Benha University **Faculty of Engineering- Shoubra** **Electrical Engineering Department** **First Year communications.**	**1st semester Exam** **Date: 29-12-2014** **ECE111: Electronic Engineering fundamentals** **Duration : 3 hours**

- Answer all the following questions
- Illustrate your answers with sketches when necessary.
- The exam consists of two pages.

- No. of questions: 5
- Total Marks: 90 Marks
- Examiners: Dr. Ehsan Abaas – Dr. Abdallah Hammad

$K=1.38\times10^{-23}$ J/K	$h=6.64\times10^{-34}$ J.s	$q=1.6\times10^{-19}$ C	$m_o=9.1\times10^{-31}$ Kg	$\varepsilon_o=8.85\times10^{-14}$ F/cm
[Si] $n_i=1.5\times10^{10}$ cm^{-3}	[Si] $\varepsilon_{rs}=11.7$	[Si] $E_g=1.12$ eV	[Ge] $n_i=2\times10^{12}$ cm^{-3}	

Question 1 (18 marks)

For the following statements, mark (√) for true statement and (X) for wrong statement and ***correct*** it.

1 Fermi level is located above the intrinsic level in n-type Si and below it in p-type Si. (√)

2 In n-type Si, as doping concentration increases, Fermi level moves toward the conduction band edge. (√)

3 For a reverse biased pn junction, as the reverse bias voltage increases the depletion capacitance ~~increases~~ (X)

4 For the same doping level, the conductivity of the p-type Si is ~~higher~~ than that of n-type Si . (X)

5 Holes move in the ~~opposite~~ direction of the applied electric field. (X)

6 In a pn junction, depletion region extends more in lightly doped side than in heavily doped side. (√)

7 ~~Forward~~ biased pn junction can be used as a variable capacitor (varactor). (X)

8 ~~Drift~~ current arises when there is a change in carrier concentration. (X)

9 The intrinsic carrier concentration of a semiconductor decreases as its energy gap increases. (√)

10 The mass action law is valid at thermal equilibrium ~~in intrinsic semiconductors only~~ (X)

11 When an intrinsic semiconductor is doped with N_D donors, the new electron concentration is: ~~$n = n_i + N_D$~~ (X)

12 At very high temperatures, doped semiconductors tend to be intrinsic (√)

13 With the rise in temp around 300 k the conductivity of an intrinsic semiconductor ~~decrease~~ (X)

14 The Hall effects occur only in (metals, intrinsic, and extrinsic) (√)

15 The depletion region in the pn junction is depleted of ~~immobile charge~~ (X)

16 The depletion region in the pn junction is reduced when the junction is forward bias (√)

17 When the diode is reveres bias it is equivalent to off switch (√)

18 As the time between collisions increases, the mobility ~~decreases~~ (X)

Correction:

3	Decreases	10	All kinds of Semiconductor
4	Lower	11	$n=N_D+p$
5	Same	13	Increase
7	Reverse	15	Mobile charge
8	Diffusion	18	Increase

Question 2 **(18 marks)**

a- **(9 marks)** Silicon semiconductor at T = 300 K is doped with donors atoms of $N_D = 3 \times 10^{10}$ cm^{-3}.Assume ni = 1.5×10^{10} cm^{-3}. Calculate:

- i- The thermal-equilibrium electron and hole concentrations in the sample.
- ii- The Fermi energy level with respect to the intrinsic Fermi level at T = 300 k.

(i)

$$n = \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2}$$

$$n = \frac{3\times10^{10}}{2} + \sqrt{\left(\frac{3\times10^{10}}{2}\right)^2 + \left(1.5\times10^{10}\right)^2} = 3.62\times10^{10} cm^{-3}$$

$$p = \frac{n_i^2}{n} = \frac{\left(1.5\times10^{10}\right)^2}{3.62\times10^{10}} = 6.21\times10^{9} cm^{-3}$$

