NATIONAL UNIVERSITY OF SINGAPORE

ESP5403 – NANOMATERIALS FOR ENERGY SYSTEMS
(Semester 1 : AY2020/21)

Time Allowed : 2.5 Hours

Total Marks: 60

INSTRUCTIONS TO STUDENTS:

1. Please write your Student Number only. Do not write your name.
2. This assessment paper contains **FOUR** questions and comprises **NINE** Printed pages.
3. Students are required to answer **ALL** questions.
4. Students should write the answers for each question on a new page.
5. This is an **OPEN BOOK** assessment.

Question 1

(Marks 18)

(a) Consider a proton exchange membrane fuel cell (PEMFC) and its voltage curve shown below in Figure 1. Possible voltage losses are shown in the same Figure. Explain in 1-2 sentences the cause for each of these voltage losses.

$H_2 + ½ O_2 \rightarrow H_2O$

Theoretical voltage at 80ºC is 1.20V

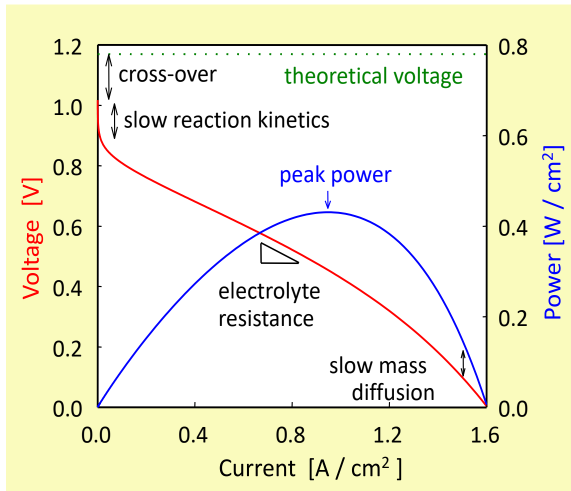

Figure 1

(8 marks)

(b) Figure 2 presents schematic diagram of a Solid Oxide Fuel Cell (SOFC).

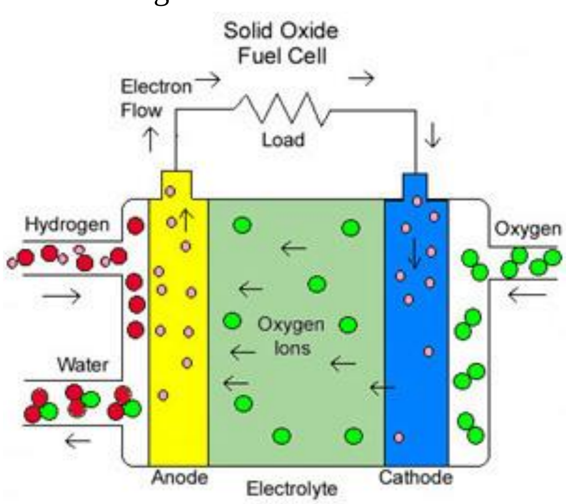

Figure 2

(i) Explain in detail working principle of this SOFC, mentioning driving force for electricity generation in the external circuit and cause for the water formation at the anode (2-4 sentence).

(ii) Mention possible electrolyte, possible anode and possible cathode used in SOFC.

(iii) Mention appropriate reactions at both the anode and cathode.

(iv) Explain the reason for the diffusion of oxygen ions through the electrolyte in this fuel cell (1-2 sentence).

(v) Provide one advantage and one disadvantage Solid Oxide Fuel Cell as compared to Proton Exchange Membrane Fuel Cell.

(10 marks)

Question 2

(Marks 13)

(a) Write a brief (1-2 lines) definition for each of the following:

(i) drift velocity

(ii) effective mass

(iii) Electrolyte

(5 marks)

(b) Figure 3 shows the directions of electron diffusion flux and current densities in a rectangular bar of Silicon and x is measured in μm. The electron concentration varies linearly from 1×10^{17} to 7×10^{16} cm^{-3} between the two ends at T = 300 K. Calculate the diffusion current density, if the electron mobility is, $\mu_n = 9.62\times10^3$ $cm^2\, V^{-1} sec^{-1}$.

