

Performance Enhancement of Polycrystalline Silicon Based Solar Cell Using $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ Phosphor

^{*1}S. Admane, ²D.Chopde

^{1,2} Department of Electronics Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur, India
Email: admanes@rknc.edu, chopdedk@rknc.edu

Received: 20th September 2018, Accepted: 11th October 2018, Published: 31st October 2018

Abstract

Solar energy is a renewable source of energy that is sustainable, clean and totally inexhaustible. The most commonly used, commercial solar cell which converts sunlight into electricity are fabricated using crystalline silicon with lower conversion efficiency. The main difficulty in improving the efficiency of solar cell is due to spectral mismatch i.e. low energy photons are not absorbed and high energy photons are partially used. One of the methods to significantly reduce the losses by using a DC(down-conversion) material which has the ability to produce from one higher energy photon to two low energy photons. This work provides details regarding the electrical characterization of the polycrystalline silicon-based solar cell. A $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphor is synthesized and this material realizes down-conversion of photons near UV and the blue region around 350–450nm and have emission around 1067 nm. To provide mechanical strength to the solar cell, various encapsulation films are applied to the solar cell and their optical characteristics are evaluated. Amongst them, EVA (Ethylene Vinyl Acetate) has proven to be adequate for encapsulating polycrystalline based solar cell. The material is uniformly spread on the solar cell and encapsulated with EVA. Further, this effect has been exhibited under the experimental setup and significant increment in blue LED light source has been seen with almost twice rise in voltage and six times rise in current of solar cell.

Keywords

Solar Cells, Down-Conversion, Polycrystalline Silicon, EVA, $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$.

Introduction

In the most recent decades, the monetary development in numerous parts of the world could be sustained because of the comprised energy cost. Due to the lead-in in global warming issues and fossil, fuel cost turned the attention to towards development of renewable and non-polluting energy sources and new technologies for power generation. hydrogen fuel cell, Nuclear fusion, renewable energies are key possibilities to meet upcoming energy demand. From these options, to overcome Energy Crisis problems and future energy demand solar energy is a promising source of energy [1]. Solar cells are unique in that they directly convert the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long-lasting. Even with the many advantages of solar energy, the efficient and cost-effective conversion of a solar energy into electricity through PV cells remains a challenging task. The most common material used in the photovoltaic cell is Silicon which is readily available in nature and over 90% of the Earth's crust is composed of silicate minerals, making silicon the second most abundant element in the Earth's crust (about 28% by mass) after oxygen [2].

The Shockley–Queisser limit states that there is a maximum limit to which the power can be collected from a single-junction solar cell, which is theoretically around 33.7% [3] [4]. The most commonly used, commercial photovoltaic solar cells are fabricated with crystalline silicon with an E_g 1.12 eV [5]. Currently, for a single-junction solar cell, it has been obtained up to $25.0 \pm 0.5\%$ [6].

Currently, efficiency recorded for large area (180cm^2) Si solar cell was 26.3% which is fabricated by Kaneka [7]. Efficiency recorded for a multi-crystalline silicon cell was 21.9% with a 4cm^2 cell area using an n-type substrate fabricated by FhG-ISE [8]. For 1cm^2 microcrystalline silicon thin-film cell, 11.9% efficiency was reported and it is measured and fabricated by AIST [9]. A new efficiency record of 25.7% was reported for a 4cm^2 n-type silicon cell with contacts on both top and rear surfaces, fabricated and measured at FhG-ISE [10].

In the PV cells, there are three types of silicon which are being used such as monocrystalline silicon, polycrystalline silicon and the amorphous silicon. The efficiency of a monocrystalline silicon solar cell is 15% - 20%, polycrystalline silicon solar cell is 13% - 16% and the amorphous silicon solar cell is 6% - 8%. [11] Monocrystalline cells are fabricated by purest form of silicon, which makes them the most efficient material for the conversion of sunlight into energy but it has the highest production cost. Polycrystalline cells are less efficient but the manufacturing process is cheaper. Thus, some experiments were performed using a commercial polycrystalline silicon solar cell and each solar cells of size 5cm^2 . A polycrystalline

cell has about 15% efficiency and is not costly compared to monocrystalline silicon cell. It is made up of many small grains of monocrystalline silicon with several grain boundaries between each crystal [12].