(ii)

$$E_F - E_i = \frac{KT}{q}\ln\left(\frac{n}{n_i}\right) = 0.026\ln\left(\frac{3.62\times10^{10}}{1.5\times10^{10}}\right) = 0.0229eV \;\; = 23meV$$

b- **(9 marks)** The electron concentration in Silicon at T = 300 K is given by: $n(x) = 10^{16}\exp\left(\frac{-x}{18}\right) \text{Cm}^{-3}$ Where *x* is measured in **μm** and is limited to $0 \leq x \leq 25$ μm. The electron diffusion coefficient is D_n =25 cm^2/s. The electron current density through the semiconductor is constant and equal to J_n = - 40 A/cm^2. The electron current has both diffusion and drift current components. Determine the electric field as a function of x which must exist in the semiconductor.

$$J_n = e\mu_n n\text{E} + eD_n\frac{dn}{dx}$$

or

$$-40 = \left(1.6x10^{-19}\right)(960)\left[10^{16}\exp\left(\frac{-x}{18}\right)\right]\text{E}$$

$$+\left(1.6x10^{-19}\right)(25)\left(10^{16}\right)\left(\frac{-1}{18x10^{-4}}\right)\exp\left(\frac{-x}{18}\right)$$

Then

$$-40 = 1.536\left[\exp\left(\frac{-x}{18}\right)\right]\text{E} - 22.2\exp\left(\frac{-x}{18}\right)$$

Then

$$\text{E} = \frac{22.2\exp\left(\frac{-x}{18}\right) - 40}{1.536\exp\left(\frac{-x}{18}\right)} \Rightarrow$$

$$\text{E} = 14.5 - 26\exp\left(\frac{+x}{18}\right)$$

Question 3 (18 marks)

a- **(9 marks)** Germanium is doped with 5 x 10^{17} **donor** atoms per cm^3 at T = 300 K. The dimensions of the Hall device shown in Figure. 1 are t = 5x10^{-3} cm, d = 2x10^{-2} cm. and W= 0.1 cm. The current is I_x = 250 µA. The applied voltage is V_x = 100 mV. The magnetic flux density is B_z = 5 x 10^{-2} tesla (Wb/m^2). Calculate:

- i- The Hall voltage.
- ii- The Hall Electric field.
- iii- The carrier mobility.

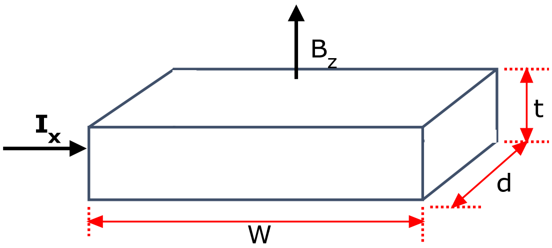


Figure 1

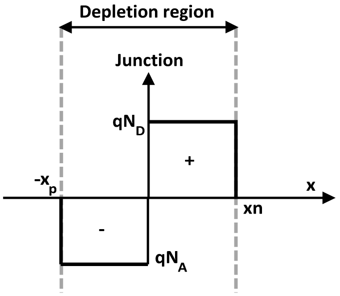
b- **(9 marks)** Silicon P^+n junction has N_A = 10^{18} cm^{-3} and N_D = 5 x 10^{15} cm^{-3}.The cross-sectional area of the junction is A = 5 x 10^{-5} cm^{-2}. Calculate

- i- The junction capacitance for V_R = 3V
- ii- Show that the curve ($[1/C]^2$ versus V_R) can be used to find N_D and V_o.

Question 4 (18 marks)

a- (9 marks) The charge distribution of an abrupt pn junction is shown in Figure.

