

ME 446.671 Fuel Cell Science and Technology

Final Exam

2007 Jul 7 14:30~16:30

1. (15 pts) A hydrogen fuel cell vehicle uses a 100kW motor for good acceleration. The fuel cell vehicle uses a power conditioning unit that changes dc input from the fuel cell to ac power for the motor. The efficiency of the unit is 80%.

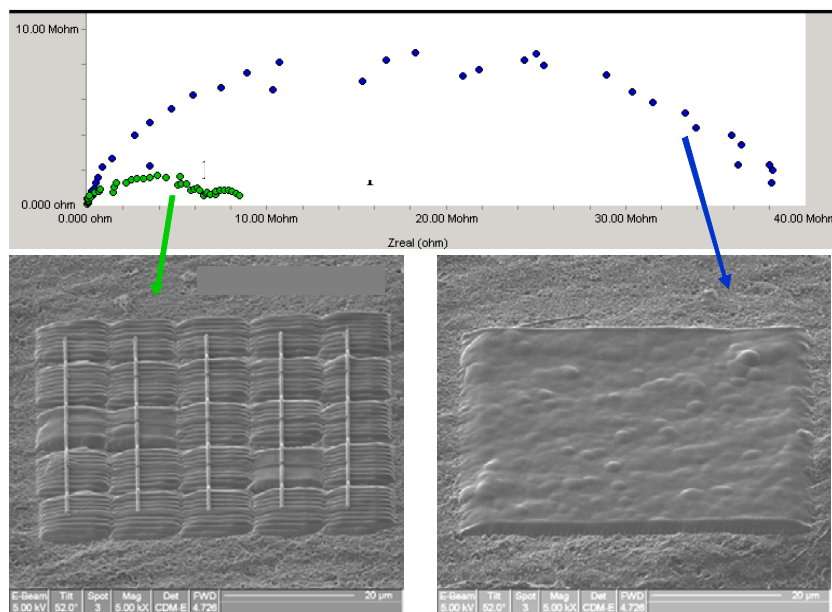
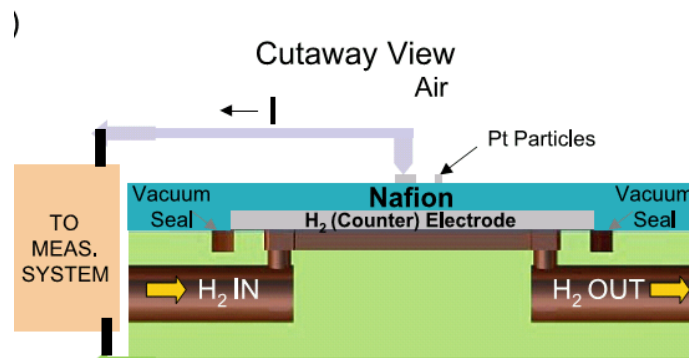
The I/V characteristic of a unit fuel cell is measured to be

$$V(V) = 1.0 - 500 \times 10^{-6} I(A)$$

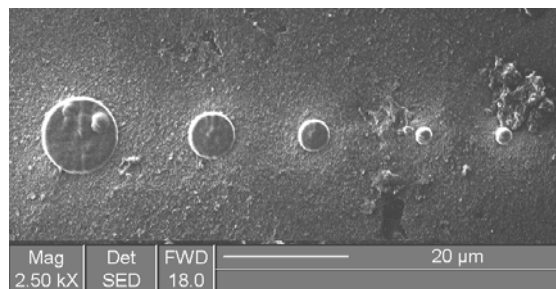
The maximum internal heat dissipation capability of the unit cell is 300 W. Assuming product water exits in vapor form only, find the input voltage of the fuel cell to the power conditioning unit if the smallest possible number of unit cells are used. (you may use 241.8 kJ/mole as hydrogen/oxygen reaction enthalpy.)

2. (10 pts) We fabricated a special PEMFC with normal the anode but with the special cathode composed of two *platinum particles*. The anode side has the normal structure, say, Pt/C catalyst and carbon cloth electrode of 2 cm² area. But, the cathode Pt particle is only 50 um X 50 um size each. A special experimental setup has been developed to measure the performance of the fuel cell with normal anode and the very small Pt particle cathode (see the 1st figure). Pure hydrogen is provided to the anode with parallel flow channel. At the cathode, a microprobe is in contact with one Pt particle that is exposed to the ambient air. Using this setup, we can measure the fuel cell performance of each Pt particles on the cathode.

