2nd Asian Physics Olympiad

TAIPEI, TAIWAN

Experimental Competition

Thursday, April 26, 2001

Time Available : 5 hours

Read This First:

1. Use only the pen provided.
2. Use only the front side of the answer sheets and paper.
3. In your answers please use as little text as possible ; express yourself primarily in equations, numbers and figures. If the required result is a numerical number, underline your final result with a wavy line.
4. Write on the blank sheets of paper the results of all your measurements and whatever else you consider is required for the solution of the question and that you wish to be marked.
5. It is absolutely essential that you enter in the boxes at the top of each sheet of paper used your ***Country*** and your student number (***Student No.***). In addition, on the blank sheets of paper used for each question, you should enter the number of the question (***Question No.***), the ***Section label***, the progressive number of each sheet (***Page No.***) and the total number of blank sheets that you have used and wish to be marked for each question (***Total No. of pages***). If you use some blank sheets of paper for notes that you do not wish to be marked, put a large cross through the whole sheet and do not include them in your numbering.
6. At the end of the exam please put your answer sheets and graphs in order.

April/18/2001

Basic Characteristics of Solar Cells

I. Background description

The purpose of this experiment is to explore the basic characteristics of solar cells. Solar cells can absorb electromagnetic waves and convert the absorbed photon energy into electrical energy. A solar cell mainly consists of a diode, whose forward dark current-voltage relationship (i.e., I-V curve under no light illumination) can be expressed as

$$I = I_o(e^{\beta V} - 1),$$

where I_o and β are constants.

The diode is made up of a semiconductor with a band gap of $E_c - E_v$ (see Fig. 1). When the energy of the incident photon is larger than the band gap, the photon can be absorbed by the semiconductor to create an electron-hole pair. The electrons and holes are then driven by the internal electric field in the diode to produce a photocurrent (light-generated current). There are several important parameters other than light-generated current involved in a solar cell.

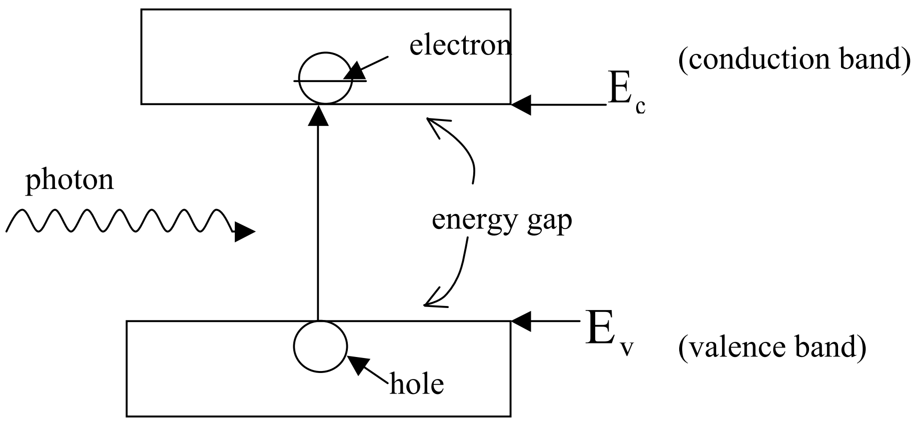

Fig. 1

Brief explanations of the terminologies and basic principles are listed below:

(1) Short-circuit current (I_{sc}) is the output current of the solar cell when the external circuit is shorted, i.e., zero load resistance.

(2) Open-circuit voltage (V_{oc}) is the output voltage of the solar cell when the external circuit is open, i.e., infinite load resistance. V_{oc} is also referred to as photovoltaic voltage.

(3) P_m is the maximum output power of the solar cell, i.e., the maximum value of $I \times V$.

(4) The filling factor (FF) is defined to be $P_m/(I_{sc}V_{oc})$, which represents an important parameter used to evaluate the quality of the solar cell.

(5) Because the photocurrent is produced by photon absorption by the semiconductor, the spectral response of the photocurrent can be used to determine the semiconductor band gap. From the band gap value, one can infer the particular semiconductor material used.

(6) Any incident photon with photon energy larger than the semiconductor band gap can contribute to the photocurrent (I_{ph}) of the solar cell, thus

$$I_{ph} \propto \int_{\lambda_C}^{\lambda_0} N(\lambda) d\lambda \ ,$$

where $N(\lambda)$ is the number of electrons per unit wavelength produced by photons with wavelength λ, λ_c is the cut-off wavelength of the optical filter (see Fig. 2, Fig. 3, and Fig. 4), and λ_o is the longest wavelength capable of producing a photocurrent. Here $N(\lambda)$ is approximately constant in the visible spectral range, and each optical filter provided in this experiment cuts off all light with wavelengths shorter than a certain cut-off wavelength λ_c. Therefore, the spectral response of I_{ph} with an optical filter can be simplified to be

$$I_{ph} \propto (\lambda_o - \lambda_c).$$

(7) The photon energy E is related to the photon wavelength as $E = 1240/\lambda$; the unit for λ is nm (10^{-9}m) and the unit for E is eV (electron-volt) in this equation.

