Electronic Devices

Lecture 7

20-08-2018

Acceptor Doping - Electron and Hole Densities

- Virtually all acceptors are ionized at room temperature (complete ionization), and N_A is normally much larger than n_i - the valence band hole density p is essentially just the density of acceptors, with n given by the mass action law

$$p = N_A \qquad n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A}$$

- Since $p >> n$ for acceptor doping, the material is termed *p-type*, holes are called the majority carriers and electrons the minority carriers
- Acceptor doping allows direct control of p

A sample of silicon is doped with 4×10^{16} /cm^3 of Gallium (Ga), a group III atom. What are the concentrations of electrons and holes?

- As a group III atom Gallium functions as an acceptor, so the doped material is therefore *p*-type. The density of holes is essentially equal to the density of acceptors, so

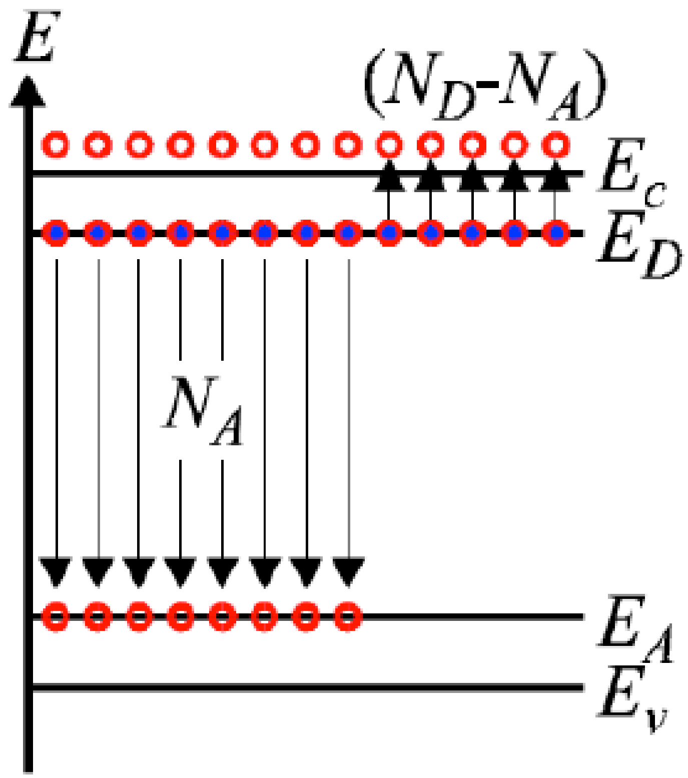
$$p = N_A = 4\times10^{16} \ / \ \text{cm}^3$$

- The density of electrons is given by the mass-action law as

$$n = \frac{n_i^{\,2}}{p} = \frac{n_i^{\,2}}{N_A} = \frac{\left(1.45\times10^{10}\right)^2}{4\times10^{16}} = 5.3\times10^3 \ / \ \text{cm}^3$$

Compensated Doping

- In practice there are many cases where both donor and acceptor dopants are present in a region of material
- This is referred to as compensated doping
- First order model is to consider that the larger doping determines the type, and the net doping determines n or p
- Example to the right is for the case $N_D > N_A$



A sample of silicon is doped with $3x10^{16}$ /cm^3 of Phosphorous (P, group V) and $6x10^{16}$ /cm^3 of Boron (B, group III). What type is the material, what are the concentrations of electrons and holes, and which are the majority and minority carriers?

