Experiment No:

Spectral Response Measurement

1. Title: Spectral Response/ Quantum Efficiency of Solar Cell

2. Objectives:

 To measure the spectral response of solar cell and

 to learn about quantum efficiency

3. Expected outcome of experiment:

An understanding of the response of a solar cell to light of different wavelengths
Determination of external quantum efficiency from spectral response and vice versa

4. Theory:

Figure shows the photon flux received from the sun over wavelengths 300 to 1200 nm (Figure 1 taken from Ref [2] listed at the end)

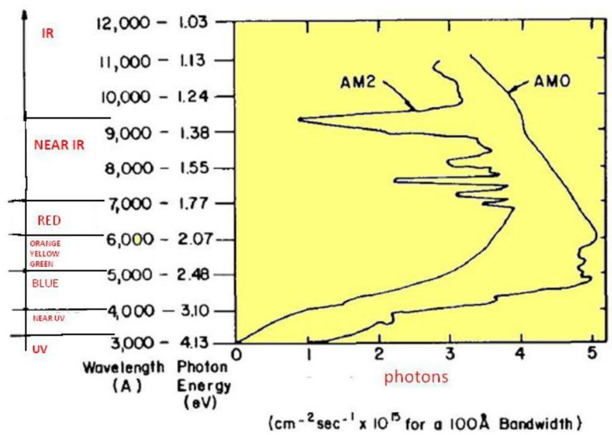


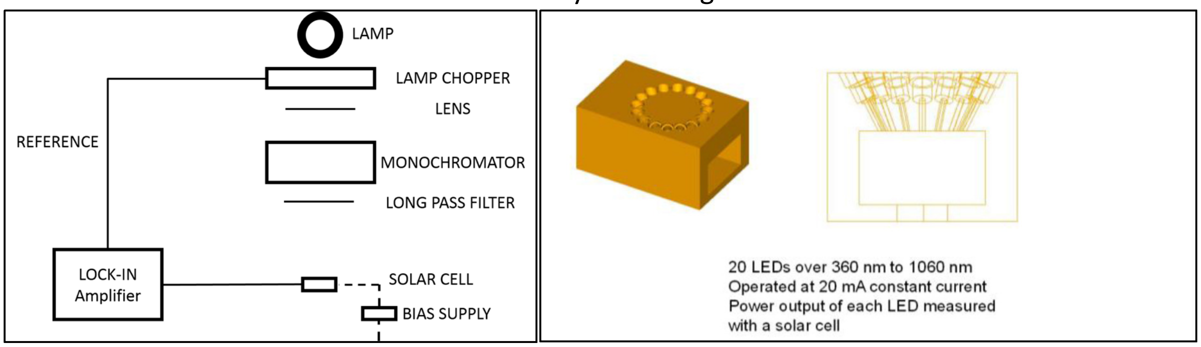
Figure 1

Spectral response is sensitivity of a cell to light of different wavelengths. Technically, spectral response is measure of "short circuit current per unit light power" expressed as A/W (or mA/mW or µA/µW), measured with spectrally pure light (narrow band width) over a broad range of wavelengths corresponding to the spectrum of solar radiation. Spectral response of a solar cell is typically zero for wavelengths longer than the band gap energy E_g of semiconductor i.e. for $\lambda > \lambda_g$ * λ_g (µm) = 1.24/ (E_g (eV)]; it rises sharply for $\lambda < \lambda_g$ and trails off again for $\lambda << \lambda_g$.

Another commonly used parameter to express the sensitivity of a cell to light of different wavelengths is "external quantum efficiency", electrons per photon, which is simply connected to spectral response of the cell. Furthermore, product of spectral response and solar radiation flux over a small wavelength interval, summed over the wavelength range of solar spectrum gives the expected short circuit current, a key parameter of the performance of the cell. If the cell responds poorly at some wavelengths , there may be some underlying i) structural design/ ii) material property/ iii) fabrication process related feature which would require alteration for improving the cell performance. Crystalline silicon response starts at about 1100 nm (band gap) and continues to about 400 nm where it declines sharply. Spectral response of silicon solar cells is found by measuring the short circuit current resulting from shining of light of a narrow band of wavelengths (few nm) centered at each selected wavelength over the range 350 - 1100 nm. A calibrated sensor is used to measure the power of light incident on the cell at each wavelength. Spectral response is found as the current per unit of light power. So the spectral response (SR) is specified as ampere per watt (A/W) or as will be done in our case μA/μW. This measured number is easily converted into external quantum efficiency (EQE, which we shall call quantum efficiency QE), which specifies the number of electrons flowing through the short circuit cell for each photon incident on the cell.

Standard arrangement for spectral response measurement requires a broad band source such as a halogen lamp or Xenon lamp followed by monochromator to select light of desired wavelength as shown schematically in the upper part of the figure. In our arrangement, we have used a synthetic light source made up of 20 LEDs covering wavelength range from 360 nm to 1060 nm required for measuring the spectral response of crystalline silicon solar cell. Schematic of the synthetic source is shown the figure.

