Improving Solar Cell Efficiency using Lead Selenium Nanocrystals

Luke Toroitich Rottok

Abstract—Solar cells convert the sun's energy into electricity. The flow of current in the solar panel generates power which can be used to drive a load. Currently, solar panels have an efficiency of up to 18 percent. Most of the solar panels are made from silicon crystals. Silicon is used due to its availability in sand and surface soils. The production of solar cells using silicon requires highly clean environment and pure silicon. This results to an expensive production process and frequent maintenance. Solar cells used in Kenya are imported from other countries. This research proposes the replacement of silicon in the solar cell with lead selenium nanocrystals, which can be produced locally. The nanocrystals are obtained from reaction solutions and separating them using a centrifuge machine. A solar cell is then fabricated by laying the lead selenium nanocrystal on a substrate by chemical vapor deposition.

Keywords— Lead selenium, nanocrystal, photovoltaic, solar cell and solar module.

I. Introduction

Energy from the sun is conveyed in packets called photons. The sun's energy can generate electricity by the photo-voltaic principle. Solar cells are used to harness the suns energy. A solar cell contains a compound which generates electricity when exposed to sunlight. First, the compound must be made of chemicals whereby, at least one of them has a free electron in its outer ring. Energy from the sun is conveyed in photons, which will have energy to remove the free electron from its ring, and cause electron flow. Adjacent atoms also have free electrons, leading to a flow of electrons. This leads to the generation of electricity, by causing a flow of current. Additionally, the suns energy contains infra-red, which is energy in form of heat. However, this heat restricts the free movement of electrons, causing them to vibrate. In order to connect a load to the solar cell, the cells are connected in series or in parallel to form arrays, which are further connected to form modules [9]. Silicon is commonly used to make solar cells due to its relative abundance in sand and in most soils [4]. Silicon crystals take the orientations of monocrystalline or polycrystalline. Mono-crystalline silicon crystals are of similar shapes, sharing the same angles and physical properties, while poly-crystalline silicon crystals take individual physical properties in shape and size [5].

The application of nanocrystals in the solar cell reduces the distance between adjacent molecules, resulting to improvement in the movement of electrons when the panel is exposed to sunlight. At the nano-scale the increased flow of current yields to higher voltages generated, thus greater efficiency as compared to a panel made of silicon crystals [3][7][8]. Currently research in solar energy has resulted in silicon based solar cells with efficiency of about 18 percent, the highest laboratory efficiency being recorded at 19.42 percent. This efficiency has been achieved by reducing reflection of the sun's rays, reducing the thickness of the cell, dye sensitizing of the solar cell and reducing the size of the silicon crystals [6][10][11].

This study focuses on the application of lead selenium nanocrystals in solar cells to improve the efficiency of the solar cell. Lead selenium exhibits a larger potential difference than silicon crystals when exposed to the same irradiation of the sun. An efficiency analysis will be done on the fabricated solar cell to prove the mathematical model.

L. T. Rottok, Department of Mechatronic Engineering, JKUAT (phone: +2540720358070; e-mail: ltoroitich@gmail.com).

II. Modeling

As earlier mentioned, the solar cell converts the sun's energy to generate electricity by a process called the photoelectric effect. The solar cell can be generally modeled as in Fig. 1 [12].

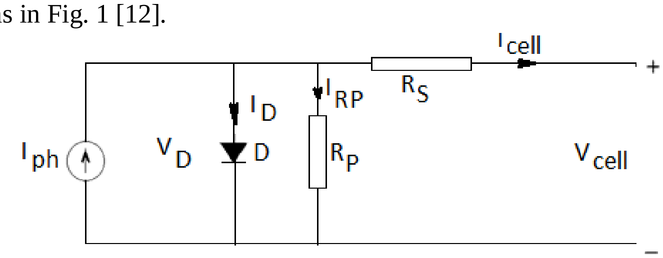

Fig.1 Solar cell modeling.

The current flowing in the cell is given by;

$$I_{cell} = I_{ph} - I_D - I_{RP} \quad (1)$$

Where;

I_{cell} is the current flowing in the solar cell
I_D is the diode current.
I_{RP} is the current that flows through the internal resistance
I_{ph} isthe photocurrent
R_p is the internal resistance of the cell
R_S is the metallic contact losses
V_{cell} is the voltage across the cell
V_D is the voltage across the diode

Diode D represents the p-n junction nature of the solar cell.

When the solar cell is exposed to sunlight, a current is generated given by;

$$I_{ph} = S.I_{SC} + I_{SC}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right) \quad (2)$$

Where;
I_{SC} is the short circuit current
S is the solar irradiance
T is the cell temperature
T_{ref} is the reference temperature

Power generated by the cell, P_{cell} is then given by;

$$P_{cell} = V_{cell}I_{cell} = V_{cell}[I_{ph} - I_D - I_{RP}] \quad (3)$$

From (1) and (2), it can be seen that the current and power generated by the solar cell are dependent on temperature, solar irradiance and short circuit current.