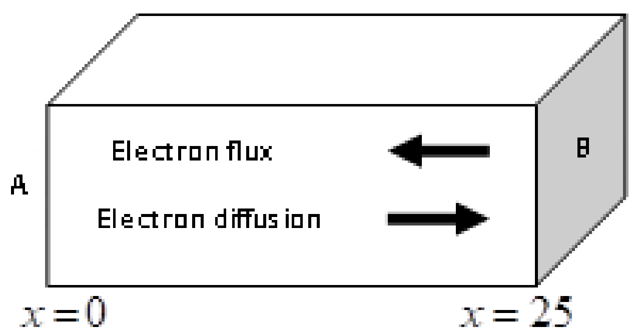

Figure 3

(3 marks)

(c) Consider a silicon p-n junction at T=300 K with the following parameters:

$N_d=10^{16}$ cm^{-3} $\quad$ $N_a=5\times10^{18}$ cm^{-3}

$D_p=10$ cm^2/sec $\quad$ $D_n=25$ cm^2/sec

$\tau_{n0}=5\times10^{-7}$ sec $\quad$ $\tau_{p0} = 10^{-7}$ sec $\quad$ & $n_i = 1.5\times10^{10}$ cm^{-3}

Assume that excess carriers are uniformly generated in the solar cell and for one sun, J_L=15 mA/cm^2. Calculate the open circuit voltage.

(5 marks)

Question 3

(Marks 12)

(a) With a neat diagram, explain the 2-probe and 4-probe resistance measurements on a device under test (DUT). Discuss the reason for the observed advantages of 4-point measurement.

[4 marks]

(b) Upon impedance measurement of a semiconductor, we observe an impedance spectrum as shown in Figure 4. Write down the equivalent circuit for the observed impedance spectrum and calculate the capacitance of the semiconductor:

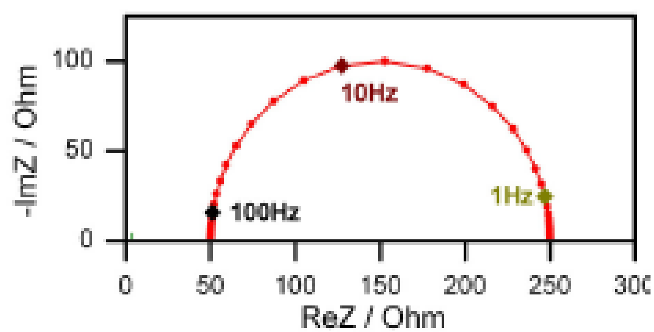

Figure 4

[4 marks]

(c) Figure 5 shows complex impedance spectra obtained for a single crystal and microcrystalline Yttria-stabilized Zirconia (YSZ) bulk specimens.

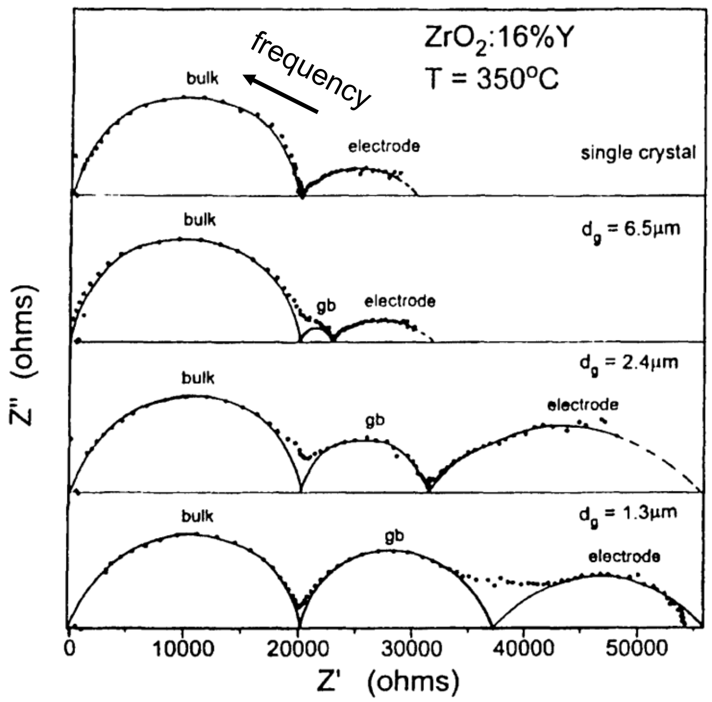

Figure 5

(i) Explain the reason for the observed semicircles (electrode contribution) at low frequency in Yttria-stabilized Zirconia single crystal.

(ii) With decrease in grain size of this YSZ, explain observed changes in the impedance spectra (consider only bulk and grain boundary contributions, ignore electrode contribution at low frequency).

[4 marks]

Question 4

(Marks 17)

(a) Figure 5 shows the energy level diagram of dye-sensitized solar cell in dark.

(i) Site four errors in the diagram and redraw it correctly.