Energy losses exist in a solar cell are mainly due to spectral mismatch i.e. Lower than band gap energy photons which are not absorbed whereas the excess energy of high-energy photons absorbed is transformed into kinetic energy of a generated electron-hole pair and appears as heat [5]. To reduce spectral mismatch, a spectral modification can be done using techniques like up-conversion, down-conversion [13] [14]. DC material has the ability to produce from one higher energy photon to two low energy photons. Moreover, degradation of several types of solar cells also occurs due to high energy photons. Effective harvesting of solar energy from UV and NIR photons is a necessary condition for enhancing the efficiency of solar cells which indirectly reduces the cost of electricity [15]. A price reduction may be achieved by either lowering the production cost or increasing the conversion efficiency.

As stated in [13], for the silicon-based device, the increment in conversion efficiency could be achieved by exploiting the solar spectrum component under 450 nm wavelength [16]. The basic requirements for phosphor are as follows 1. Excitation from 300 nm or below, to 500 nm (4.5 eV - 2.5 eV) 2. The absorbed energy should be emitted near absorption energy of solar cell (1 μm) with quantum efficiency of more than 100% [17].

As described in [18] Eu^{2+} -doped phosphors can serve as a luminescent DC material to improve the efficiency of PV devices for the Crystalline silicon-based solar cell. On the successful outcome accounted for $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphors in [19], in which Eu^{2+} emission is in predominantly near UV region, that for the Nd^{3+} emission around 1067 nm extends into visible region covering violet and blue part of the spectrum [19]. These results are highly significant for improving the efficiency of the c-Si solar cell, for designing NIR sources.

Materials and Methods

In the present work, $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphor was prepared with 3 mol% of Eu^{2+} and Nd^{3+} [19]. BaCO_3 , $\text{SiO}_2 \cdot \text{H}_2\text{O}$, Eu_2O_3 and Nd_2O_3 were used as seed materials. All the materials were of analytical grade. NH_4Cl (2 wt. %) was utilized as a flux. The sample was heated in the furnace

1. at 700°C for 4 hrs.
2. temperature was increased to 1200°C for 6 hrs. and after that, it is cooled to room temperature. 3. the sample was then reduced to 950°C for 2 hrs. provided by burning charcoal in a reducing atmosphere.

Further, the characterization was done using Hitachi F7000 fluorescence spectrophotometer for UV-VIS and Photon Technology International QM-51 for NIR Photoluminescence spectra.

This is delineated in Fig.1, Crystalline silicon solar cell response decreases rapidly underneath 500 nm. By converting this region to around 1000nm, can significantly give efficiency improvement. As there is good overlap between the solar spectrum suitable for quantum cutting, and Eu^{2+} absorption i.e. around 350-450 nm as appeared in fig.2 and this phosphor gives emission at around 1067nm as appeared in fig.3.

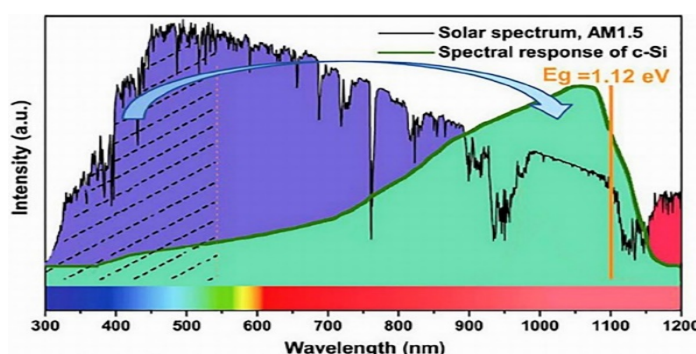


Fig. 1: Spectral Response of Crystalline Silicon Solar Cell and Solar Spectrum [20].

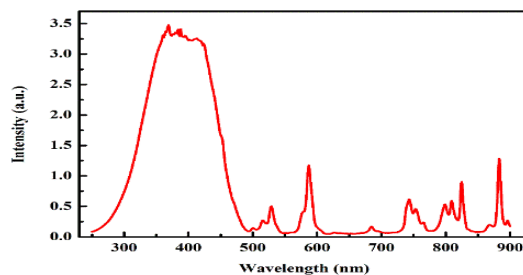
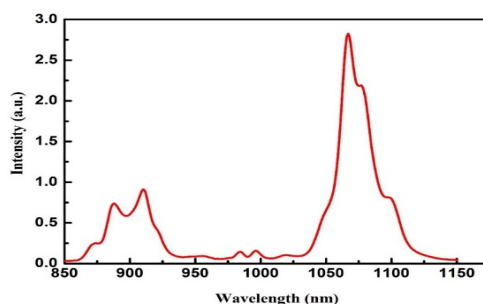


