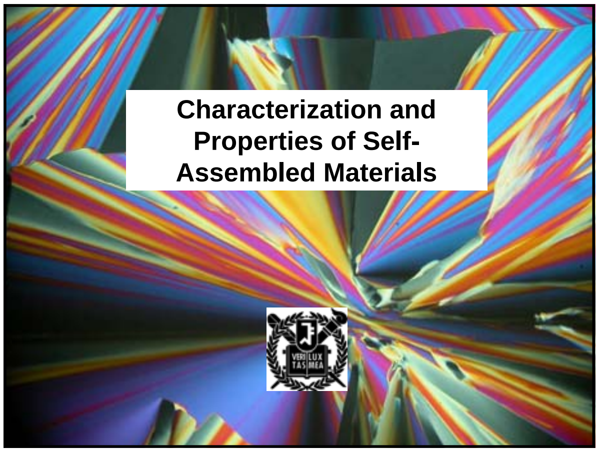
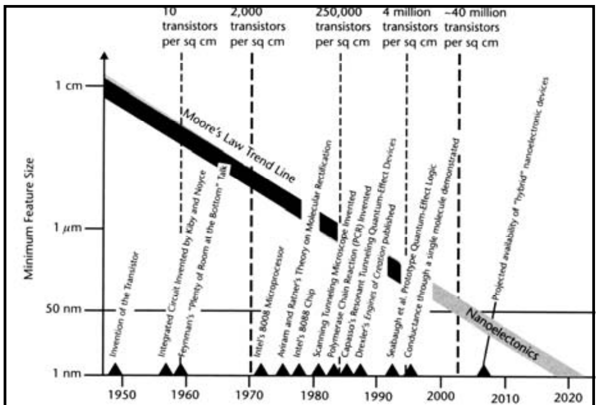


Characterization and Properties of Self-Assembled Materials

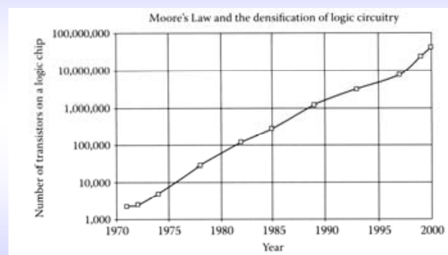
Some early milestones in nanotechnology



from M S Montemerlo et al., Techniques and Design for Electronic Nanocomputers"

Moore's law

- exponential increase in number of transistors per unit volume



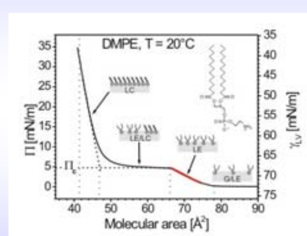
from: J.M. Tour, D.K. James, in "Nano- and Molecular Electronics Handbook", S.E. Lyshevsky, Ed., Chap. 2, CRC Press, 2007

Some limitations to scaling down

- diffraction effects in lithography
- decreasing thickness of insulating layer
  - gate oxide typically 100 nm thick
  - with 5 V – el. field 5×10^8 V/m – tolerable
  - for 20-30 nm → 2×10^9 V/m – danger of electric **breakdown**
- Inhomogeneity - dopant in low concentration
  - p-type Silicon – typically 10^{22} B-atoms/m^3
  - surface conc. = 500 B /μm^2
  - MOSFET channel 1x1 μm^2 – 500 B under gate
  - if channel reduced to 0.1x0.1 μm^2 – only 5 B on average could be 3, or 8 → **unreliable**
- problems with **heat dissipation**
- **thermal fluctuations**
- also **quantum** effects

Langmuir-Blodgett films

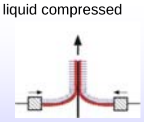
1960-1970 – Irving Langmuir, Katherine Blodgett



from http://www.mpip-mainz.mpg.de/~grafk/Monolayer_LB.html

Surface pressure vs. surface area of a Langmuir (i.e. monolayer) film on water

(different phases:
LE = liqui expanded
LC = liquid compressed



LB transfer to substrate (e.g. Si)

