2.626 Fundamentals of Photovoltaics
Fall 2008

2.626 – Fundamentals of Photovoltaics

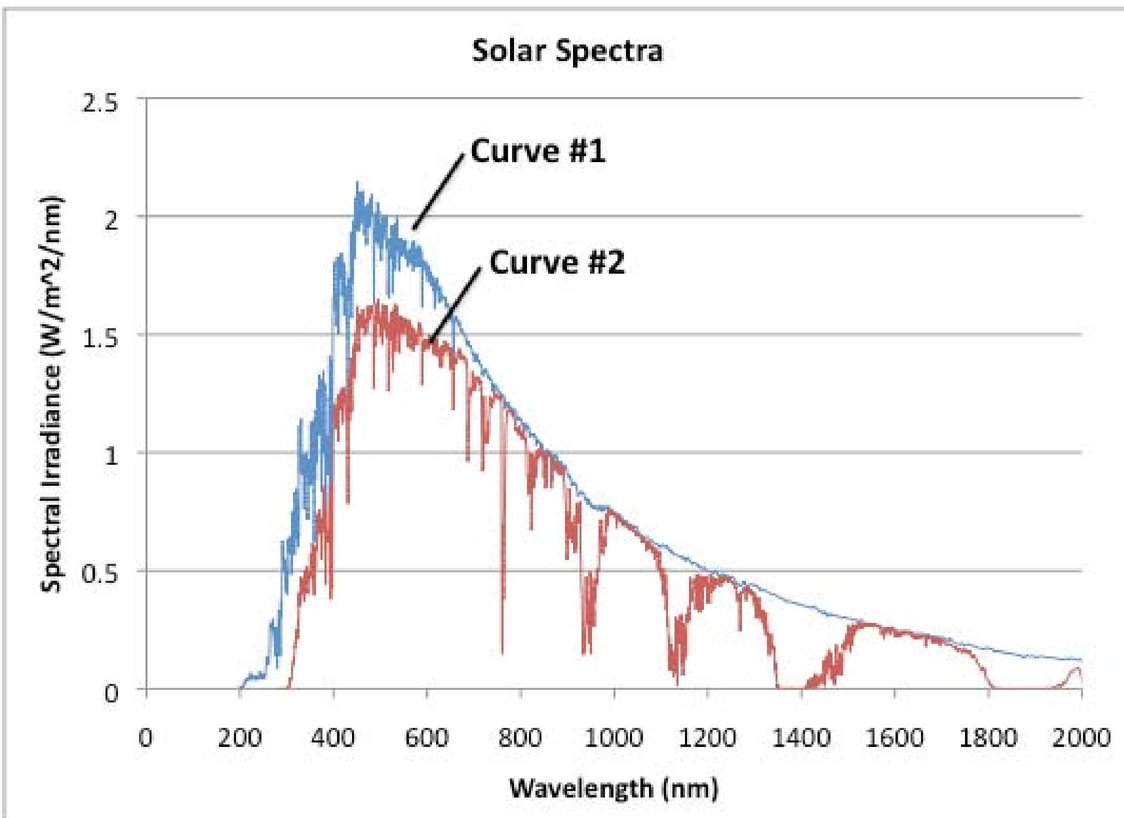
Quiz #1 – October 7, 2008

Question 1: Solar Resource

1. What words does "AM" stand for, in the context of solar spectra (e.g., AM0, AM1.5)? [1 pt.]

2. On the graph below, specify which curve (#1 or #2) is AM0, and which is AM1.5. [1 pt.]

Figure 1



3. On the graph above, what physical phenomenon is responsible for curve #2 being greatly attenuated in the short wavelengths, relative to curve #1? [1 pt.]

4. On the graph above, mark which wavelengths ranges correspond to ultraviolet (UV), visible, and infrared (IR) light. [2 pt.]

