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MIME 262 – Properties of Materials in Electrical Engineering

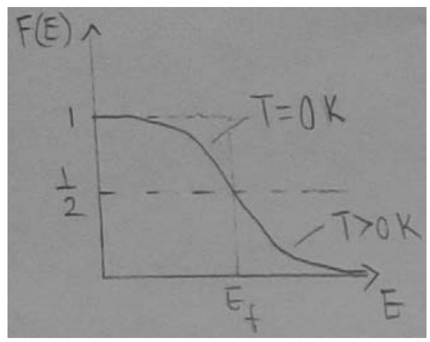
Lecture Notes – November 11th, 2013

Fermi energy (E_f): the energy of a state that has a probability, ½, of being occupied, is located in the center of the band gap, half-way between the highest filled state and the lowest empty state.

Fermi function, F(E): probability of finding an electron at energy level, E.

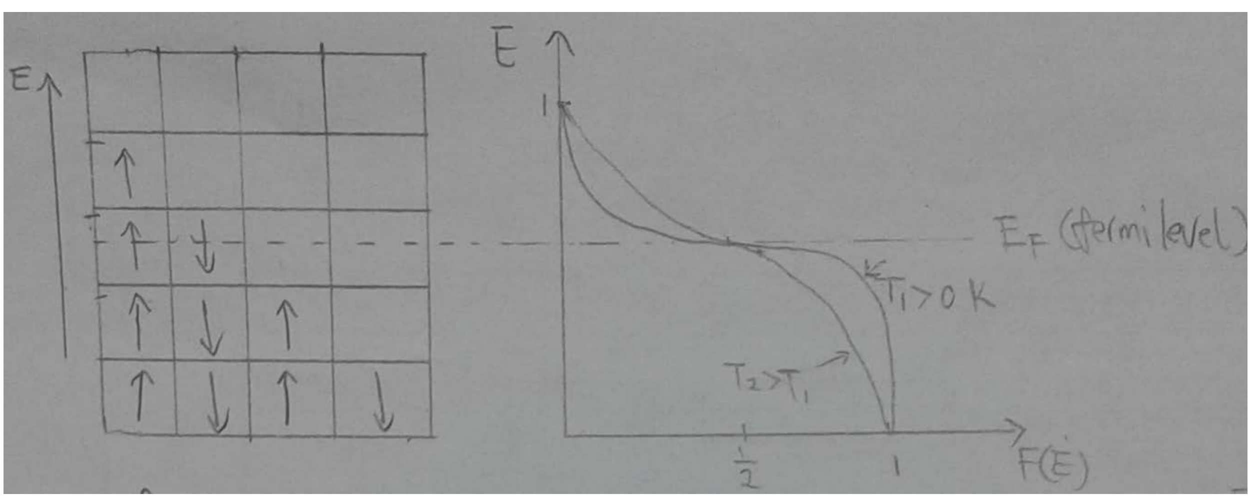
At T = 0, Fermi function = 1

Probability of finding an electron = 1/2



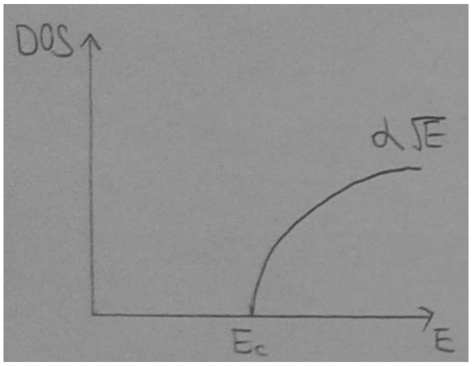
Density of states (DOS): the number of allowed places for electron at energy, E.

E.g.: in this example, there are 4 places for filling electrons at each level



At lower energy level, 4 possible states are all filled. At higher level, there might be only 1 and in between, there are maybe 3 are filled.

