Feynman's vision

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Motor < 1/64th of an inch

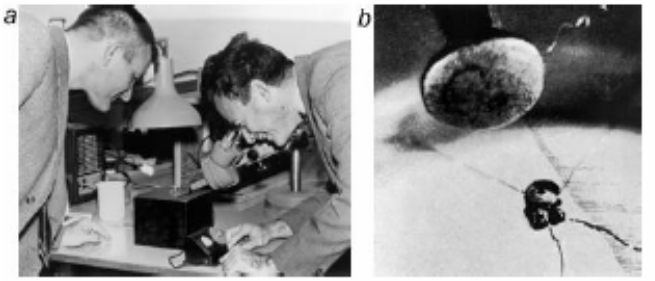
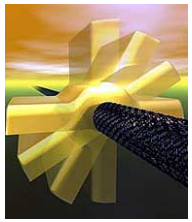
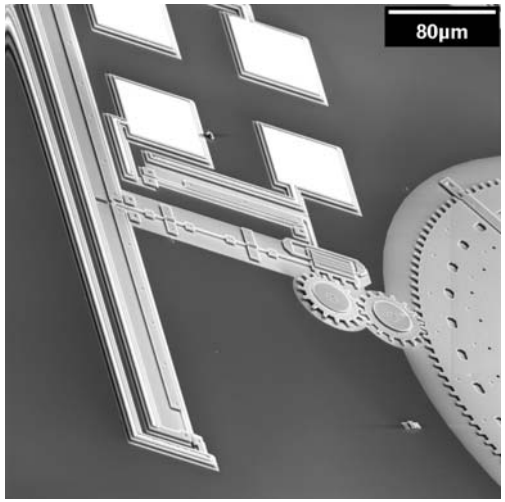


Figure 1. (a) Richard Feynman viewing the micromotor built by William McLellan (left) who won the challenge to build the first motor smaller than 1/64th of an inch. (b) The motor, 3.81 mm wide, photographed under an optical microscope. The huge object above it is the head of a pin. (Picture credit: Caltech Archives)

MEMS/NEMS Motors

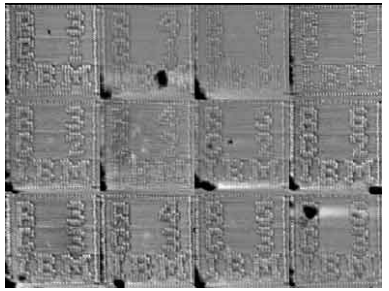


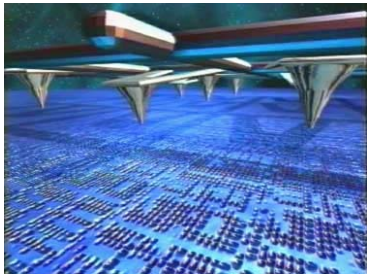


http://www.sfu.ca/immr/gallery/motors.html

Information density

- 1985 using e-beam, "Tale of two cities" inscribed in 1/160mm per side
- Magnetic Disks can approach 60Gbit/in^2
- AFM based work at IBM gets 400Gbit/in^2





http://www.zurich.ibm.com/st/storage/millipede.html

AFM based approach

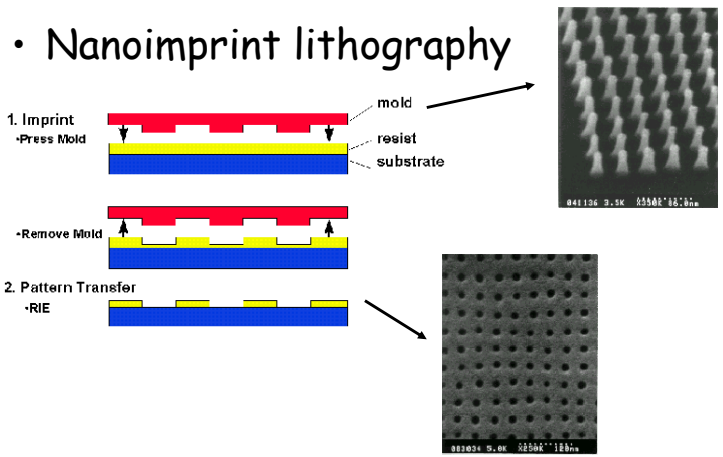
- Use afm tip to make holes in plastic
- Write:
  - Heat the tip to make a dent
  - thermomechanical system
- Read:
  - Scan with moderately heated tip
  - Detect changes in efficiency of thermal conductance (through changes in resistance) to indicate presence of a dent.
- Slow, but use lots of tips

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

- Using AFM tip:
  - 1 bit ~ 20nmx20nm
    10^{15} bits = $4x10^{17}$ nm^2
  - 1 in^2 = $6.45x10^{14}$ nm^2
  - 10^{15} bits = 620 in^2
    ‹ 7 pages!
  - ~40K atoms per bit
- Using molecular memories/crossbars
  - Fabricated as by HP/UCLA
  - Similar bit density

