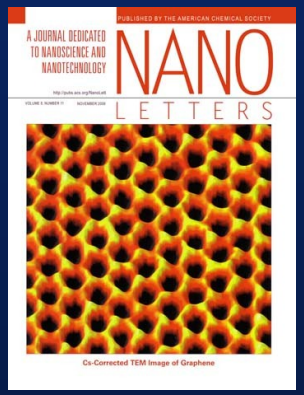
- Synthesis and characterization of novel nanomaterials

  Graphene, h-BN, nanotubes

- Nano-electromechanical systems (NEMS)

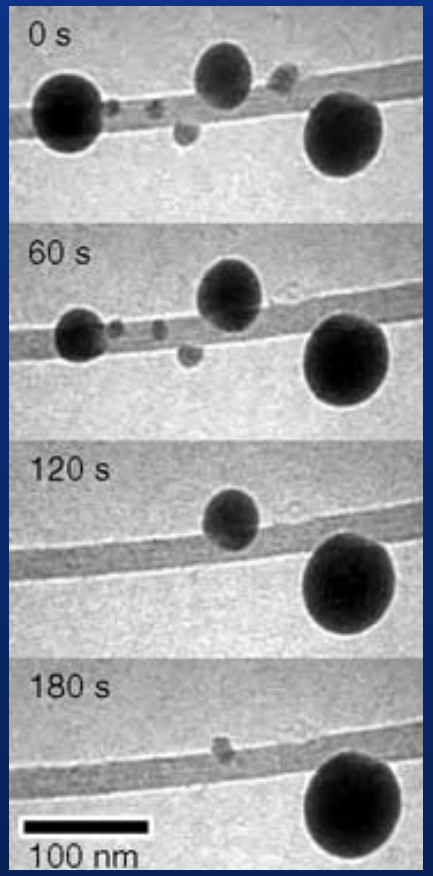
  Graphene/CNT resonators, rotors





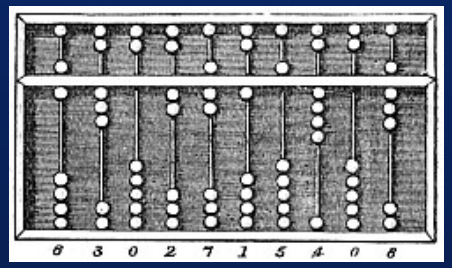
Material Properties Used for Data

Charge density	NAND flash
Ferromagnetic orientation	Tape, HDD
Crystalline phase	PCM

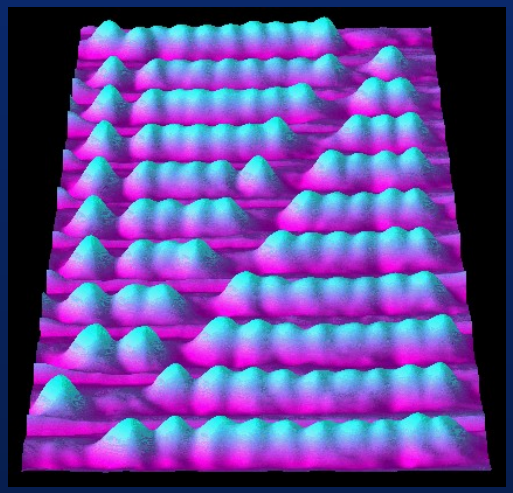


B.C. Regan, A. Zettl *et al.*, *Nature* **428,** 924 (2004)

- Position?

