COE 360 **Dr. Aiman El-Maleh**

HW# 1 (Solution)

Q.1. Indicate whether the following true or false, and if it is false indicate why it is false:

(i) An atom in an intrinsic silicon semiconductor has 5 valence electrons **(True, <u>False</u>)**.
A silicon atom has 4 valence electrons.

(ii) Current density increases with the increase in the total charge and the decrease in area **(<u>True</u>, False).**

(iii) The applied voltage across a semiconductor increases with the increase in the length of the semiconductor **(<u>True</u>, False)**.

(iv) With the addition of acceptor atoms to an intrinsic semiconductor, the hole concentration increases while the electron concentration remains the same **(True, <u>False</u>)**.
With the addition of acceptor atoms to an intrinsic semiconductor, the hole concentration increases and the electron concentration decreases.

(v) An n-type semiconductor is doped with pentavalent impurity while a p-type semiconductor is doped with tetravalent impurity **(True, <u>False</u>)**.
An n-type semiconductor is doped with pentavalent impurity while a p-type semiconductor is doped with trivalent impurity.

(vi) The mass-action-law states that $n=p=n_i$, the intrinsic concentration **(True, <u>False</u>).**
The mass action law states that under thermal equilibrium, $n\,p = n_i^2$

(vii) The charge neutrality law states that $N_A + p = N_D + n$ **(True, <u>False</u>)**.
The charge neutrality law states that under thermal equilibrium, $N_D + p = N_A + n$.

(viii) With increasing temperature, the density of electron-hole pairs, mobility and conductivity increase **(True, <u>False</u>).**
With increasing temperature, the density of electron-hole pairs and conductivity increase while the electron and hole mobilities decrease.

(ix) In a pn-junction, free electrons will diffuse from the n to the p side leaving negative ions, and free holes will diffuse from the p to the n side leaving positive ions **(True, <u>False</u>).**
In a pn-junction, free electrons will diffuse from the n to the p side leaving positive ions, and free holes will diffuse from the p to the n side leaving negative ions.

(x) The width of the depletion region and the transition capacitance decrease with the increase in the doping concentration **(True, <u>False</u>)**.
The width of the depletion region decreases with, and the transition capacitance increases with, the increase in the doping concentration.

(xi) In a forward-biased pn-junction, the depletion region width is smaller than in the reverse-biased pn junction **(<u>True</u>, False)**.

(xii) V_{IH} is the maximum input voltage which can be interpreted as high while V_{IL} is the minimum input voltage which can be interpreted as low **(True, <u>False</u>)**.

V_{IH} is the minimum input voltage which can be interpreted as high while V_{IL} is the maximum input voltage which can be interpreted as low.

(xiii) V_{OH} is the maximum input voltage which can be interpreted as high **(True, <u>False</u>)**.

V_{OH} is the maximum output voltage produced when the output is high.

(xiv) V_{IH} is defined as, the maximum output voltage V_{OH} minus the noise margin NM_H. **(<u>True</u>, False)**.

(xv) V_{OL} is the output voltage produced when the input voltage is greater than or equal to V_{IH} **(True, <u>False</u>)**.

V_{OL} is the output voltage produced when the input voltage is greater than or equal to V_{OH}.

Q.2. Calculate the conductivity of a piece of silicon at 300K in the following cases:

(i) No impurities added.

$$\text{Conductivity} = q\, ni\ (\mu_n + \mu_p) = 1.6X10^{-19}\, C\, X\, 1.45X10^{10}\ cm^{-3}\, X\, (1500+475)\ cm^2/V.s$$
$$= 4582X10^{-9}\ C/V.s.cm$$
$$= 4.582X10^{-6}\ (\Omega.cm)^{-1}$$

(ii) The material is doped with Arsenic at a density of $4X10^{16}$ atoms/cm^3.