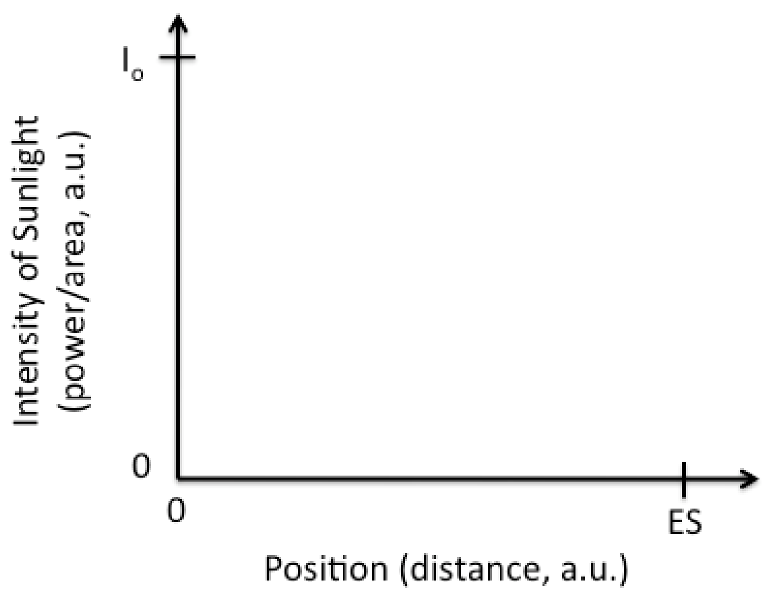
5. Values of insolation for fixed (non-tracking) systems are typically provided assuming latitude tilt. For Boston, this value is approximately 4.6 kWh/m^2/day. Calculate the amount of energy a 40 kW$_p$ flat roof-mounted system (e.g., mounted flat against the horizontal rooftop of a large department store) will produce in Boston (42° North, 71° West), over the course of one year. [3 pt.]

6. Theoretically, how much more energy would this system produce, if it were tiled at latitude tilt? [1 pt.]

7. List one practical consideration, which might make "latitude tilt" infeasible in the case of a large department store. [1 pt.]

8. Consider three wavelengths: 320 nm, 550 nm, and 1000 nm. On the graph below, plot the relative intensities of incoming solar radiation as it travels through the atmosphere, as a function of distance to a given point on the Earth's surface, for the three wavelengths above. [3 pt.]

Figure 2



0 = Outer Atmosphere; ES = Earth's Surface

9. What equation would you use, to describe the absorption of light shown in the plot above? *(No numbers, just variables or a name.)* [2 pt.]

10. Which component of the solar spectrum would increase more strongly in Miami relative to Boston: the ultraviolet or the visible? [2 pt.]

Question 2: Charge Excitation

Figure 3

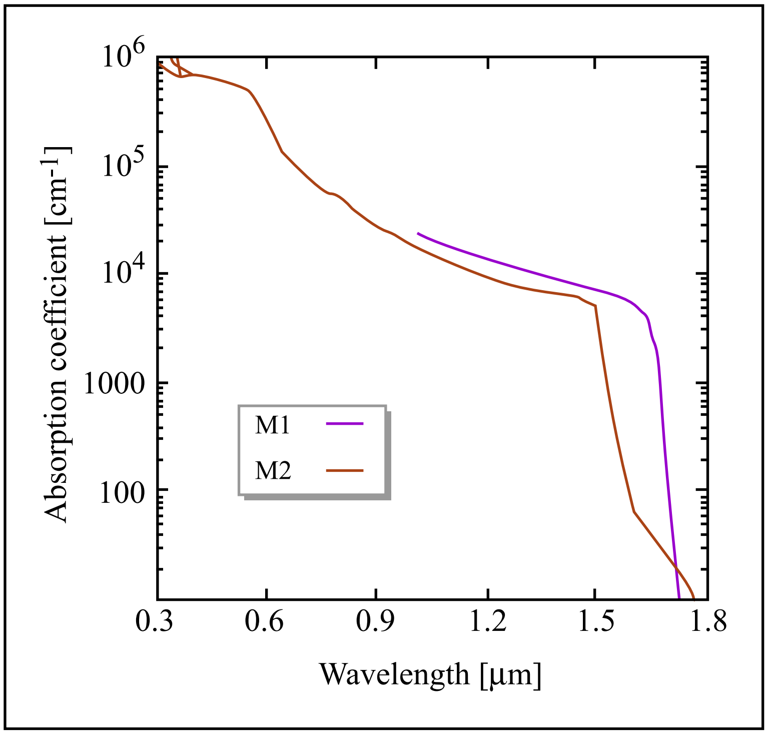


Figure by MIT OpenCourseWare.