The efficiency of the solar cell, η is obtained from;

$$\eta = \frac{V_{cell}I_{cell}}{P_{in}} \quad (4)$$

Where;
P_{in} is the incident light power density.

The ratio of the maximum power generated by the solar cell to the power generated when a load is connected is called the Fill Factor, FF given by;

$$FF = \frac{P_{max}}{V_{cell}I_{cell}} \quad (5)$$

Where;
P_{max} is the maximum power generated by the solar cell

III. MODEL NANOCRYSTAL SOLAR CELL

The lead selenium solar cell is modeled as shown in Fig. 2.

TABLE I
EFFECIENCIES FOR DIFFERENT CELL TYPES

Cell type	Area (cm^2)	V_o(V)	I_{sc} (mA/cm^2)	FF	Efficiency (%)
Crystalline Silicon	4	0.706	42.2	82.8	24.7
Crystalline GaAs	3.9	1.022	28.2	87.1	25.1
poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
CuInGaSe	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

I_{sc} = short circuit current, FF = form factor, a-Si = amorphous silicon; poly-Si = polycrystalline silicon

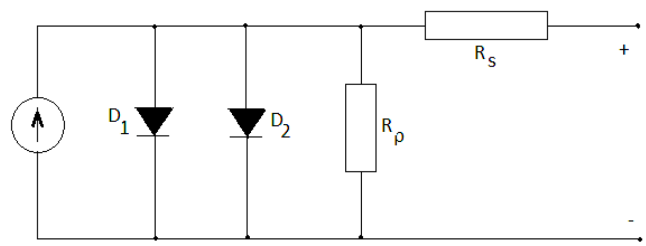

Fig.2 Model for nanocrystal solar cell

When the solar cell is exposed to sunlight, a current flows through the diodes D_1 and D_2.
The current densities of these diodes are given by;

$$I_{D_i} = I_{sat}e^{\frac{qV_{cell}+R_sI_{cell}}{n_ikT}} - 1$$

Where;
i is the diode number
I_{sat} is the saturation current
k is Boltzman constant
q is electron charge
n_i is the ideal factor for D_1 and D_2

From the current densities through the diodes, the power generated by the nanocrystal solar cell can be calculated using (3).

Table 1 shows a comparison between the efficiencies of different photovoltaic types [13]-[15]. It can be noted that high efficiency is attained with pure silicon. However, a large area of pure silicon solar cell is needed to achieve this efficiency. As other compounds are used, a double digit efficiency is obtained even when the solar cell area is small.

IV. EXPERIMENTAL SET UP

Lead selenium nanocrystals are obtained using a solution based reaction [2]. The chemicals used are; Trioctylphosphine, selenium powder, lead acetate trihydrate, oleic acid, diphenyl ether, anhydrous ethanol, toluene, and tetrachloroethylene.

A. *Preparation*

Dissolve 0.47 g of selenium in 4 ml of trioctylphosphine over 2 hr at 50 °C to form Trioctylphospine Selenide (TOPSe).

B. *Lead Selenium Nanocrystal Synthesis*

2 mmol of lead acetate trihydrate, 3 ml of oleic acid and 2 ml of trioctylphosphine were dissolved in 25ml of diphenyl ether in a flask equipped with a condenser. This mixture was heated to 150 °C for 1.5 hr under vigorous stirring and under a continuous flow of argon. During this process, lead acetate trihydrate decomposed, acetic acid was replaced with oleic acid, forming lead oleate. 4 ml of 1.5 $moll^{-1}$ TOPSe was added into the reaction solution, changing the color of the reagent mixture from colorless to black. This indicated that small lead selenium (PbSe) clusters immediately nucleated and began to grow. Additionally, there was a drop in to 145°C. At this temperature, the PbSe nanocrystals grew for about 30 min. The crystals were then cooled to room temperature.
PbSe nanocrystals were precipitated from other components by adding ethanol to the crude solution. Separation o the crystals was done using a centrifuge. The nanocrystals are visible using an electron microscope.

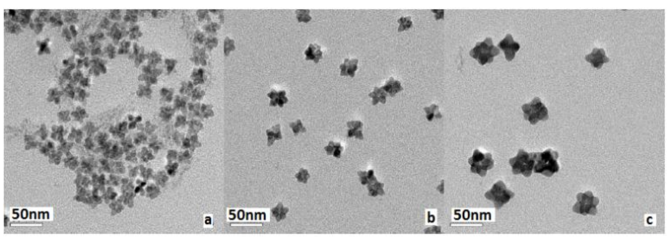

Fig.3 Lead Selenium nanocrystals

C. *Characterization of Lead Selenium Nanocrystals*

Lead selenium nanocrystal growth is proportional to the time the crystals were allowed to form (cooling time). Sample crystals which were formed at intervals of 3min, 5min and 30 min were selected. Fig. 3(a) shows crystal size at 3min, Fig.3 (b) crystals size at 5min and Fig.3(c) crystals at 30min [2].

