ISD 2023 - Week 11 Assignment

There are 10 questions for a total of 20 marks.

1. (2 marks) Consider a slab of silicon $5\ \mu m$ thick. Determine the percentage of photon energy that will pass through the slab if the photon wavelength is $\lambda = 800\ nm$. Take the absorption coefficient of that semiconductor is $1000\ cm^{-1}$ at $800\ nm$. (Recall Beer-Lambert law.)

$I/I_0 = e^{-\alpha z}$

% photon energy $= I/I_0 \times 100 = e^{-\alpha z} \times 100$

$= e^{-10^3 \times 5 \times 10^{-4}} \times 100 \simeq 60.6\ \%$

$z = 5 \mu m = 5 \times 10^{-4} cm$

   A. 40

   B. 60

   C. 37

   D. 25

   E. 10

2. (2 marks) Consider GaAs of thickness $10\ \mu m$ at T =300 K. A photon intensity (I) of 0.05 W/cm^2 at $\lambda = 793\ nm$ is incident on it. If the absorption coefficient (α) is $10^4\ cm^{-1}$ and excess minority carrier lifetime is $0.1\ \mu s$, the steady state excess carrier concentration due to incident photon intensity is ______ cm^{-3}. (Recall $g = \frac{\Delta n}{\tau} = \frac{\alpha I}{hf}$)

$\frac{1.24}{0.793} = 1.56 eV$

$\Delta n = \frac{\alpha I}{hf} \times \tau = \frac{10^4 \times 0.05}{1.563 \times 1.6 \times 10^{-19}} \times 0.1 \times 10^{-6}$

$= 1.99 \times 10^{14}\ /cm^3.$

   A. 2×10^{14}

   B. 2×10^{21}

   C. 2×10^{17}

   D. 1×10^{19}

   E. 1×10^{15}

3. (2 marks) A solar cell is an example of ______ device.

   A. photoconductive

   B. photovoltaic

   C. photo-thermo electric

   D. phototransistor

   E. bolometric

> **Reflect and remember:** Recall the devices that convert light to electricity (Solar cells, photodetectors, CCD, etc.) and the devices that convert electricity to light (LEDs, lasers etc.) A solar cell is a type of PN junction photodiode that works without any external electric field, and the carriers are separated by the internal built-in field.

4. (2 marks) A bar of Silicon is doped with Boron at $\underbrace{10^{15}\ cm^{-3}}_{}$ (p_o). It is exposed to light such that electron–hole pairs are generated throughout the volume of the bar at the rate of $\underbrace{10^{20}\ cm^{-3}s^{-1}}_{g}$. The recombination lifetime is $10\ \mu s$. The hole carrier concentration is ______ cm^{-3} (Hint: It is the sum of equilibrium carriers and excess carriers due to incident light)

$g = \frac{\Delta n}{\tau} \Rightarrow \Delta n = g.\tau = 10^{20} \times 10 \times 10^{-6} = 10^{15}/cm^3.$

$\Delta n = \Delta p = 10^{15}/cm^3.$

$p' = p_o + \Delta p = 10^{15} + 10^{15} = 2\times 10^{15}/cm^3.$

   A. 2×10^{15}

   B. 2×10^{20}

   C. 2×10^{17}

   D. 1×10^{15}

   E. 1×10^{20}

> **Reflect and remember:** As a practice, also try to find the electron carrier concentration in silicon. The non-equilibrium minority carrier concentration is often much larger than the equilibrium concentration $(n' >> n_0)$.
>
> If the light is suddenly turned off at $t = 0$, $n'(p')$ will decay with time until they become zero and the net carrier concentration reaches equilibrium $n_0(p_0)$. This is referred to as recombination, and the time required is called recombination time or carrier lifetime, τ.

5. (2 marks) Consider a long Silicon p-n junction solar cell with an area of $4\ cm^2$ at T=300 K. The solar cell has an optical absorption coefficient $\alpha = 10^3\ cm^{-1}$, the reverse saturation current is $7\ pA$, and the photocurrent is $I_L = 1\ A$, calculate the maximum output power in W, if the fill factor is 0.75. (Recall the relation among FF, I_{sc}, V_{oc}, Power)

$V_{oc} = \frac{KT}{q} \ln\left(1 + I_L/I_s\right)$

$= 0.026 \times \ln\left(1 + \frac{1A}{7pA}\right)$

$= 0.667\ V$

$FF = \frac{V_m I_m}{V_{oc} I_{sc}}$ ($V_m I_m \rightarrow$ power)

$\text{Power} = V_{oc} \cdot I_{sc} \cdot FF$

$= 0.667 \times 1 \times 0.75$

$\boxed{P = 0.5\ W}$

   A. 0.25

   B. 0.75

   C. 0.50

   D. 0.125

   E. 2.5

6. (2 marks) A photodiode has a responsivity of $0.25\ A/W$ at $532\ nm$. Find the % efficiency of the detector.