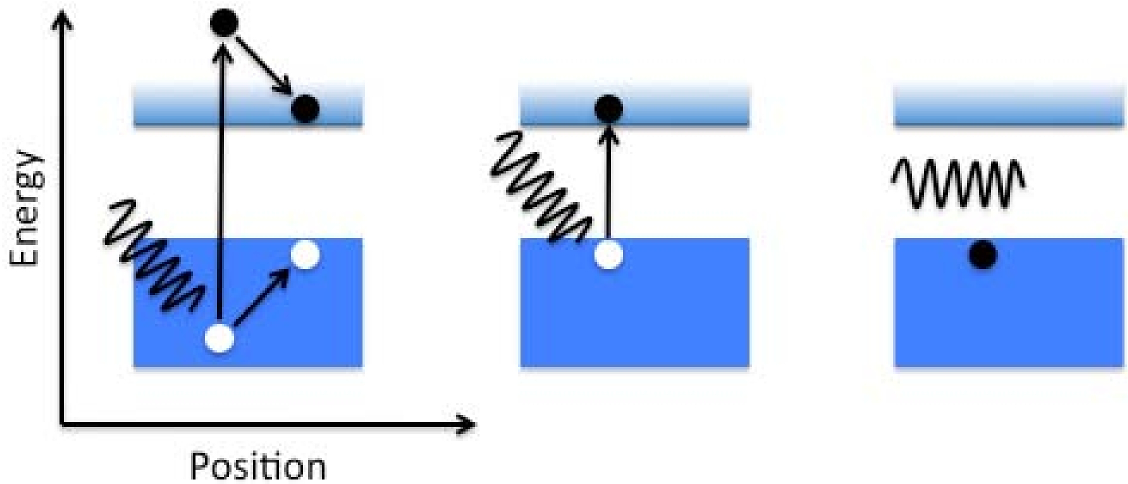
1. Consider the graph above. Circle the correct statement below. [1 pt.]

   $E_g(M1) > E_g(M2)$ $E_g(M1) \approx E_g(M2)$ $E_g(M1) < E_g(M2)$

2. For each material, state whether the bandgap is direct or indirect. [2 pt.]

3. Consider three photons, with wavelengths of 320 nm, 850 nm, and 1500 nm. For GaAs (E_g = 1.4 eV), specify which photons are correlated with the transitions below. [2 pt.]

Figure 4



4. On the figures above, indicate where thermalization losses and non-absorption losses are present. [1 pt.]

5. From Figure 5, provide the bandgap energies (in electron volts, eV) for each of the following alloys: $Al_{0.31}Ga_{0.69}As$, $Al_{0.37}Ga_{0.63}As$, and $Al_{0.55}Ga_{0.45}As$. [3 pt.]

Figure 5

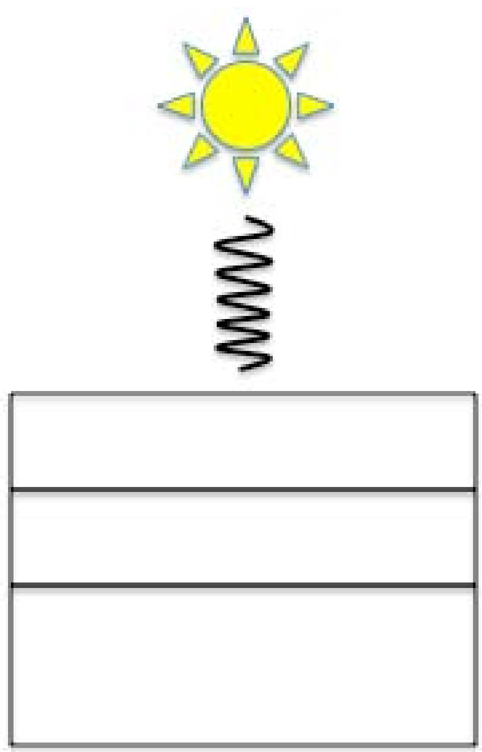
Absorption Coefficient for $Al_xGa_{1-x}As$