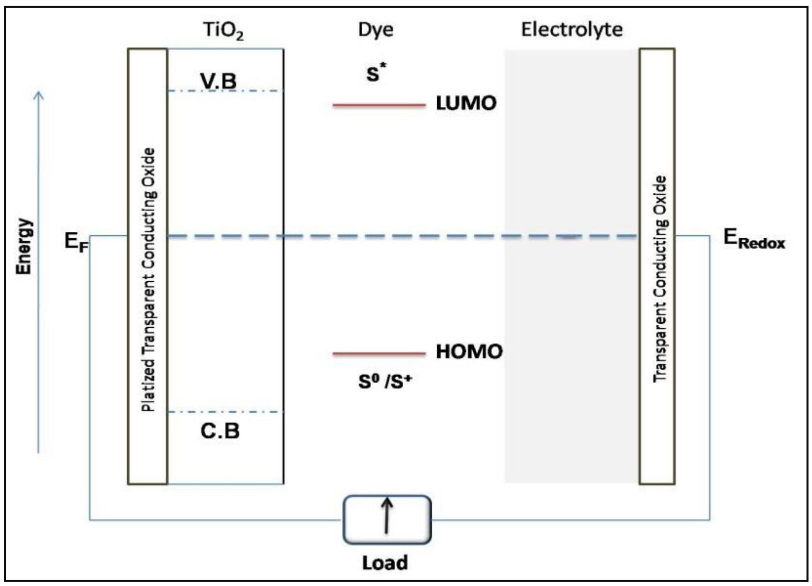

Figure 5

(ii) With the help of the correct diagram which you sketched for part (i), draw the corresponding energy level diagram when the cell is illuminated with light. Indicate the direction of electron movement by arrows. Also, indicate the possible recombination path ways.

[8 marks]

(b) Consider the cathodes and anodes given in the Figure 6 below:

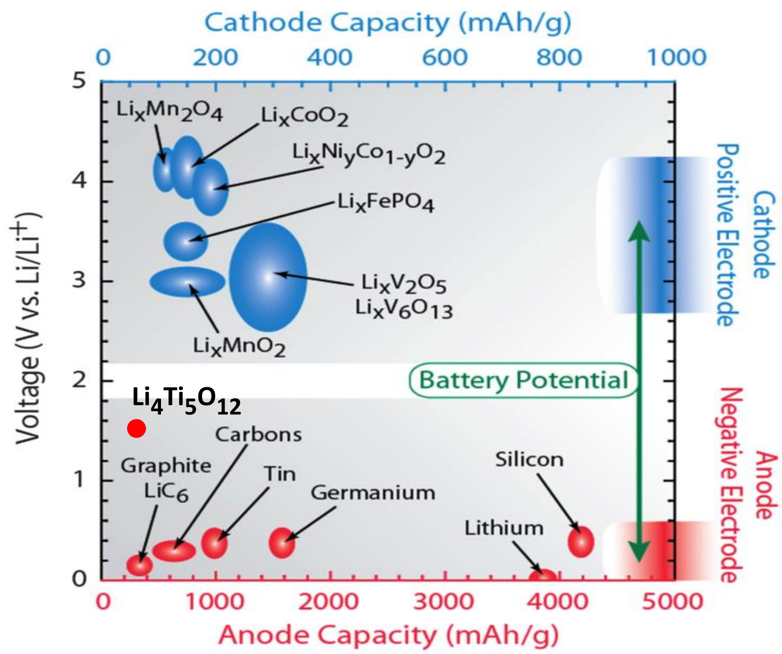

Figure 6

Cathode material $LiCoO_2$ in micron size has redox potential of 4.1V and storage capacity of 140 mAh/g, while carbon coated $LiFePO_4$ ($LiFePO_4/C$) in nanosize has redox potential of 3.4V and storage capacity of 170mAh/g.

(i) Explain why $LiFePO_4$ is carbon coated while $LiCoO_2$ is not carbon coated.

(ii) Explain why $LiFePO_4/C$ is chosen in nanosize while $LiCoO_2$ is in micron size.

(iii) Compare the lithium storage mechanisms in graphite and Si anode materials. Also mention advantage and disadvantage (at least one each) of both graphite and Si anode materials.

(iv) Given both $Li_4Ti_5O_{12}$ (LTO) and graphite anodes, we observe that LTO (10,000 cycles) has longer cycle life than graphite (1000-2000 cycles). Provide at least two reasons.

[5 marks]

(c) Both mesoporous TiO_2 as well as TiO_2 nanoparticles are used in dye-sensitized solar cell and lithium battery.

(i) Mention two advantages of mesoporous TiO_2 as compared to TiO_2 nanoparticles while used in dye-sensitized solar cells?

(ii) What are the two advantages of mesoporous TiO_2 as compared to TiO_2 nanoparticles while used for lithium storage?

(iii) Why mesoporous TiO_2 has higher electronic conduction as compared to TiO_2 nanoparticles?

[4 marks]

---*END OF THE QUESTION PAPER*---