ECE 111
Electronic Engineering Fundamentals
2015-2016

Semiconductors

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content

- semiconductors and their structure
- production of silicon
- band diagram
- intrinsic carrier concentration
- influence of temperature

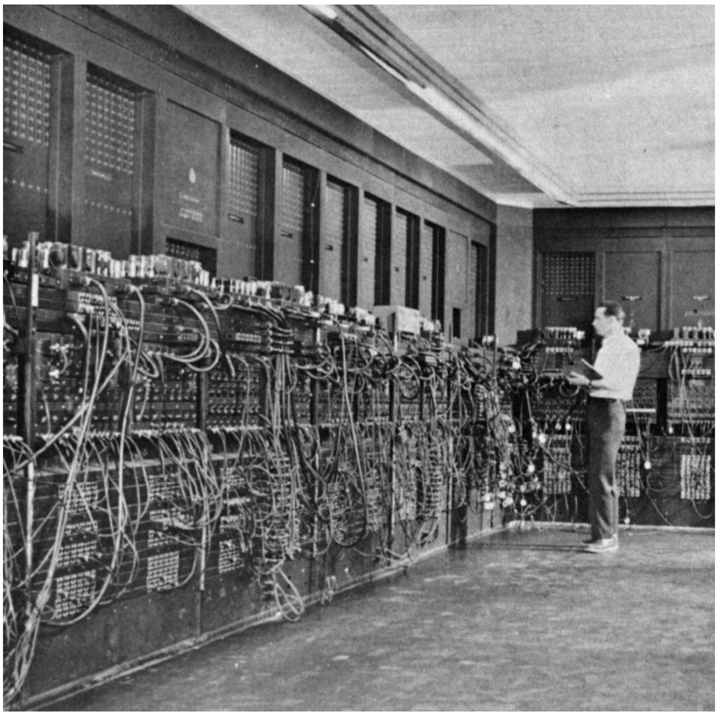
Semiconductor Devices

Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide.

Semiconductor devices have replaced thermionic devices (vacuum tubes) in most applications. They use electronic conduction in the solid state as opposed to the vacuum state or gaseous state.

Semiconductor devices are available as discrete units (such as those sold in electronics stores) or can be integrated along with a large number — often millions — of similar devices onto a single chip, called an integrated circuit (IC).

The first computers using vacuum tubes



The first computers using vacuum tubes appeared around 1945 : (ENIAC.)

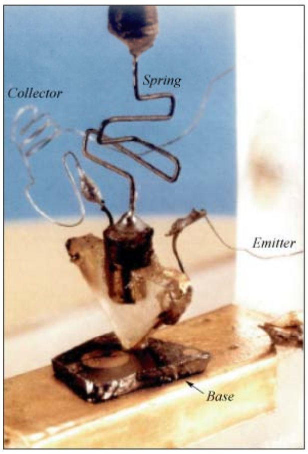
They were quite power hungry and heavy machines. The ENIAC contained around 17500 vacuum tubes as well as 1500 relays.

First transistor

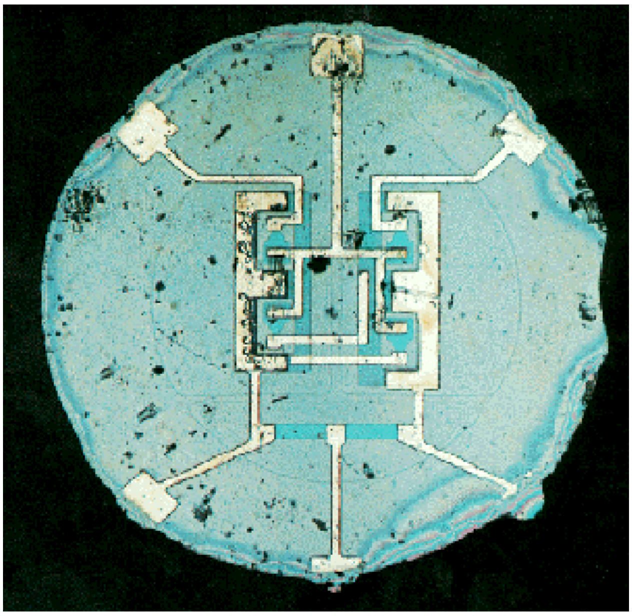
1947

Picture shows a point-contact transistor structure comprising the plate of n-type germanium and two line-contacts of gold supported on a plastic wedge.