2nd figure shows the how two Pt particles looks like. Two particles have identical sizes of 50 um X 50 um. One particle has a pattern of single flat square shape. But, the other has internal patterns of 25 squares which gives 5 times more perimeter than the first particle. At OCV, we measure the EIS of the two particle fuel cells respectively. The result is also shown in the 2nd figure. Interestingly, even though two particles have same area, the impedance measurement exhibits quite different result. Explain the reason of impedance difference quantitatively.



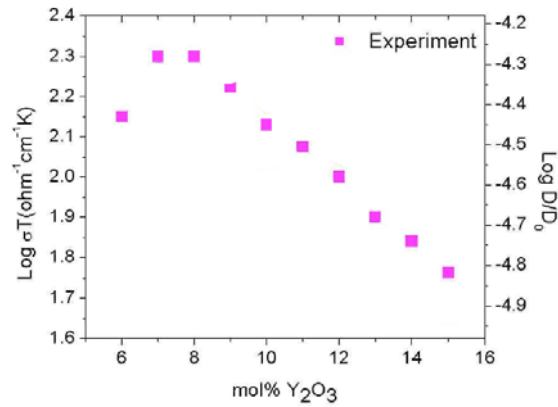
3. (10 pts) We continue our experiments from previous problem. Now, we use circular Pt particles of different diameter (see the figure). We measure the Faradaic (or charge transport) resistance of each particles. From the measurement result, 1μm diameter particle has 10 MOhm Faradaic resistance.



a) Assuming we have an ideal fuel cell, find the Faradaic resistance for 10 μm diameter particle

b) Establish the relationship between Faradaic resistance and particle size. In other word, sketch a curve in the plot with log of Faradaic resistances as y axis and log of the particle diameter as x axis. What is the slope of the curve?

4. (15 pts) It is well known that the oxygen ionic conductivity of YSZ is a strong function of Yittria mole fraction in Zirconia as shown in the figure.

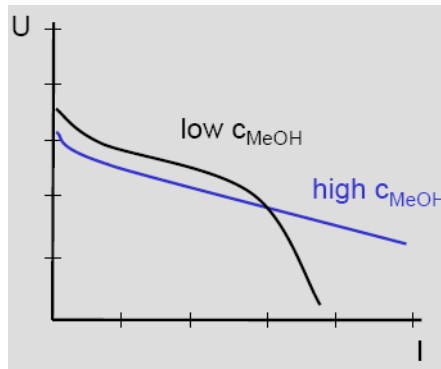


From the class, we learned that ionic conductivity can be expressed as

$$\sigma = \frac{c(z_i F)^2 D}{RT}$$

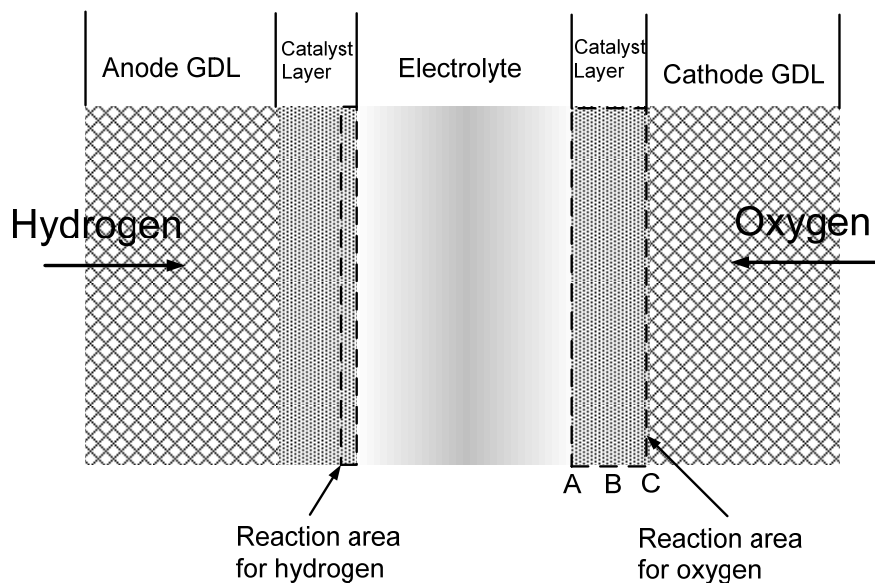
Explain qualitatively how the Yittria mole fraction affects the variables in the above equation to results in the change of YSZ conductivity as shown in the figure (say, why optimum mole fraction exists.).

5. (15 pts) The following figure shows a typical IV curve from DMFC stack when low concentration methanol and high concentration methanol are provided respectively. Qualitatively explain the difference of polarization curve in terms of typical fuel cell internal losses.



