Feynman’s vision

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MEMS/NEMS Motors

Information density

- 1985 using e-beam, “Tale of two cities” inscribed in 1/160mm per side
- Magnetic Disks can approach 60Gbit/in²
- AFM based work at IBM gets 400Gbit/in²
AFM based approach

- Use AFM tip to make holes in plastic
- Write:
  - Heat the tip to make a dent
  - Thermomechanical system
- Read:
  - Scan with moderately heated tip
  - Detect changes in efficiency of thermal conductance (through changes in resistance) to indicate presence of a dent.
- Slow, but use lots of tips

Size of all info (10^{15} bits?)

- Using AFM tip:
  - 1 bit \sim 20nm \times 20nm
  - \( 10^{15} \text{ bits} = 4 \times 10^{17} \text{ nm}^2 \)
  - 1 in^2 = 6.45 \times 10^{14} \text{ nm}^2
  - \( 10^{15} \text{ bits} = 620 \text{ in}^2 \)
  - \( < 7 \text{ pages!} \)
  - \sim 40K \text{ atoms per bit}
- Using molecular memories/crossbars
  - Fabricated as by HP/UCLA
  - Similar bit density

Writing the bits

- Nanoimprint lithography

- Photolithography

http://www.princeton.edu/~chouweb/newproject/page3.html
Writing the bits

- Nanoimprint lithography
- Photolithography
- E-beam litho (first ~1967)

http://www.nanophys.kth.se/nanophys/facilities/nfl/sem-ebeam.htm

Bio-inspiration

- Biology is one of the main inspirations for all nanotechnologists
- Self-assembly
  - Protein formation
  - Differentiation
- Density of information
  - 1 base pair 2-3nm
  - 50 atoms per bit
- Energy system
  - Atp motor
  - Ion pumps

Bio

- Inspired by us!
- But, be careful with biomimetic approaches

http://www.chimica.unige.it/membrane/eng/in

A Better Microscope

- SEM
- TEM
- STM
- AFM

http://sibener-group.uchicago.edu/facilities.html
http://www.semitech.ee.ttu.edu/html/facility.html
A Bit of Microscopy History

Optical Microscope
~1700

Electrons: TEM
1931

SEM: 1942

1981: STM

1986: AFM

Time

Size/parallelism/scale

- The \( \frac{1}{4} \frac{1}{4} \frac{1}{4} \) argument?
- Precision and scaling
- What are some ways to deal with imprecision?
  - Surface/volume
  - Van der walls (\( \alpha r^{-6} \))
  - Quantization
    - Thermal
    - Conductance
  - Adsorbtion
  - Grain boundaries
  - Gravity
  - Friction
  - ?

Nanomedicine

- Not exactly nano, ...
- Cancer treatments based on nanoparticle

Molecular Manufacturing

- The drexlarian nanotechnology
- Placement of individual atoms
- Is this possible?
- If so, what are the benefits?
Tentative plan

- Intro
- Feynman
- CMOS Fabrication
- Nano-Lithography
- Self-assembly 1
- Transistor and scaling
- Molecular devices
- Molecular wires
- Circuits
- Architectures
- ITRS future directions
- DNA computing
- DNA-base self-assembly
- Tiling systems

For Next Time


- Describe how different steps in this process may be affected by nanometer dimensions
  - Wavelength of light
  - Thicknesses
  - Defects
  - Dopants
  - masks