EC233
ELECTRONIC DEVICES 1

SHEET 5 SOLUTIONS

THERMAL EQUILIBRIUM

At thermal equilibrium:

No external effects
No change with time
No electric current
No change in the Fermi level with space (will be proved hereinafter)

PART I:
TRUE OR FALSE

<u>Indicate whether each of the following statements is true or false *(give reasons)*:</u>

- If an electronic system is in equilibrium, it must in a steady state. ✓
- If an electronic system is in steady state, it must be in equilibrium. ✗
- For a semiconductor in equilibrium, the current must be constant. ✗
- The diffusion coefficient and mobility of electrons in a semiconductor can have totally independent values. ✗

PART II:
CHOOSE THE CORRECT ANSWER

1 - When an external voltage is applied on an intrinsic semiconductor material ….
(a) mass action law $np = (n_i)^2$ can be applied (b) it will still be at equilibrium
(c) it will be p-type semiconductor (d) it will not be at equilibrium

2 - When an n-type semiconductor material is heated …………..
(a)Fermi Level position does not change (b) it will still be at equilibrium
(c) it will be p-type semiconductor (d) it will not be at equilibrium

3 - The height from the bottom of the conduction band indicates the ………………. of carriers
(a) kinetic energy (b) potential energy (c) total energy (d) mobility

4 - The rise of the bottom of the conduction band in the +ve x direction indicates the presence of an external electric field which is ……………….. .
(a) in the +ve x direction (b) in the -ve x direction
(c) zero (d) normal to the x direction

5 - The rise of the top of the valence band in the +ve x direction indicates the presence of an external electric field which is ……………….. .
(a) in the +ve x direction (b) in the -ve x direction
(c) zero (d) normal to the x direction

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PART II:
CHOOSE THE CORRECT ANSWER

6 - The bottom of the conduction band decreases in the +ve x direction. This means that the electrons are affected by an **electric force** which is ....

(a) in the +ve x direction
(b) in the -ve x direction
(c) zero
(d) normal to the x direction

7 - The increase of the concentration of holes in the +ve x direction leads to a diffusion current which is ……..........

(a) in the +ve x direction
(b) in the -ve x direction
(c) zero
(d) normal to the x direction

8 - The increase of the concentration of electrons in the +ve x direction leads to a diffusion current which is ……..........

(a) in the +ve x direction
(b) in the -ve x direction
(c) zero
(d) normal to the x direction

9 - For a semiconductor at equilibrium,

(a) the Fermi level must be zero
(b) the Fermi level must be constant in space
(c) the temperature must be zero
(d) the doping must be zero

PART III:
PROBLEM 1

An intrinsic Si sample is doped with donors from one side such that $N_d = N_o exp[-ax]$:

a) Find an expression for ε_x (electric field) at equilibrium over the range for which $N_d >> n_i$. Also sketch ε_x taking $a = 1\ (mm)^{-1}$.

b) Sketch the variation of the semiconductor energy bands induced by the electric field computed in V/cm.

PART III:
PROBLEM 1

- At equilibrium:

$$J_n = J_{drift} + J_{diffusion} = 0$$

$$J_n = qn\mu_n\varepsilon + qD_n\frac{dn}{dx} = 0$$

$$\varepsilon_x = -\frac{D_n}{n\mu_n}\frac{dn}{dx} \qquad \text{-------------------1}$$

Since $N_d >> n_i$: n $\approx N_d = N_o\exp[-ax]$:

$\frac{dn}{dx}$=-aN_o exp[-ax]

Substituting with both n and $\frac{dn}{dx}$ in 1:

$$\varepsilon_x = -\frac{-D_n}{N_o\exp(-ax)\mu_n}aN_o\exp(-ax) = \frac{D_n a}{\mu_n}$$

PART III:
PROBLEM 1

$$\varepsilon_x = \frac{D_n a}{\mu_n}$$

For a =1mm^{-1} : $\varepsilon_x = \frac{D_n a}{\mu_n} = 25\text{mV}(1 \times 10^3) = 25\text{V/m}$

PART III:
PROBLEM 1

a) Sketch the variation of the semiconductor energy bands induced by the electric field computed in V/cm.

Since $\boldsymbol{\varepsilon_x}$ is positive, $\boldsymbol{Slope}(\boldsymbol{E_{c/v/i}})$ is also positive.

Before Diffusion

After Diffusion