COOLING SOLAR CELLS USING ZnO NANOPARTICLES AS A DOWN-SHIFTER

by

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Down-shifting material is used to enhance the overall efficiency of the photovoltaic solar cell by reducing the energy of incident photons and then cooling down the temperature of the photovoltaic solar cells. This experimental work focused on studying the effect of ZnO nanoparticles as a downshifting material on reducing the temperature of the photovoltaic cells. Readings of temperature and voltage – which were collected on different days in summer July showed a good effect of ZnO nanoparticles on solar cell temperature. Where there was a significant decrease in cell temperature of up to 4.5 °C, in addition an increase in voltage of about 1.5 V.

Key words: *down-shifting, nanoparticles, photovoltaic, ZnO, cooling, solar cell, efficiency*

Introduction

Solar cells convert solar radiation into electrical energy, unfortunately, large amount of solar energy is lost due to the high temperature of photovoltaic (PV) cells, this, in turn, leads to a drop in the cell's efficiency, as well as it reduces its lifespan.

Two common methods are used to cool down the PV panel.

Cooling solar cells

In literature, there exist significant amount of work conducted on cooling PV cells,-Teo, *et al.* developed a hybrid photovoltaic /thermal (PV/T) system consisting of a parallel array of ducts with an inlet/outlet manifold designed for uniform air-flow distribution attached to the back of the PV panel [1]. The experimental study showed that with an air cooling, the temperature of the panel dropped significantly and solar efficiency was increased to between 12-14 %. While a cooling device designed by Rahimi *et al.* [2] which tried to join up the wind and solar energy showed that the total generated power from PV cell and wind is 21% higher than the simple cooling system.

Water cooling method using by Kumar *et al.* [3] to increase PV module performance due to an evaporation of water and self-cleaning effect, and to minimize the amount of water and electrical energy needed for cooling of the solar panels. They used a mono-crystalline and amorphous silicon PV module as a solar absorber. They found that the water cooled solar PV system has got better performance than the simple PV.

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Drabiniok and Neyer [4] conducted on exceptional technique of cooling PV solar cell using the bionic method of evaporation cooling which inspired from plant's transpiration and human perspiration. Using thin micro-structured polymer foil by evaporating water through micro-pores on the back side of PV-modules. The bionic evaporation foil showed a significant enhancement due to large drop in temperature (11.7 °C) .

Another method for cooling a PV solar cell is by using natural vapor as coolant with various distribution and different mass-flow rates to enhance the efficiency of the PV cell [5]. Increasing natural vapor flow rate reduced the temperature of solar cell about 7-16 °C which caused a large enhancement of the electrical efficiency to be about 23%.

Ceylan *et al.* [6] design a new PV and thermal system for cooling PV modules. A spiral pipe was placed behind PV module as heat exchanger in order to provide active cooling. The experimental study showed that the efficiency of the module with a cooling spiral pipe was higher than that of the one without a cooling of about 3%.

Photoluminescence down-shifting

Photoluminescence (PL) is the phenomenon of temporary photon absorption (which excites an electron a higher quantum state), and subsequent photon emission, where the ex-cited electron returns to a lower energy quantum state [7].

Yuan *et al.* [8] observed a relative increase of the internal quantum efficiency when using silicon nanocrystals (Si-NC) as PL down-shifter layer on a Si solar cell. The (Si-NC) embedded in Si-rich silicon oxide (SRO). The SRO layers absorb high energy photons and emit photons at a longer wavelength, which are in turn absorbed by Si. While a thin film of Si NC in a matrix of SiO_2 on a p-type c-Si solar cell used by Luxembourg *et al.* [9] showed that, gain in short-circuit current densities (Jsc) is only achieved for a Si NC layer with high emission quantum efficiencies, which requires efficient quantum cutting.

The silicon nanocrystals also used by Sgrignuoli *et al.* [10] as a luminescence down-shifting (LDS) material to enhance the efficiency of the silicon PV solar cell, the (Si-NC) embedded in a silicon oxide matrix. A double layer stack of SiO_2/Si-NC was used as an antireflection coating (ARC) and as a LDS material showed a relative enhancement of the energy conversion efficiency about 6% .

Hung and Chen [11] used antireflection-coating (ARC) of submicron spherical Europium-doped gadolinium oxysulfide ($Gd_2O_2S:Eu^{3+}$) phosphor impregnated in a polyvinylpyrrolidone (PVP) matrix on the surface of the polycrystalline silicon (pc-Si) solar cell, which achieved about 2.75% enhancement in energy conversion efficiency.

A monocrystalline silicon solar cell coated by Ce^{3+}-doped yttrium aluminum garnet ($YAG:Ce^{3+}$) phosphors as LDS material used by Shao *et al.* [12] could reduce the energy loss in the short wavelength range a slight increase in power conversion efficiency.