Image removed due to copyright restrictions. Please see Fig. 1 and 2 in Monemar, B., K. K. Shih, and G. D. Pettit. "Some Optical Properties of the Al_xGa_{1-x} As Alloy System." *Journal of Applied Physics* 47 (June 1976): 2604-2613. http://www.ioffe.rssi.ru/SVA/NSM/Semicond/AlGaAs/Figs/b14_04.gif.

6. For $Al_{0.31}Ga_{0.69}As$, $Al_{0.37}Ga_{0.63}As$, and $Al_{0.55}Ga_{0.45}As$, calculate the thickness required to absorb 85% of incident light at 540nm (near the peak of the solar spectrum). [3 pt.]

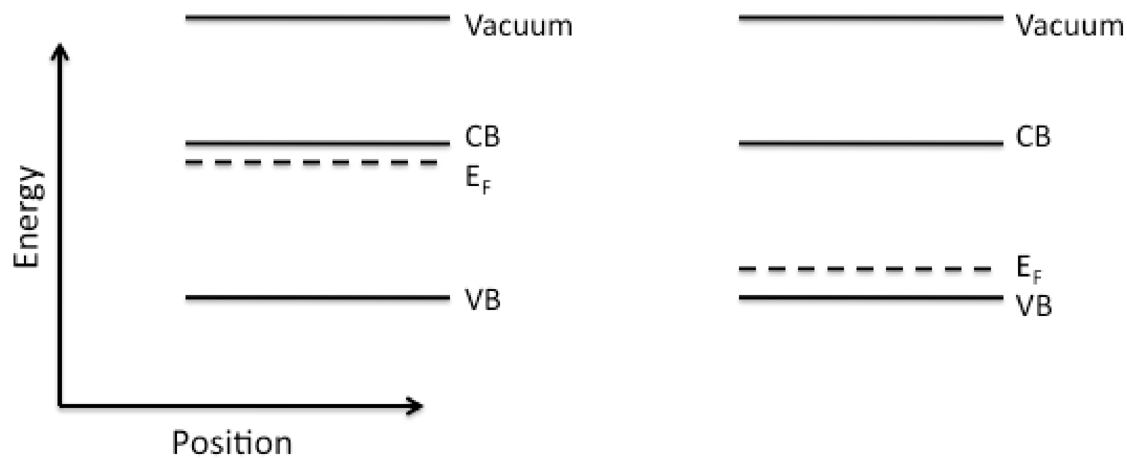
7. In homework #1, we saw how small-bandgap materials absorb light well, but lose much incident solar energy to thermalization. On the other hand, large-bandap materials have far less thermalization losses, but suffer from non-absorption of incident light (they are transparent). In principle, we can combine different materials in a stack, each of which absorbs a different portion of the solar spectrum most efficiently. Using the absorption data from Fig. 5, label the multijunction device in Fig. 6 with GaAs, AlAs, and $Al_{0.55}Ga_{0.45}As$. *(Hint: consider how the top material would absorb low- and high-energy photons, and which photons would transmit through, based on the absorption data in Figure 5.)* [4 pt.]

