ECE 497NC:
Unconventional Computer Architecture

Lecture 15:
Computing With Nanotech –
Carbon Nanotubes II

Objectives

- Look at some proposed techniques for building systems out of nanotubes or nanowires.

- Again, all images are credit www.research.ibm.com

Nanotube-Based Memory Cells

- Could create memory out of the same circuits used in CMOS
  - Here's another approach
- Nanotubes positioned at right angles have two stable states:
  - Separated such that top nanotube is straight
  - Top nanotube deflected to make contact with bottom
- Resistance between wires varies strongly (10x) depending on whether wires in contact or not
  - Can read device by sensing I-V characteristics
  - Allows grid structure with electrical contacts only at grid edges
    - Device switched by applying voltage pulses at appropriate contacts

How Small, How Fast?

- Size limited by how much tube can be deflected without breaking/kinking
  - Estimate minimum of 10nm spacing between bits with hard supports
  - Possible 5nm spacing with soft
- Speed – two factors
  - Base time to change the state of a bit suggests write times approaching 100 GHz (200 GHz for 5nm devices)
  - Read time depends on sensitivity of interface circuitry
  - These times don't account for time to set up read/write, propogation delay across nanowires
- Issue: reliability
  - Physical deflection of tubes cause for concern
  - Authors claim shouldn't be a problem, because tubes well within acceptable deflection levels

System Issues

- Nanotubes currently very expensive, can't create only metallic or only semiconducting tubes
  - Expense issue likely to be less of a problem as use of nanotubes grows
  - Would need breakthrough of some sort to be able to make tubes of only one type
- Current manipulation techniques don't scale
  - Today: Use scanning electron microscope to push individual tubes around a chip
  - For practicality: Need to be able to fabricate many devices in parallel, similar to VLSI

Advances in Fabrication

- Big breakthrough: ability to grow nanotubes selectively from deposited sites
  - Fabricate regions of material on a chip, then grow nanotubes out of the material
  - Some ability to control direction of nanotube growth

- Still lack good control over whether a given nanotube turns out to be conducting or semi-conducting
  - "killer" issue in terms of mass fabrication

Creating Arrays of Nanotubes

- Basic idea: use fluid flow to create parallel arrays
  - Place mold on substrate
  - Flow solution of nanowires across substrate
  - Nanowires that adhere tend to be in parallel
  - Can vary density of nanowires
  - Can create layers of wires that point in different directions by rotating mold

Engineering Nanotubes With Electrical Breakdown

- Problem: Single-walled nanotubes tend to clump into bundles of both metallic and semiconducting tubes
  - Related issue with multi-walled nanotubes, which have complex I-V characteristics
  - Metallic nanotubes in bundle conduct regardless of gate voltage, turn transistor into wire
- Solution: Selectively burn out metallic nanotubes
  - Place bundle of tubes on gate contacts
  - Apply appropriate gate voltage to turn off semiconducting tubes
  - Apply source-drain voltage until current through metallic tubes exceeds carrying capacity, destroying them
  - Only semiconducting tubes left
- Similar approach can be used to destroy individual shells of multi-walled nanotubes.

Illustration of Process