The first point contact transistor
William Shockley, John Bardeen, and Walter Brattain
Bell Laboratories, Murray Hill, New Jersey (1947)



First monolithic integrated circuit

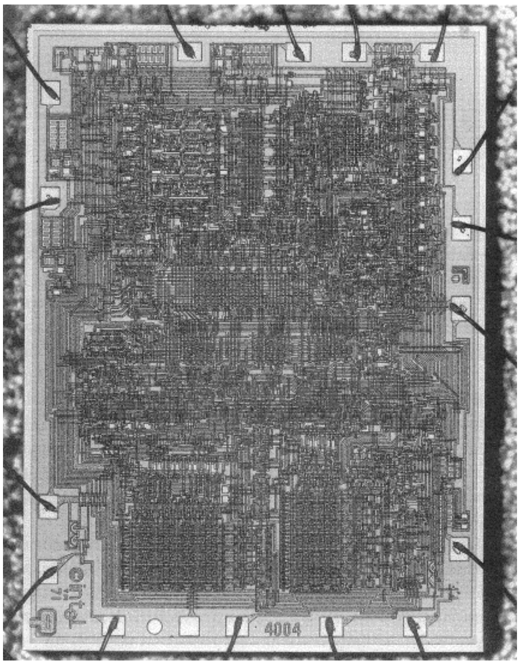


1961

Picture shows a flip-flop circuit containing 6 devices, produced in planar technology.

Source:
R. N. Neyce, "Semiconductor device-and-lead structure", U.S.Patent 2,981,877

First microprocessor



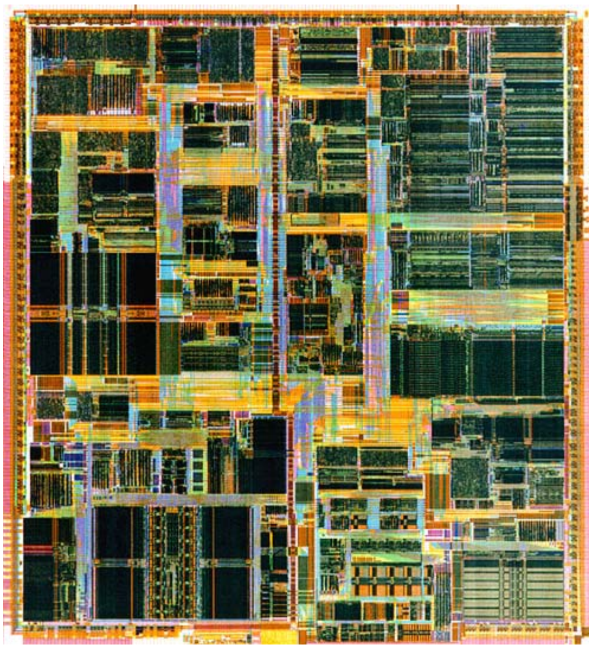
1971

Picture shows a four-bit microprocessor *Intel 4004*.

- 10 µm technology
- 3 mm × 4 mm
- 2300 MOS-FETs
- 108 kHz clock frequency

Source:
Intel Corporation

Pentium IV processor



2001

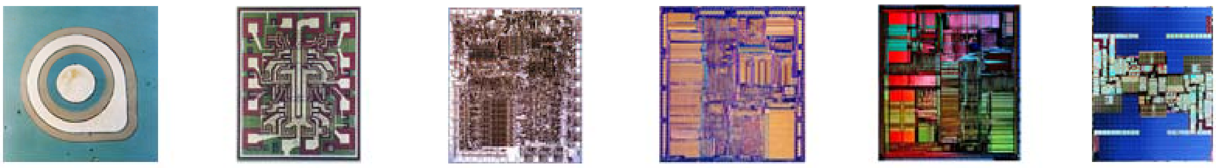
Picture shows a ULSI chip with 32-bit processor ***Intel Pentium 4*****.**

- **0.18µm CMOS technology**
- **17.5 mm × 19 mm**
- **42 000 000 components**
- **1.6 GHz clock freuqncy**

