Section A (50 marks)

Answer ALL questions in this section. All questions carry equal marks.
You should spend about 1 hour 15 minutes on the questions in this section.

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1. A Schottky contact is to be made on an *n*-type semiconductor. The work function of the metal used is 4.5 eV. The semiconductor has an electron affinity of 3.5 eV, a bandgap energy of 1 eV, a critical electric field of 2.7×10^{5} V/cm, a relative permittivity of 12.5 and an intrinsic carrier concentration of 2×10^{11} cm^{-3} at 300 K.

   (a) What should the doping concentration of the semiconductor be if the desired built-in voltage is 0.75 V? [3]

   (b) Calculate the bias voltage that will give a maximum electric field equal to the critical field. [3]

   (c) Briefly describe what will happen to the contact when the condition stated in part (b) is met. [4]

2. A light emitting diode has a forward biased current of 10.3 mA. The radiative recombination efficiency is 0.95. The bandgap energy and refractive index of the semiconductor are 1.42 eV and 3.3, respectively.

   (a) Estimate the wavelength of the light emitted. Which part of the electromagnetic spectrum does the wavelength belong to? [2]

   (b) Determine the optical power generated in the semiconductor. Only a small fraction of the emitted photon flux becomes useful light output. Why? [6]

   (c) Assuming a flat semiconductor surface, estimate the fraction of emitted photon flux that would become useful light output. [2]

3. (a)

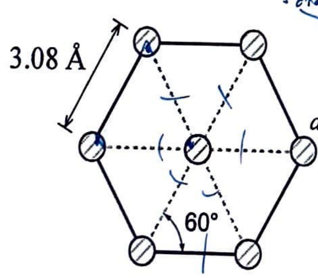

Figure 1

Figure 1 shows the position of atoms on a hexagonal plane (which is made up of six equilateral triangles) of a semiconductor. Determine the surface density of atoms on the plane. [6]

   (b) Explain what is meant by the effective mass of a carrier in a semiconductor. [4]

4. A p-type semiconductor sample has a bandgap energy of 3.2 eV and its Fermi level is 0.2 eV above the valence band edge. The effective density of states in the conduction and valence bands are 2.23×10^{18} cm^{-3} and 4.62×10^{19} cm^{-3}, respectively. Assume that $k_BT = 0.0276$ eV, $D_n = 11$ cm^2/s and $\tau_n = 0.1$ µs.

   (a) Determine the value of n_i and hence calculate the majority carrier concentration in this semiconductor sample. [5]

   (b) Excess minority carriers are injected continuously at one end of the sample such that the excess carrier concentration at $x = 0$ is 3.3×10^{14} cm^{-3} under steady state condition. Determine the position in the sample where the minority carrier diffusion current density is 225 mA/cm^2. [5]

5. The electric field in an n-type semiconductor sample at 300 K is

$$\xi = \left(\frac{k_BT}{q}\right)\frac{10^6x}{10^6x^2+1}\ \text{V/cm}$$

The distance x is in units of cm and is valid for $0 \leq x \leq 22$ µm. The total electron current density is zero throughout the sample and $n(x=0) = 10^{16}$ cm^{-3}. The hole and electron diffusion coefficients are $D_p = 40$ cm^2/s and $D_n = 110$ cm^2/s, respectively.

   (a) Determine the electron concentration, $n(x)$, in the sample. [6]

   (b) Sketch the electron concentration profile of the semiconductor. Indicate, in the same diagram, the directions of the electron flux and the corresponding current arising from the non-uniform electron concentration. [4]

Section B (50 marks)

*Answer **ALL** questions in this section. All questions carry equal marks.*
You should spend about 1 hour and 15 minutes on the questions in this section.

6. A uniformly doped semiconductor has a bandgap of 2.07 eV. The initial probability of finding a hole at the valence band edge of the semiconductor is 9.12×10^{-5}. Additional donor impurity atoms of N_d cm^{-3} are added to the semiconductor to achieve the desired doping level and the resulting probability of finding a hole at the valence band edge decreases to 1.85×10^{-7}. Assume $n_i = 400$ cm^{-3} and $T = 300$ K.