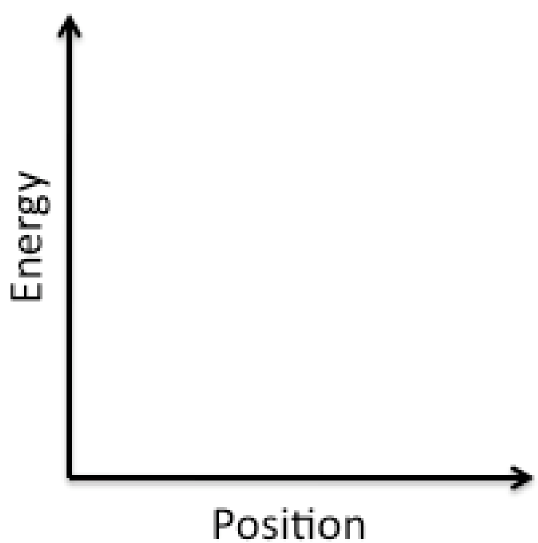
Figure 6



Question 3: Charge Separation

1. Consider the two (physically separated) semincoductor materials below. Draw the band diagram, if these two materials were placed in direct contact. Label the Fermi Level, the conduction band, the valence band, and the vacuum level. [2 pt.]



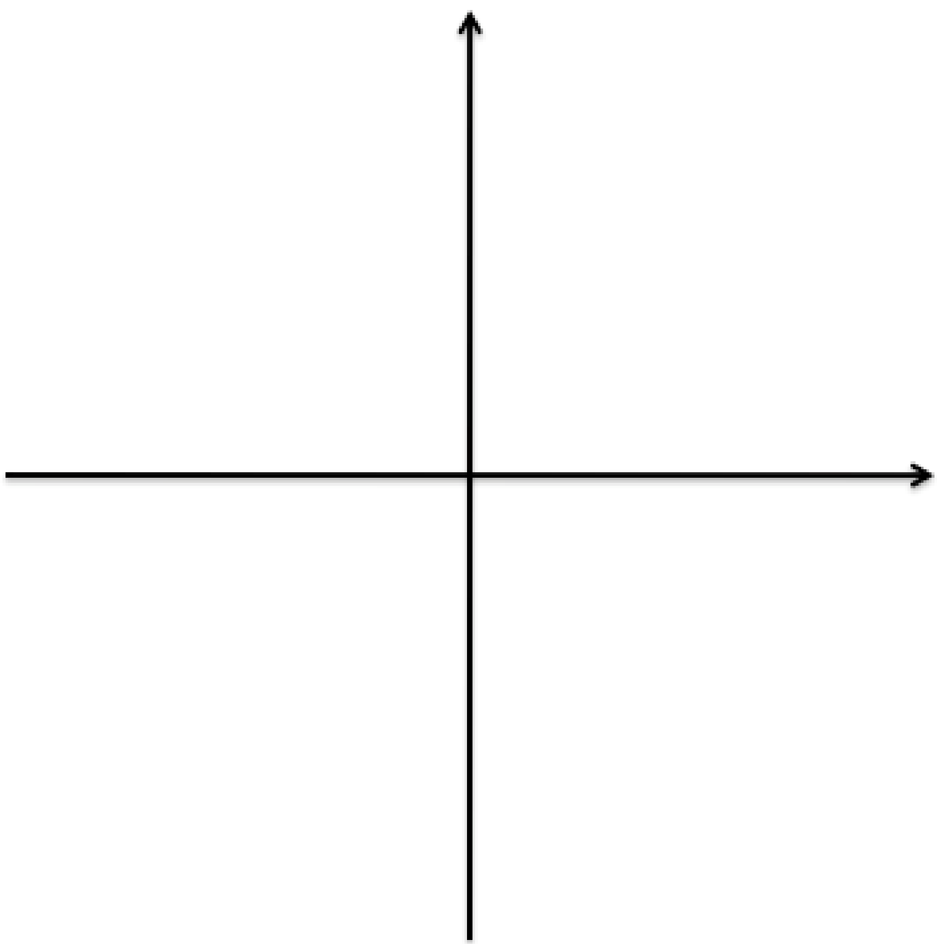


2. For the diagram in the previous question, use arrows to indicate the magnitudes (size of arrows) and directions (directions of arrows) of the electron drift and diffusion currents. [1 pt.]