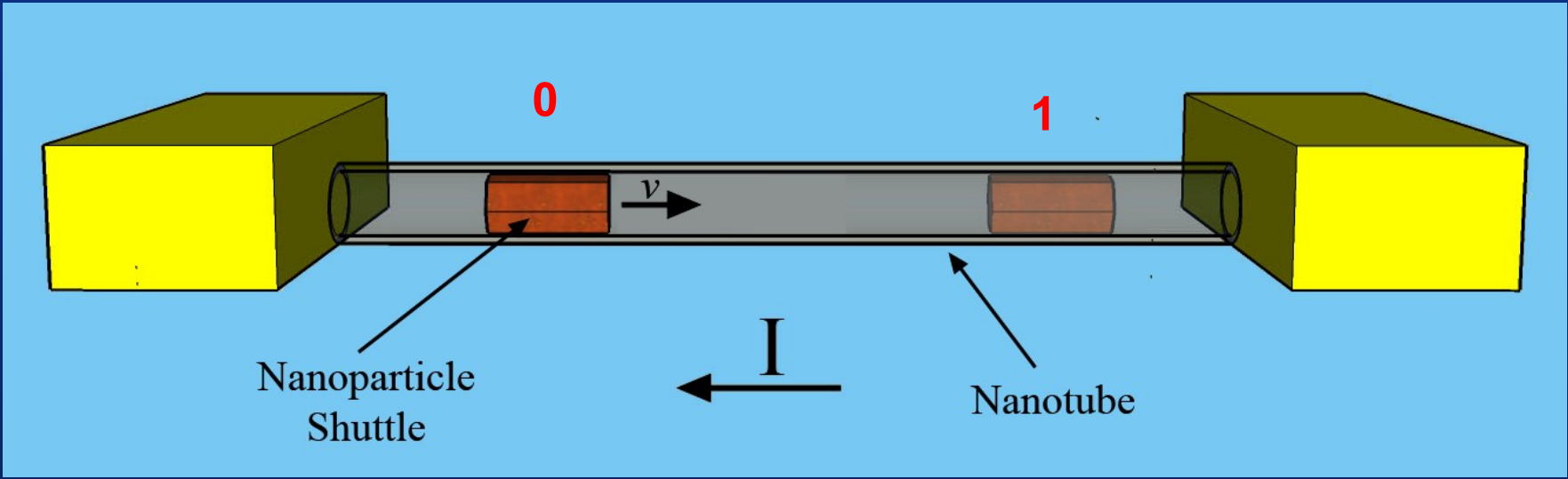


http://commons.wikimedia.org/wiki/File:Abacus_6.png



M. T. Cuberes, R. R. Schlittler, and J. K. Gimzewski
Appl. Phys. Lett. 69, 3016 (1996). (IBM Zurich)
http://www.research.ibm.com/atomic/nano/abacus.gif