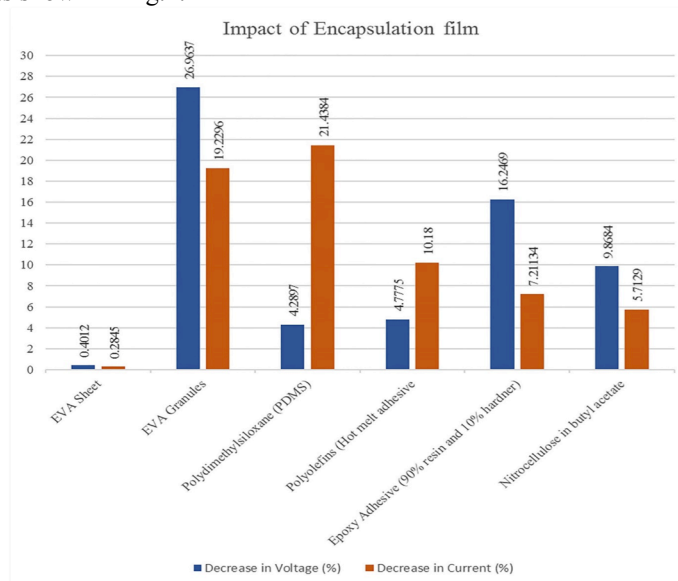
Fig. 2: Photoluminescence Excitation Spectra of $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphor**Fig. 3: Photoluminescence Emission Spectra of $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphor**

The solar cell is exceptionally sensitive and delicate, so it must be given mechanical strength. Various encapsulants were used which are listed in table 1 at room temperature in controlled condition.

Encapsulation film	Without encapsulant		With encapsulant	
	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
EVA sheet	0.4984	10.542	0.4964	10.512
EVA granules	0.4825	9.8452	0.3524	7.952
PDMS	0.5012	10.546	0.4797	8.2851
Polyolefins (Hot melt adhesive)	0.4856	9.982	0.4624	8.982
Epoxy adhesive	0.4824	8.972	0.4124	8.325

Table 1: Impact of Encapsulation Film

The best among all of these was EVA sheet. So, EVA sheet is selected as an encapsulant and sealant. It gives 0.4012% variation in voltage and 0.2845% variation in current which is acceptable thus it provides better reliability and performance on a solar cell as shown in Fig.4.

**Fig. 4: Comparison of Various Encapsulation Film**

Results and Discussion

The experiments were performed using a polycrystalline silicon solar cell with an area of 5cm^2 .

Under illumination from a natural light source, when the Sun was directly overhead, placed the solar cell and measure the open circuit voltage and short circuit current.

Recorded results were used to compare it later with the results after modifications on the solar cell. Powered form material

was then deposited consistently over the solar cell with the weight of 0.025gm and it is then encapsulated with EVA sheet as appeared in Fig.5.

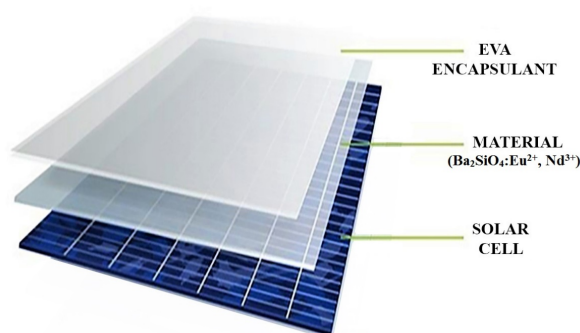


Fig. 5: Solar Cell Doped Material With EVA Sheet Encapsulation

After applying material and encapsulant there is an increment in voltage and current values i.e. 5.8027% and 10.7866% respectively, as appeared in table 3.