Source:
Intel Corporation

MOORE'S LAW "Transistor density on integrated circuits doubles about every two years." *

1950s	1960s	1970s	1980s	1990s	2000s
Silicon Transistor	TTL Quad Gate	8-bit Microprocessor	32-bit Microprocessor	32-bit Microprocessor	64-bit Microprocessor
1 Transistor	16 Transistors	4500 Transistors	275,000 Transistors	3,100,000 Transistors	592,000,000 Transistors



Semiconductors

Period	II	III	IV	V	VI
2		B	C	N	O
3	Mg	Al	Si	P	S
4	Zn	Ga	Ge	As	Se
5	Cd	In	Sn	Sb	Te
6	Hg		Pb	Bi	

III-V semiconductors

Period	II	III	IV	V	VI
2		B	C	N	O
3	Mg	Al	Si	P	S
4	Zn	Ga	Ge	As	Se
5	Cd	In	Sn	Sb	Te
6	Hg		Pb	Bi	

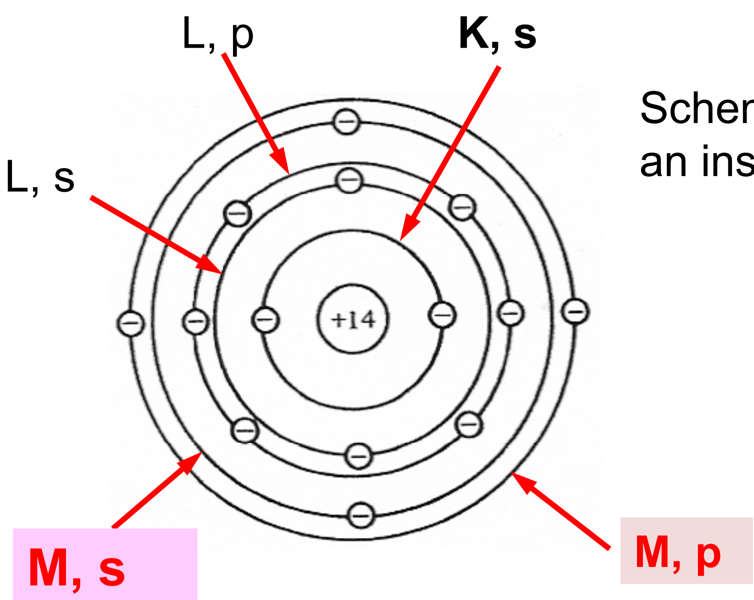
II-VI semiconductors

Period	II	III	IV	V	VI
2		B	C	N	O
3	Mg	Al	Si	P	S
4	Zn	Ga	Ge	As	Se
5	Cd	In	Sn	Sb	Te
6	Hg		Pb	Bi	

Electron shells and sub-shells

shell	K	L		M			N			
n	1	2		3			4			
sub-shell	s	s	p	s	p	d	s	p	d	f
l	0	0	1	0	1	2	0	1	2	3
electron number	2	2	6	**2**	**6**	10	2	6	10	14
	2	**8**		**18**			**32**			