   A. 100

   B. 58

   C. 82

   D. 26

   E. 15

$532\ nm \to 2.33\ eV$

$$R = \frac{e\eta}{(hc/\lambda)}$$

$$\eta = 0.25 \times 2.33 = 0.582 \approx 58\%$$

7. (2 marks) A silicon photocell has dimensions $4\ cm$ X $4\ cm$ at T=300 K is being tested and $\eta = 100\%$. Initially, the cell is kept in the dark. When a current of $I_L = 100\ \mu A$ is forced through it in the direction of good conduction, the voltage across the diode, $V_{oc} = 0.466\ V$. The reverse saturation current, I_s is ______ pA.

   A. 16.5

   B. 65

   C. 165

   D. 0.65

   E. 1.65

$$V_{oc} \approx \frac{kT}{q} \cdot \ln(1 + I_L/I_s)$$

$$I_L/I_s = \exp\left(\frac{V_{oc}}{kT/q} - 1\right)$$

$$I_s \approx I_L \cdot \exp(-V_{oc}/kT/q) = 100\,\mu A \times \exp(-0.466/0.026)$$

$$= 1.64 \times 10^{-12} A. \approx \underline{\underline{1.65\,pA}}$$

> **Reflect and remember:** In a PN junction diode, the photocurrent density through the diode is in the reverse-biased condition and is many orders of magnitude larger than the reverse-biased saturation current density.

8. (2 marks) Consider the following statements S1 and S2.

   $S1$: The PIN photodiode can be used as a better photodetector than the PN photodiode. The intrinsic region width in a PIN photodiode is much larger than the space charge width in a normal PN photodiode.

   $S2$: If the reverse bias is applied to a PIN junction, the space charge region extends completely through the intrinsic region and has no electron-hole recombination.

   Which of the following is true?

   Recall & refer to the lecture

   A. Both $S1$ and $S2$ are true.

   B. $S1$ is true and $S2$ is false.

   C. $S1$ is false and $S2$ is true.

   D. Both $S1$ and $S2$ are false.

> **Reflect and remember:** The photocurrent density of a PIN photodiode will be larger than that of a regular PN photodiode since the space charge region is much larger in PIN.

9. (2 marks) **(EC-GATE 2016)** The figure shows the I-V characteristic of a solar cell illuminated uniformly with solar light of power $100\ mW/cm^2$. The solar cell has an area of $3\ cm^2$ and a fill factor of 0.7. The maximum efficiency (in %) of the device is ______.

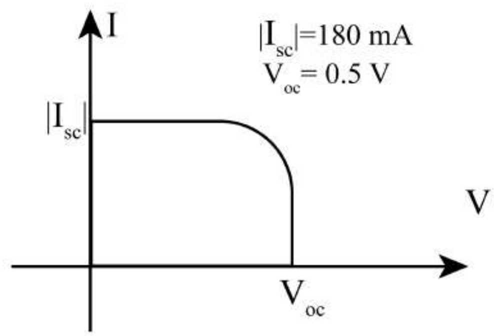
$P_{in} = 100mW \times 3 = 0.3W$

$\eta = \frac{\text{output power}}{\text{input power}} \times 100 = \frac{P_{out}}{P_{in}} \times 100$

$FF = \frac{P_{out}}{V_{oc} \cdot I_{sc}}$

$P_{out} = FF \times V_{oc} \cdot I_{sc}$

$\eta = \frac{FF \cdot V_{oc} \cdot I_{sc}}{P_{in}}$



$\eta = \frac{0.7 \times 0.5 \times 0.18}{0.3} \times 100 = 21\%$.

A. 11

B. 5.84

C. 21

D. 2.1

E. 58

$P_{in} = 100mW = 0.1W$

10. (2 marks) **(EC-GATE 2020)** A pn junction solar cell of area $1\ cm^2$, illuminated uniformly with $100\ mW/cm^2$, has the following parameters: efficiency, $\eta = 15\%$, open circuit voltage, $V_{OC} = 0.7\ V$, fill factor $FF = 0.8$ and thickness $= 200\ \mu m$. The average optical generation rate is ______ $\times 10^{18}\ cm^{-3}s^{-1}$. (Recall optical generation rate, $G = I_{sc}/qV$, where V is the volume.)

A. 1.04

B. 0.84

C. 8.4

D. 0.4

E. 0.55

$I_{sc} = \frac{\eta \cdot P_{in}}{FF \cdot V_{oc}} = \frac{0.15 \times 0.1}{0.8 \times 0.7} = 0.026A$

$\text{Gen rate} = \frac{I_{sc}/q}{\text{Volume}} = \frac{0.026/1.6 \times 10^{-19}}{1 \times 0.02} = 8.37 \times 10^{18} /cm^3/sec.$