Fundamentals of Semiconductors

EPL213

Problem sheet 4

(IV) Aim: Concepts of Drift-diffusion-optical processes

1. Estimate the (a) effective density of states for valance and conduction bands and (b) intrinsic carrier concentration for silicon at 300K.

Q. 1. (a) DOS for VB & CB (b) Intrinsic Carrier conc. for Si at 300K.

$N_n(E) = \boxed{\frac{\pi}{2}\left(\frac{8 m_n^*}{h^2}\right)^{3/2}} (E-E_c)^{1/2}$ ... CB

$N_p(E) = \boxed{\frac{\pi}{2}\left(\frac{8 m_p^*}{h^2}\right)^{3/2}} (E_v-E)^{1/2}$ ... VB

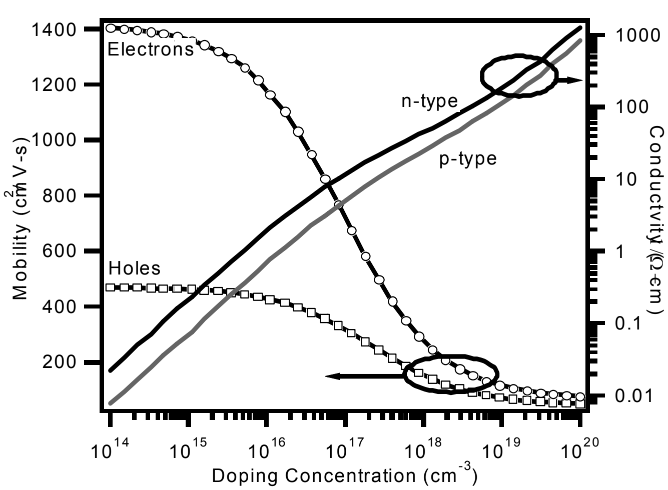
effective density of states.

Intrinsic carrier conc: $\cancel{\sqrt{N_c N_v}\exp\left(\frac{-E_v - E_c}{}\right)^{1/2}}$

$n_i = p_i = n_g$

2. The energy gap in Ge is 0.67 eV. The electron and hole effective masses are 0.12 me and 0.23 me, respectively (me is the free electron mass). Calculate, for T = 300 K, (a) the Fermi energy, (b) the electron number density and (c) the hole number density.

3. A sample of Ge is doped with P. Assume the excess electron revolves around the P+ ion in a hydrogen-like orbit. The dielectric constant of Ge is 16 and the electron effective mass is 0.12 me. Calculate (a) the ionisation energy of the excess electron and (b) the orbital radius.
4. Estimate the resistivity of phosphorous doped (10^{13} cm^{-3}) Silicon at room temperature. Also estimate the carrier scattering time. Is there any effect of holes? (m^* (conductivity) = $0.26m_0$, $n_i=1.5\times10^{10}cm^{-3}$) (use the figure of doped Si characteristics at 300K for further information)



Q. 4] $N_d = 10^{13}\ cm^{-3}$

(i) Resistivity $\rho = \frac{1}{\sigma}$ (ii) Carrier scattering time (τ)
(iii) Effect of holes?

$m^*_{conductivity} = 0.26\ m_o$, $n_i = 1.5 \times 10^{10}\ cm^{-3}$

$\mu_{e^-} = 1400\ cm^2 V\text{-}s$ $\mu_h = 480\ cm^2 V\text{-}s.$

$\sigma = ne\mu_n + pe\mu_p$ $p = \frac{n_i^2}{n} = \frac{2.25 \times 10^{20}}{10^{13}}$

$n = 10^{13}\ cm^{-3}$ $e = e$ $\approx 2.25 \times 10^7$

$\mu_n = 1400\ cm^2 V\text{-}s$

$p << n$, $\mu_p << \mu_n$

$\therefore$ We can neglect $pe\mu_p$ in comparison with $ne\mu_n$.

