Ch. 9: Quantum Engineering

Feynman (1959): "plenty of space on the bottom." – birth of nanotechnology

prize for - electric motor 1/64 inch cube (1yr)

- writing a page of a book 1/2500 smaller (26yr)

Electron beam lithography

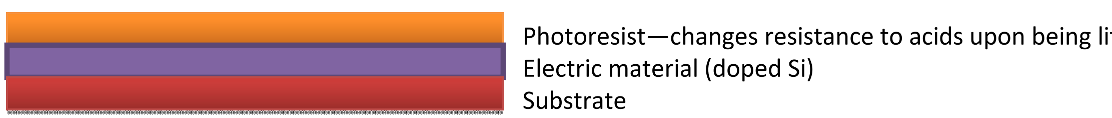
Moore's law: # of transistors on IC doubling every 18 months

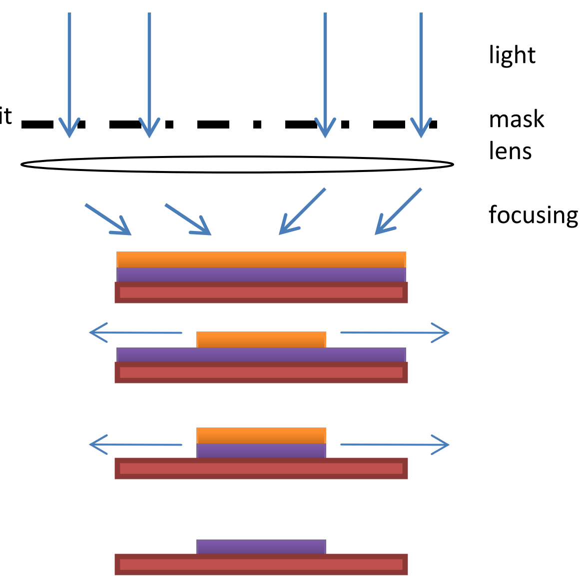
1970	Intel	1000 bit	DRAM	2300 tr.	10 μ wide
1995	Intel	64 M bit	DRAM	4 million tr.	0.35 μ wide
2000		1000 M bit		13 million tr.	0.18 μ wide

Cost of labs is rising fast too: 2 -3 -4 billion $

Problems - Progress

I. Photolithography





1. Project image of circuit on photoresist
2. Flush away changed photoresist with acid
3. Remove electric material where exposed
4. Remove photoresist very corrosive, toxic

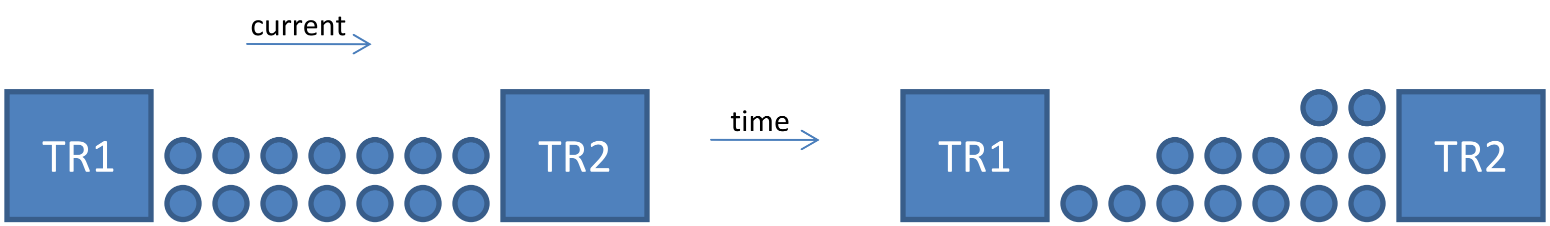
IBM earthquake

Feature size: ~ wavelength of light 400-700 nm (0.4-$0.7\ \mu$)
Far ultraviolet $0.13\ \mu$ -- Limit
How to go further -- X-ray - no efficient optics
-- electron beam - expensive

II. Inter connect: the wires between transistors

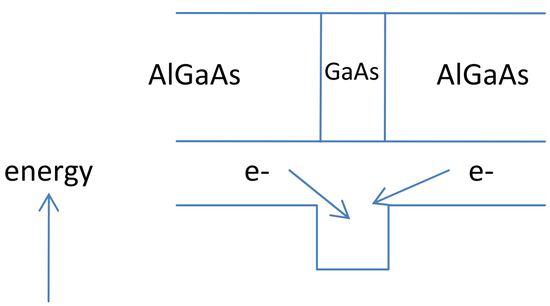
Very thin metals—large resistance – creates HEAT -- BIG problem

i. AL → Cu change to better materials: expensive
ii. migration – like pebbles in river: atoms keep going in direction of current



III. Materials GaAs, AlGaAs: resistance 10 times smaller than Si

Quantum wells



Electrons are trapped (in one direction)

By varying geometry the quantum states can be varied in a wide range.
e.g. energy levels can very widely→ color of emitted light

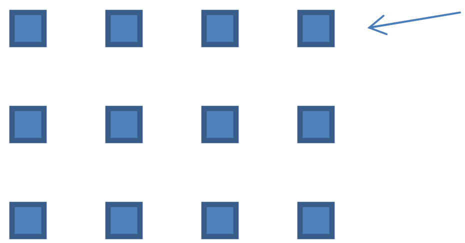
- With electric field we push electrons to upper level
- They decay to lower level and emit light -- LED (Light Emitting Diode)

100s atoms thick -- Chemical Vapor Deposition
Few atoms thick -- Molecular Beam Epitaxy

* Super-lattices: many quantum wells in a periodic array

Lattice in both directions: Quantum dots

“artificial atoms” with tunable properties



* Light emission	Red	- 1961	Nick Holonyak	Bell Labs	
	Blue	- 1992	Sugi Nakamura	Nichia	against all odds

* Quantum wells can be 2D – 1D – 0D
* Solar cells (Klimov) one photon in – many electron out
* Coulomb blockade – dots are so small that pushing a single electron costs considerable energy because of the Coulomb Repulsion: current is one electron at a time

Quantum Computers

Superposition of states	*Uncertainty Principle: the quantum particle is in more than one state: “Superposition” delta x >0: quantum particle is at x_1 & x_2 at the same time * Extreme case: Schrodinger’s cat
Quantum computer	* Performs computation on superposed states in parallel * Quantum computers: needed for decryption * Decryption requires factoring large numbers * Multiplying two large numbers is easy * Factoring is exponentially hard: breaking RSA ~ 8months With quantum computers: breaking RSA ~ minutes
Superconducting Quantum Dots	* Most promising quantum computers
Teleportation	* Not actual matter, only state information is teleported