

Improving Solar Cell Efficiency using Lead Selenium Nanocrystals

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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 photovoltaic principle. Solar cells are used to harness the sun's 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 sun's 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.

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].

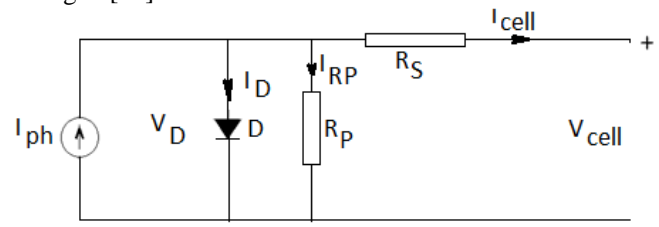


Fig.1 Solar cell modeling.

The current flowing in the cell is given by;

$$I_{cell} = I_{ph} - I_D - I_{RP}$$

(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} is the 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;

$$I_{ph} = S \cdot I_{sc} + I_{sc} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)$$

(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;

$$P_{cell} = V_{cell} I_{cell} = V_{cell} [I_{ph} - I_D - I_{RP}]$$

(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;

$$\eta = \frac{V_{cell} I_{cell}}{P_{in}}$$

(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;

$$FF = \frac{P_{max}}{V_{cell} I_{cell}}$$

(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

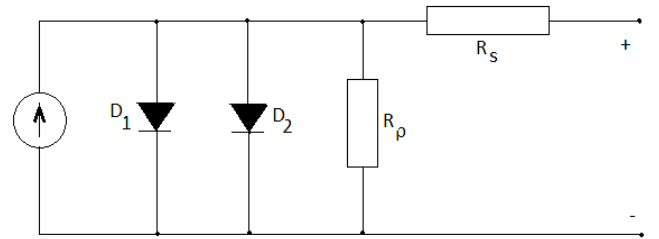


Fig.2 Model for nanocrystal solar cell

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;

$$I_{D_i} = I_{sat} e^{\frac{qV_{cell} + R_s I_{cell}}{n_i k T}} - 1$$

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 Trioctylphosphine 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 mol⁻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.

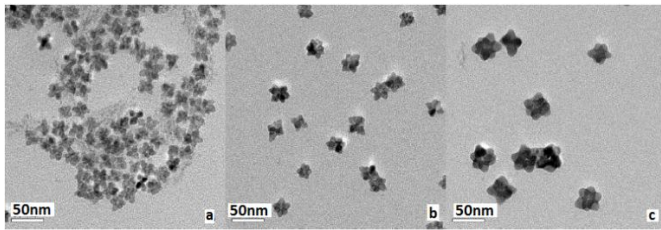


Fig.3 Lead Selenium nanocrystals

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.

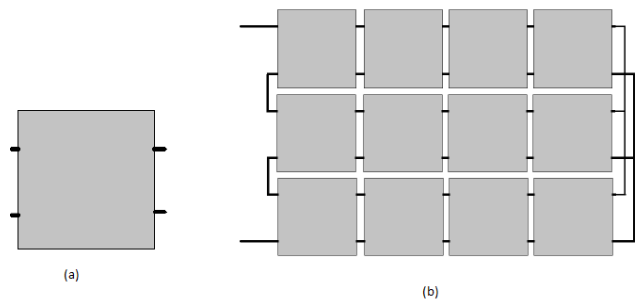


Fig.4 Connection of solar cell

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.

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