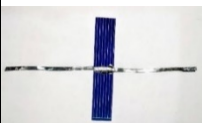
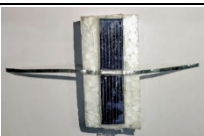
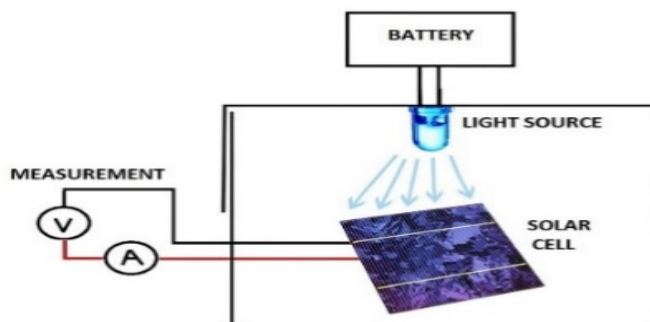
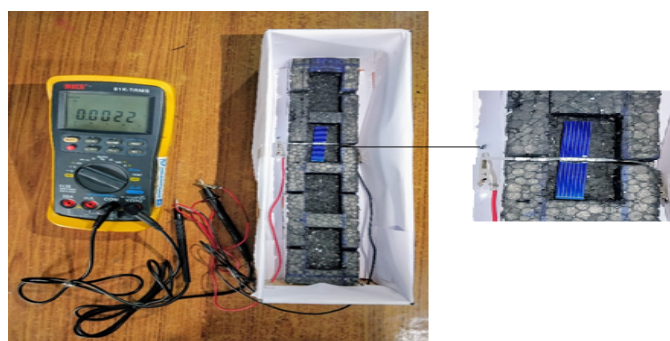
Condition	Without material & EVA encapsulation	With material & EVA encapsulation
Image		
Voltage	0.4607 V	0.4896 V
Current	8.982 mA	10.068 mA

Table 3: Comparison of a Solar Cell with and without the Material and EVA Sheet Encapsulation Over Sunlight

However, there will be variability of natural sunlight most of the time. For accurate and precise measurement in controlled conditions commercially available LED light source is used. For the experiment under controlled condition, an experimental setup was made. It can be closed to acquire full dark condition, inside having four chambers to put the distinctive LED light source to perform the experiment quicker as appeared in Fig.6. Above each chamber, there was a LED light source. 6 cm beneath the LED light source there's space where a solar cell can be kept. Different LED light sources were compared with their respective wavelength such as UV, Blue, Green, Yellow, Red and IR LEDs above the solar cell as appeared in table 4.



(a) Circuit Diagram



(b) Inside Top View
Fig. 6: Experimental setup

LED light source colour	Without material & EVA encapsulation		With material & EVA encapsulation	
	Voltage (V)	Current (mA)	Voltage (V)	Current (mA)
UV	0.245	0.215	0.275	0.315
Blue	0.254	0.224	0.382	1.312
Green	0.006	0.002	0.001	0.003
Yellow	0.049	0.016	0.057	0.017
Red	0.075	0.028	0.104	0.043
IR	0.437	3.54	0.429	2.956

Table 4: Comparison for With and Without Applying the Material and EVA Encapsulation Over Solar Cell on the Various Wavelengths

As can be seen in table 4., increment in values of open circuit voltage and short circuit current for UV and blue LED light source, after applying material and EVA encapsulation with a wavelength in between 380-500nm.

1. For blue LED light source, 1.5 times in voltage and 1.4 times in current
2. For UV LED light source, 1.1 times in voltage and 5.8 times in current

Conclusion:

In a polycrystalline silicon-based solar cell, maximum efficiency can be obtained if the proper spectral modification is done. This is obtained by using a down-conversion method which effectively harvests the solar energy from UV and NIR to enhance the efficiency and indirectly reduces the cost of the solar cell. To achieve this $\text{Ba}_2\text{SiO}_4: \text{Eu}^{2+}, \text{Nd}^{3+}$ phosphor is synthesized which has an excitation near UV light and NIR emission at 1067nm. To provide mechanical strength to solar cell EVA sheet is used as encapsulant with a negotiable variation in voltage and current values i.e. 0.4012% and 0.2845% respectively. After applying material with encapsulate increment of 5.8027% in open circuit voltage and 10.7866% in short circuit current is observed. As there is variation during measurement in direct sunlight, an experimental setup is used to measure open circuit voltage and short circuit current with various LED light sources. Almost twice rise in open circuit voltage and six times rise in short circuit current has been seen in blue LED light source. This can be used as a primary method for measurement of open circuit voltage and short circuit current values of the solar cell at a different wavelength.