3. What is the net electron current of this junction (assume in the dark and unbiased)? [1 pt.]

4. How would the net charge flow change, if the Fermi level were not position invariant? [1 pt.]

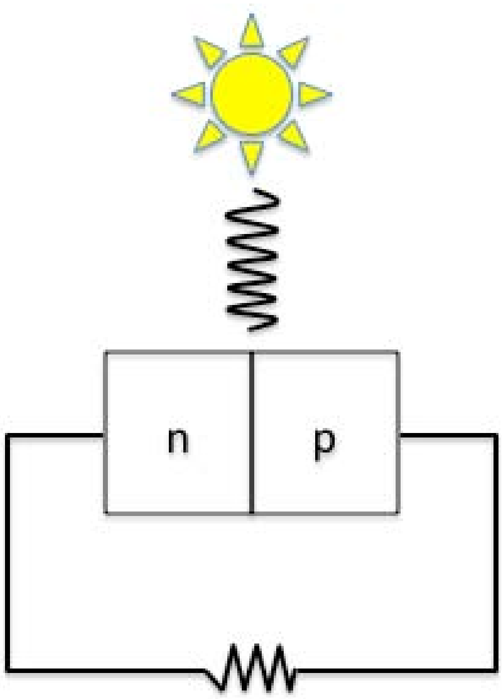
5. On the graph below, plot the current-voltage (IV) relationships for this pn-junction (a) in the dark, and (b) when illuminated. Label axes. [2 pt.]

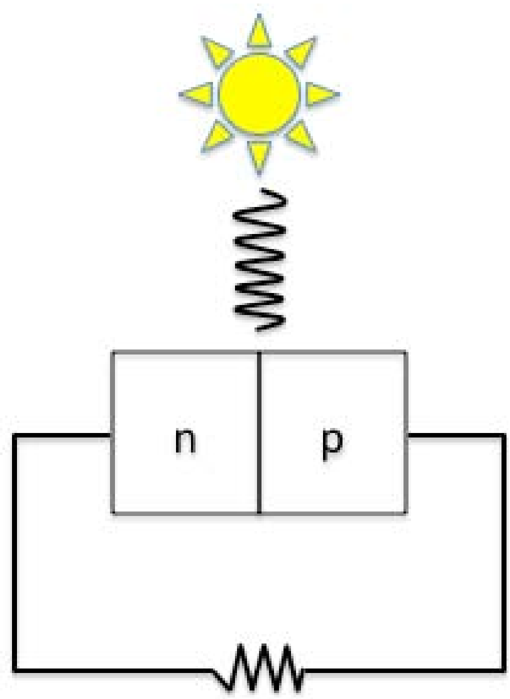


6. Write the equations used to describe each of the curves above. [2 pt.]

7. Consider the same pn junction. [4 pt.]
    a. Design in two separate sketches: a) the junction under reverse bias, b) under forward bias.
    b. Label the Fermi levels outside the depletion region.
    c. Sketch the external circuit, with the voltage source.
    d. Draw an arrow indicating the direction of current flow within the external circuit. *(Hint: Remember the convention that the direction of current flow is* *__opposite__* *to electron flow.)*

8. Consider the pn-junction of GaAs (E_g = 1.4 eV) shown below. Draw the current flow when this pn-junction is illuminated with: [3 pt.]
    a. 1500 nm light.
    b. 850 nm light.





Useful Equations

$$I = I_o\left(\exp\left(\frac{qV}{kT}\right) - 1\right)$$

$$I = I_o \cdot \exp(\alpha \cdot t)$$

$$I = I_o\left(\exp\left(\frac{qV}{kT}\right) - 1\right) - I_L$$

$$E = h\nu = \frac{hc}{\lambda}$$

$$E\ (\text{kWh/day}) = \frac{I\ (\text{kWh/m}^2\text{/day}) \cdot P\ (\text{W}_p)}{\Phi\ (1000\ \text{W/m}^2)}$$