- i- Derive an expressions for the electric field in the region $-x_p < x < x_n$.
- ii- By using Poisson's Equation find the expressions for the potential distribution in the region $-x_p < x < x_n$



$$\frac{d^2\psi(x)}{dx^2} = -\frac{d\mathbf{E}(x)}{dx} = -\frac{\rho_s(x)}{\varepsilon}$$

$$-x_p \le x < 0$$

$$\frac{d\mathbf{E}(x)}{dx} = \frac{-qN_A}{\varepsilon}$$

$$\mathbf{E}(x) = -\frac{qN_A}{\varepsilon}x + \mathbf{E}_1$$

$$\mathbf{E}_1 = -\frac{qN_A}{\varepsilon}x_p$$

$$\mathbf{E}(x) = -\frac{qN_A}{\varepsilon}\left(x + x_p\right)$$

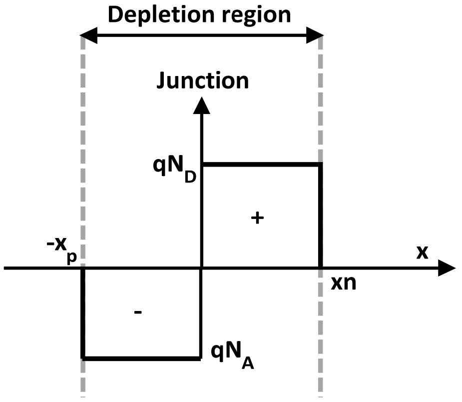
$$0 < x \le x_n$$

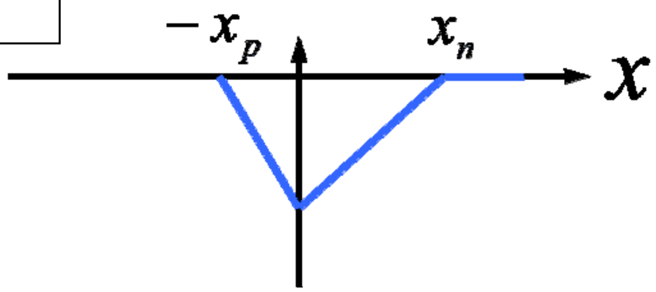
$$\frac{d\mathbf{E}(x)}{dx} = \frac{qN_D}{\varepsilon}$$

$$\mathbf{E}(x) = \frac{qN_D}{\varepsilon}x + \mathbf{E}_2$$

$$\mathbf{E}_2 = -\frac{qN_D}{\varepsilon}x_n$$

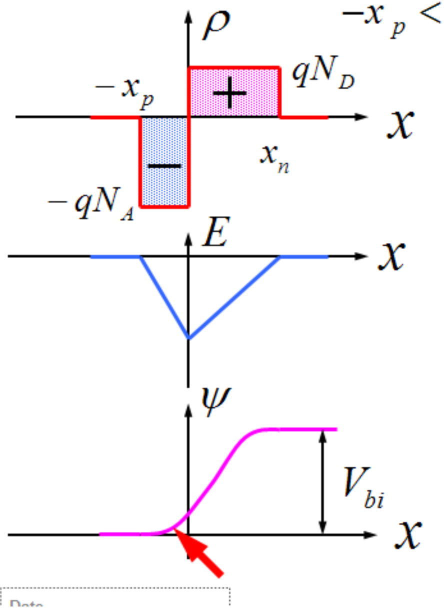
$$\mathbf{E}(x) = \frac{qN_D}{\varepsilon}\left(x - x_n\right)$$





$$\mathbf{E}_{\max} = \mathbf{E}(0) = -\frac{qN_A}{\varepsilon}x_p = -\frac{qN_D}{\varepsilon}x_n$$

(b)



$$-x_p < x < 0$$

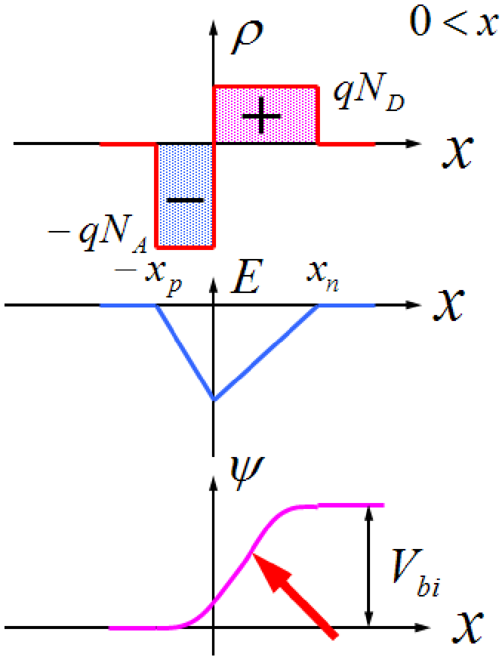
$$\psi(x) = \int \frac{qN_A}{\varepsilon}\left(x + x_p\right)dx$$