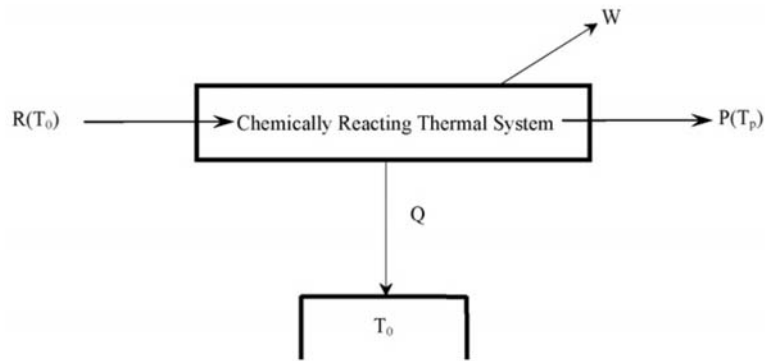
6. (20 pts) A typical hydrogen-oxygen PEMFC anode and cathode are made of carbon cloth gas diffusion layer (GDL) electrode layer and Pt/C catalyst layer. Carbon cloth GDL provides diffusion path for gases and conductive path for electrons. In Pt/C catalyst layer, mixed porous structure of carbon-supported platinum powder and Nafion fibers provides electronic conduction, ionic conduction, and gas diffusion path for electrochemical reaction on platinum surfaces. In other words, triple phase boundary exists throughout $\sim 10\mu\text{m}$ thickness of the catalyst layer.

Research showed that when PEMFC operates at *medium current density*, oxygen reduction at the cathode uses all available triple phase boundary throughout the 10 μm thickness of the catalyst layer. However, hydrogen oxidation at the anode uses only 1 μm thick area close to the electrolyte. (see figure) In other words, hydrogen oxidation uses only 10% of available triple phase boundary in the catalyst layer. From this observation answer the following questions. (Note: this may be a fairly difficult question with no clear answer. Write down your logical thought and I'll give scores accordingly)

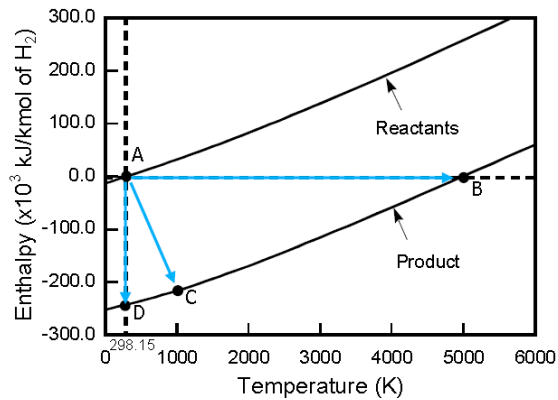


- Qualitatively explain why hydrogen uses less reaction area.
- Why hydrogen reaction zone is formed near electrolyte?
- At the cathode catalyst layer, which part is most active for oxygen reduction reaction through thickness among A, B and C? Justify your answer.
- Repeat the question b) if the fuel cell operates at very high current density (close to limiting current density).
- If the fuel cell operates at low current density, what change do you expect to observe about the thickness of active reaction area at the anode? Is it going to be thicker or thinner or same?

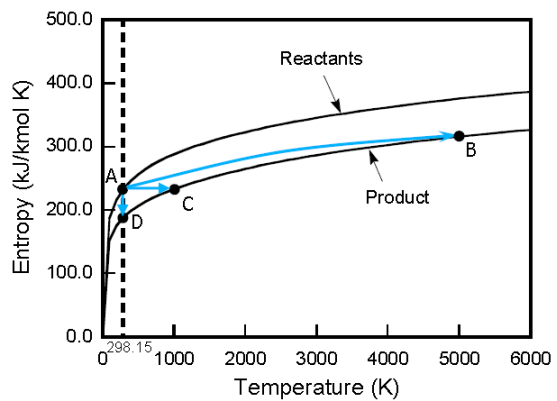
7. (15 pts) Let's assume a ideal thermodynamic device with following configuration.



Reactants at ambient temperature T_0 enter the device and products exit at temperature T_p . Through the chemical reaction in the device, it generates some work, W . At the same time the device releases heat, Q to the environment at ambient temperature T_0 . (Hints: use thermodynamics laws and following enthalpy and entropy charts of reactant and products)



(a) Enthalpy



(b) Entropy

- Establish the equation describing the relation between enthalpy of the reactants, H_R and products, H_P .
- Establish the equation describing the relation between entropy of the reactants, S_R and products S_P .
- Using equations from a) and b), show that W is equal to Gibb's energy if the devices is an ideal fuel cell. (Hint: ideal fuel cell operates in isothermal condition)