(a) Find the value of N_d. [8]

(b) The additionally doped semiconductor is illuminated uniformly with a suitable wavelength light to produce a steady state excess carrier concentration of Δn_0. Thereafter the light is turned off at time $t = 0$. Determine the excess minority carrier concentration as a function of time after the light is turned off, assuming that it is a *high-level injection condition*, i.e. $\Delta n_0 >> p_0$. The rate of change of the minority carrier concentration with respect to time *t* is given by

$$\frac{dn}{dt} = G_{th} + G_L - R$$

[7]

(c) Identify and describe the dominant scattering mechanism in the additionally doped semiconductor. How will the carrier mobility change when the temperature of the semiconductor decreases? [5]

(d) The additionally doped semiconductor is subsequently converted to a p^+ semiconductor through further doping. A metal-insulator layer is then deposited onto the p^+ semiconductor to form a metal-oxide-semiconductor (MOS) device. A voltage is applied across the MOS device and the resulting band diagram is illustrated in Figure 2. Comment on the polarity of the voltage that is applied to the MOS device and the type of carrier that can be found in region R_x. Discuss how the carrier concentration in region R_x compares with those in the bulk of the semiconductor, i.e. towards the right side of region R_x. [5]

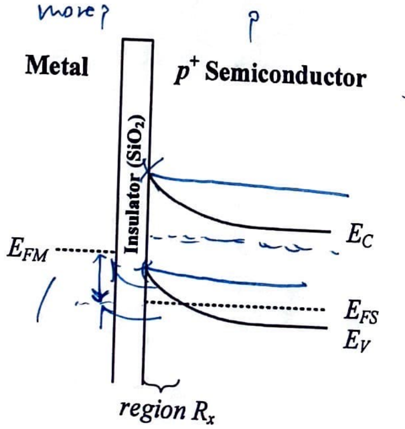

Figure 2

7. Figure 3 shows a partial carrier distribution plot of an ideal silicon abrupt *p-n* junction diode at steady state. Symbols have their usual meanings. The intrinsic carrier concentration at 300 K is 1.5×10^{10} cm^{-3}, the relative permittivity is 11.7, the lifetimes of excess electrons and holes are both 0.1 μs, and the electron and hole mobilities are 1300 cm^2/V-s and 400 cm^2/V-s, respectively.

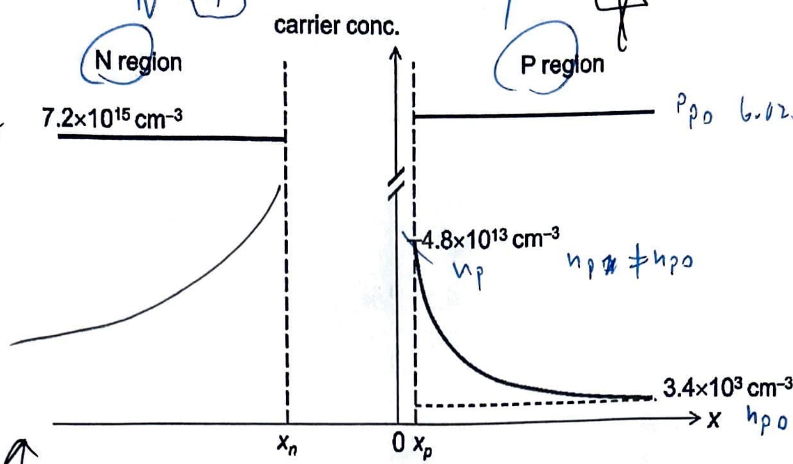

Figure 3

(a) Is the diode under forward or reverse bias? Explain your answer. [2]

(b) Determine the bias voltage applied. Is the low-level injection assumption valid? Justify your answer. [6]

(c) Reproduce the diagram on your answer book and complete it to reasonable accuracy, indicating the missing carrier concentration values and the values of x_p and x_n. [5]

(d) Determine the steady state diode current density. Hence, estimate the electric field deep in the quasi-neutral N region, i.e., at $x \to -\infty$. [6]

(e) Derive an expression for the excess hole charge density stored in the quasi-neutral N region. Hence, calculate the diffusion capacitance density due to the excess holes stored. What impact does the diffusion capacitance has on the diode operation? [6]

END OF PAPER