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Using ZnO/PMMA Nanocomposite Coating to Improve the Polycrystalline Solar Cell in Hot Weather Conditions

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Abstract

Solar energy is the most significant future energy source as the world keeps working to minimize emissions caused by the use of fossil fuels. The most popular method for transforming sunlight into electrical energy is the photovoltaic solar cell (PV). The main two problems with PV solar cells highlighted in this paper are the high solar cell surface temperature and the high reflection light of PV solar cells. Because each 1 °C increase in surface temperature reduces efficiency by 0.45%, and approximately 35% of total sunlight reflected in crystalline silicon solar cells. In this experimental work, the sol-gel process was used to prepare different concentrations of zinc oxide/polymethyl methacrylate (ZnO/PMMA) nanocomposite coatings and apply them to the top side of the polycrystalline solar cell in order to increase the solar cell efficiency. The results demonstrate a maximum temperature drop of 8.6 ºC and light reflection reduced up to 5.6%, so this led to an increase in solar cell efficiency from (11.33%) to (15.22%), where the results of the electrical properties after one hour (test time) showed that the uncoated cell was (I_{SC} = 0.33 A, V_{OC} = 0.38 V, and P_{max} = 97 mW), while the results of the coated cell with the best concentration (3.875 wt%) were (I_{SC} = 0.36 A, V_{OC} = 0.43 V, and P_{max} = 130 mW).

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Introduction

One of the most significant renewable sources of energy sources is solar energy because of its minimal environmental effect and worldwide accessibility. In comparison to carbon-emitting fossil resources, solar energy is renewable and readily available to the general public, making it a critical green power source [1]. Solar cells have comprised of semiconductors which utilize photons from the sun to excite the electrons, resulting in a direct electric current and the conversion of energy from the sunlight,

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whenever a PV solar cell is exposed to light, voltage - current are produced [2]. Photovoltaic systems (PVs) are one of the most potential solar energy harvesting approaches. The PV technology power generation system does have certain basic issues, such as snow, dust, high reflection light and the operating temperature, that can reduce the generator system's efficiency [3]. Solar cells usually operate in a temperature range of 50 °C to 55 °C or higher. Not all solar radiation absorbed by PV solar cell is converted into electricity, a large part of it converts into heat that causes the solar cell to heat up [4]. For example, solar cells are made of crystalline silicon, each increase in surface temperature by 1 °C leads to about 0.45% reduction in efficiency, as a result, the heat dissipation of a solar module is critical to lowering its temperature, which has a severe impact on energy output [5]. Normally PV solar cells are comprised of silicon (Si), which may be the second most prevalent substance found on the earth's mantle and has a high surface reflection characteristic. As a result, after striking the PV panel, approximately 35% of the entire amount of sunlight reflects, according to recent developments, either micro coating or nano-composite coating of antireflection compounds on the PV panel improves solar energy conversion and compounds that are fluorescent to lower the conversion rate capabilities that can be used to solve the high temperature problem [6]. The sun is located 150 million kilometers away with a solar constant of 1367 w/m^2, this number changes by ±3% depending on how far the Earth is from the Sun. The light we see every day is only a small part of the total energy generated by the sun. It is an electromagnetic wave that extends from gamma rays to radio rays, among which are X-rays, ultraviolet, visible, infrared, and microwave rays, the photon's energy and the wavelength of light are inversely related [7]. The sunlight in ground level consists of 44% visible light, 3% ultraviolet light and the remaining is infrared light. Since the atmosphere blocks 77% of the sun's UV-radiation [2].
The solar cells have comprised of semiconductors which utilize photons from the sun to excite the electrons, resulting in a direct electric current and the conversion of energy from the sun. Whenever a PV cell is exposed to light, voltage - current are produced. Although the connection between absorbed light and electricity generated production is linear, numerous factors influence the solar cell performance and, as a result, its output power. The operating temperature has a great impact on the efficiency of the PV cell. The photovoltaic cell's produce electrical current that passes across a P-N junction. As a result, only photons with energies equal to or greater than the band-gap energy are engaged, whenever the energy of a photon exceeds the energy bandgap, electrons are liberated, and the excess is transformed into heat, raising the temperature of the solar cell, so about 20% of overall light is transformed into electrical energy, and the remaining is wasted as light reflects, as heat in the silicon semiconductor, or light that passes along the photovoltaic cells without being absorbed or reflected. The formation of electrical charge and heat in solar cells are caused by the activation of the semi-conducting of sunlight electrons, and these may maximize the efficiency by collecting the complete solar spectra inside that range's band without sacrificing any energy [8]. Therefore, the process of absorbing high-energy photons, such as ultraviolet photons, is one of the factors causing the rise in the temperature of the solar cell. Ultraviolet rays (UV) are divided into three regions based on their intensity (A, B, and C), where UVA (315-400) nm, UVB (280-315) nm, and UVC (100-280) nm where UV-C has the highest energy within the range of 100–280 nm, where it has electron energy of about 4.43 to 4.40 electron volts (eV), and it causes the most generating thermal energy that causes the heat of the solar cell [9]. The high transmittance of visible light in the wavelength rang (400-700) nm [10].