# of electrons at a particular energy level = # of allowed place X probability of finding an electron at that energy level

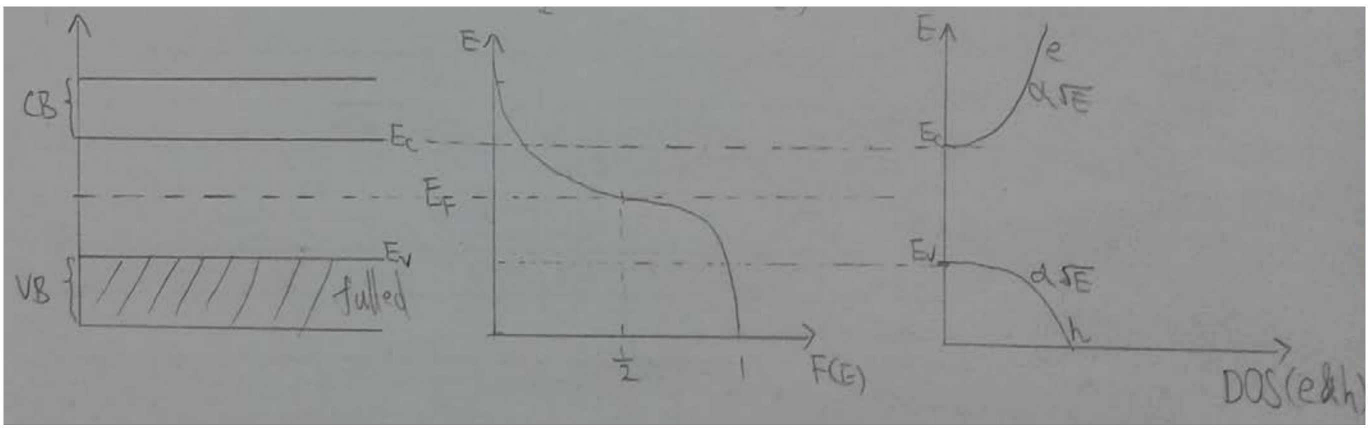


Note: Ec – energy of conduction band

α - proportional

e – electron

h - hole



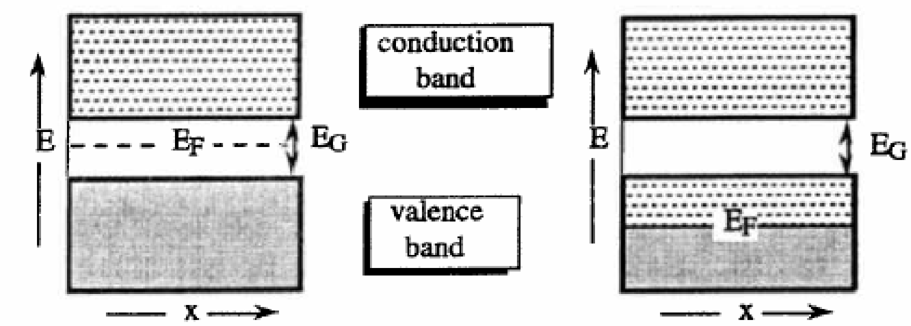
We could consider holes and electrons are opposite. The probability of finding an electron below E_F = 1.

Doping

Pure semi-conductors are not really useful while the “engineered” ones can suit our need. One way to achieve that is by doping. Doping intentionally introduces impurities into an extremely pure (intrinsic) semiconductor for the purpose of modulating its electrical properties. The impurities are dependent upon the type of semiconductor. Lightly and moderately doped semiconductors are referred to as extrinsic.

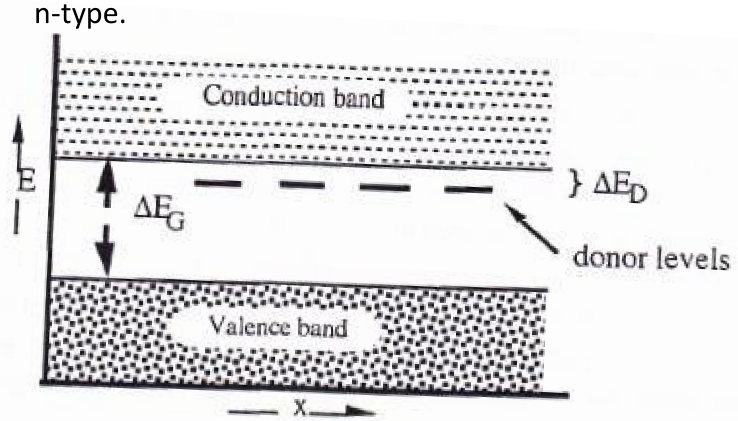
Intrinsic semiconductor

Intrinsic semiconductors are pure semiconductors without any significant dopant species present. The number of charge carriers is therefore determined by the properties of the material itself instead of the amount of impurities. They are distinguished from insulators by the magnitude of the band gap. The following figure shows its band structure.

