EE 2 – Spring 2005

UCLA

Mid-term examination
May 16, 2005

2:00 PM to 3:00 PM

Physical Constants:

Planck's Constant h	6.626 X 10^{-34} J-s
Electron rest mass m_0	9.1 X 10^{-31} kg
Electron-volt eV	1.602 X 10^{-19} J
Boltzmann Constant k	1.38 X 10^{-23} J/K
Charge of an electron q	-1.602 X 10^{-19} C
Thermal energy(at 300^0K) kT	0.0259 eV
Velocity of light c	3 X 10^8 m/sec

Material Properties:

Useful properties of silicon;

Energy gap:	1.16 eV
Intrinsic carrier density n_i (300^0K)	1 X10^{10} cm^{-3}

1. a) In a photoconductor, light is made to fall on a semiconductor sample and the light consists of photons of sufficient energy to excite electrons from the valence band to the conduction band. If one were to use silicon as a photoconductor what is the maximum wavelength of light that can be used? (2 points)

b) Consider a physical quantity that depends on kinetic energy E as $F = E^{1/2}$. Compute the average of F at T = 0K for electrons in a box in terms of the highest energy (Fermi energy). (8 points)

2. In an extrinsic silicon, the Fermi energy is 0.35 eV above the intrinsic Fermi energy.

a) What type silicon is it? (1 point)
b) Assuming all the impurity atoms are ionized what is the density of impurity atoms? (6 points)
C) If in this material, $10^{17}cm^{-3}$ impurity atoms of the opposite type are added, what will be the position of the Fermi energy? (3 points)

3.GaAs has an energy bandgap of 1.43 eV. Effective mass of electron in the conduction band is $0.067m_0$ and effective mass of hole in the valence band is $0.5m_0$ where m_0 is the mass of the electron in vacuum.

(i) Find the intrinsic carrier density, n_i at 400K. (5points)
(ii) Find the position of the intrinsic Fermi energy E_i (5points)

Midterm Solutions

Q1

(a) $E_g = h \cdot \nu_{min} = h \cdot \dfrac{c}{\lambda_{max}}$

$$\longrightarrow \lambda_{max} = \frac{h \cdot c}{E_g} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{(1.16\,eV) \times 1.602 \times 10^{-19}}$$

$$\boxed{\lambda_{max} = 1.07 \times 10^{-6}\ m}$$

(b)

$$\langle E^{1/2} \rangle = \frac{\int_0^{E_F} E^{1/2} \cdot Z(E)\, f(E)\, dE}{\int_0^{E_F} Z(E) \cdot f(E)\, dE} = \frac{\int_0^{E_F} E^{1/2} \cdot E^{1/2}\, dE}{\int_0^{E_F} E^{1/2}\, dE}$$

$$= \frac{\frac{1}{2} E_F^{2}}{\frac{2}{3} E_F^{3/2}} = \frac{3}{4} E_F^{1/2}$$

Q2

(a) Equation (53) on page 67:

$$E_F = KT \ln \frac{n_{X0}}{n_i} + E_i$$

$$\rightarrow \ln \frac{n_{X0}}{n_i} = \frac{E_F - E_i}{KT} = \frac{0.35\,eV}{KT} > 0$$

$$\rightarrow n_{X0} > n_i \quad : \quad \boxed{n\text{-type}}$$

(b)

$$n = n_i \cdot e^{\frac{E_F - E_i}{KT}} = 10^{10} \cdot e^{\frac{0.35}{0.0259}} = \boxed{7.39 \times 10^{15}\ cm^{-3}}$$

(c) $N_A - N_D = 10^{17} - 7.39 \times 10^{15} = 9.26 \times 10^{16}\ cm^{-3}$

$$E_F = E_i - KT \ln\left(\frac{N_A - N_D}{n_i}\right) = E_i - 0.0259 \ln\left(\frac{9.26 \times 10^{16}}{10^{10}}\right)$$

$$= \boxed{E_i - 0.416\ eV}$$

Q3

(a) $n_i^2 = N_c \cdot N_v \cdot e^{-E_g/2KT}$

$$N_c \cdot N_v = 4\left(\frac{2\pi\sqrt{m_c \cdot m_v}\; KT}{h^2}\right)^3$$

$\rightarrow n_i = 3.07 \times 10^{9}\ cm^{-3}$

(b) $E_i = \frac{KT}{2}\ln\left(\frac{N_v}{N_c}\right) + \frac{E_c+E_v}{2}$

$= \frac{KT}{2}\ln\left(\frac{m_v}{m_c}\right)^{3/2} + \frac{E_c+E_v}{2}$

$= \frac{3}{4}KT\ln\left(\frac{0.5}{0.067}\right) + \frac{E_c+E_v}{2}$

$= 0.052\,eV + \frac{E_c+E_v}{2}$