Repeat → multilayer

Lithographic methods

- Classical manufacture of integrated circuits
  - shine visible light through mask onto radiation-sensitive "photoresist"
    - positive: where exposed → soluble (polymer degrades)
      - e.g. PMMA (poly(methyl methacrylate))
    - negative: where exposed → insoluble (monomer polymerizes)
      - e.g. novolac (phenol formaldehide) resin
  - But resolution limited to wavelength of light (ca. 0.5 μm) by diffraction effects
  - → use shorter wavelengths

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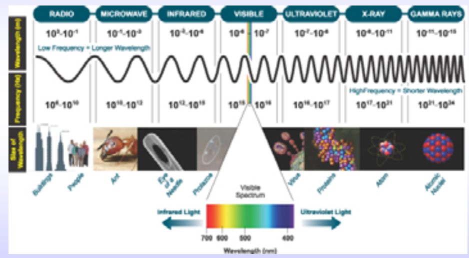
Electromagnetic spectrum



λ (m)

ν (Hz)

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UV lithography

Wavelengths (nm)	Optics
350 - 250	fused silica, quartz
250 - 150	CaF_2 (hygroscopic – becomes cloudy)

< 100 nm

• no window transmits UV

•even air absorbs it

→ Vacuum UV (VUV) - inpractical

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X-ray lithography

- for λ around 10 nm – known as:
  - Extreme UV (EUV), or Soft X-rays
  - produced by Xe plasma
  - no transmitting material
  - no focusing optics based on refraction (lenses)
  - focusing by diffraction on artificial multilayers
- harder X-rays – produced by small synchrotrons
  - same focusing problems
  - source expensive
  - but great advantage: large depth of focus
    - high pillars in photoresist can be made, sharp steep walls

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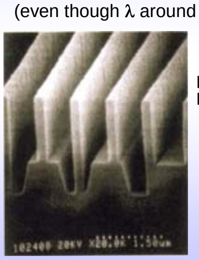
X-ray lithography

- However, since in industrial process mask cannot be held closer than 5 – 40 μm
- → resolution limited to 70 – 200 nm
  (even though λ around 10 nm)



photoresist patterned by X-ray lithography

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(from R. Waser (ed.), Nanoelectronics and Information Technology)

Two types of X-ray producing synchrotrons

A scientific research synchrotron with a 2 GeV electron storage ring (Diamond Light Source, UK)

A compact synchrotron for X-ray lithography with two superconducting 180° bending magnets

(Jefferson Labs, USA)

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Ion beam lithography

- e.g. ions of liquid metals (e.g. gallium)
- focused ion beam – can write metal nanowires directly (no need for masks and photoresists)
- can be used to write and repair masks
- e.g. 150 keV H-ions → resolution 0.1 μm
- advantage over electrons:
  - ions are scattered less
  - electrons cannot write directly

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Electron beam lithography

- used in a number of research labs
- used commercially for making masks
- wavelength typically 10 pm (= 0.01 nm = 0.1 A)
- resolution down to 5 nm
- can be focused using electrostatic lenses (electron microscope technology)
- beam travel programmable
- not practical for production – too slow

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Other lithographies

- Nanoimprint lithography (using rubber stamp)
- also other "top-down" methods
  → will be discussed later

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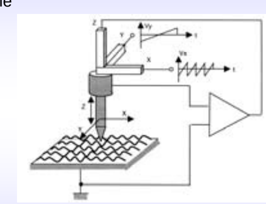
Scanning Tunnelling Microscopy (STM)

- invented in early 1980s
- conducting nano-probe hovers over surface of a molecularly thin sample on a conducting substrate
- probe feels proximity to atomic orbitals by measuring tunneling current – strongly depends on distance
- → signal in feedback loop with piezoelectric elements driving the cantilever with the probe
- systems tries to keep constant distance from surface
- → output = surface topography
- atomic resolution



from: A. Nabok, "Organic and Inorganic Nanostructures", Artech House, Boston 2005

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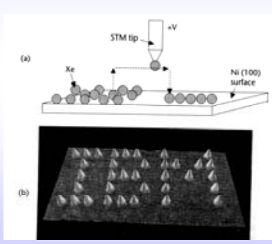
STM

- moving Xe atoms on Ni surface
  ultimate top-down technique, but highly inpracticable



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