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A Study on Spectral Response and External Quantum Efficiency of Mono-Crystalline Silicon Solar Cell

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Abstract- This paper presents a study on spectral response and external quantum efficiency of mono-crystalline silicon solar cell at room temperature. The experiment was undertaken in the wavelength range 350-1100 nm employing spectral response meter. The results show that the spectral response increases with wavelength, reached to maximum at 890 nm and beyond the maximum decreases rapidly. The external quantum efficiency also increases with wavelength, reached to maximum at 590 nm, slowly decreases up to 970 nm and subsequently decreases rapidly. The energy band gap is calculated and found to be 1.12 eV. The results are in good agreement with the available literature.

Keywords—Silicon solar cell, Spectral response, External quantum efficiency, Spectral response meter.

1. Introduction

The solar cell is a device which converts electromagnetic energy into electrical energy and the conversion process is based upon the photovoltaic effect. There are three generations of solar cells, mono-crystalline silicon (mono-Si) solar cell comprises in the first which is also known as single-crystalline silicon solar cell. At present, the silicon solar cell family fulfills the maximum need of the photovoltaic industry [1]. The mono-Si solar cells are fabricated using high purity materials (solar grade or silicon wafers) which showed excellent efficiency and long term stability. The mono-Si has ordered crystal structure with each atom ideally lying in a predefined position of diamond structure. It exhibits not only predictable and uniform behavior but also most expensive which may be attributed to requirement of carefulness and slow manufacturing process. It is most important technological material of the last decades due to easy availability at an affordable cost. The mono-Si and amorphous silicon solar cells are bearing important areas of research due to good power conversion, stable characteristics, eco-friendly and semiconductor industrial applications [2-5]. The market share of mono-Si solar cells in 2013 is observed 36% which is equivalent to the production of 12,600 megawatts photovoltaic capacity. It is ranked second after the polycrystalline silicon solar cells which are cheaper than mono-Si solar cell. The 25% efficiency is recorded in laboratory for mono-Si solar cells which is highest in the commercial photovoltaic market [6]. Now days, the current area of research demands an increment in efficiency combine with economic usage of resources and low price.

An analytical model that simulates the performance of thin poly-silicon solar cells with porous silicon contact on the front surface was developed by Trabelsi and Zouari [7]. They observed that the emitter reverse saturation current density was decreased with porous silicon layer while the solar cell photovoltaic parameters were increased. A simplified method to modulate colors on industrial multi-crystalline silicon solar cells with reduced current losses has been undertaken by Zeng et al. [8]. The studies of the effect of photons conversion on the characteristic parameters of the single crystalline silicon solar cells is reported by Ayad at el. [9]. They observed an increment in short circuit photocurrent density about 9% and consequently increment in photovoltaic conversion efficiency was observed. McIntosh et al. [10] studied an increase in external quantum efficiency of encapsulated silicon solar cells from a luminescent down-shifting layer. Yang and Yang [11] analyzed the light trapping and internal quantum efficiency of a silicon solar cell with back reflector using grating structure. The analysis of the dependence of the spectral factor of some PV technologies on the solar spectrum distribution is carried out by Nofuentes et al. [12]. The most important parameters those describe the performance of a mono-Si solar cell are the spectral distribution of the irradiance, total irradiance and temperature [8, 13]. The spectral response is the key parameter of silicon solar cells. In principle, it is the sensitivity of a solar cell corresponding to light of different wavelengths while it is a measure of short circuit current per unit light power in general. The spectral response is measured with spectrally pure light over a broad range of wavelengths corresponding to the spectrum of solar radiation and the suitable range for mono-Si solar cell is 350-1100 nm [3]. The influence of variation of the solar spectrum on the performance of the different type solar devices is still not generalized on a large scale due to the difficulty of spectral response measurements [12]. Another commonly used parameter to express the sensitivity of a solar cell is external quantum efficiency which is also known as quantum efficiency. Each incident photon would generate electron-hole pair in an ideal solar cell and all these photo carriers move towards the depletion region and thereafter these are separated and collected. The photons which are having energy less than the band gap energy, are not able to generate photo-carriers and even if these have sufficient energy then it is not necessary to contribute to the photocurrent [3, 14]. The quantum efficiency of the solar cell is the ratio of the number of carriers collected by the solar cell to the number of incident photons. It is a measure of the effectiveness of a device to produce electronic charge from incident photons. It describes the response of the device with different wavelengths of light [15-16] and expected to be zero for photons with energy less than the absorber band gap. The quantum efficiency could be as large as 100% for photons with larger energy but it is often lower owing to the probability of reflection of the photons at the top interface which never enters into the solar cell.

Thorough literature survey reveals that there is a need to study the spectral response and quantum efficiency of mono-Si solar cell in detail. Hence, an attempt has been made in this paper to bridge the gap and enhance the spectral response and quantum efficiency of mono-crystalline silicon solar cell at room temperature in the wavelength range 350-1100 nm employing spectral response meter. The band gap of mono-Si solar cell is also calculated.