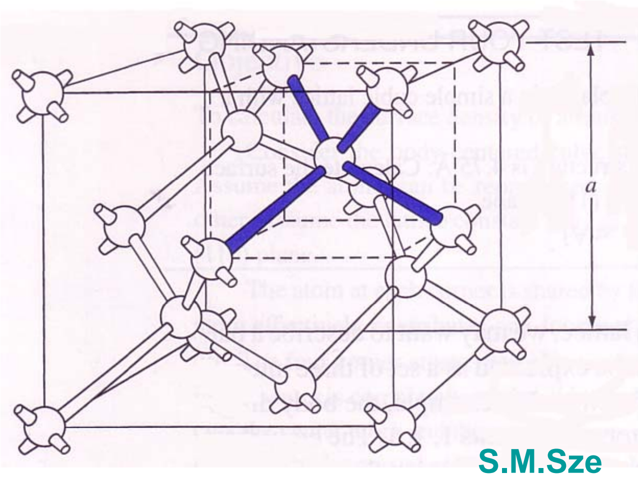
atomic structure of silicon



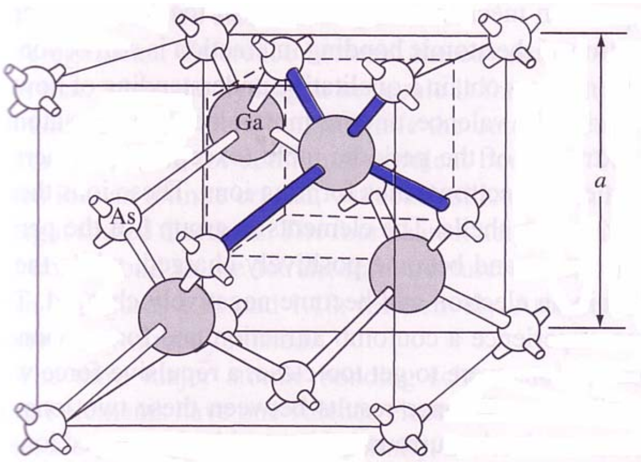
Schematic representation of an insulated silicon atom.

Crystal structure

Si: diamond lattice

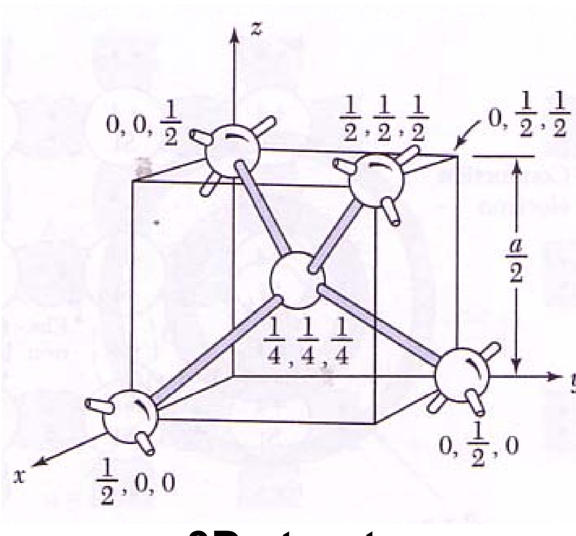


GaAs: zincblende lattice



S.M.Sze

Tetrahedron bond and lattice



3D structure
covalent bonding

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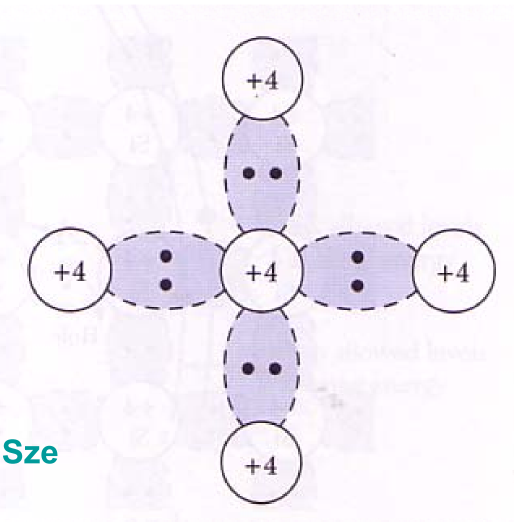


2D representation
electron pair

Silicon production

production steps of silicon

"95% of materials used by the electronic industry is silicon"

SiO_2 sand (quartzite)

$$SiC\ (solid) + SiO_2\ (solid) \rightarrow Si\ (solid) + SiO\ (gas) + CO\ (gas)$$