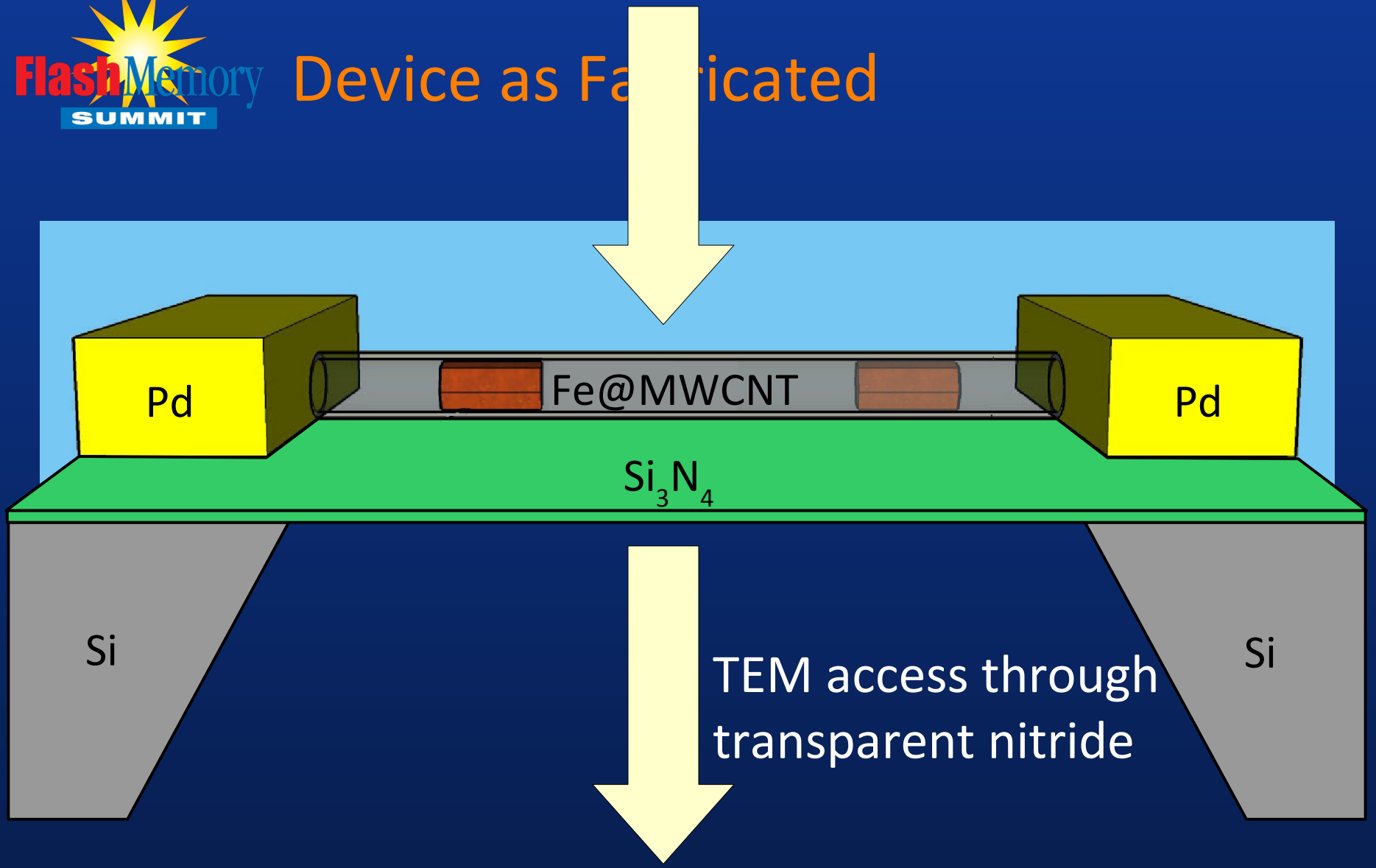
Proposed Nanomechanical Memory



G.E. Begtrup, W. Gannett, T. D. Yuzvinsky, V. H. Crespi and A. Zettl. Nanoscale reversible mass transport for archival memory. *Nano Letters* **9** (5), 1835-1838 (2009).

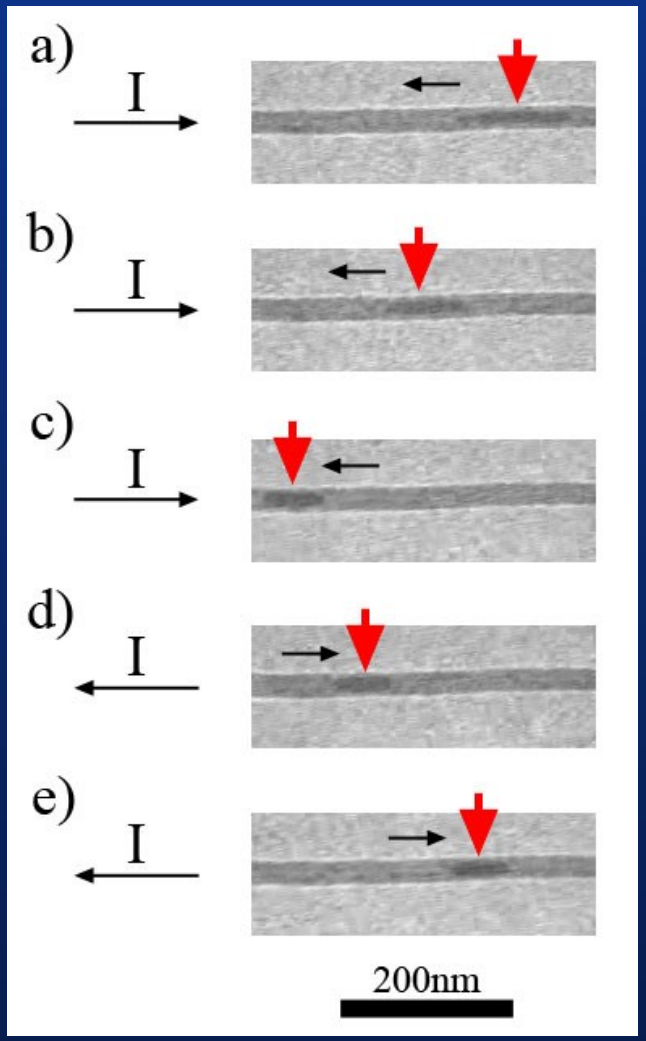
- Nanoparticle slides within carbon nanotube
- Nanotube protects particle from environment