2. Experimental Details

The experimental setup used in this study is presented in Fig.1. A fabricated mono-crystalline silicon solar cell of (4×4) cm^2 area was used. The measurements of short circuit current $I_{sc}(\lambda)$, output light power $P(\lambda)$ and spectral response were undertaken in the wavelength range 350-1100 nm at room temperature employing spectral response meter. The spectral response meter is a combination of broad band light source and a synthetic source which is a composition of light emitting diodes (LEDs) having wavelength between 360-1060 nm. Each LED emits power corresponding to current of 20 mA which was measured using mono-Si solar cell and to cover the required wavelength range, a set of 20 light emitting diodes was mounted on a holder. The mono-Si solar cell was inserted into the holder just below the LED set and a lid was used to close the holder which was able to avoid the stray light incident on the solar cell. The mono-Si solar cell was exposed with light of each wavelength by exciting the corresponding diode and was followed by measurement of the photo current and the power.

Fig.1. An experimental setup to measure the spectral response and external quantum efficiency of mono-Si solar cell [17].

The spectral response was calculated using relation concerned [3].

$$\text{Spectral Response (SR)} = \frac{I_{sc}(\lambda)}{P(\lambda)} \quad (1)$$

Here, $I_{sc}(\lambda)$ and $P(\lambda)$ are the short circuit current and output light power respectively for silicon solar cell at different wavelengths. The external quantum efficiency (QE) was calculated by relation [2].

$$QE(\lambda) = \frac{1}{q}\frac{hc}{\lambda}\frac{I_{sc}(\lambda)}{P(\lambda)} \quad (2)$$

Here, λ is the photon wavelength, q is the electronic charge, h is Planck's constant and c is the speed of light. The band gap energy of silicon solar cell was calculated using relation concerned [2].

$$E_g(eV) = \frac{1.239}{\lambda_g(\mu m)} \quad (3)$$

Here, E_g is the energy band gap and λ_g is the wavelength corresponding energy band gap.

3. Results and Discussion

The spectral response of mono-crystalline silicon solar cell at room temperature for the wavelength range 350-1100 nm is presented in Fig 2.

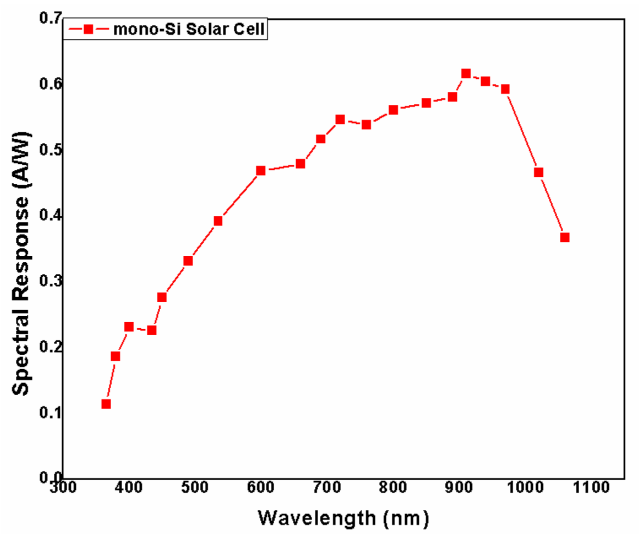

Fig.2. Spectral response of mono-Si solar cell.

It is clearly visible in Fig.2 that the spectral response is observed to be increased with wavelength in the range of 350-890 nm. It is reached to maximum at 890 nm, beyond this maximum decreased rapidly and found minimum at the wavelengths 350 nm and 1100 nm. The different peaks in the spectral response of mono-Si solar cell are observed which may be attributed to different doping concentrations used in fabrication process of the solar cell [2]. The spectral response characteristic with wavelength showed trend similar to the solar radiation spectrum of pure light within the entire range in which the acquisition of experiment was taken into account. The spectrum covers the entire visible range as well as partially infrared and ultraviolet ranges.

The external quantum efficiency of mono-crystalline silicon solar cell at room temperature for the wavelength range 350-1100 nm is shown in Fig. 3.

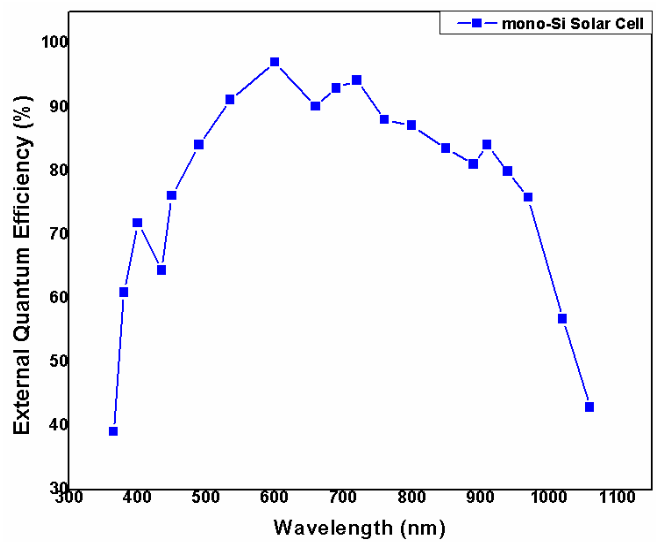

Fig. 3. External quantum efficiency of mono-Si solar cell.