98% pure silicon

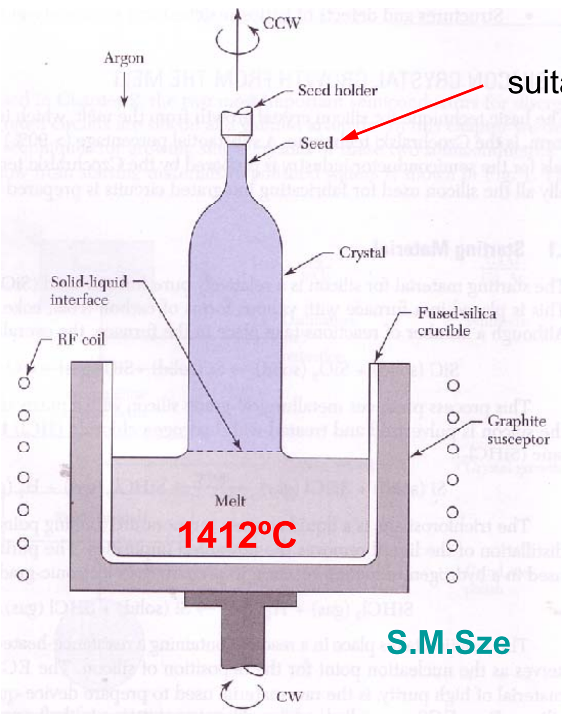
$$Si\ (solid) + 3HCl\ (gas) \xrightarrow{300^\circ C} SiHCl_3\ (gas) + H_2\ (gas)$$

gaseous trichlorosilane

$$SiHCl_3\ (gas) + H_2\ (gas) \rightarrow Si\ (solid) + 3HCl\ (gas)$$

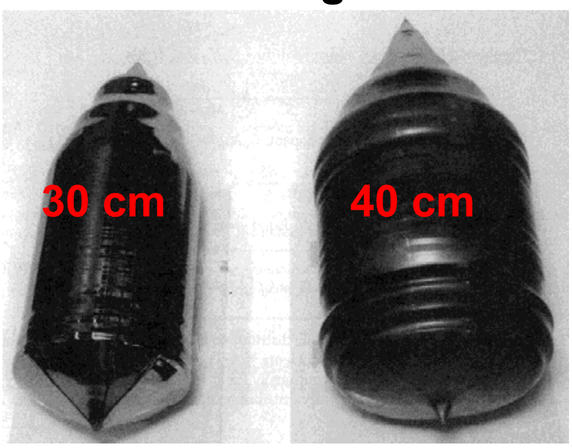
rods of ultrapure polycrystalline silicon

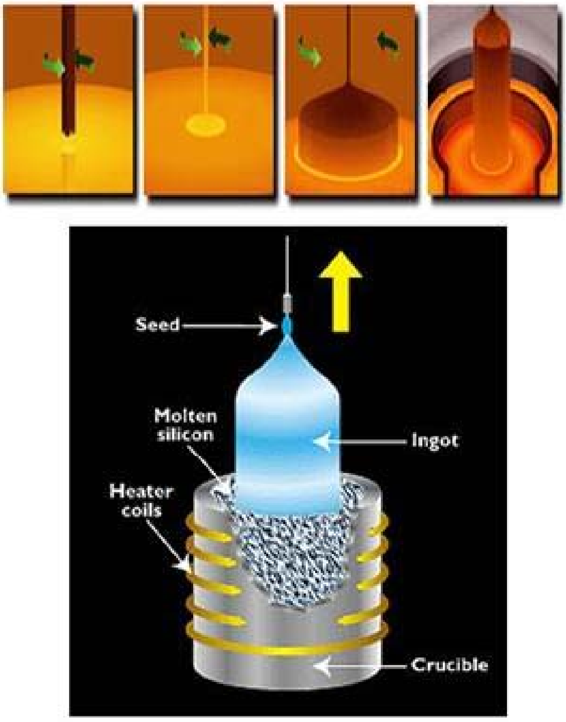
Czochralski technique



suitable orientation (e.g. [111])

