2.626 Fundamentals of Photovoltaics
Fall 2008

2.626 – Fundamentals of Photovoltaics

Quiz #2 – November 4, 2008

Quiz Instructions

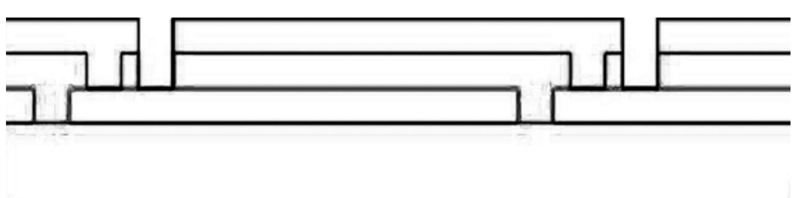
This quiz, consisting of six (6) questions, is a take-home examination. All written resources (books, websites, class notes) are at your disposal. This is an individual effort. Do not talk, discuss, or otherwise share information pertaining to this quiz with others. Each class participant is expected to complete the quiz on her or his own. The quiz will be handed out Tuesday November 4th, and is due completed in class on Thursday November 13th.

Part 1: Descriptive Differences Between Technologies.

1. Cell & Module Architectures (6 points)

a) **Thin films on glass:**

  i. Sketch a cross section of an amorphous silicon solar cell module, starting from the glass panel on one side and ending with the glass panel on the other side, and including all device layers such as the transparent conducting oxide (TCO). Label each component and specify approximate thickness dimensions. Sketch does not have to be to scale. You may use the partial sketch below as a starting point (NB: (a) that this drawing denotes the separation of adjacent devices by laser processing; (b) this drawing is incomplete, as it does not illustrate the glass panels on both sides nor encapsulation material).



  ii. On your sketch, specify the direction sunlight enters the module.

  iii. On your sketch, specify the direction of current flow (positive charge flow) within the device under operating conditions (illumination).

  iv. How might the use of a conducting substrate (e.g., stainless steel) change the device and module architecture?

b) **Crystalline silicon:** Sketch a cross section of a crystalline silicon module, starting from the glass panel on one side and ending with the back sheet on the other. Label each component and specify thickness dimensions. In a separate drawing, draw the cross section of a solar cell device, including aluminum back contact, front contacts, anti-reflection coating, and other device features, labeling each component and specifying approximate dimensions. Sketch does not have to be to scale. Specify what direction sunlight enters the module.

2. Cell & Module Properties (3 points)

a) On the basis of realistic **commercial** module efficiency estimates, and the materials specified in Question #1 (excluding processing and labor costs), provide an estimate for:
   i. Dollars per watt peak ($\$/W_p$)
   ii. Kilograms per square meter (kg/m^2)
   iii. How do your calculations relate to the adage, "all manufacturing goods cost roughly $(20-25)/kg"? Is this true also for PV technologies?

b) Given your work thus far, describe one way of reducing the $\$/W_p$ of each: a thin film and a crystalline silicon module.

c) Describe one terrestrial application in which kg/m^2 is a limiting factor for technology adoption.

d) Pointing to specific elements of your sketches in Question 1, describe one way of reducing the kg/m^2 of each: a thin film and a crystalline silicon module.

Part 2: Evaluating Performance.

3. Performance Limiting Parameters (3 points)

a) Draw a line connecting each *material parameter* in the left column to the *device parameter* in the right column that it most strongly impacts:

Material Parameters	Device Parameters
Energy band misalignment	FF
α (optical absorption coefficient)	V_{oc}
μ (charge carrier mobility)	J_{sc}

4. Solar Cell Performance at Operating Conditions (6 points)

a) Starting with the ideal diode equation:

$$I = I_o\left(e^{qV/kT} - 1\right) - I_L$$

Derive a mathematical expression for the temperature dependence of V_{oc}, J_{sc}, FF, and η.

b) For a wafer-based silicon solar cell, plot the four curves (V_{oc} vs. T, J_{sc} vs. T, FF vs. T, and η vs. T) on the same graph, using a relative scale. Start all curves at "1" at 25 °C, and plot up to 60 °C). Label each curve.

c) Repeat (a) and (b) above for a cadmium telluride solar cell.

5. Solar Cell Performance (6 points)

Given the Quantum Efficiency (QE) measurement data for a silicon solar cell posted at:

http://pv.mit.edu/iqe_data

calculate each of the solar cell device parameters below, or explain what additional information is needed to complete the calculation.

i. Short-circuit current density (J_{sc})
ii. Open-circuit voltage (V_{oc})
iii. Fill factor (FF)
iv. Efficiency (η)

6. Solar Cell Diagnostics (6 points)

Given the IV curve posted at:

http://pv.mit.edu/iv_data

a) Determine current density at maximum power point (J_{mp}) and voltage at the maximum power point (V_{mp}).

b) Determine FF, J_{sc}, V_{oc}, and efficiency.

c) Determine series resistance (R_s) and shunt resistance (R_{sh}).

d) What device efficiency would result, if R_s were 10x larger?