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According to standard definitions, nanomaterials are those that "have structural or surface features with one or several dimensions in the range of sizes of 1–100 nm". Since their tiny size and high surface (area to volume ratio), nanoparticles are seen as different from their bulk counterparts and are made up of unique chemical and physical features. A new phase in the development of nanotechnology has emerged during the past two decades as a result of the obvious benefits of employing nanoparticles for many applications [11]. A practical way to integrate inorganic and organic elements to create a hybrid nanocomposite material is realized through inorganic and organic elements. Since organic–inorganic nanocomposites, sol–gel hybridization techniques have emerged as an exciting new field of research in material science. The creation of innovative organic-inorganic hybrid multi-purpose coating systems with intriguing physiochemical properties for potential application is the result of increased scientific research in this sector. Nanocomposite coating is used in a variety of applications, including corrosion protection, anti-fog coating, anti-reflective coating, self-cleaning coatings, anti-stain coatings, and water repellent anti-static coatings, etc. [12]. **Vandana Kaler et al.** [13] Polyvinyl alcohol (PVA) which had been dissolved in distilled water (DW), was combined with various amounts of titanium dioxide (TiO_2) nanoparticles to create a nano-composite coating mixture. It was used on the solar cell's top surface to filter ultraviolet (UV) radiation and minimize visible light reflection, which improved the optical characteristics and increased efficiency. As a consequence of using 0.25 wt.% titanium dioxide in the TiO_2/PVA nanocomposite, the maximum absorbance for the full UV spectrum (200-400 nm) was at wavelength 338 nm. And the melting point of the TiO_2/PVA nanocomposite was substantially higher than that of pure PVA. The TiO_2/PVA nanocomposite was found to have the maximum thermal stability. **Jinsu Jung et al**. [14] A double layer ARC of TiO_2/Al_2O_3 was successfully produced by the experimental use of spin coating sol-gel precursors and applied to a silicon solar cell. The double-layer TiO_2/Al_2O_3 anti-reflective coating, which has an average reflection of 4.74 % in the 400-1000 nm wavelength area and a high refractive index (n = 2.89), proved the minimum reflectance result of 3.02 % at 970 nm when compared to single layers of titanium dioxide (TiO_2) and aluminum oxide (Al_2O_3). This result shows that the double layer TiO_2/Al2O_3 anti-reflection coating on silicon solar cells increased conversion efficiency by 13.95% compared to the single layer TiO_2 and Al_2O_3 anti-reflection coating. **A. Kumar and A. Chowdhury** [15] A selective radiative antireflective coating (SR-ARC) was created by combining SiO_2, Si_3N_4, and Al_2O_3. They were used and tested to see how the (SR-ARC) affected the single and double Si_3N_4-coated layers of the crystalline silicon solar cell. At an ambient temperature of 30 °C, the results showed temperature reductions of 5.6 °C and 5.4 °C for double and triple ARC layers, respectively, and a maximum reduction of 6.8 °C found at an ambient temperature of 45 °C with double-layer ARC. **Ali kadim et al.** [16] The solvent casting method is utilized to conduct exploratory studies on the nanocomposite Titanium Dioxide/Polyvinyl Alcohol (TiO_2/PVA), and nanoparticle concentration (10-20) nm, for coating on the top surface of the crystalline silicon solar cell. The aim is to investigate the impact of TiO_2/PVA nanocomposite on the polycrystalline silicon solar cells. For the 0.2 wt% nanocomposite coating, it was discovered that the improvement in solar cell proficiency was (+2.3%), the reflection obtained was 3.9 %, and the solar cell showed the most significant temperature change is 9.7 °C when compared to a solar cell without a coating.