Writing the bits

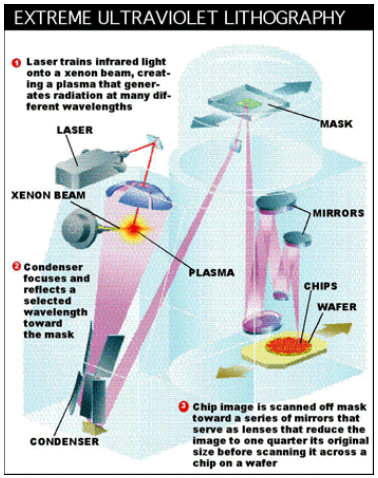
- Nanoimprint lithography



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

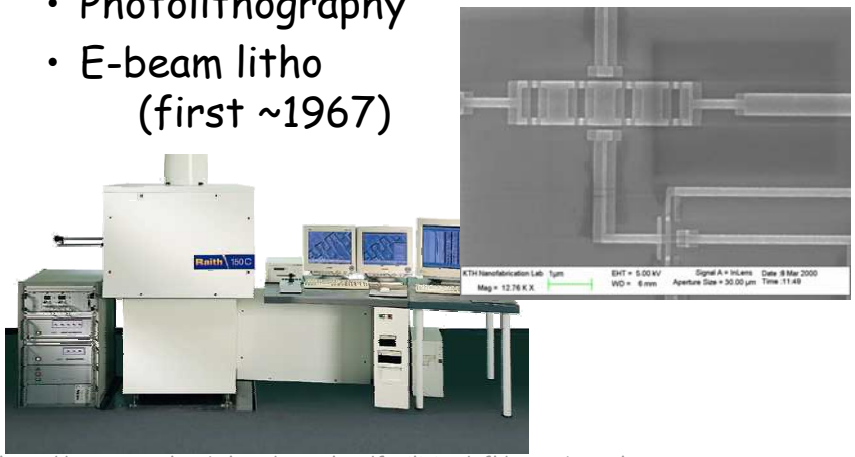
Writing the bits

- Nanoimprint lithography
- Photolithography



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

A Better Microscope

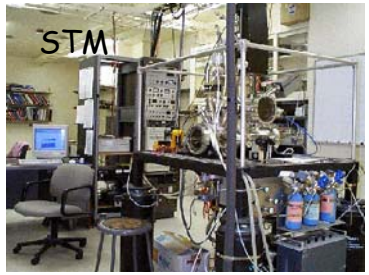
www.chimica.unige.it/membrane/eng/ir

- SEM
- TEM
- STM
- AFM

http://sibener-group.uchicago.edu/fac

http://www.mos.org/sln/SEM/gallery/

http://www.semitech.ee.ttu.edu/html/facility.html



http://sibener-group.uchicago.edu/facilities.htm

A Bit of Microscopy History

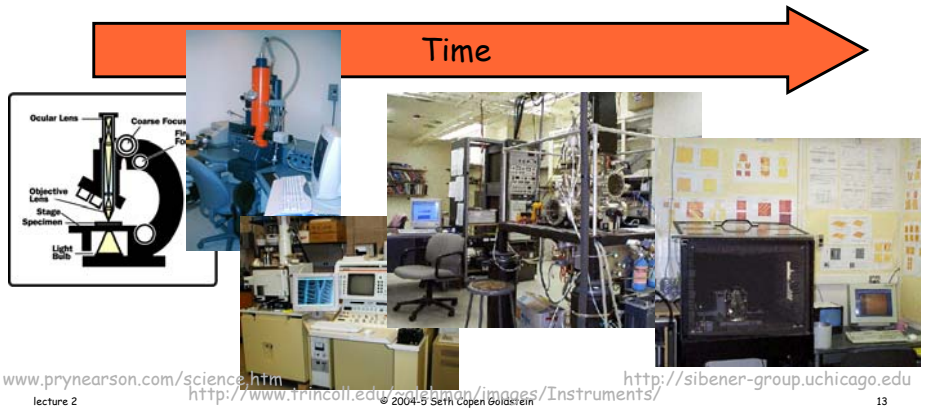
Optical Microscope
~1700

SEM: 1942

Electrons: TEM
1931

1981: STM

1986: AFM



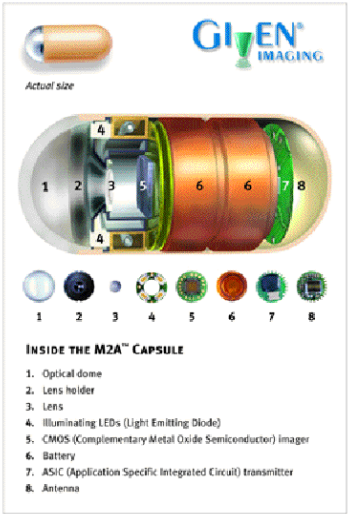
www.prynearson.com/science.htm http://www.frincoll.edu/galeman/images/Instruments/ http://sibener-group.uchicago.edu

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?
- Are things really the same, only smaller?
  - Surface/volume
  - Van der walls (α 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

- http://lsmwww.epfl.ch/Education/former/2002-2003/VLSIDesign/ch02/ch02.html

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