$$= \frac{qN_A}{\varepsilon}\left(\frac{x^2}{2} + x_p x\right) + \psi_1$$

with $\psi(-x_p) = 0$

$$\psi_1 = \frac{qN_A}{\varepsilon}\frac{x_p^{\ 2}}{2}$$

$$\boxed{\psi(x) = \frac{qN_A}{2\varepsilon}\left(x_p + x\right)^2}$$



$$0 < x < x_n$$

$$\psi(x) = \int \frac{qN_D}{\varepsilon}(x_n + x)\,dx$$

$$= \frac{qN_D}{\varepsilon}\left(x_n x - \frac{x^2}{2}\right) + \psi_2$$

with $\psi(x_n) = V_{bi}$

$$\psi_2 = V_{bi} - \frac{qN_D}{\varepsilon}\frac{x_n^{\ 2}}{2}$$

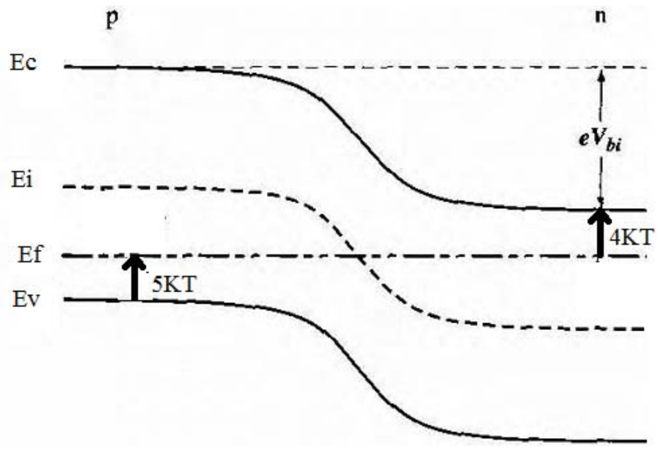
$$\boxed{\psi(x) = V_{bi} - \frac{qN_D}{2\varepsilon}(x_n - x)^2}$$

a- (9 marks) A silicon pn junction diode is doped such that $E_F = E_V + 5KT$ on the p-side and $E_F = E_C - 4KT$ on the n-side.

- **i- <u>Draw</u> an equilibrium energy band diagram of this junction.**
- **ii- <u>Calculate</u> the built-in voltage at 300K. Given that Eg = 1.12 eV**
- **iii- If the donor concentration N_D= $6.2\mathrm{x}10^{17}$ cm^{-3}, <u>Calculate</u> N_A**

i-

ii-



$$Vo = E_g - (E_1 + E_2)$$

$$Vo = 1.12 - (5KT + 4KT)$$

$$Vo = 1.12 - 9(0.0259) = 0.8869V$$

iii-

$$Vo = \frac{KT}{q}\ln\left(\frac{N_A N_D}{n_i^{\,2}}\right) = 0.8869$$

$$N_A = \frac{(1.5 \times 10^{10})^2}{6.2 \times 10^{17}} e^{\left(\frac{0.8869}{0.0259}\right)} = 1.8 \times 10^{17}\,cm^{-3}$$

Question 5 (18 marks)

a- **(6 marks) Define: barrier potential, Static forward resistance, PIV, Reverse Stauration current.**

a- **barrier potential**:

when the n type material put in contact with the p type material, free electrons from n type diffuse and cross the junction and combine with holes in the p type material leaving behind (+ve ions) in the surface of the n type. While (-ve ions) on the p type reign. These positive and negative ions create an electric field which in turn produces an electric potential (barrier potential) that prevent more electrons from crossing the junction.