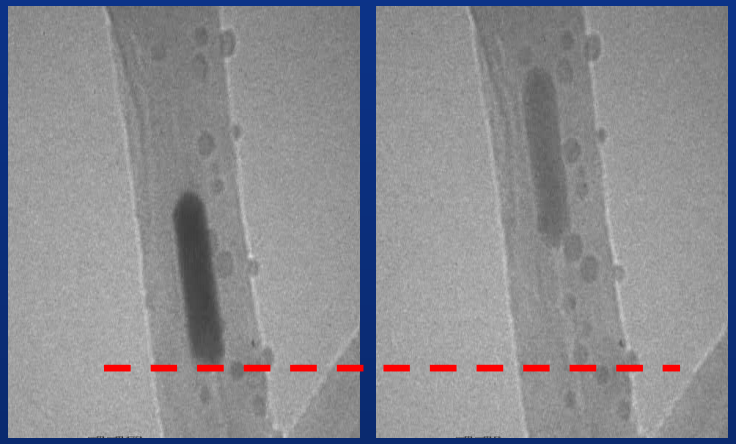
Device as Fabricated



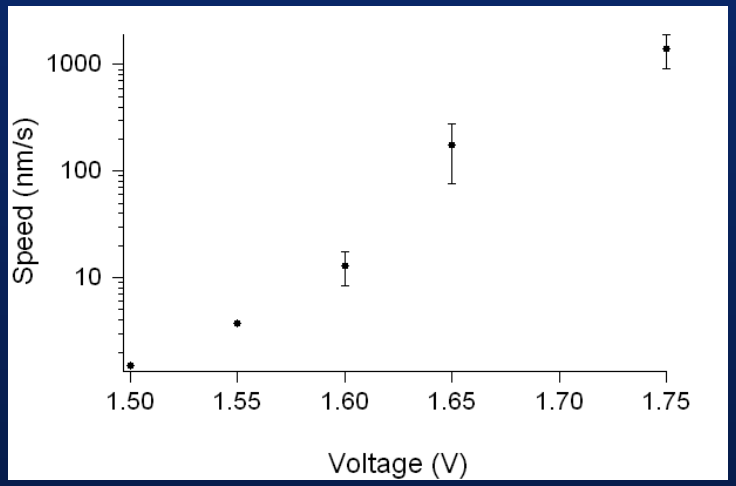
Writing and Rewriting

Nanocrystal Movement





Max observed velocity: >25 µm/sec



How to read out?

- TEM
- Scanning probe (STM)