Apostoluk *et al.* [13] examined the employment of ZnO nanoparticles as a luminescent down-shifting layer for three different types of cells (Si, CIGS; copper indium gallium selenide and CdTe; cadmium telluride). The experimental, analytical and simulation studies showed that the I-V characteristics of the CIGS and CdTe solar cells are strongly affected by the presence of the PL down-shifting layer on their top. On the other hand, Cadmium Telluride (CdTe) and Cadmium Sulfide (CdS) solar cells are used to investigate the application of concentrating luminescent down-shifting (C-LDS) with a poor short wavelength response using multiple fluorescent species with energy transfer improving the efficiency of the solar cell by increasing the output current about 20% [14].

Sgrignuoli *et al.* [15] fabricated an interdigitated back-contact crystalline silicon solar cells coated with the optimized Si-NCs layer. The experimental study showed a relative enhancement of efficiency about 0.8 % due to purcell effect and luminescent downshifting layer.

The lanthanide-based metal complex was used as (LDS) layers for P3HT:PCBM organic PV (OPV). The work showed that the LDS layer can act as a UV filter without compromising the efficiency of the solar cell [16]. Another Luminescent downshifting material used to improve the conversion efficiency of silicon solar cell used by Dai Pre *et al.* [17] is manganese-doped Zinc sulfide (ZnS:Mn) nanoparticles. A set of samples with a different concentration of ZnS were prepared, the experimental study showed that using 0.1 wt% of ZnS:Mn could raise the efficiency about 2% .

In this study, the potential of using ZnO nanoparticles as a down-shiftng material on cooling the PV pannels was studied.

Experimental work

The ZnO nanoparticles are in powder form, so it is not possible to deposit it directly on the solar cell. Therefore, ZnO nanoparticles must be embedded in a host material in the form of suspension. This would allow controlling the concentration of ZnO nanoparticles easily to obtain a UV-absorbing, but visible transparent film. Also, the host material required to be photo-stable, water-resistant and most importantly, transparent over the wavelength region suitable for solar cells. A suitable material is a polymethylmethacrylate polymer (PMMA) commonly known as *Acrylic* has been used as embedding matrix for ZnO Nanoparticles.

The ZnO-PMMA suspension preparation

For embedding ZnO nanoparticles in the PMMA, a commercially available surfactant named dioctyl sodium sulfosuccinate (AOT) has been applied. A 4:1 ratio of ZnO nanoparticles powder and AOT has been put in the mixture to achieve a standard outcome. The amount of AOT has been scaled with the amount of ZnO nanoparticles so that the agglomeration of ZnO nanoparticles can be avoided [18].

To produce a thin film of ZnO nanoparticles and PMMA, it should be taken into account that the thickness of the film depends on the viscosity of PMMA solution. Therefore, a fixed amount of Ethyl Acetoacetate is used to dissolve the PMMA pellets and thus control its viscosity. For a direct comparability, two identical solar panels are used, the outside glass plate of the first solar panel have been coated with these suspensions, where the ZnO-PMMA coating acts as LDS layer, and the second solar panel left without coating, it has been taken as a reference so that the effect of ZnO nanoparticles can be studied.

Spin coating

Spin coating is a process to produce thin and uniform films of a certain coating material on a flat substrate. An excess amount of coating solution is applied either manually or automatically on the substrate; as the substrate is rotated at high speed, the resulting centrifugal force spreads the solution homogeneously. The viscosity of the solution and spin speed are two major parameters in film-forming process. Higher viscosity results in thicker film. The reverse holds for the dependency of thickness on spin speed.

In the experiment, 10 ml of the ZnO-PMMA-ethyl acetoacetate suspension has been deposited on a 20.4×31.2 cm^2 solar cell's cover glass. It should be mentioned that, before the deposition, the cover glass has been cleaned with acetone. As the spinning has started with 200 rpm speed for 10 seconds the suspension is spread over the glass. Then the speed has been

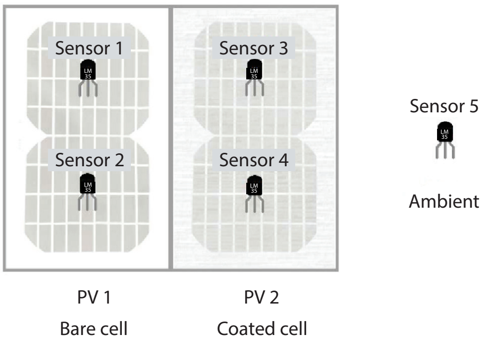

Figure 1. The LM35 sensors location on solar panels

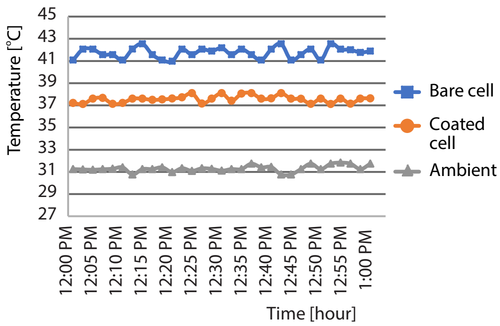

Figure 2. Temperature difference of PV with and without ZnO, July 6, 2017 (12:00 p. m. – 1:00 p. m.) Amman, Jordan

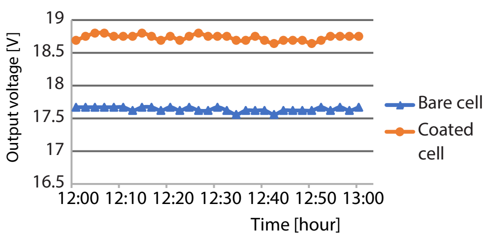

Figure 3. Voltage difference of PV with and without ZnO, July 6, 2017 (12:00 p. m. - 1:00 p. m.)

