Physics of Electronics

Problem Set 3:
Chapter 7

July – December 2008

Junctions

1. Explain qualitatively the I-V curve of an ideal diode using the band energy diagram (i.e. you should be able to explain the current saturation on one side of the curve and the monotonous increase of current on the other side).

2. Consider a metal–p-type-semiconductor junction. If ϕ_m and ϕ_s are the work functions of the metal and semiconductor, respectively:

a.Sketch the band energy diagram of the junction for both, the unbiased and biased cases.

b. Calculate the majority-carriers current through the junction when forward and reversed biased.

Consider both cases, $\phi_m > \phi_s$ and $\phi_m < \phi_s$. For which of the two the contact is ohmic?

Junctions

3.

Prove that the magnitude of the maximum electric field, E_m, in an abrupt pn junction with $N_a \gg N_d$ is given by

$$E_m = 2V_j/d_j$$

where V_j is the junction voltage and d_j is the depletion-layer width, which can be assumed to be given by the usual expression

$$d_j = (2\epsilon V_j/eN)^{1/2}$$

Zener breakdown occurs in germanium at a field intensity of 2×10^7 V m^{-1}. Find the resistivity of the n-type material in the above diode, if the Zener breakdown voltage of the diode is 10 V. Assume an electron mobility of 0.38 m^2 V^{-1} s^{-1} and a relative permittivity of 16.

Junctions

4. An ideal abrupt pn junction has the following properties: doping concentration on the p-side, $10^{24}\ m^{-3}$; doping concentration on the n-side, $10^{22}\ m^{-3}$; area of cross section, $10^{-6}\ m^2$; hole mobility, $0.2\ m^2\ V^{-1}\ s^{-1}$; electron mobility, $0.4\ m^2\ V^{-1}\ s^{-1}$; diffusion length of minority holes, 2×10^{-4} m; diffusion length of minority electrons, 3×10^{-4} m; bulk relative permittivity, 16; intrinsic carrier density, $10^{19}\ m^{-3}$. Evaluate the following parameters of the diode at room temperature: (a) the majority and minority concentrations; (b) the conductivities of each region; (c) the contact potential; (d) the diffusion constants for each carrier type; (e) the diode saturation current; (f) the current flowing when 0.25 V is applied to the diode with the positive terminal connected to the p-type material; (g) the current flowing for large reverse bias voltages; (h) the battery polarity for the application of reverse bias; (i) the width of the depletion layer when a reverse bias voltage of 10 V is applied; (j) the incremental depletion-layer capacitance under the bias conditions as for (i); and (k) the approximate ratio of hole to electron current across the junction.

Junctions

5.

A hypothetical device consists of a p-type semiconductor, resistivity $0.1\ \Omega$ m, diameter $100\ \mu$m, thickness $2\ \mu$m and workfunction 1 eV, sandwiched between two different metal contacts, M_1 with workfunction 1.4 eV and M_2 with workfunction 0.6 eV. Explain in general terms how the structure would behave electrically.

When a voltage of 0.5 V is connected between M_1 and M_2 with M_2 positive, 10 nA flows. Estimate the current flowing with the polarity reversed, assuming operation at 290 K, explaining the reasoning behind the calculation. Neglect all surface-charge effects.

Junction

6. Figure 1 represents the band diagram of a p- and a n-doped semiconductors showing their Fermi energies. Figure 2 shows the band diagram resulting from creating a junction with the two semiconductors. Finally, Figure 3 shows the carriers densities once the junction is formed. You have to write an interactive program (you can use any software you want) that reproduces those figures in the correct scale. The input parameters will be the energy gap, in eV, of the semiconductor (E_g), the effective masses, in multiples of m_e, of the carriers (m_h^*, m_e^*), the concentrations, in cm^{-3}, of impurities (N_A, N_D), and the applied voltage (V), in volts. Be sure that your program also accepts negative voltages. Express the distances in nm. Check your results for Si and Ge.

Figure 1

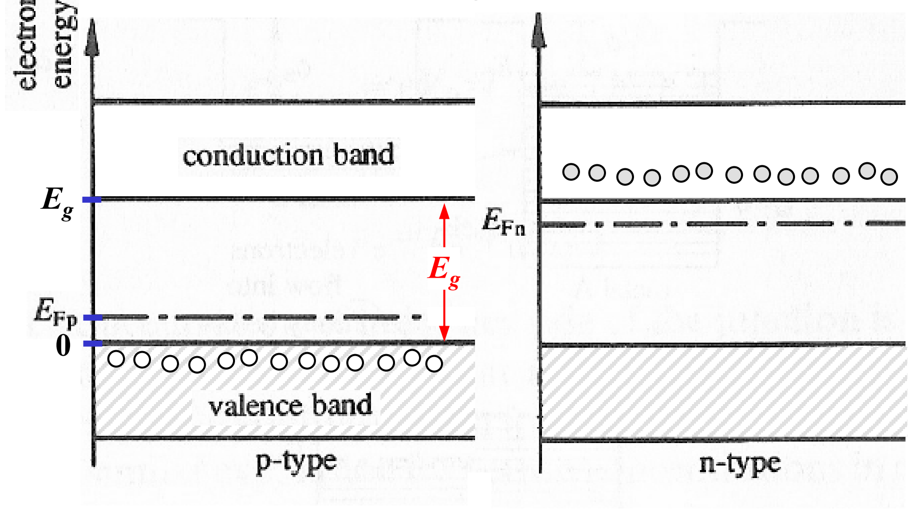
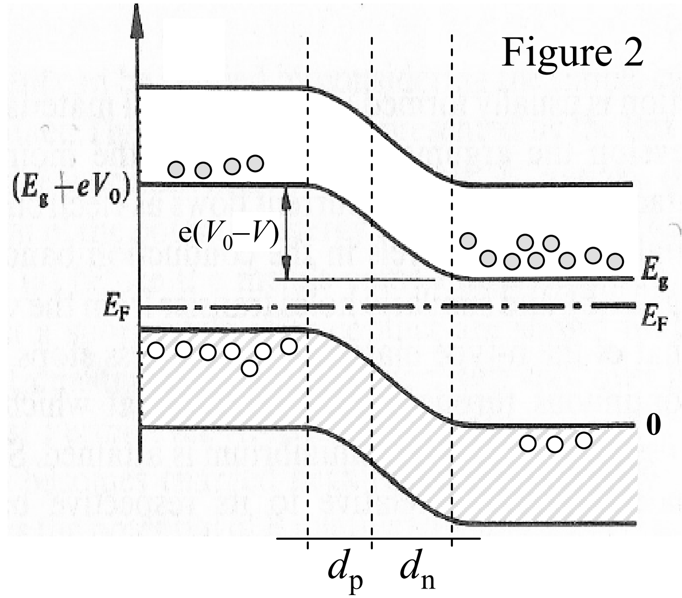


Figure 2



Junctions & Doping