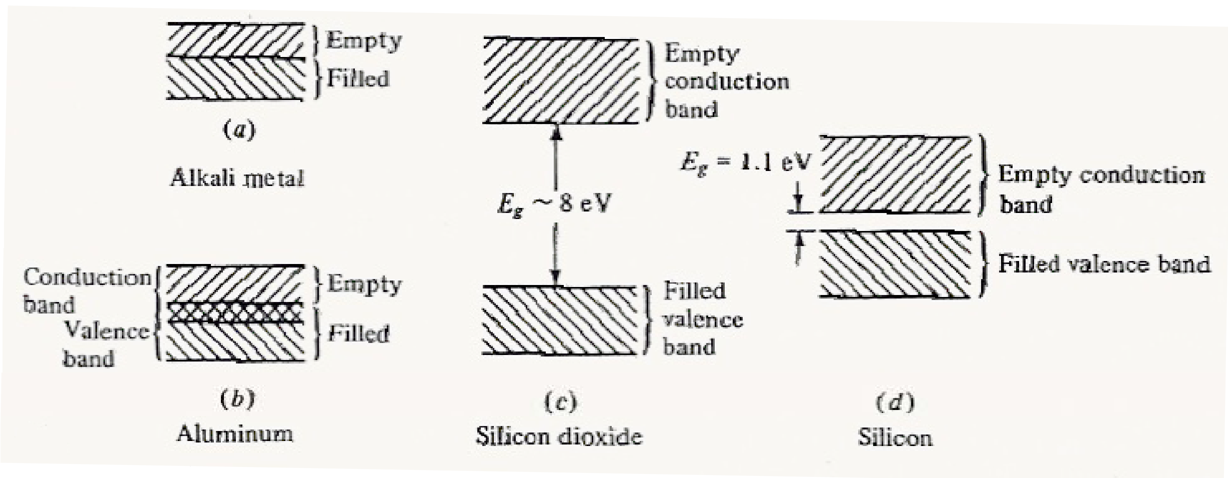
silicon ingots





Band diagram

energy band representation



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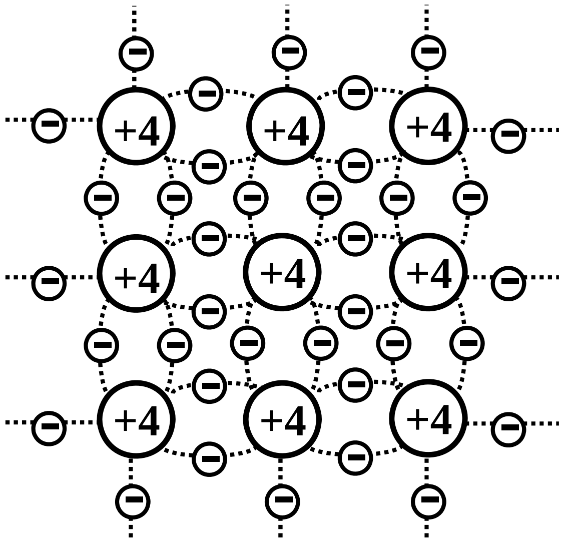
Schematic energy band representations for different materials

Intrinsic semiconductors

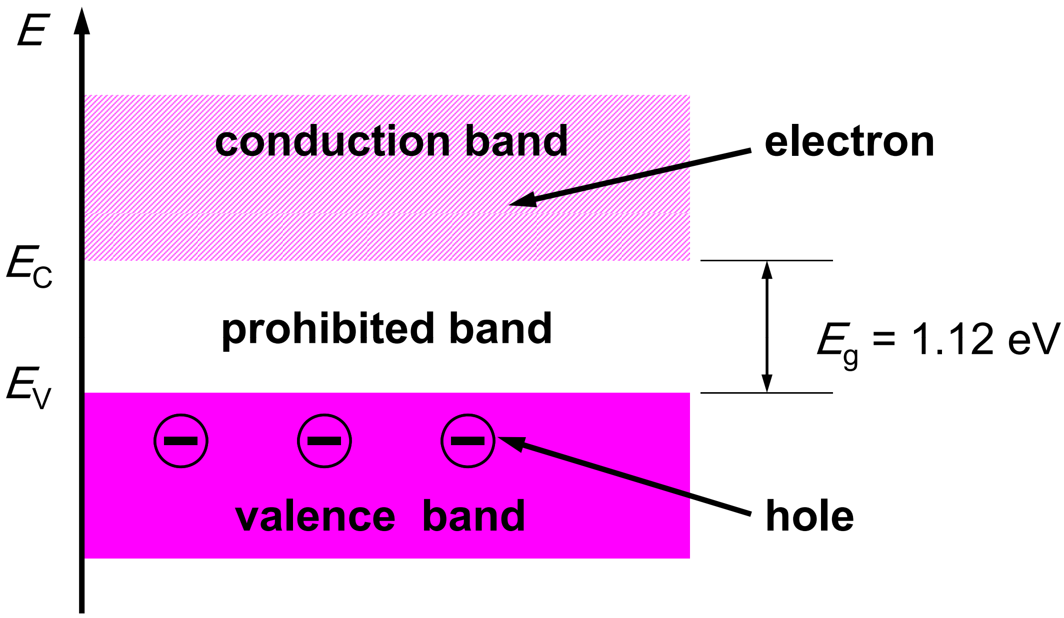


valence bonds model

properties:

- No impurities – only tetrahedron bonds.
- All bonds complete at 0K.
- Part of electrons from tetrahedron bonds is released at higher temperatures.