  Far too bulky/costly

- Asymmetric gate

  Better, but still 3-wire

- Would like a simple “in-line” measurement

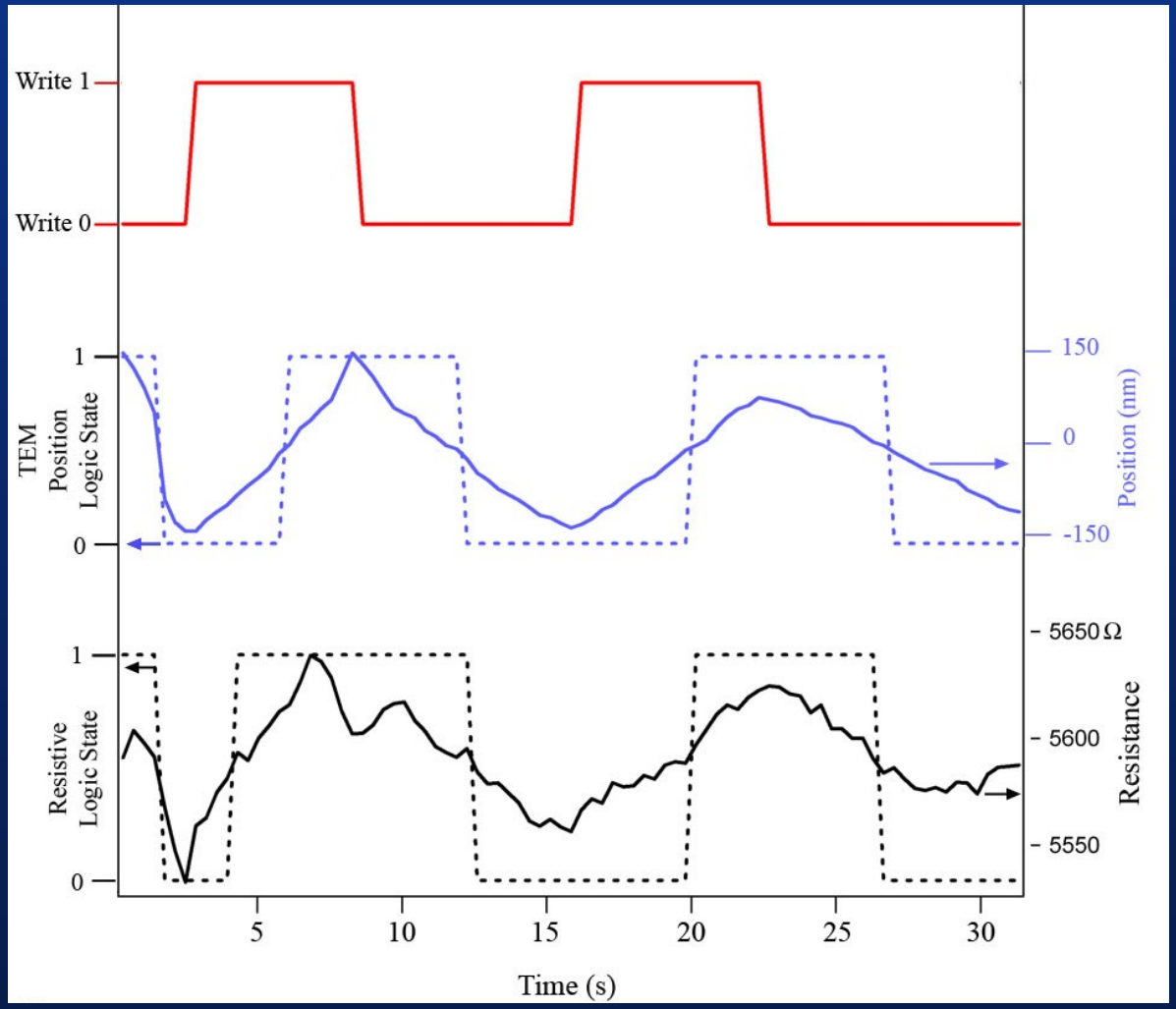
  2-probe...what about resistance?

Write and Read - Timeseries

Write signal

TEM observation
Read-out

Resistance
Read-out

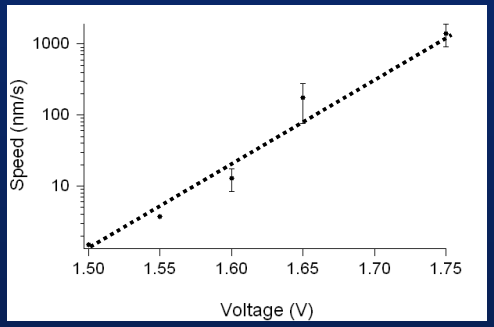


Stability

- Modeled as sawtooth potential of height ΔE

$$v \sim \omega L e^{-\left(\Delta E - \frac{1}{2} Q_{eff} V \frac{L}{D}\right) / k_B T}$$

- Speed vs voltage data → ΔE ~ 1.5-1.7 eV



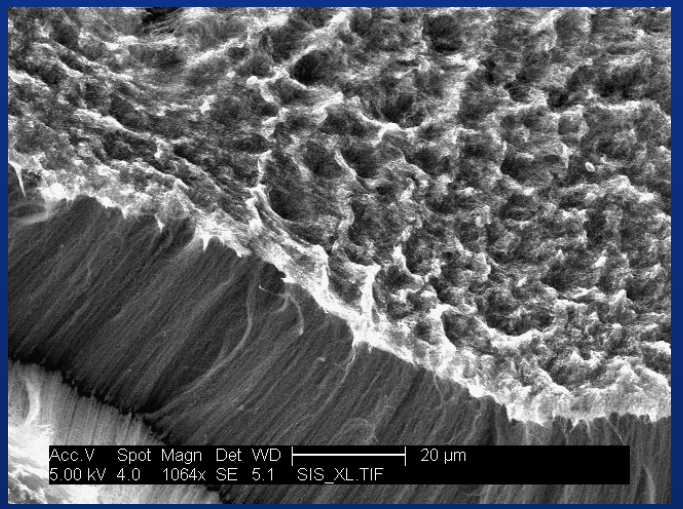
- Estimated dwell time of >10^9 years at 300K