- For this example, the density of acceptors (B) is greater than the density of donors (P). The material is $\therefore$ *p*-type.
- The hole density is determined by the net acceptor doping

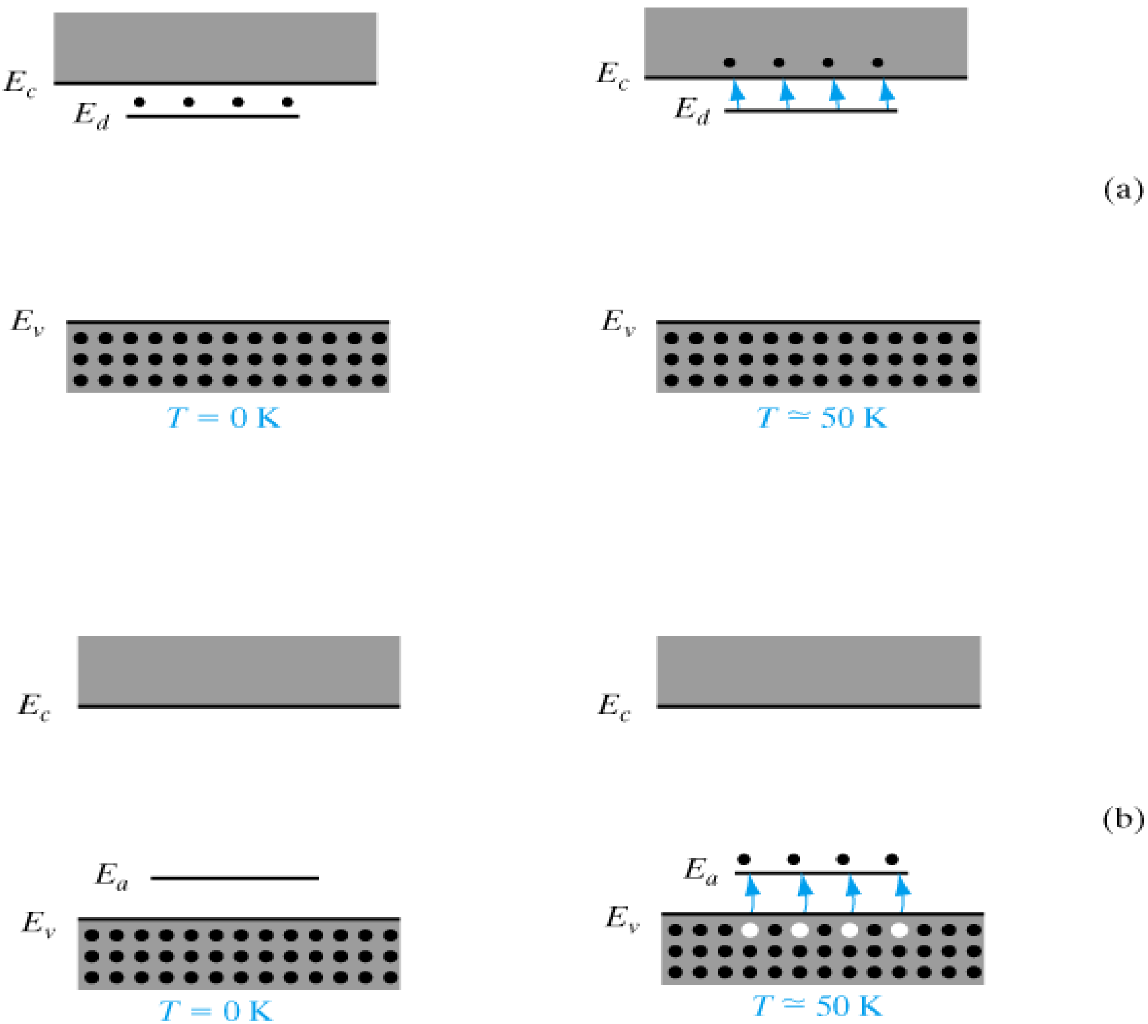
$$p = N_A - N_D = 6 \times 10^{16} - 3 \times 10^{16} = 3 \times 10^{16} \ / \ \mathrm{cm}^3$$

- The density of electrons is given by the mass-action law as

$$n = \frac{n_i^{\ 2}}{p} = \frac{n_i^{\ 2}}{N_A - N_D} = \frac{\left(1.45 \times 10^{10}\right)^2}{3 \times 10^{16}} \approx 7 \times 10^3 \ / \ \mathrm{cm}^3$$