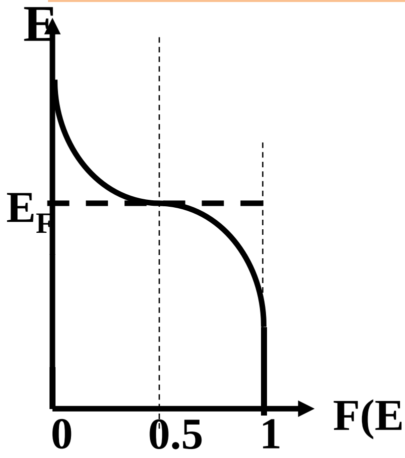
electrons and holes in Si

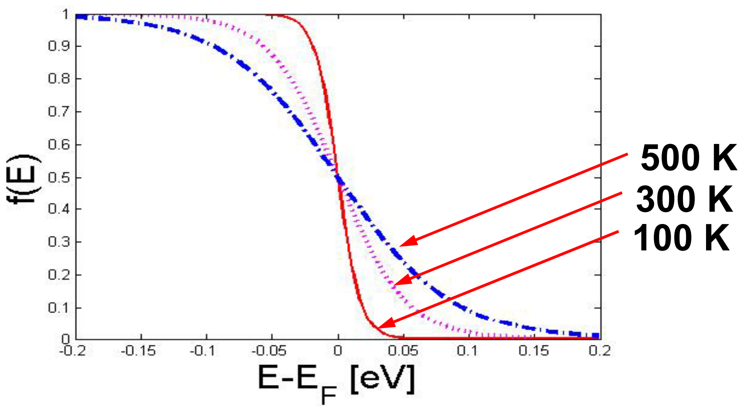


Fermi distribution function

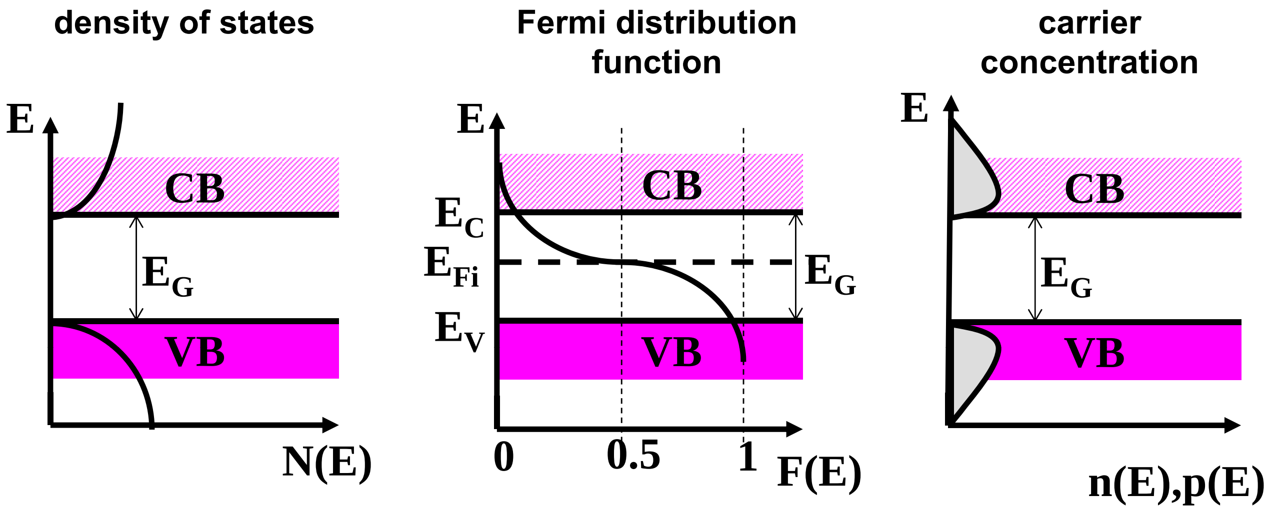
$$F(E) = \frac{1}{1 + \mathbf{e}^{(E - E_F)/kT}}$$

