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).
- $N_d^+ \cong N_d$
- Ionized acceptors provide a semiconductor with free holes (p-type).
- $N_a^- \cong N_a$

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).

	IIIA	IVA	VA	VIA
	5 B	6 C	7 N	8 O
IIB	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

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contribute in the conduction. The electron leaving the atom by ionization does, and is counted in the electron concentration n.

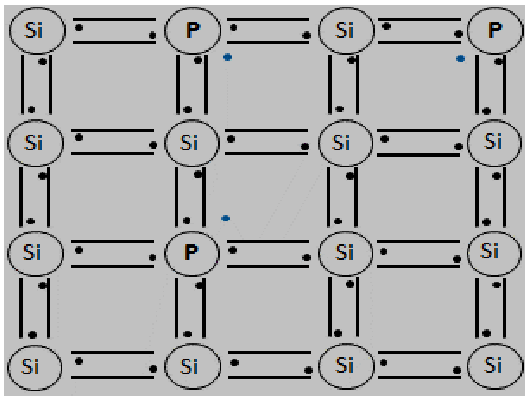

Fig. 2.6. n-type semiconductor

- 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.

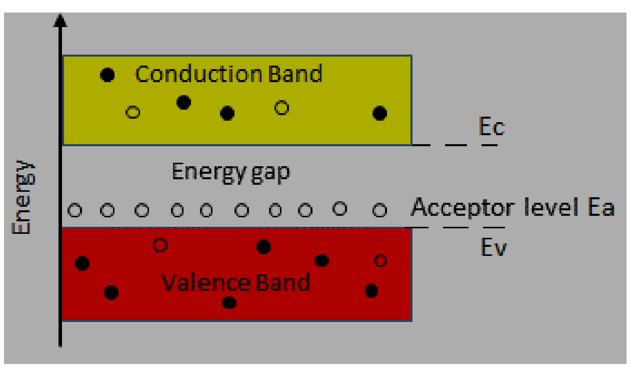

Fig. 2.9. Energy bands of p-type semiconductor.

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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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