It is seen from Fig. 3 that the external quantum efficiency has minimum at wavelength 350 nm and 1100 nm. Initially, it is observed to be increased with wavelength and reached to maximum at wavelength 590 nm. Beyond the maximum, it is found to be decreased slowly upto 970 nm of wavelength and thereafter decreased rapidly owing to the effect of recombination and optical losses due to transmission and reflection [14]. The external quantum efficiency is disappeared below 350 nm and beyond 1100 nm which revealed the loss of transmitted and reflected lights. It could not measure much below 350nm due to low power that is contained from the air mass of AM1.5 [3].

It is also visible in Fig. 3 that the wavelength corresponding to the energy band gap (λ_g) for mono-Si solar cell is observed 1100 nm or 1.1 μm. The corresponding energy band gap was calculated using relation (3) and was found to be 1.12 eV. The results are in good agreement with the standard results and available literature [15-18].

4. Conclusions

In this paper, a study on spectral response and external quantum efficiency of mono-crystalline silicon solar cell at room temperature is reported. The experiment was undertaken within the wavelength range 350-1100 nm employing spectral response meter. The results show that the spectral response is increased with wavelength, reached to maximum at 890 nm and beyond the maximum decreased rapidly. The spectral response characteristic with wavelength showed a similar trend to the solar radiation spectrum of pure light within the entire range of wavelength. The external quantum efficiency is also found to be increased with wavelength, reached to maximum at wavelength 590 nm, slowly decreased upto 970 nm and beyond this it decreased rapidly owing to the effect of recombination and optical losses doe to transmission and reflection phenomenon. The energy band gap is calculated and found 1.12 eV. The results are in good agreement with the standard results and available literature.

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References

[1] G.N. Tiwari and S. Dubey. *Photovoltaic Modules and Their Applications*, RSC Publishing, London (2010).

[2] S.R. Wenham, M.A. Green, M.E. Watt and R. Corkish, *Applied Photovoltaics*, Earthscan, London, UK (2012).

[3] C.S. Solanki, B.M. Arora, J. Vasi and M.B. Patil, *Solar Photovoltaics*, Cambridge University Press India Pvt. Ltd., New Delhi (2013).

[4] E. Radziemska, Effect of temperature on dark current characteristics of silicon solar cells and diodes, *International Journal of Energy Research* 30, 127-134 (2006).

[5] W. Cai, F. Chao, T.J. Long, L.D. Xiong, H.S. Fu and X.Z. Gang, The influence of environment temperatures on single crystalline and polycrystalline silicon solar cell performance, *Sci. China-Phys Mech Astron* 55, 235-241 (2012).

[6] Fraunhofer Institute for Solar Energy Systems: Photovoltaic reports 18-29 (2014).

[7] A. Trabelsi and A. Zouari, Analytical model and photovoltaic parameters improvement of polysilicon solar cells with porous silicon emitter, *Solar Energy* 107, 220-226 (2014).

[8] L. Zeng, M. Li, Y. Chen and H. Shen, A simplified method to modulate colors on industrial multi-crystalline silicon solar cells with reduced current losses, *Solar Energy* 103, 343-349 (2014).

[9] M. Ayed, M. Fathi, M. Abderrazak and A. Aissat, *International Journal of Renewable Energy Research* 2 (4), 596-599 (2012).

[10] K.R. McIntosh, G. Lau, J.N. Cotsell, K. Hanton, D.L. Batzner, F. Bettiol and B.S. Richards, *Prog.Photovolt: Res.Appl.17*, 191-197 (2009).

[11] K.H. Yang and J.Y. Yang, *Solar Energy* 85, 419-431 (2011).

[12] G. Nofuentes, B. Garcia-Domingo, J.V. Munoz and F. Chenlo, *Applied energy* 113, 302-309 (2014).

[13] S.K. Sharma, H. Im, D.Y. Kim and R.M. Mehra, I*ndian Journal of Pure & Applied Physics* 52, 293-313 (2014).

[14] L. Fang, L. Danos and T. Markvart, *Proceedings of the 28th European photovoltaic solar energy conference and exhibition* (2013) Sept. 30-Oct.01, Paris, France.

[15] S. Ashok and K.P. Pande, *Solar Cells* 14, 61-81 (1985).

[16] S.R. Messenger, J.H. Warner, P.P. Jenkins, R.J. Walters and J.R. Lorentzen, IEEE 978-1-4244-1641-7/08 (2008).

[17] A.B. Mohan, N.A. Mahadev, O.A. Haradchandra, S.H. Hitesh, C.G. Devram, K. Ramankutty, LED based solar cell spectral response IP application 2869/MUM/2012 (2012).

[18] C.S. Solanki, *Solar Photovoltaics: Fundamentals, Technologies and Applications, Second Edition*, PHI Learning Pvd. Ltd., New Delhi (2013).