II. Equipments and materials

(1) A solar cell in a black box with pre-installed electrical connections
(2) Two digital electrical multimeters
(3) A set of dry cell batteries (1.5 V × 2)
(4) One precision variable resistor (0-5 kΩ)
(Caution: Do not connect the central connecting lead (the red wire) of the variable resistor directly to the battery, it may damage the resisitor.)
(5) A white light source with power supply
(6) Two polarizers (Note: these polarizers are less effective for light with wavelengths shorter than that of yellow light,that is the cut-off wavelength of the yellow filter.)
(7) Red, orange, and yellow optical filters, one of each (their spectral specifications are shown in Fig. 2, Fig. 3, and Fig. 4)
(8) An optical mount for the optical filters or polarizers (Note: optical filters and polarizers can be mounted together on the same optical mount.)
(9) One optical bench
(10) Wire joining devices: 6 small springs
(11) One 45 cm ruler

(12) Regular graph paper (10 sheets), semi-log graph paper (5 sheets)
(13) Two light-shielding boards
(Note: To avoid deterioration due to heat, polarizers and filters should be set at a distance as far away from the light source as possible.)

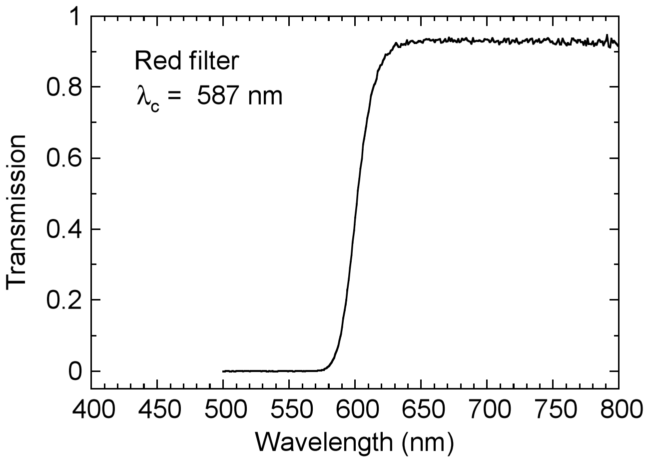

Fig. 2

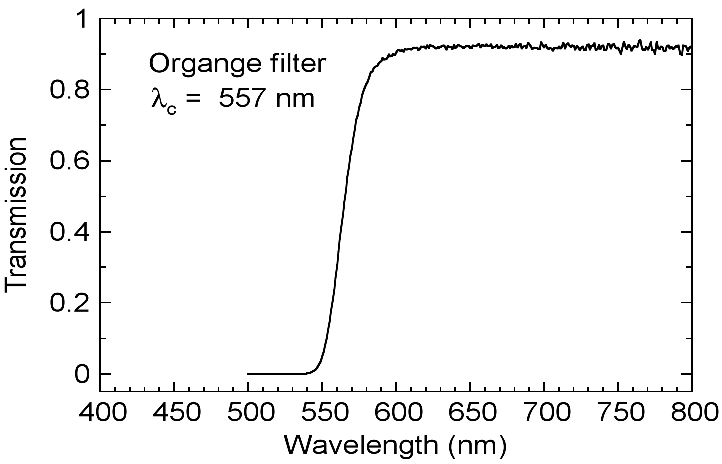

Fig. 3

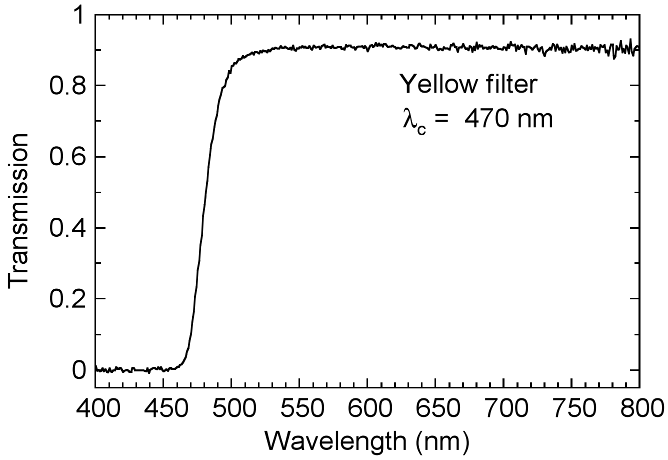

Fig. 4

III. Experimental steps

(1) (Question (1) : 3 points)

Measure the dark I-V characteristic of the **forward biased** solar cell.

a. Draw a diagram of the electrical circuit you used.

b. Plot the I-V curve and determine the values of β and I_o using the I-V data you obtained..

