ESP 5403 Nanomaterials for Energy Systems

Quiz-2/Solutions

06/11/2020

Marks 15 (Grade 15%)

This is an open-book quiz. Please attempt all questions in this quiz. You are given 40 min. to complete the quiz.

Write your Metric Number and answers on the quiz question sheets and submit this document as a PDF file to LUMINUS at the end of the quiz.

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Matric No.:__________________

1. Dominated volume recombination in *p*-region of a monocrystalline Si-solar cell at high doping level is:

~~(a) Radiative recombination~~
(b) Auger recombination √
~~(c) Trap-assisted SRH recombination~~
~~(d) Surface recombination~~

Mention one subsequent effect during this recombination process.
During Auger recombination, heat is generated due to thermalization process.

2. During the analysis of I-V curve and its Fill Factor of a solar cell, we note that the main impact of high series resistance is to reduce the __short circuit current__ while the main impact of low shunt resistance is to reduce the _open circuit voltage___.

Provide reason why either OCV or short circuit current is affected substantially (as mentioned above) at high series resistance (1-2 sentences only):
I_{sc} is the maximum current one would expect in the measured short circuit condition. With high series resistance of the solar cells, one expects considerable voltage drop across it, hence the short circuit current will drop significantly.

3. Upon increasing the band gap of semiconductors, the conversion efficiency of solar cells made by such semiconductors increases steadily.
(a) True (b) False [b]

Provide the reason (1-2 sentences only).
The open circuit voltage increases and the short circuit current decreases with increasing bandgap of the semiconductors. The cell efficiency is a composite effects of I_{sc} and V_{oc} with increasing the bandgap, hence it will show a maximum instead of increasing steadily with increase in bandgap.

4. Consider a perovskite solar cell, in which a perovskite is sandwiched between TiO_2 and Spiro-MeOTAD. Upon light illumination, electron-hole pair is formed in the perovskite. From thermodynamic point of view, the valance band maximum of perovskite is suitable for ____hole__ separation and conduction band maximum is suitable for ____electron___ separation.

   Mention the reason why perovskites have high diffusion length (>1 micon) or high carrier mobility.

   Perovskite materials have high crystallinity with less defects, hence they have high carrier mobility and high diffusion length.

5. The OCV of a Si solar cell is always smaller than its bandgap 1.12eV. Explain the reason in 1-2 sentences.

   V_{oc} is always smaller than E_g even though the electrons and holes are created at the bottom of the CB and at the top of the VB respectively. Because V_{oc} is the difference between two E_F of n-Si and p-Si and both the E_F are located inside the energy band gap, V_{oc} is always smaller than E_g.

6. In a practical Si solar cell the fill factor is always less than 1. Explain the reason in 1-2 sentences.

   The Fill factor which is given by (V_{max}*I_{max}/V_{oc}*I_{sc}) is always smaller than unity. When the maximum power is extracted from a solar cell with optimal load, the V_{max} and I_{max} are always smaller than the V_{oc} and I_{sc}.

7. Mention one advantage and one disadvantage of using hole transport medium instead of liquid electrolyte in dye-sensitized solar cells.

Advantage of hole transporting medium (HTM) is that it will not leak unlike liquid electrolytes. One disadvantage of HTM is that it cannot make contact with all dye molecules which are absorbed on surfaces of TiO_2. The viscosity of HTM is high that it cannot pass through all nano-pores to wet all dye molecules hence the efficiency will be low as compared to liquid electrolytes.

8. Mention five predominant recombination processes in a perovskite solar cell (no need to draw figure, only mention between what and what).

Refer to you lecture slides please..

9. Select the most fast process among the following in a dye-sensitized solar cell:

~~(a) Electron transport within TiO_2~~

(b) Electron transfer from the LUMO of the dye molecule to the conduction band edge of TiO_2

~~(c) Electron transfer from Fermi level of TiO_2 to the HOMO level of dye molecule~~

~~(d) Electron transfer from Fermi level of TiO_2 to the redox level of the electrolyte.~~

Give possible reason for this fast process just in one sentence.

Due to energetic reason that the LUMO of dye molecules is just above the conduction band edge of TiO2, this electron injection process is too fast in femto seconds.

10. The bandgap of quantum dots is always __higher _ than the band gap of corresponding bulk semiconductor. Explain the reason in 1-2 sentences.

Quantum dots have discrete energy levels due to quantum confinement as compared to bulk which has continuum energy levels. In quantum dots of 3-8nm size, upon removing few atoms, the photons emission will have wavelength which is blue shifted. This confirms that quantum dots have higher bandgap than bulk semiconductor.

11. Impedance measurement at different frequencies are referred to measure different processes within a dye sensitized solar cells as compared to DC measurement. Which process occur at very low frequency (say in mHz – 1Hz range). Provide your reason why this process is too slow.

At low frequency ionic diffusion occurs.
Ionic diffusion is slow due to heavy mass and hence this diffusion of ions occurs in large time scale or at low frequency.

12. In a dye sensitized solar cell device, micron sized TiO_2 is used to as blocking layers. Provide one reason (1-2 sentence) for designing this blocking layers.
Micron size TiO_2 is used on top of dye coated TiO_2 nanoparticles to trap the scattered light radiation from the TiO_2 nanoparticles. This process helps in absorbing more light radiation by the dye molecules.

13. At room temperature in Si semiconductor, we expect certain amount of electrons in conduction band and same amount of holes in valance band. (i) Explain why you these carriers appear at room temperature in these bands and (ii) explain why notice same amount of electrons and holes occur.
At room temperature, we have certain amount of electrons in conduction band and same amount of holes in valance band due to thermal excitations.
In an intrinsic semiconductor, the number of holes created in valance band is the same as the number of electrons excited to the conduction band due to thermal excitations.

14. In a fuel cell what is the driving force for the OCV? Provide your answer precisely in 2-3 sentences.

The Fermi level of electrons corresponding to hydrogens at the anode is at higher energy compared to the Fermi level of the electrons belonging to the oxygens at the cathode. In view of this energy difference, we notice the OCV. Due to this, the electrons will flow spontaneously from anode to cathode if connected through the external circuit.

15. In semiconductors, with increasing doping level the Fermi level for electron __increase____while the Fermi levels for holes __decrease_ . Provide your explanation, enter relevant equations if required.

As seen from the equations below, upon donor doping the Fermi level for electrons will move up and upon acceptor doping the Fermi levels for holes will move down with doping level.

$$\boxed{\begin{aligned} E_F - E_i &= kT \ln(N_D/n_i) \\ E_i - E_F &= kT \ln(N_A/n_i) \end{aligned}} \qquad \begin{aligned} &\ldots N_D \gg N_A, \quad N_D \gg n_i \\ &\ldots N_A \gg N_D, \quad N_A \gg n_i \end{aligned}$$