References

- [1] Kannan, Nadarajah, and Divagar Vakeesan, Solar Energy for Future World: - A Review, Renewable and Sustainable Energy Reviews, 2016 vol. 62, pp. 1092–1105.
- [2] Doug Donald, The Eight Most Abundant Elements in the Earth's Crust, Sciencing, sciencing.com/eight-abundant-elements-earths-crust-8120554.html, 26 Apr. 2018
- [3] Shockley, William, and Hans J. Queisser, Detailed Balance Limit of Efficiency of P-n Junction Solar Cells, Journal of Applied Physics, 1961 vol. 32, no. 3, pp. 510–519.
- [4] Albert Polman¹, Mark Knight¹, Erik C. Garnett, Bruno Ehrler, Wim C. Sinke, Photovoltaic Materials: Present Efficiencies and Future Challenges, Science, 2016, vol. 352, no. 6283.
- [5] P.V.Tumram P.R.Kautkar, S.A.Acharya and S.V.Moharil, 2nd International Conference on Solar Energy Photovoltaic. Elsevier, NIR Emission and $\text{Eu}^{2+}, \text{Nd}^{3+}$ Energy Transfer in $\text{KSrCl}_3: \text{Eu}^{2+}, \text{Nd}^{3+}$ Phosphor, 2017.
- [6] National Renewable Energy Laboratory (NREL) Home Page | NREL, National Renewable Energy Laboratory (NREL) Home Page | NREL, www.nrel.gov/, 28 Apr. 2018

- [7] Yoshikawa, Kunta, et al, Silicon Heterojunction Solar Cell with Interdigitated Back Contacts for a Photoconversion Efficiency over 26%, *Nature Energy*, 2017, vol. 2, no. 5, p. 17032.
- [8] Benick, Jan, et al., High-Efficiency n-Type HP Mc Silicon Solar Cells. *IEEE Journal of Photovoltaics*, 2017, vol. 7, no. 5, pp. 1171–1175.
- [9] Sai H, Maejima K, Matsui T, et al., Effect of front TCO layer on properties of substrate-type thin-film microcrystalline silicon solar cells, *IEEE Journal of Photovoltaics*. 2015;5(6):1528–1533
- [10] Richter, Armin, et al, n-Type Si Solar Cells with Passivating Electron Contact: Identifying Sources for Efficiency Limitations by Wafer Thickness and Resistivity Variation, *Solar Energy Materials and Solar Cells*, 2017, vol. 173, pp. 96–105.
- [11] Green, Martin A., et al, *Solar Cell Efficiency Tables (Version 50)*, *Progress in Photovoltaics: Research and Applications*, 2017, vol. 25, no. 7, pp. 668–676.
- [12] Ganesh, R. Bairava, et al, Growth and Characterization of Multicrystalline Silicon Ingots by Directional Solidification for Solar Cell Applications, *Energy Procedia*, 2011, vol. 8, pp. 371–376.
- [13] B.S. Richards, Luminescent layers for enhanced silicon solar cell performance: Down-conversion, 29 August 2005
- [14] A. Shalava, B.S. Richards, M.A. Green, Luminescent layers for enhanced silicon solar cell performance: Up-conversion, 4 February 2007
- [15] W.G.J.H.M. van Sark, A. Meijerink, R.E.I. Schropp, J.A.M. van Roosmalend, E.H. Lysen, enhancing solar cell efficiency by using spectral Converters, 2 December 2004
- [16] A. Le Donne, M. Dilda, M. Crippa, M. Acciarri, S. Binetti, Rare earth organic complexes as down-shifters to improve Si-based solar cell efficiency, 28 October 2010
- [17] W.G.J.H.M. van Sark, A. Meijerink and R.E.I. Schropp (2012). *Solar Spectrum Conversion for Photovoltaics Using Nanoparticles*, *Third Generation Photovoltaics*, Dr Vasilis Fthenakis (Ed.), ISBN: 978-953-51-0304-2, InTech, Available from <http://www.intechopen.com/books/third-generation-photovoltaics/solar-spectrum-conversion-for-photovoltaics-using-nanoparticles>
- [18] Wen Bin Hung, Juyn Ye Chen, Kien Wen Sung and Teng Ming Chen, Enhanced conversion efficiency of crystalline Si solar cells via luminescent down-shifting using Ba₂SiO₄: Eu²⁺ phosphor, *Journal of Ceramic Processing Research*, 2014 Vol.15, No. 3, pp. 157 – 161.
- [19] A. Vyas, C.P. Joshi, P.D. Sahare, S.V. Moharil, NIR emission IN Ba₂SiO₄: Eu²⁺, Nd³⁺ phosphors with near UV/violet excitation, *Journal of Alloys and Compounds* 2018.
- [20] Jin Zhao, Chongfeng Guo, and Ting Li, Near-Infrared Down-Conversion and Energy Transfer Mechanism of Ce³⁺-Yb³⁺-Co-Doped Ba₂Y(BO₃)₂Cl Phosphors, August 28, 2015