Synthetic Light Source



$$\text{Spectral Response (SR)} = I_{sc}(\lambda) / [P(\lambda) \text{ (A/W)}]$$

$$\text{External Quantum Effciency } (\eta) = \{ Isc(\lambda)/e\}/\{P(\lambda)/ \hbar\omega\}$$

We can convert SR to EQE by

$$EQE (\lambda) = 1.238 * [SR (\lambda)/\lambda] \quad \text{(where } \lambda \text{ is in micron unit)}$$

And convert EQE to SR by using

$$SR (\lambda) = 0.808 \lambda * [EQE (\lambda)] \quad \text{(where } \lambda \text{ is in micron unit)}$$

Multiplying EQE (λ) with the solar flux at each λ, over interval λ to λ+ Δλ , and summing over the wavelength range of excitation of electrons in the semiconductor, we can find the short circuit current density. Another quantity of interest, connected to Spectral Response, is internal quantum efficiency (IQE), which is characteristic of the solar cell material. One can obtain IQE from EQE by knowing the loss of light incident on the solar cell by reflection R (λ) and transmission T (λ).
Relation between IQE and EQE is

$$IQE = EQE / [1-R (\lambda) - T (\lambda)$$

Since R (λ) and T (λ) are not measured during this experiment, IQE is not obtained as such.

5. Equipments Required:

Sr. No.	Unit	Description/Rating	Qty
1	Solar Cell	4x4cm^2 c-Si cell	1
2	Light Source made from 20 LEDs with provision to turn on one LED of selected wavelength at a time	360 nm to 1060 nm	1
3	Constant current source for turning on selected LED	20 mA current flow through selected LED	1
4	Measurement of light power emitted by each LED	Power emitted by each LED at 20 mA provided	1
5	Controller for Selecting LED and Recording short circuit current	LED wavelength, power, and response current display	1

6. Methodology for Measurements:

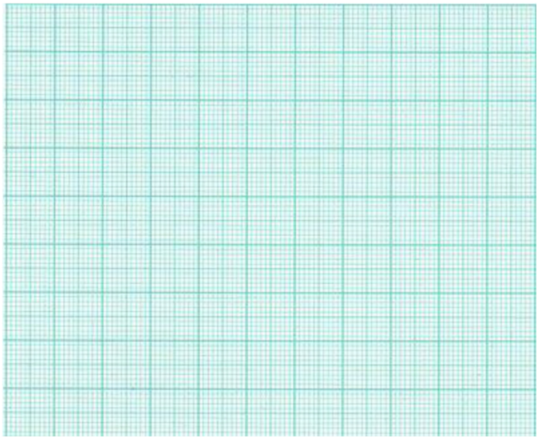
Choose the LED of specific wavelength by pressing increment /decrement button on the front panel. 20 mA current passes through the selected LED (this is preset in the present apparatus). Read the response current I. Each LED gives different light power at 20mA. This power has been measured from each LED at 20mA by using a calibrated solar cell and it is displayed along with the wavelength of the selected LED. Using these readings, construct the following table.

7. Observations:

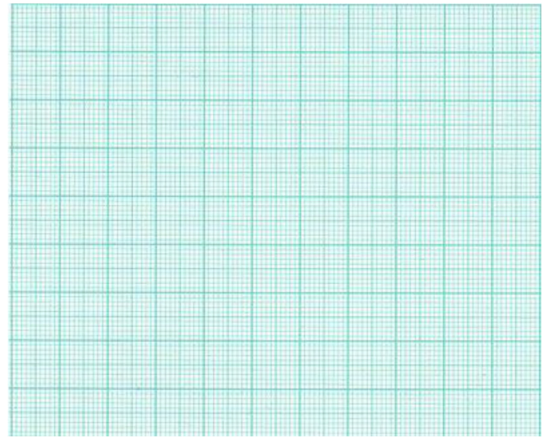
Record current at every wavelength

Sr. No.	**Wavelength (μm)**	***Current* (μA)**
1		
2		
3		
4		
5		
6		
7		
8		

Divide current by power to get the spectral response (SR) or responsivity of the solar cell and plot SR versus λ wavelength. Obtain external quantum efficiency (EQE) by using the relation given above and plot EQE versus λ



Plot of current versus wavelength on simple graph paper



Plot of EQE versus wavelength on simple graph paper.

Results

Comment on the shape of the SR versus λ plot, comparing with the expected ideal plot.

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9. Answer the following

EQE (λ) rises sharply at the wavelength corresponding to the band gap of semiconductor. Estimate band gap of silicon from your SR plot. Why does EQE fall at the short wavelength side of the graph?

References

1. Solar Photovoltaic Technologies, book by C S Solanki.

2. Photovoltaic measurements, S Ashok and K P Pande, Solar Cells 14, 61 (1985)