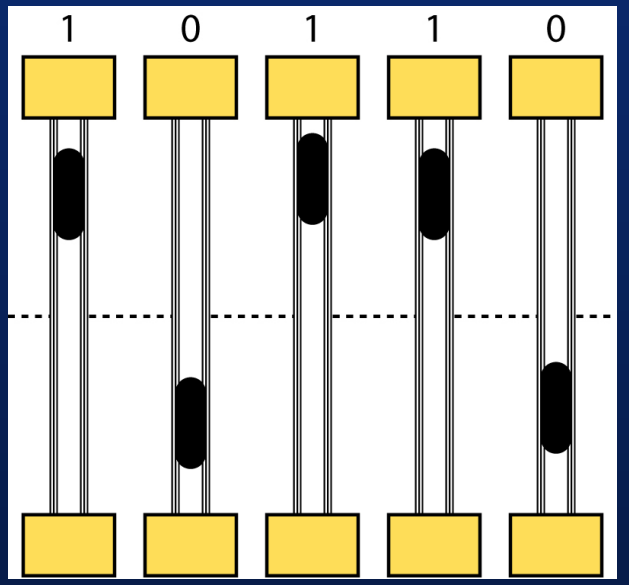
Arrays of devices?

- Growth of CNT forests
- How to address individual devices?
- Density:

  5 nm x 100 nm / bit

  → 1 Tbit/in^2



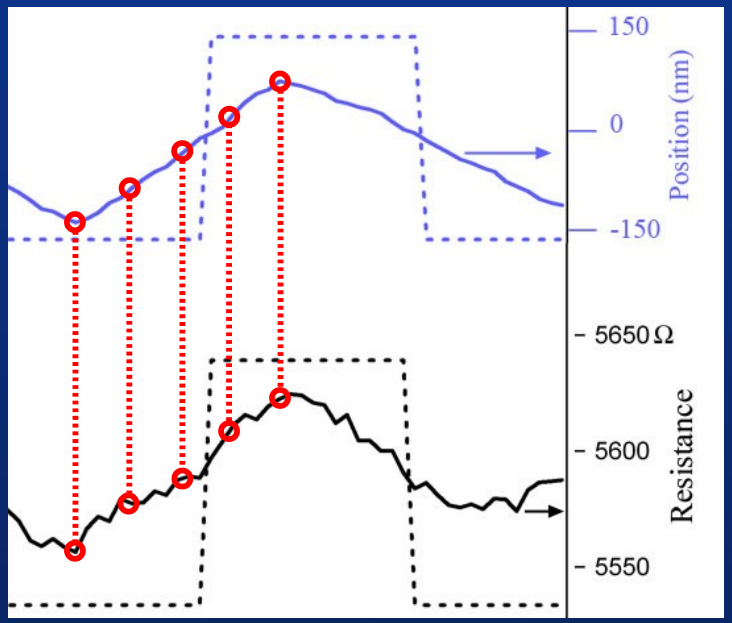


Future directions for Zettl group

- Preliminary fabrication of Fe@CNT arrays
- Determine mechanism of motion
  - Electromigration, electron wind
- Origin of resistance changes
  - Intershell coupling perturbation
  - Geometry effects (with diffusive transport)
  - Electron resonance effects

Further research

- Multistate devices?
  - 20ns pulses @2V
  - 3nm steps



- Signal enhancement?
  - Electrode/nanoparticle material
  - Geometry changes
  - Fewer nanotube walls

Conclusions

- Stable, sealed mechanism
- Easy to synthesize (initially)
- Easy to read out

  Electronic, nonperturbative

  (TEM just for observation)
- R/W voltages compatible with existing tech.

Acknowledgments

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- National Science Foundation
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References:

G.E. Begtrup, W. Gannett, A. Zettl, et al. Nanoscale reversible mass transport for archival memory. *Nano Letters* **9** (5), 1835-1838 (2009).

G.E. Begtrup, W. Gannett, A. Zettl et al. Facets of nanotube synthesis: High-resolution transmission electron microscopy study and density functional theory calculations. *Phys. Rev. B* **79** (20), 205409 (2009).