- Since the material is *p*-type, holes are the majority carriers and electrons are the minority carriers

Energy Band Model vs. Covalent Bond Model



What are the majority carriers and minority carriers in Semiconductors ?

n-type semiconductor

Majority carrier-n
Minority carrier-p

$$n_o \simeq N_D$$

$$p_o \simeq \frac{n_i^2}{N_D}$$

p-type semiconductor

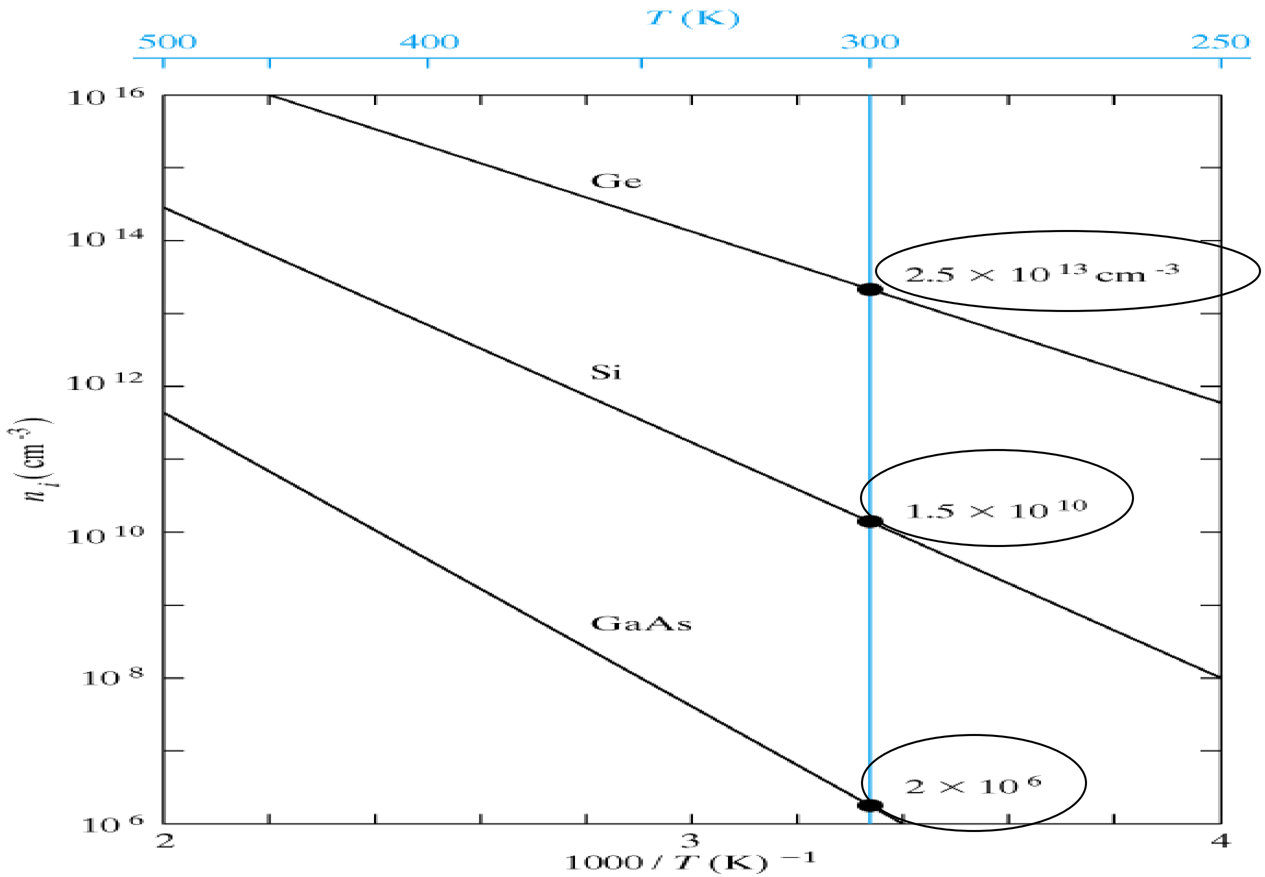
Majority carrier-p
Minority carrier-n

$$p_o \simeq N_A$$

$$n_o \simeq \frac{n_i^2}{N_A}$$

In Si the intrinsic carrier conc. is $1.5\times10^{10}/cm^3$. With a donor conc. Of $10^{15}/cm^3$ the conductivity can be increased by 5 orders of magnitude.

Temperature dependence of carrier concentrations



Intrinsic carrier concentration for Ge, Si, and GaAs as a function of inverse temperature. The room temperature values are marked for reference.