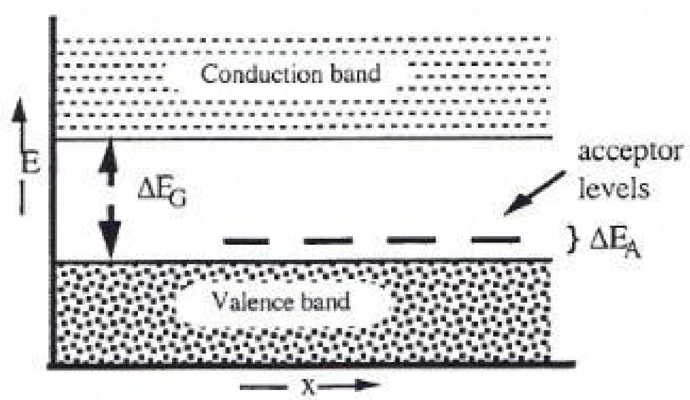


Extrinsic semiconductor

An Extrinsic semiconductor is a semiconductor whose charge carriers are primarily due to ionization of defects in the crystal lattice. If extrinsic carriers are electrons in the conduction band the defect called donors and the extrinsic semiconductor is said to be n-type.



If the extrinsic carriers are holes in the valence band the defects are acceptors and the semi conductor is p- type.



Conductivity

δ is proportional to $n_e\mu_e + n_h\mu_h$

n_e: # of electron per unit volume

μ_e: mobility of electron ($\mu_e \alpha T^{-3/2}$)

n_h : # of holes

μ_h : mobility of holes

In **semiconductor**: $\boldsymbol{\delta = qn_e\mu_e + qn_h\mu_h}$

where q is the electron charge energy

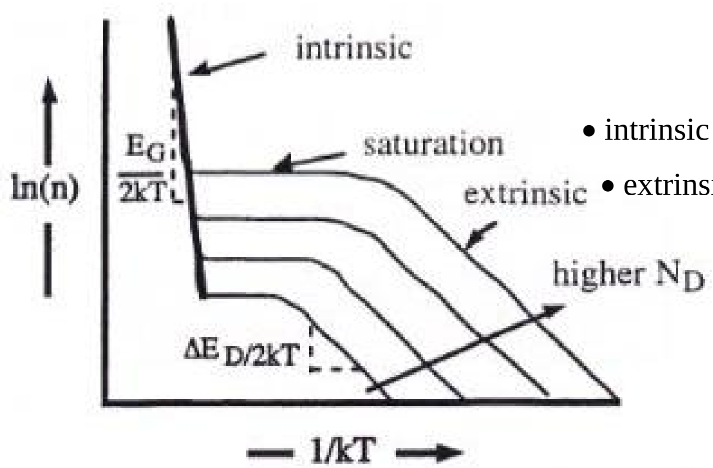
In **metal**: $\boldsymbol{\delta = qn_e\mu_e}$ (because in metal, n_e is much bigger than n_h)

$\boldsymbol{n_e = N_c exp(-(E-E_F)/(KT))}$ where N_c is the density of state in conduction band

$\boldsymbol{n_h = N_v exp(-E_F/(KT))}$ where N_v is the density of state in valent band

For intrinsic semiconductor: $n_e = n_h = \sqrt{NcNv}$ exp $(-E_g/(2KT))$

For intrinsic semiconductor: $n_e = n_D$ exp $(-E_D/(KT))$



- intrinsic behaviour at high temperatures
- extrinsic behaviour at low temperature

The temperature variation of the density of carriers, n, in the conduction band of an n-type semiconductor, for several values of the donor density (N_D) is showed in the figure above.