$\therefore$ $\sigma \approx 10^{13}\ cm^{-3} \times 1.6 \times 10^{-19} \times 1400\ cm^2 V\text{-}s.$

$$\boxed{\rho_{e^-} = \frac{1}{\sigma} = 446.428\ \Omega\cdot cm}$$

$\rho_{holes} = \frac{1}{pe\mu_p} = \frac{1}{2.25 \times 10^7 \times 1.6 \times 10^{-19} \times 480}$

$= 5.78 \times 10^8\ \Omega\cdot cm$

$$\boxed{\mu = \frac{e\tau_{sc}}{m^*}}$$

5. How long does it take to drift electron in 1 µm length in the above sample (use same mobility value) if we apply electric field of 100V/cm? Repeat the same for 10^5V/cm and explain your result.

Q. 5. $l = 1\,\mu m$.

$E = 100\ V/cm$

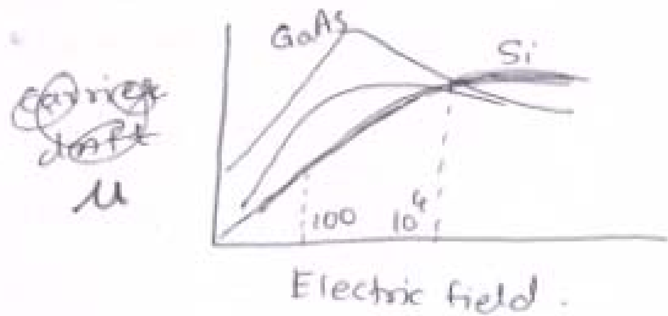
$V_d = \mu E = 1400 \times 100\ cm/s$.

$\therefore\ \tau_1 = \dfrac{10^{-4}}{1.4 \times 10^5} \approx 700\ ps$

For $10^5\ V/cm$: $\boxed{\text{High field region}}$

$\therefore\ V_d$ is nonlinear with E.

$\therefore\ \tau$ can not be calculated !!!



6. If a pure semiconductor mobility (at 300K) is 8500cm^2/V-s, calculate scattering time. If impurity donors (N_d=10^{17}cm^{-3}) are added, the mobility decreases by 59%. Estimate the relaxation time due to ionised impurity scattering. (m^*=0.067m_0)

Q. 6]

$$\mu_{300K} = 8500 \ cm^2/V\cdot s$$

$$\tau_{sc} = \frac{\mu m^*}{e} = \frac{8500 \times 0.067 \, m_0}{1.6 \times 10^{-19}}$$

$$= 3.56 \times 10^{21} \, m_0$$

$$N_d = 10^{17} \ cm^{-3}$$

$$\mu_{new} = 0.61 \times 8500 \ cm^2/V\cdot s.$$

$$\tau_{rel.} = \frac{\mu_{new} m^*}{e}$$

7. Minority carriers are injected in n-type of unknown semiconductor. Under electric field of 50V/cm, carriers move 1cm in time of 100μs. Find the diffusion and drift coefficients of minority carriers. (m_0= 0.97x10^{-30}Kg, e= 1.6x10^{-19}C)

Q.7]

$$E = 50 \ V/cm$$

$$l = 1 \ cm \qquad t = 100 \ \mu s.$$

$$V_d = 10^6 \ cm/s = \mu E \ ; \ \mu = 2 \times 10^4 \ cm^2/V\cdot s.$$

$$m_0 = 0.97 \times 10^{-30} \ kg \ , \ e = 1.6 \times 10^{-19} C$$

$$D_n = \frac{kT\mu}{e} \qquad l = \sqrt{D\tau}$$

$$\cancel{d} \quad \tau = \frac{e\mu}{m^*}$$

8. (a) Derive generalised expression for the Fermi level (E_F) of extrinsic semiconductor in terms of E_{Fi} (intrinsic Fermi level), n and p (electron and hole carrier densities respectively). (b) Determine the position of Fermi level at 300K in silicon doped with Arsenic of 10^{18}cm^{-3}. Specify any assumptions you make (n_i = 1.45x10^{10}cm^{-3} at 300K) . (c) If we have the data for carrier concentration vs temperature for the above material, explain, how you determine the band gap value.