Compensation and space charge neutrality in an n-type semiconductor

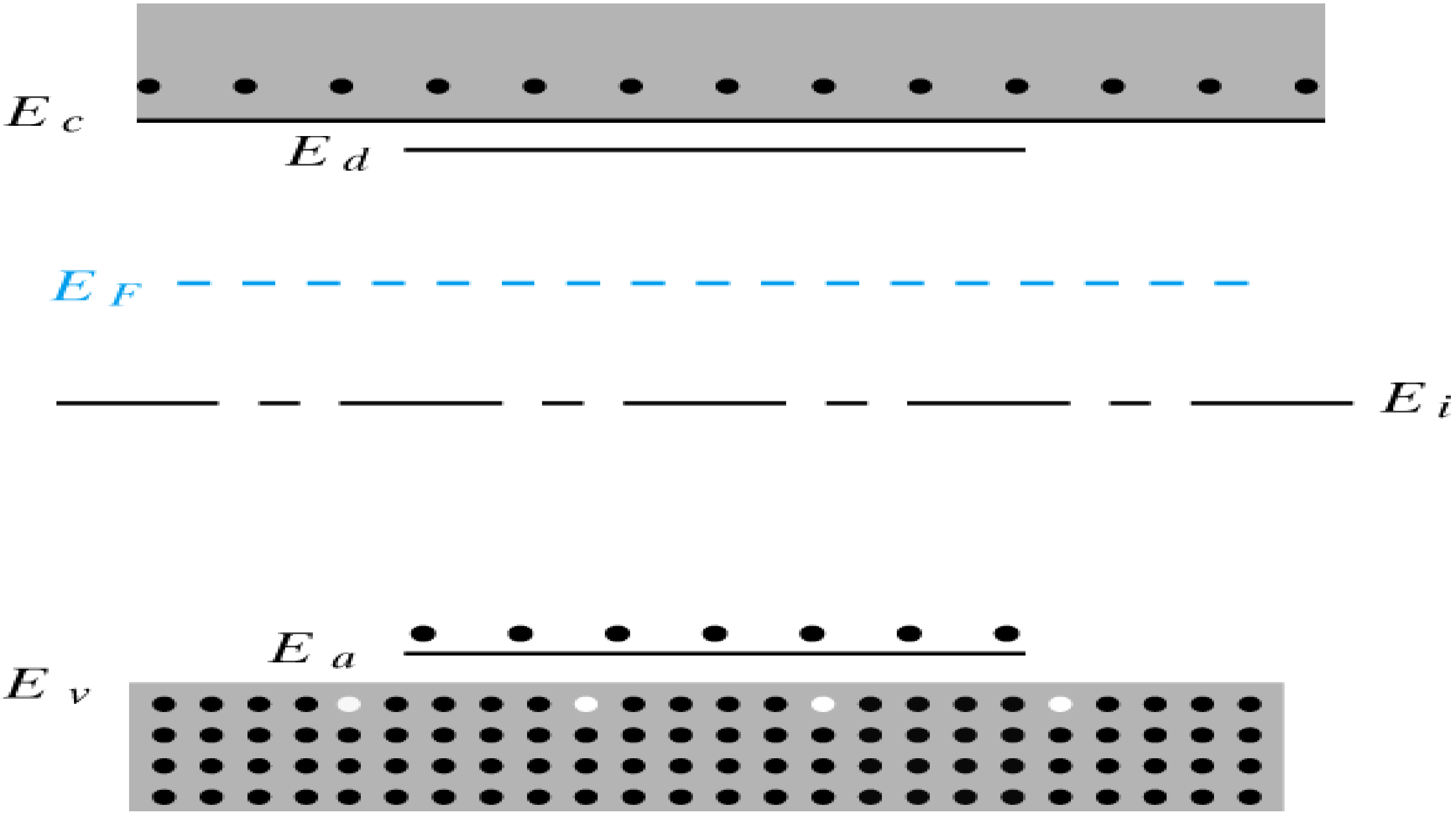
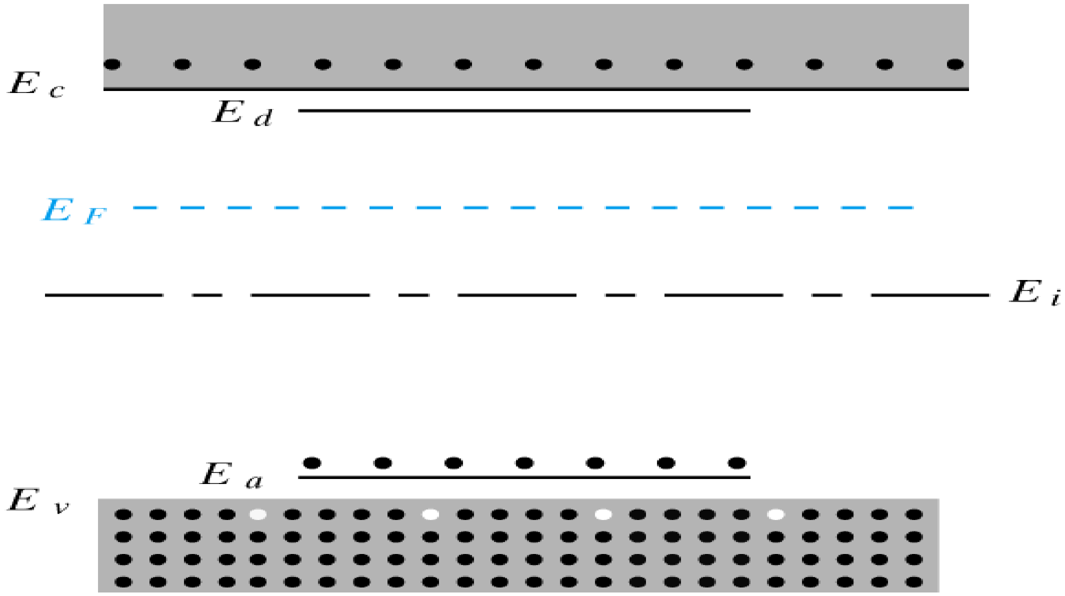


Figure 3—19
Compensation in an **n-type** semiconductor (**N_d > N_a**).



$$n_o = n_i = p_o$$
$$p_o + N^+_d = n_o + N^-_a$$

n_o → electrons

p_o → holes

N^+_d → donor ions

N^-_a → acceptor ions

$$p = \frac{n_i^2}{n}$$

$$N_d + p = N_a + n$$

$$n - \frac{n_i^2}{n} = N_d - N_a$$

$$\text{or } \mathrm{n} = \frac{N_d - N_a}{2} + \left[\left(\frac{N_d - N_a}{2} \right)^2 + n_i^2 \right]^{1/2}$$

$$\text{If } N_d > N_a \text{ then } \mathrm{n} \approx (N_d - N_a) \text{ and } p = \frac{n_i^2}{n} = \frac{n_i^2}{(N_d - N_a)}$$