The Three Upcoming Revolutions in Physics and Astronomy that will Affect Everyone

Nanotechnology

Nov. 5, 2002
Why do I have to keep replacing my computer?

Warm-up

- **How many atoms in a Pentium IV?**
  - Assume atoms are 0.5 nm apart
  - ~100 million transistors in a Pentium IV

- **Answer methodology**
  - Estimate dimensions of Pentium IV
  - Calculate volume of Pentium IV and atom
  - Divide to get atoms/Pentium IV
Why do I have to keep replacing my computer?

- **Moore’s Law and you**
  - History of transistor
    - Vacuum tubes
      - Radio
      - The ENIAC
    - Bardeen and Bell lab transistor
    - Lithography and Integrated circuits

"Where a calculator on the ENIAC is equipped with 18000 vacuum tubes and weighs 30 tons, computers in the future may have only 1000 tubes and weigh only 1 1/2 tons”

- Popular Mechanics, March 1949
Why do I have to keep replacing my computer?

• **Moore’s Law and you**
  – **Basic operating principles of a computer**
    • Central Processing Unit
      – E.g. Pentium IV
      – Clock speed
    • Memory
      – E.g. RAM, Hard Drive, CD
    • Bus
      – Moving info. Around
      – Bus speed
    • I/O
      – Keyboard, display, modem, ethernet

Magnetic recording process.
Why do I have to keep replacing my computer?
Why do I have to keep replacing my computer?

- **Moore’s Law and you**
  - **Moore’s law**
    - Features sizes halve every 3 years
    - Originally recognized in the 60s
  - **Economic drivers**
    - Cost of computers
    - Depreciation
    - Cost of retooling
Why do I have to keep replacing my computer?

- The end of Moore’s law
  - Size of transistors
    - Pentium IV: gate length 130 nm
    - Atoms: 0.5 nm apart
Why do I have to keep replacing my computer?
How to make small things smaller

Warm up

• How has the world been changed by computers?
  – In your lifetime?
  – In your parents’ lifetime?

• Where have electronics become critical today in places they didn’t exist
  – before you were born?
  – before your parents were born?
How to make small things smaller

- **How small is 1 nm?**
  - Atoms are ~0.1 nm is diameter
    - Atoms in a crystal are ~0.5 nm apart
  - Molecules
    - Can be from 0.2-200 nm
  - Viruses
    - Smaller than 100 nm
How to make small things smaller

- Microfabrication and Nanofabrication
  - Lithography: The patterning of surfaces
    - Optical/UV lithography
      - Resolution limited by wavelength of light
    - Electron beam patterning
      - 10 nm features demonstrated
      - Slow, registration
    - Stamp
      - e-beam features, but much faster
How to make small things smaller

- **Microfabrication and Nanofabrication**
  - **Writing and Etching**
    - Chemical etching
      - Lithography defines etch
    - Direct write e-beams
      - Scanning & Transmission Electron Microscopy
    - Implantation
      - Focused Ion Beam
  - **Atomic Scale Probes**
    - Scanning Tunneling Microscopy
    - Atomic Force Microscopy
    - Magnetic Force Microscopy
How to make small things smaller

- **Electronic and Optical Devices**
  - **Band engineering**
    - Building semiconductors atomic layer by atomic layer
      - 3D: bulk materials
      - 2D: quantum wells
      - 1D: quantum wires
      - 0D: quantum dots

- Mercury Nanotube Fiber
- 1 µm
How to make small things smaller

- **Electronic and Optical Devices**
  - **Band engineering**
  - **Devices**
    - Q well transistors and lasers
    - Q wires
    - Q dot transistors and lasers
      - Single Electron Transistors
Commercial Applications

CD: 0.7GB, DVD: 4.7GB, Blue Laser DVD: 12.4GB

From Nichia Corp.
How to make small things smaller

- **Mechanical Devices**
  - Micro-electrical-mechanical devices (MEMS)
    - Accelerometers for air bags
    - Microturbines

- **Bio-molecular Devices**
  - Molecular motors
  - Microfluidics
    - Micro-cooling
    - Micro drug delivery
How to make small things smaller

- **Medical Devices**
  - Medical internal nanosensors
  - Bionics
    - Artificial Eye and Nose

- **Smart Clothing**
  - Wearable electronics
  - Institute for Soldier Nanotechnologies
How to make small things smaller
Materials built from the ground up

- **A 3D periodic table**
  - Carbon
    - Buckyballs & buckytubes
  - **Molecular carpet**
    - Self-assembled monolayers of molecules
  - **Designer materials**
    - Dendrimers
    - Clusters & Composite materials
    - DNA-based assembly

1) 
Denatured BWA genomic DNA
2) 
Ag⁺ hydroquinone
Ag(s) quinone

BA = Bacillus Anthracis
FT = Francisella Tularensis
Materials built from the ground up

- **New materials**
  - Photonic crystals
    - Designer, artificial optical materials
    - Control and reflect light in ways we decide
New materials
- Smart materials
  - Selectively permeable
  - Sense hot & cold, humidity
- Sensors
  - Pathogen detection
  - CB agent detection
- Cure
  - Catalysis & decontamination
  - Nano drug delivery

Lead and Glucose Detection

Fig. 1 Concept for glucose sensing device for tear fluid and for implants. The color of light diffracted defines the glucose concentration.
Living in a nanomaterial world

- The impact of the nanotechnology revolution
  - Computers, computers, everywhere!
    - Speculation about the most possible computerized and interconnected world.
    - In 10 years
    - In 20 years
    - In 50 to 100 years

- Science fiction?
  - Cyborgs and Nanites?
    - Star Trek
  - Smart displays and robotic sensors?
    - Minority Report
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