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In this experimental study, the polymethyl methacrylate (PMMA) polymer and zinc oxide (ZnO) nanoparticles were used to prepare different concentrations of ZnO/PMMA nanocomposite coating, which were then applied to the top surface of polycrystalline silicon solar cells to investigate its effect on solar cell efficiency in order to lower the polycrystalline silicon solar cells' surface temperature while working in hot weather conditions (blocking ultraviolet UV-rays), and reduce the amount of light that reflects intensely in polycrystalline silicon solar cells.

Experimental procedure

Materials used

Polymethyl Methacrylate (PMMA)

The Iraqi A white powder of PMMA (polymethyl methacrylate) has a 1.18 g/cm^3 density and a 160 °C melting point. Table 1, listing some of the physical and chemical properties of Poly (methyl methacrylate). PMMA is one of the most well-known and well-established polymers with the chemical formula ($C_5H_8O_2$) n. PMMA was formerly thought to be a viable alternative to glass in a number of applications, and it is now widely utilized in glazing. The toughest polymers should be a stiff substance, transparent, and weather-resistant. PMMA is colorless and transparent by nature. Visible light transmittance is extremely great. PMMA matrix materials are well-known for their use in technological applications[17].

Table 1. Spectro- Physical and chemical properties of polymethyl methacrylate (PMMA).

Property	Polymethyl methacrylate (PMMA)	Unit
Color	Colorless	-
Density	1.18	g/cm^3
Melting point	160	°C
Thermal conductivity	0.12	w/m.k
Surface hardness	M90	Rockwell
Refractive index	1.4	-
Chemical formula	$(C_5H_8O_2)_n$	-
Organic solvents	Acetone, Chloroform and Toluene	-

Zinc Oxide (ZnO)

Zinc oxide has the formula ZnO and is an inorganic substance. It is a white powder that is water insoluble. ZnO may be found in many different forms, including nanoengineered, nanoparticles, nanostructured, and nan-building materials. It is also simple to change the qualities of a nanostructure by changing its shape and size. Figure 4-2. Zinc oxide crystallizes mostly in wurtzite, zinc-blende, and rock salt cubic regimes [18]. They have outstanding optoelectronic characteristics and can be readily manufactured into various geometries, making them potential photovoltaic solar cell possibilities. ZnO nanoparticles have a low reflectivity, which increases optical absorption, table 2. Nanostructures of ZnO are commonly used as the anti-reflective coating in photovoltaic systems, in this study used ZnO nanoparticles of 40–50 nm size.

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Table 2. Zinc Oxide general specifications.

Property	Zinc Oxide
Chemical formula	ZnO
Color	White
Molar mass	81.406 g/mol
Melting point	1974 °C
Density	5.606 g/cm^3
Band gap	3.3 eV
Refractive index	2.013

Polycrystalline silicon solar cell

A commercial polycrystalline silicon solar cell was used with the specifications shown in table 3 and figure 1, to test the effect of the nanocomposite coating. The solar cell, with dimensions of (39*22) mm, forms part of the solar module that contains several cells connected in series.

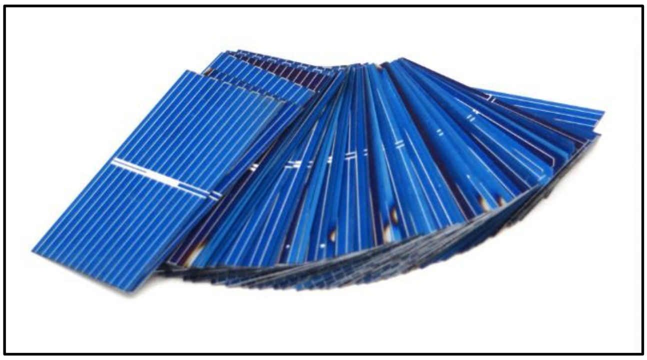

Figure 1. The commercial polycrystalline silicon solar cell.

Table 4.3. Commercial Polycrystalline Silicon Solar Cell Properties.

Item	Description
Type	Polycrystalline silicon
Size	(39×22) mm
Area	858 mm^2
Maximum power (P_{max})	0.14 W
Rated Voltage	0.5 V
Rated Current	0.28 A
Standard test conditions (STC)	1000 w/m^2, 25 °C

Thin film preparation

PMMA amount (1.25 g) were weighed and added to the vial with 40 ml of acetone solvent and placed the PMMA solution on the magnetic stirrer at 400 RPM and a temperature of 60 ºC for about an hour

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until it is fully dissolved, this procedure used for 1.25 g PMMA amount to get the 3.125 wt% concentration.
In other hand four amounts of ZnO nanoparticles powder (0.1 g, 0.2 g, 0.3 g, and 0.4 g) were weighed by using a sensitive balance, and then 40 ml of the acetone solution was added to each weighted amount to prepare the four different concentrations as shown below.

