Intrinsic and Extrinsic Semiconductors

- Intrinsic semiconductor behaves as an insulator at R.T. , where all the outermost electrons are “bounding in” and unable to move freely.
- At absolute zero no conductivity can arise.
- Small amount of thermal energy is required to release electron from its location (free –Ve charge carrier).
- This electron will leave a hole behind: (free +Ve charge carrier).
- At room temperature No(-Ve)= No(+Ve) .

Intrinsic Semiconductor

It is ideally a perfect crystal of a semiconductor material.
Silicon and Germanium have four valance electrons. If an electron in an intrinsic semiconductor acquires a sufficient energy, it will transfer to the conduction band and leave a hole behind. Then, a pair e-h will form.

: electrons concentration.
: holes concentration.

$$n = p = n_i$$
$$np = n_i^2$$

n_i: intrinsic carrier concentration {(Si) = 1.5E10 cm^{-3}}

$$\sigma = ne\mu$$

σ: electric conductivity of semiconductor
μ: mobility of electrons

✓ Electric conductivity of intrinsic semiconductor is very bad.

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Doping semiconductor

A process by which the electric conductivity of semiconductor can be strongly increased. This process involves incorporation of foreign atoms (impurities) to an intrinsic semiconductor resulting in a so called extrinsic semiconductor with high conductivity.
Two types of doping are available: $n\ and\ p$ type.

- Shallow impurities: impurities that need a little energy - typically around the thermal energy or less - to ionize.
- Deep impurities: impurities that need larger energies than the thermal energy to ionize and consequently a small amount of the impurities might contribute to free carriers.
- Ionized donors provide a semiconductor with free electrons (n-type).
- $N_d^+ \approxeq N_d$
- Ionized acceptors provide a semiconductor with free holes (p-type).
- $N_a^- \approxeq N_a$

N-type semiconductor

- The dopant atoms added to a semiconductor crystal are called donors.
- Phosphorus (P), arsenic (As) or antimony (Sb) have FIVE valence electrons, and therefore they behave like Si with an extra electron (donors).

IIB	IIIA	IVA	VA	VIA
	5 B	6 C	7 N	8 O
	13 Al	14 Si	15 P	16 S
30 Zn	31 Ga	32 Ge	33 As	34 Se
48 Cd	49 In	50 Sn	51 Sb	52 Te

- When P, As or Sb atoms are added to a silicon crystal, one of the outermost shell electrons in this shell can easily jump to the conduction band, leaving a positively charged atom behind. This process is sometimes called “activation” or “ionization” of the donor atoms. The positively charged donor atoms are immobile and can not contribute in the conduction. The electron leaving the atom by ionization does, and is counted in the electron concentration n.

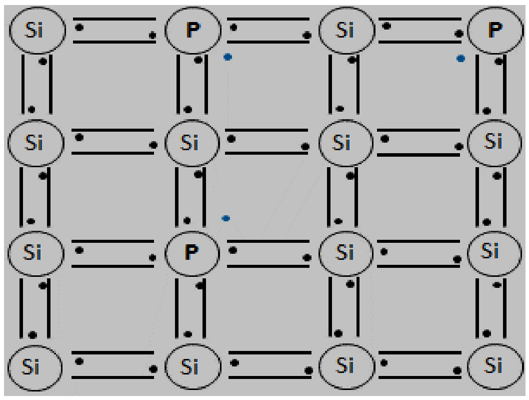

Fig. 2.6. n-type semiconductor

- When B, Ga or Al atoms are added to a silicon crystal, one of the valence electrons of Si can easily jump to the valence shell of one of the added atoms, leaving a positively charged atom of Si behind. Consequently, the added atoms will have negative charges. Off course, the electrons of these atoms can not contribute in the conduction.
- Because the activation energy at room temperature is low, almost all of the acceptor atoms included in the crystal will accept an electron from the valence band. So if N_A is the acceptor concentration, for an n-type material at equilibrium:

$$p_o \approx N_a \; cm^{-3}$$

where p_o is the hole concentration.

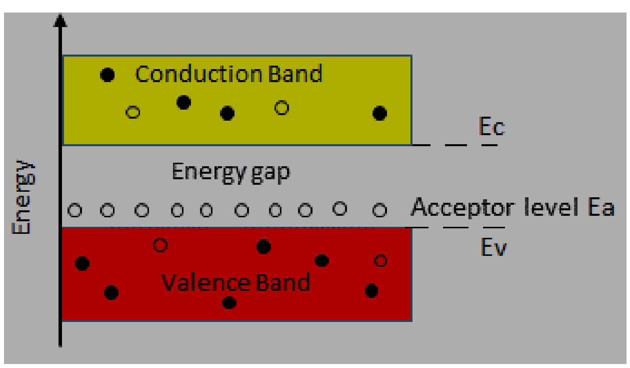

Fig. 2.9. Energy bands of p-type semiconductor.

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In general, there exists a number of donors and acceptors together in the extrinsic semiconductor, and thence type of doping will be classified as below:

A - $N_D > N_A$, *n-type*

$$n_o = N_D - N_A$$

$$n_o = \frac{n_i^2}{p_o}$$

B - $N_A > N_D$, *p-type*

$$p_o = N_A - N_D$$

$$p_o = \frac{n_i^2}{n_o}$$

Charge in semiconductor

The charge density in a semiconductor depends on the

- Free electron
- Hole density
- Positively charged ionized donors (that lost an electron)
- Negatively charged ionized acceptors (that gain an electron)

The **total charge density** is therefore given by:

$$\rho=(P-N+N_D^{+}+N_A^{-})$$

Fermi level

Fermi level : Average work done to remove an electron from the material (work function)

- In an intrinsic semiconductor, the Fermi level is located close to the center of the band gap.
- In an extrinsic semiconductor, Fermi level position lies either close the conduction band or valence band depending on the type of dopant.
- N-type semiconductor:

$$n = N_C \, exp\left(-\frac{E_C - E_{fn}}{K_B T}\right)$$

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N_C: Effective density of state in the conduction band (Si: 2.82 x 10^{19} cm^{-3}).

- For intrinsic semiconductor:

$$n_i = N_C \, exp\left(-\frac{E_C - E_{fi}}{K_B T}\right)$$

thus

$$E_{fn} - E_{fi} = K_B T \, \ln\left(\frac{n}{n_i}\right)$$

$n = N_d$ for fully ionized.

- P-type semiconductor:

$$E_{fp} - E_{fi} = -K_B T \, \ln\left(\frac{p}{n_i}\right)$$

$n = N_a$ for fully ionized.

Example

Determine the position of Fermi level for n-type Si, if $N_d = 10^{15}\ cm^{-3}$, $n_i = 10^{10} cm^{-3}$
$n = N_d$

Ans: 0.25 eV above E_{fi}.

Temperature dependence of carrier concentration

$$n_i = \sqrt{N_C N_V} \, \exp\left(-\frac{E_g}{2K_B T}\right)$$

N_V: Effective density of state in the valence band.

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