Static forward resistance:

it is the ratio dc voltage across the diode and the current passes through it.

PIV:

it equals the peak value of the input voltage and the diode must be capable of withstanding the amount of repeatative reverse voltage

Reverse Stauration current:

is the current in a semiconductor diode caused by drift of minority carriers from the neutral regions to the depletion region. This current is almost independent of the reverse voltage.

b- **(6 marks) Assuming an ideal diode, the dc output across the resistor V_{dc} =2 V.**

- **i- Sketch (V_i, V_D, I_D) for the half-wave rectifier of Figure. 3. The input is a sinusoidal waveform with a frequency of 50 Hz.**
- **ii- Determine the PIV of the diode.**

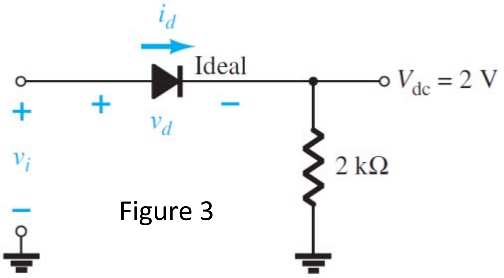
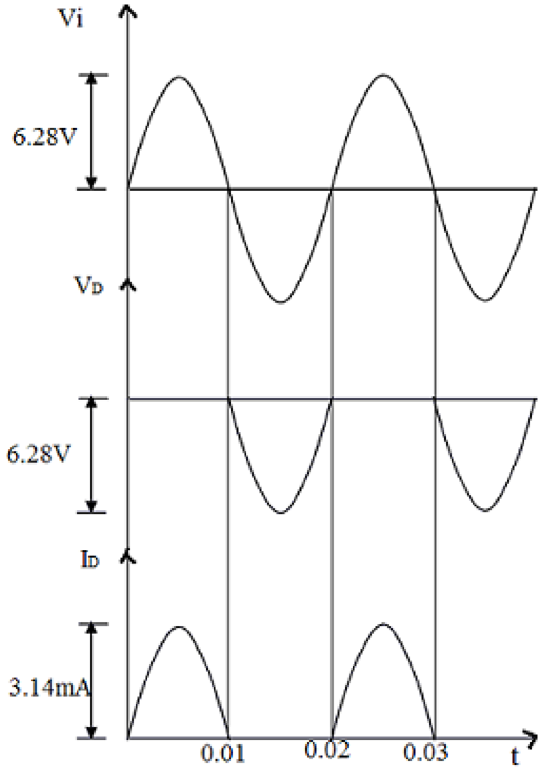


Figure 3



PIV=V_i(p)=6.28V

a- **(6 marks) Consider a silicon pn junction with the following parameters.**
$N_D = 10^{16}$ cm^{-3} $N_A = 5\text{x}10^{16}$ cm^{-3}, $n_i = 1.5\text{x}10^{10}$ cm^{-3}
$\tau_n = \tau_p = 5\text{x}10^{-7}$ S, $D_p = 10$ cm^2/S, $D_n = 25$ cm^2/S, $\varepsilon_{rs} = 11.7$, and the cross sectional area is 10^{-3} cm^2
Calculate the reverse saturation current I_o.

$$I_o = Aq\left[\frac{D_P p_{no}}{L_P} + \frac{D_n n_{po}}{L_n}\right]$$

$$I_o = Aq{n_i}^2\left[\frac{1}{N_A}\sqrt{\frac{D_n}{\tau_n}} + \frac{1}{N_D}\sqrt{\frac{D_p}{\tau_p}}\right]$$

$$\mathrm{I_o} = 10^{-3} \times 1.6 \times 10^{-19} \times (1.5 \times 10^{10})^2\left[\frac{1}{5 \times 10^{16}}\sqrt{\frac{25}{5 \times 10^{-7}}} + \frac{1}{10^{16}}\sqrt{\frac{10}{5 \times 10^{-7}}}\right]$$

$$\mathrm{I_o} = 2.12 \times 10^{-14} A$$

Good Luck

Dr. Abdallah Hammad