- 0.1 gram ZnO powder +40 ml (acetone): 0.25 wt%
- 0.2 gram ZnO powder +40 ml (acetone): 0.5Wt%
- 0.3 gram ZnO powder +40 ml (acetone): 0.75 wt%
- 0.4 gram ZnO powder +40 ml (acetone): 1 wt%

The four different concentrations (0.25 wt%, 0.5 wt%, 0.75 wt%, and 1 wt%) were prepared by weighing four different amounts of ZnO nanoparticles, size 40-50 nm, (0.1 g, 0.2 g, 0.3 g, and 0.4 g), using a sensitive balance, and then adding 40 ml of the acetone solution to each weighted sample. To disperse the ZnO nanoparticles in the solution, the four created varied concentrations placed individually in the ultrasonic device, type NT-628, for six hours (total time for preparing one sample of nanocomposite). The preparation of ZnO/PMMA is shown in figure 2 and 3
The four ZnO concentrations prepared were doped with a 3.125 wt% PMMA (1.25 g) in order to prepare the four concentrations ZnO/PMMA (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) as below listed.

- (1.25 g PMMA/40ml acetone)+(0.1 g ZnO /40 ml acetone):3.375 wt%
- (1.25 g PMMA/40ml acetone)+(0.2 g ZnO /40 ml acetone):3.625 wt%
- (1.25 g PMMA/40ml acetone)+(0.3 g ZnO /40 ml acetone):3.875 wt%
- (1.25 g PMMA/40ml acetone)+(0.4 g ZnO /40 ml acetone):4.125 wt%

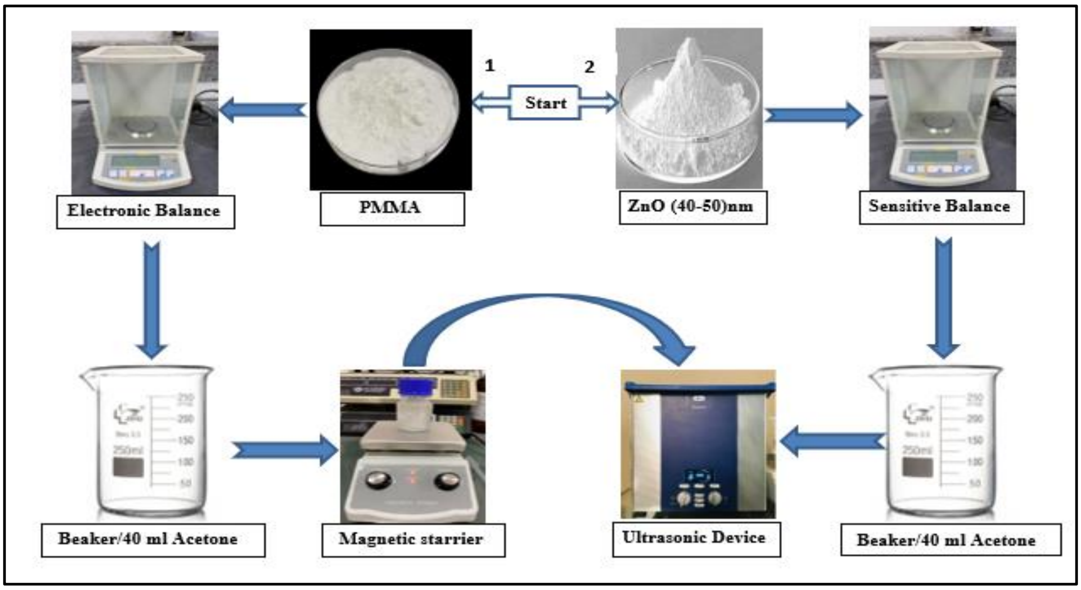

Figure 2. The production of ZnO/PMMA nanocomposites coating.