(2) (Question (2) : 7 points)

Measure the characteristics of the solar cell, without electrical bias under white light illumination. (Note: the distance between the light source and the solar cell box should be kept at 30 cm as shown in Fig. 5.)

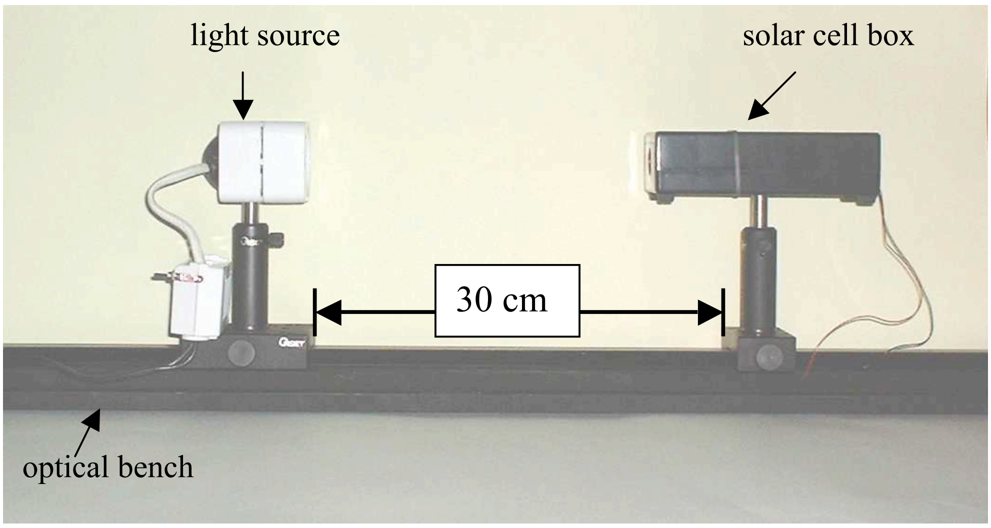

Fig. 5

a. Draw the circuit diagram you used.

b. Measure the short-circuit current , I_{sc}.

c. Measure the open-circuit voltage, V_{oc}.

d. Measure the I vs. V relationship of the solar cell with varying load resistance and plot the I-V curve.

e. Determine the maximum output power of the solar cell.

f. Determine the load resistance for the maximum output power.

g. Calculate the filling factor, $FF \equiv P_m/(I_{sc}V_{oc})$

(3) (Question (3) : 3.0 points)

Assume that the solar cell can be modeled as a device consisting of an ideal current source (light-generated current source), an ideal diode, a shunt resistance R_{sh}, and a series resistance R_s,

a. Draw an equivalent circuit diagram for the solar cell under light illumination.

b. Derive the I-V relationship for the equivalent circuit. Express the result in terms of R_{sh}, R_s, I_{ph} (light-generated current), and I_d (the current passing through the diode).

c. Assuming that R_{sh} = infinity and R_s = 0 and can be neglected, find the I-V relationship and prove that it can be written in the form as given below:

$$V_{oc} = \beta^{-1} \ell n \left(\frac{I_{sc}}{I_0} + 1 \right)$$

where V_{oc} is the open-circuit voltage, I_{sc} is the short-circuit current, and I_0, β are constants.

(4) (Question (4) : 4 points)

Find effects of irradiance.

a. Measure and plot the I_{sc} vs. relative light intensity curve, and determine the approximate functional relationship between I_{sc} and the relative light intensity.

b. Measure and plot the V_{oc} vs. relative light intensity curve, and determine the approximate functional relationship between V_{oc} and the relative light intensity.

(5) (Question (5) : 3.0 points)

Find the wavelength response of the solar cell.

a. Measure and plot the I_{sc} vs. different cut-off wavelengths using the three optical filters.

b. Estimate the longest wavelength for which the solar cell can function properly.

c. Infer which semiconductor material the solar cell is made of. (Hint: the band gaps for commonly used semiconductors are InAs: 0.36 eV, Ge: 0.67 eV, Si: 1.1 eV, amorphous Si(a-Si : H): 1.7 eV, GaN: 3.5 eV)