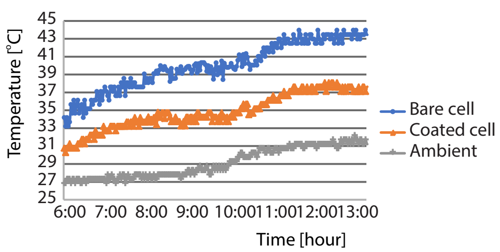

Figure 4. Effect of ZnO DSL on average temperature on July 6, 2017

increased to 500 rpm for 20 seconds. Finally, it is spun at 70 rpm for 10 seconds before the spinning stops. The outcome is a homogeneous, wet and thin film of only ZnO-PMMA on the cover glass, and ethyl acetoacetate is supposed to be evaporated during this coating process.

Experimental procedure

Both coated and bare solar panels were installed side by side and experiments were conducted on both panels simultaneously. Each panel is connected to two LM35 sensors to measure and compare the average temperature with and without ZnO LDS layer. One LM35 sensor is connected separately to measure the ambient temperature as shown below in fig.1. Arduino IDE software is used to collect data of PV temperatures from all sensors and voltage of coated and bare solar panels.

Results and discussion

The effect of the ZnO LDS layer on the temperature of the solar cell in Amman, Jordan for one hour (12:00 p. m. – 1:00 p. m.) on June 6, 2017, is illustrated in fig. 2. As shown, the coated cell's temperature is less than the temperature of the bare cell of about 4 °C, this shows the effect of ZnO nanoparticles on the PV temperature, while the LDS layer decrease incident photons energy.

The effect of the ZnO LDS layer on the voltage of the solar cell for one hour (12:00 p. m. – 1:00 p. m.) on June 6, 2017 Amman, Jordan, is shown in fig. 3. For the bare cell (PV1), average voltage is about 17.6 V, while the average voltage of coated cell (PV2) is 18.8 V. The difference of output voltage between coated and bare cell (about 1.2 V) shows the effect of ZnO Nanoparticles on the cells efficiency.

Figure 4 shows the temperature variation for coated and bare cells. The temperatures difference between bare cell and the coated cell at early morning (at 6:00 a. m.) is about 2.5 °C, and the difference increase to the maximum of 5 °C at midday at 12:30 p. m. Which means that the LDS material acts better at high temperature.

The change in temperature affects the power output from the cells. Current-voltage (I-V) characteristics of both bare and coated solar cell are shown in fig. 5. The voltage is dependent on the temperature and an increase in temperature will decrease the voltage.

Figure 6 shows the maximum daily temperature of ambient and the solar panels from July 1 to July 13, as shown, the temperature of coated solar panel is less by 3-5 °C than the temperature of a bare solar panel, which confirms the effect of ZnO Nanoparticles on the solar cell temperature and efficiency.

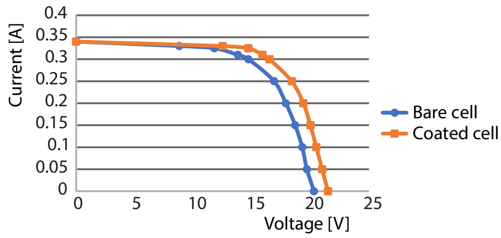

Figure 5. The I-V characteristics of solar cells with and without ZnO

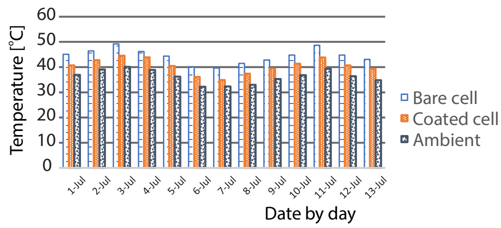

Figure 6. Effect of ZnO on maximum temperature from 1 July – 13 July, Amman, Jordan

Conclusions and future work

In this work, the performance of ZnO Nanoparticles as a luminescent down-shifting material for Si solar cell has been investigated experimentally. From the temperature measurement, it is observed that when the ZnO Nanoparticles placed on the front side of a photovoltaic solar cell it can reduce the solar cell temperature by 4.5 °C.

Also, ZnO Nanoparticles slightly increase the output voltage of about 1.2 V, which makes a small improvement in electrical efficiency.

Further future research and experiments can be implemented, in order to investigate the optimum effect of ZnO Nanoparticles on solar cell temperature by using different concentrations of ZnO Nanoparticles in the mixture coated on the panels.

Using a spin coating machine yields more accurate results, where experiments can be performed using higher speeds with fewer vibrations to produce very thin luminance down-shifting layer

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