D. *Fabrication of solar cell*

Fig.4(a) shows the solar cell of 10cm x 10cm in dimension. This cell is then connected in series with other similar cells to form a module as shown in Fig 4(b). There is a drop in efficiency with these connections due to resistances at the connection points.

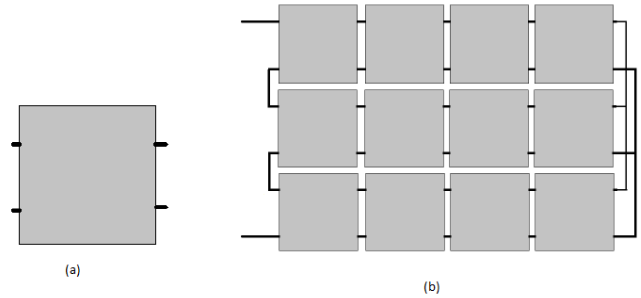

Fig.4 Connection of solar cell

V. CONCLUSION

This research is on going, the nanocrystals have been obtained using solution method and currently in the process of monitoring consistency in the nanocrystals before using them in fabricating the solar cell. A comparison of efficiencies of silicon and lead selenium modules is to be done to complete the analysis.

ACKNOWLEDGEMENT

L.T Rottok would like to thank Ms. Chester Everia for helping in the nanocrystal production and giving valuable advise.

REFERENCES

[1] Zakaria Anwar Zakaria, Bai-Chao Chen and Mohammed Osman Hassan, “Modeling of Photovoltaic Power Plants,” IEEE Xplore, pp. 3835-3839, 2006.

[2] Lin Yuan, Daoli Zhang, Jianbing Zhang, Yunxiang Hu, “Shape Evolution of Star-shaped Colloidal PbSe Nanocrystals,” Proceedings of the 3rd IEEE International Conference on Nano/Micro Engineered and Molecular Systems, January 6-9 2008, Sanya China.

[3] Wei-zhong Lva and Wen-jian Wenga, “Preparation of lead selenide nanoparticles under ultrasonic-microwave co-irradiation,” vol. 978-1-4244-4813-5/10, 2010.

[4] S. N. Michitoshi Ohnishi, Akio Takeoka and Y. Kuwano, “Advanced photovoltaic technologies and residential applications,” Renewable Energy, vol. 6, No.3, pp. 275-282, 1995.

[5] Xiaomei Jiang, Richard D. Schaller, Sergey B. Lee, Je_rey M. Pietryga , Victor I.Klimov and Anvar A. Zakhidov, “PbSe nanocrystal/conducting polymer solar cells with an infrared response to 2 micron,” Materials Research Society, vol. Vol. 22, No. 8, Aug 2007, pp. 2204-2210.

[6] Roberto F. Coelho, Filipe Concer, Denizar C. Martins, “A proposed photovoltaic module and array mathematical modelling destined to simulation,” International Symposium on Industrial electronics, vol. ISIE 2009, pp. 1624-1629, 2009.

[7] Cristinel Ababei, Subbaraya Yuvarajan, Douglas L Schulz, “Toward integrated PV panels and power electronics using printing technologies”, Solar Energy 2010-Elsevier, pp. 6-7, 2010.

[8] D. Anderson, M.A. Green, E. Lorenzo, T. Markvart, “The Physics of Solar Cells.”London: Imperial College Press, pp 7-16, 2002.

[9] Srinivasamohan Narayanan, Stuart R Wenham, Martin A Green, ”17.8 Percent efficiency polycrystalline silicon solar cells," IEEE Transactions on Electronic Devices, vol. Vol 37 No.2, pp. 382{384, February 1990.

[10] D. S. Ruby, P. Yang, S. Zaidi, S. Brueck, M. Roy and S. Narayanan, “Plasma Etching, Texturing, and Passivation of Silicon Solar Cells”, vol. IEEE Xplore, pp. 456-465, 1998.

[11] L. Zhao, Y.H. Zuo, C.L. Zhou, H.L. Li, H.W. Diao , W.J. Wang, “A highly efficient light-trapping structure for thin-film silicon solar cells”, Solar Energy 84 (2010), p. 110115, 2010.

[12] OmidShekoofa and Mohsen Taherbaneh, “Modelling of Silicon Solar Panel by MATLAB/Simulink and Evaluating the Importance of Its Parameters in a Space Application”, Solar Energy IEEE, pp. 719-724, May 2007.
[13] Green, M.A. et al., 2004. Crystalline silicon on glass (CSG) thin-film solar cell modules. Solar Energy 77 (6), 857–863.
[14] Green, M.A., 2009. Polycrystalline silicon on glass for thin-film solar cells. Applied Physics A: Materials Science & Processing 96, 153–159.
[15] Green, M.A., Emery, K., Hishikawa, Y., Warta, W., 2009. Solar cell efficiency tables (Version 34). Progress in Photovoltaics: Research and Applications 17 (5), 320–326.