NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

Mid-semester Examination-2010

Semiconductor Devices (EC204)

Max. Marks: 30

Duration: 2hrs.

Instructions:

1. *Answer any three questions.*
2. *Use the following physical constants wherever necessary:*

Boltzmann's constant,	$k = 1.38 \ x\ 10^{-23}$ *J/K*
Electron rest mass,	$m_o = 9.1 \ x\ 10^{-31}$ *Kg*
Planck constant,	$h = 6.63 \ x\ 10^{-34}$ *J-s*
Speed of light in vacuum,	$c = 3 \ x\ 10^{8}$ *m/s*
Elementary charge,	$q = 1.6 \ x\ 10^{-19} C$

1. (a). A semiconductor device requires n-type material; it is to be operated at 400K. Would Si doped with 10^{15} atoms/cm³ of arsenic be useful in this application? Could Ge doped with 10^{15} atoms/cm³ antimony be used? Justify your answer. Given that the intrinsic carrier concentrations of Si and Ge at 400K are $2x10^{12}\ cm^{-3}$ and $5x10^{15}\ cm^{-3}$ respectively. **(2 marks)**

H (b). Show that the intrinsic Fermi level E_i lies below the middle of the bandgap by $kT ln(m_n^*/m_p^*)^{3/4}$. Show that this displacement is small (i.e. compared to kT) for Si but significant for GaAs. Here m_n^* and m_p^* are effective mass of electrons & holes respectively. Pg - 92 **(4 marks)**

(c). Show that in a semiconductor, whether p-type/n-type, the product of electron & hole concentrations (i.e. n_0 and p_0) at thermal equilibrium is a constant and is equal to the square of the intrinsic carrier concentration. **(4 marks)**

H **2.** (a). Silicon atoms are added to a piece of GaAs. The silicon can replace either trivalent Gallium or pentavalent Arsenic atoms. Assume that silicon atoms act as fully ionized dopant atoms and that 5% of $10^{10}\ cm^{-3}$ silicon atoms added replace Gallium atoms and 95% replace Arsenic atoms. The sample temperature is 300K. Calculate:

(i). The donor and acceptor concentrations.

(ii). Find the electron and hole concentrations and the location of the Fermi level. (n_i at 300K is $1.79\ x\ 10^{6}\ cm^{-3}$, $N_c = 4.7x10^{17} cm^{-3}$ and $N_v = 7x10^{18} cm^{-3}$).

(4marks)

(b). The forbidden energy band of GaAs is 1.42eV at 300K. Determine the minimum frequency of the incident photon that can interact with a valance electron and elevate the electron to the conduction band. What is the corresponding wavelength? **(3 marks)**

(c). Show that an intrinsic semiconductor has its minimum conductivity at thermal equilibrium when

$$n = n_i(\mu_p / \mu_n)^{1/2} \text{ and } p = n_i(\mu_n / \mu_p)^{1/2}.$$

where n_i is intrinsic carrier concentration, n and p are electron and hole concentrations and μ_n and μ_p are electron and hole mobilities. **(3 marks)**

3. (a). An intrinsic Si sample is doped with acceptors from one side such that a doping profile $N_a = N_o \exp(-bx)$ is obtained. Here x represents the direction into the sample and N_o is concentration on the surface ($x = 0$). Note also that for $x \to \infty$, $N_a \to n_i$, the intrinsic carrier concentration.

(i). Sketch the doping profile and derive the expression for the electric field that will develop under thermal equilibrium conditions for $N_a \gg n_i$ due to doping profile.

(ii). Evaluate the value of the electric field when $b = (2\mu m)^{-1}$. **(4 marks)**

(b). In an experiment the voltage applied across a uniform 2-μm long region of 1 Ω-cm, n-type silicon is doubled. But the current only increases by 50% (which is supposed to increase proportionately to the applied voltage). Explain? (the silicon remains neutral at both current levels). **(3 marks)**

(c). Briefly describe the effect of temperature on the mobility of a semiconductor.

(3 marks)

4. (a). An electron is moving in a piece of lightly-doped silicon under an applied field at 27°C so that its drift velocity is one-tenth of its thermal velocity. Calculate the average number of collisions it will experience in traversing by a drift region 1μm wide. What is the voltage applied across this region? The effective mass of electron (m_n^*) is 0.98 m_o, mobility of electron (μ_n) is 0.15 $m^2/V-s$. **(4 marks)**

(b). What is the Fermi energy level? In a semiconductor the Fermi level is 40meV below the edge of the conduction band and bandgap is 1.3eV. What would you do to bring the Fermi level to mid-bandgap? Will the resistivity of the semiconductor change? If so, how? **(2 marks)**

(c). Show that the probability a state ΔE above the Fermi level E_f is filled equals the probability a state ΔE below E_f is empty **(4 marks)**