E_F	Fermi level
K	Boltzmann's constant **1.38x10^{-23}J/K**
T	temperature in kelvins





carrier concentration



$$n = p = n_i = \int_{E_C}^{\infty} f(E)N(E)dE$$

Density of energy states

Density of states in the conduction band: $$N(E) = \frac{4\pi}{h^3}(2m_e)^{3/2}\sqrt{E - E_c}$$

Density of states in the valance band: $$N(E) = \frac{4\pi}{h^3}(2m_h)^{3/2}\sqrt{E_v - E}$$

where:
- h – Planc's constant **6.62x10^{-34}J.s**
- m_e – effective mass of electron
- m_h – effective mass of hole

Total number of electrons in the conduction band:

$$n = \int_{E_C}^{\infty} f(E)N(E)dE = N_C e^{E_F - E_C/kT}$$

N_c – effective density of states in the conduction band

$$N_C = \frac{4\sqrt{2}}{h^3}\left(KT\pi m_e^*\right)^{3/2}$$

Holes in valence band:

The total number of holes in the valence band:

$$p = \int_{-\infty}^{E_V} \left[1 - f(E)N(E)\right]dE = N_V e^{E_V - E_F/kT}$$

N_V – effective density of states in the valence band

$$N_V = \frac{4\sqrt{2}}{h^3}\left(KT\pi m_h^*\right)^{3/2}$$

Fermi level in intrinsic semiconductor

assuming: $n = p = n_i$

from: $n = N_C e^{-(E_C - E_F)/kT}$

and: $p = N_V e^{-(E_F - E_V)/kT}$

$$E_{Fi} = \frac{E_C + E_V}{2} + \frac{kT}{2} \ln \frac{N_V}{N_C}$$

Intrinsic carrier density

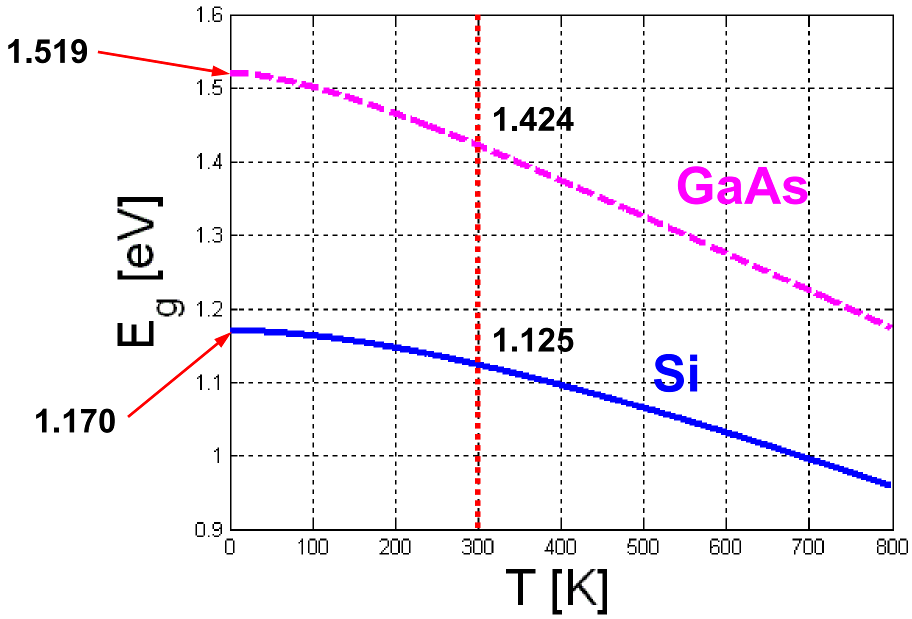
$n = p = n_i$

$$np = n_i^2$$

$$pn = N_C N_V e^{-E_g/kT}$$

$$n_i = \sqrt{N_C N_V} \exp\left(- E_g / 2kT\right)$$

Influence of temperature on band gap



Influence of temperature