ESP5403 Nanomaterials for Energy Systems (AY2021-22)

Solution to Mock Quiz Questions

20 Septem 2021

This is a closed book quiz,

Please attempt all 15 questions in this quiz. You are given 25 min to complete the quiz.

Write your Metric Number and answers on the quiz question sheets and submit this document at the end of the quiz.

No need to provide drawing for any question below.

Matric No.:_____

1. To produce electron rich Si we do extrinsic doping by -----five/penta------ valance atoms. Give an example of a such donor atom and explain how this doping results in excess electrons (in 1-2 sentence).

   One e.g., is Phosphorous. When penta-valent P is doped in place of Si, it shares four electrons with neighboring Si atoms leaving one extra electrons which fill up Fermi level and conduction band edge resulting in n-Si.

2. (a) Mention three processes that could happen when photons of visible light interact with a semiconductor, say n-type Si with bandgap of 1.12eV.
   (b) Mention the conditions at which these three processes occur.
   (c) Explain the reason why such processes happen at these conditions (1-2 sentence for each).

(a) (1). Reflection, (2) Transmission and (3) absorption.
(b) (1) Reflection happens at incident light is partially reflected; (2) Transmission occurs when $E_{photon} < E_{bandgap}$; and (3) Absorption occurs when $E_{photon} \geq E_{bandgap}$.
(c) (1) Reflection of incident photon happens due to high reflectivity of n-Si surface; (2) Transmission of photon happens as its energy is less than bandgap energy and does not interact with Si and (3) absorption happens as incident photon energy is equal or greater than the bandgap and due to interaction of photons with semiconductor.

3. --**Direct**----- (Direct/Indirect) bandgap semiconductor such as InP (Indium Phosphide) has efficient optical absorption while –**indirect** --- (direct/indirect) bandgap semiconductor such as Si does not exhibit efficient absorption process. Explain reason for each (1-2 sentence each).

Direct bandgap absorption is efficient as it involves only transfer of energy from incident photon to the semiconductor. Indirect bandgap absorption is inefficient because it involves transfer of both energy as well as momentum within the semiconductors.

4. The LED device uses the principle of emission of **photon** (electrons/photons/ phonons/ holes) from a **direct** (direct/indirect) bandgap semiconductor during the process of **recombination** (absorption/recombination/change separation).

5. When n-Si and metal (work function of metal is higher than n-Si) are brought together to form a junction, we form **Schottky** contact. Upon formation of such a contact, the Fermi levels are aligned.

(a) Explain why Fermi level of n-Si is aligned with Fermi level of metal (1-2 sentence).
(b) Provide three different changes that happen in energy levels of n-Si.
(c) Explain the reason for each observed change (1-2 sentence).

(a) Upon forming junction between metal and n-Si, electrons are transferred from n-Si leaving positive ions forming depleted region or Schottky barrier. This results in lowering of Fermi level until the drift current at the barrier and diffusion current balance each other. At this stage, the Fermi levels of metal and n-Si are aligned.
(b) Bending of vacuum level, conduction band edge and valance band edge occurs.
(c) Since work function and bandgap energy are fixed, lowering of Fermi level in n-Si until it aligns with Fermi level of metal causes bending of vacuum level, conduction band edge and valance band edge.

6. (a) If light falls on the surface of a semiconductor, its intensity falls exponentially within the semiconductor from the surface due to the process, called recombination.
(b) Mention two such possible relevant processes in n-Si.
(c) Provide the conditions at which these two above mentioned processes predominate in n-Si semiconductor.

(b) SRH recombination and Auger recombination
(c) SRH recombination occurs at low doping level and low temperature; Auger recombination occurs at high temperature and high doping level.

7. (a) When light is illuminated on n-Si/p-Si junction, we generate the current I_L which flows in the external circuit from **p-Si** (n-Si or p-Si) to **n-Si** (or p-Si).
(b) Mention all components of I_L
(b) Mention the condition at which I_L will be the same as I_{sc} (short circuit current).

(b) Components of I_L : I_n and I_p

(c) When the series resistance is negligible I_L will be the same as I_{sc}.

8. At high doping the mobility of electron in Si drops substantially, provide one cause and explain the reason (1-2 sentence).

At high doping mobility of electron drops due to lattice scattering. As the doping level increases, the probability for scattering of the mobile electrons due to applied electric field is high thus causing decrease in its mobility.

9. The direction of drift currents of electron and hole in a semiconductor is - **same** -- (same/opposite), while the direction of diffusion currents of electron and hole in a semiconductor is -- **opposite** (same / opposite). Explain the reason for each of your answer above (1-2 sentence).

Drift current due to an applied electric field for electrons and holes are same due to negative charge of electron and positive charge of holes.
Diffusion current is caused by concentration gradient from high concentration to low concentration region. The diffusion current is different due to opposite charges for the electrons and holes.

10. KCl (potassium Chloride) crystal exhibits - **Schottky** --- (Schottky / Frenkel) defects. Possible defects are: ---**cation vacancy**------ and ---**anion vacancy**-----.

11. By doping $CaCl_2$ by $CdCl_2$ we create the following defect, provide your reason (1-2 sentence).

~~a) Defect at Ca site~~
~~b) Defect at Cl site~~
c) No defect formation
d) ~~Defect at both Ca and Cl sites~~.

Because doping Ca^{2+} by Cd^{2+} does not introduce any defects as they both have same valance state or charge (2+).

12. Consider AgCl single crystal placed between two Pt electrodes. Upon impedance measurement how many semicircles you would observe? Explain the reason for the observed semicircle(s).

Two semicircles.

One due to bulk of the AgCl single crystal and the other due to blocking nature of Pt electrodes.

13. Mention one top down approach for synthesis of nanomaterials which induces chemical reaction to form the final product. Explain why this process is efficient in the formation of nanomaterials (2-3 sentence).

Mechanochemical method.

In this mechanochemical method reactants are milled at room temperature to form the product at nanosize. Upon mechano-milling process the size of the reactants are reduced to nanosize. At such nano-size all the starting materials react fast to form nanomaterial product even at room temperature.

14. During synthesis of nanomaterial by hydrothermal method using autoclave, we make use of internal pressure within the autoclave in addition to the temperature. What is the role of high pressure.

Hydrothermal synthesis using autoclaves combine high pressure and low temperature. Role of pressure is to lower temperature for chemical reaction to form nanomaterials.

15. $YBa_2Cu_3O_{7-\delta}$ is a superconductor and has conductivity due to both ions and electrons. This create ohmic (Schottky / ohmic) contact when used with Y_2O_3 doped ZrO_2 single crystal for electrical measurements. Explain the reason for the type contacts created (1-2 sentence).

The ohmic contact is formed on Y_2O_3 doped ZrO_2 single crystal during electrical measurement as this $YBa_2Cu_3O_{7-\delta}$ superconductor a very good conductor for both oxygen ions and electrons.