Since Arsenic is pentavalent impurity, then it is donor i.e., N_D=$4X10^{16}$ atoms/cm^3, and N_A=0. So, the material becomes n-type with n approximately equals to N_D. Thus, conductivity can be approximated to

$$q\, n\, \mu_n = 1.6X10^{-19}\, C\, X\, 4X10^{16} cm^{-3}\, X\, 1500\ cm^2/V.s$$
$$= 9.6\ (\Omega.cm)^{-1}$$

(iii) The material is doped with Boron at a density of $4X10^{16}$ atoms/cm^3.

Since Boron is trivalent impurity, then it is acceptor i.e., N_A=$4X10^{16}$ atoms/cm^3, and N_D=0. So, the material becomes p-type with p approximately equals to N_A. Thus, conductivity can be approximated to

$$q\, p\, \mu_p = 1.6X10^{-19}\, C\, X\, 4X10^{16} cm^{-3}\, X\, 475\ cm^2/V.s$$
$$= 3.04\ (\Omega.cm)^{-1}$$

(iv) The material is doped with both Arsenic and Boron, each at a density of $4X10^{16}$ atoms/cm^3.

Since N_A= N_D, this implies that n=p=n_i. Thus, the conductivity of the material will be the same as the conductivity of the intrinsic silicon = $4.582X10^{-6}\ (\Omega.cm)^{-1}$

Q.3. An intrinsic silicon bar is 4 mm long and has a rectangular cross section of 40X80 μm. The material has a resistivity of 200K Ω.cm. Determine the following:

(i) The concentration of Arsenic atoms added to the material to convert it to an n-type material with a resistivity of 20 Ω.cm.

Conductivity $\sigma = 1/\rho = 1/(20) = 5X10^{-2}\ (\Omega.cm)^{-1}$
Since the material is n-type material, conductivity can be approximated to $q\ n\ \mu_n$, and the concentration of Arsenic atoms N_D can be assumed equal to n.
Thus, $N_D = \sigma / q\ \mu_n = 5X10^{-2} / (1.6X10^{-19}\ X\ 1500)$
$= 2.08\ X10^{14}$ atoms/cm^3.

(ii) The concentration of Boron atoms added to the material to convert to a p-type material with a resistivity of 20 Ω.cm.

Conductivity $\sigma = 1/\rho = 1/(20) = 5X10^{-2}\ (\Omega.cm)^{-1}$
Since the material is p-type material, conductivity can be approximated to $q\ p\ \mu_p$, and the concentration of Boron atoms N_A can be assumed equal to p.
Thus, $N_A = \sigma / q\ \mu_p = 5X10^{-2} / (1.6X10^{-19}\ X\ 475)$
$= 6.58\ X10^{14}$atoms/cm^3.

(iii) Determine the electric field intensity in the intrinsic silicon bar and the voltage across the bar when a steady current of 1 μA is measured.

The electric field intenisty $= J/\sigma = I/(A\ .\ \sigma)$
$I = 1X10^{-6}\ A$
Area $= 40X10^{-6}\ X\ 80X10^{-6}\ m^2 = 3200\ X10^{-12}\ m^2 = 32\ X10^{-6}\ cm^2$
Conductivity $\sigma = 1/\rho = 1/(200X10^3) = 5X10^{-6}\ (\Omega.cm)^{-1}$
So, the elctric field $= 1X10^{-6} / (32\ X10^{-6}\ X\ 5X10^{-6})$
$= 6.25X10^3\ V/cm$

The voltage across the bar = electric field X bar length
$= 6.25X10^3\ V/cm\ X\ 0.4\ cm$
$= 2500$ V

Q.4. Determine the fanout and the noise margins of a gate with V_{IL}=1.2V, V_{IH}=3V, V_{OH}=4.5V, V_{OL}=0.2, I_{IH}=30μA, I_{IL}=2mA, I_{OH}=600μA, and I_{OL}=30mA.

$NM_H = V_{OH} - V_{IH} = 4.5 - 3 = 1.5\ v$
$NM_L = V_{IL} - V_{OL} = 1.2 - 0.2 = 1.0\ v$
Maximum fanout allowed $= Min\ (I_{OH}/ I_{IH},\ I_{OL}/ I_{IL})$
$= Min\ (600\mu A / 30\mu A,\ 30mA / 2mA)$
$= 15$