Q. 8. $n = N_c \exp\left(\frac{-(E_c - E_F)}{kT}\right)$

$= N_c \exp\left(-\frac{E_c - E_{Fi}}{kT}\right) \exp\left(\frac{E_F - E_{Fi}}{kT}\right)$

$= n_i \exp\left(\frac{E_F - E_{Fi}}{kT}\right)$

$E_F = E_{Fi} + kT \ln \frac{n}{n_i}$

$n_i = \sqrt{np}$ → $\boxed{= E_{Fi} + \frac{kT}{2} \ln \frac{n}{p}}$

7.2

(b) $T = 300\,k$ Si doped with As.

$N_D = 10^8 = n$

$n_i = 1.45 \times 10^{10}$

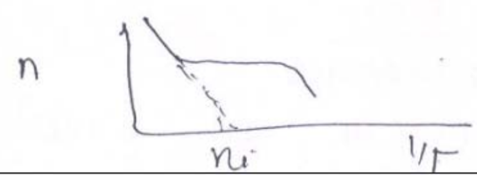
$n_i^2 = N_c N_v \exp\left(\frac{-E_g}{kT}\right)$ $E_{Fi} \Rightarrow \frac{E_c + E_v}{2} + \frac{3}{4} kT \ln \frac{m_h^*}{m_e^*}$

$n = n_i \exp\left\{\frac{E_F - E_{Fi}}{kT}\right\}$

from n calculate,

$\sigma = ne\mu$

$\sigma = \sigma_0 \exp(-E_g/kT)$



log n Vs $1/T$.

9. Show that in 2D electron gas at absolute zero temperature the Fermi level E_f is $E_f = 2\pi \frac{\hbar^2}{2m^*}\left(\frac{N_e}{A}\right)$ where A is area of the system, N_e is number of electrons in the system and m* is effective mass.

10. Show that in a simple two atom per primitive basis model, the phonon dispersion show a gap close to 1.15 $(C/M)^{1/2}$, at the Brillouin zone edge. C stands for force constant and consider the ratio between two atomic mass is 3.

11. A small piece of semiconductor having dopant profile is N(x) along x-axis: (a) find the 'internal' electric field inside the semiconductor at temperature T; (b) find the electric field profile at a constant dopant profile and (c) plot the electric field vs length when the mobility is 1500 cm^2/V-s and the profile along x-axis vary as $N(x)=N_o \exp(-x/\lambda^2)$ (N_o= $10^{18}cm^3$and λ=100nm)

12. In impact ionisation process, the initial hot electron has a velocity v_s. Assume after the collision all the carriers posses same effective mass, kinetic energy and momentum. Now show that the kinetic energy required to initiate ionisation process is equal to $1.5E_g$. where E_g is the band gap of the semiconductor.

13. Show that in a simple two atom per primitive basis model, the phonon dispersion show a gap close to 1.15 $(C/M)^{1/2}$, a the Brillouin zone edge. C stands for force constant and the ratio between two atomic mass is 3; (a) Draw a rough sketch and explain conductivity behaviour in extrinsic semiconductor operating in the working temperature region, involving various scattering mechanisms.
14. A piece of 0.055 Ωm p-type silicon has a carrier drift velocity of $2x10^3$ ms^{-1} at an applied field of 10^5 Vm^{-1}. Calculate the hole concentration and diffusivity at 27°C.

15. A silicon sample is having impurity of $10^{15}cm^{-3}$. These impurities create a mid band gap level of cross-section of $10^{-14}cm^2$. Calculate the electron trap time at 77K.

16. Measurements on the conductivity of a specimen of semiconducting material are made at several temperatures as in the table below. Estimate the temperature at which intrinsic behaviour begins. What is the energy gap of this material? At what wavelength will optical absorption begin?

T(°C)	300	400	500	600	700	800	900
σ $(k\Omega m)^{-1}$	8.1	9.1	14.0	21	67	196	470

17. Explain the terms lattice, Brillouin zone and symmetry points as applied to the crystal structures. If a silicon "photonic crystal" has been given to you for analysis, how you perform experiment in order to draw a E-k graph