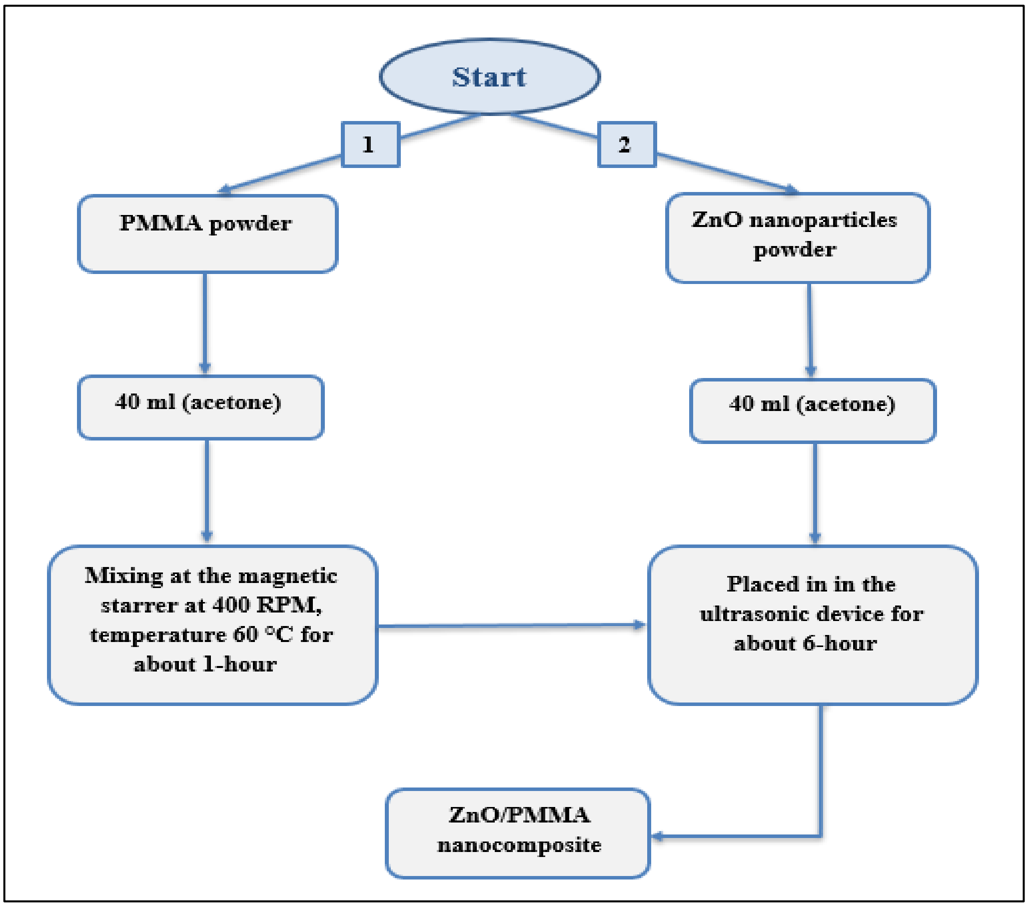

Figure 3. Flowchart for the production of ZnO/PMMA nanocomposites coating.

Coating process

The first step of the coting process is the cleaning and surface preparation of commercial polycrystalline silicon solar cells of size (39×22) mm. This is done by placing a number of cells in a beaker and adding 20 ml of distilled (DI) water, sonicating in the ultrasonic device, for 10 minutes, and repeating the procedure with acetone instead of DI water. The solar cells were then allowed to dry at an ambient temperature. As a result, the polycrystalline silicon solar cells are freed from dust and pollutants and are ready for coating. There were several techniques used to coat the silicon solar cells, but the casting procedure was the most economical and easiest one [13]. 0.5 ml of ZnO/PMMA nanocomposite coating was enough to coat one of the commercial polycrystalline silicon solar cells with a size of (39*22) mm, so by using a pipe tube, 0.5 ml of coating was applied to the top surface of the solar cell. The coating was then moved to cover the entire solar cell, where the coating layer was formed with an almost even thickness, as conformed by measuring the coating thickness using a dry film thickness gauge (DFT). And then leave the solar cell at room temperature for about 30 minutes to dry the coating. See figure 4.

Dry film thickness measurement (DFT)

The most essential metric in protective coatings operations is dry film thickness, which is defined and monitored in almost every coating application. Modern digital gauges allow for the rapid and precise collection of readings, providing a full image of the coating job [19]. After the coating has been dried and cured, the thickness of the film has been measured by using a digital thickness gauge in different locations. The thickness of the coating layer was measured by the coating thickness gauge TT-260, shown in figure 4. The average reading for the ZnO/PMMA thin film coating was found to be about 2 μm.

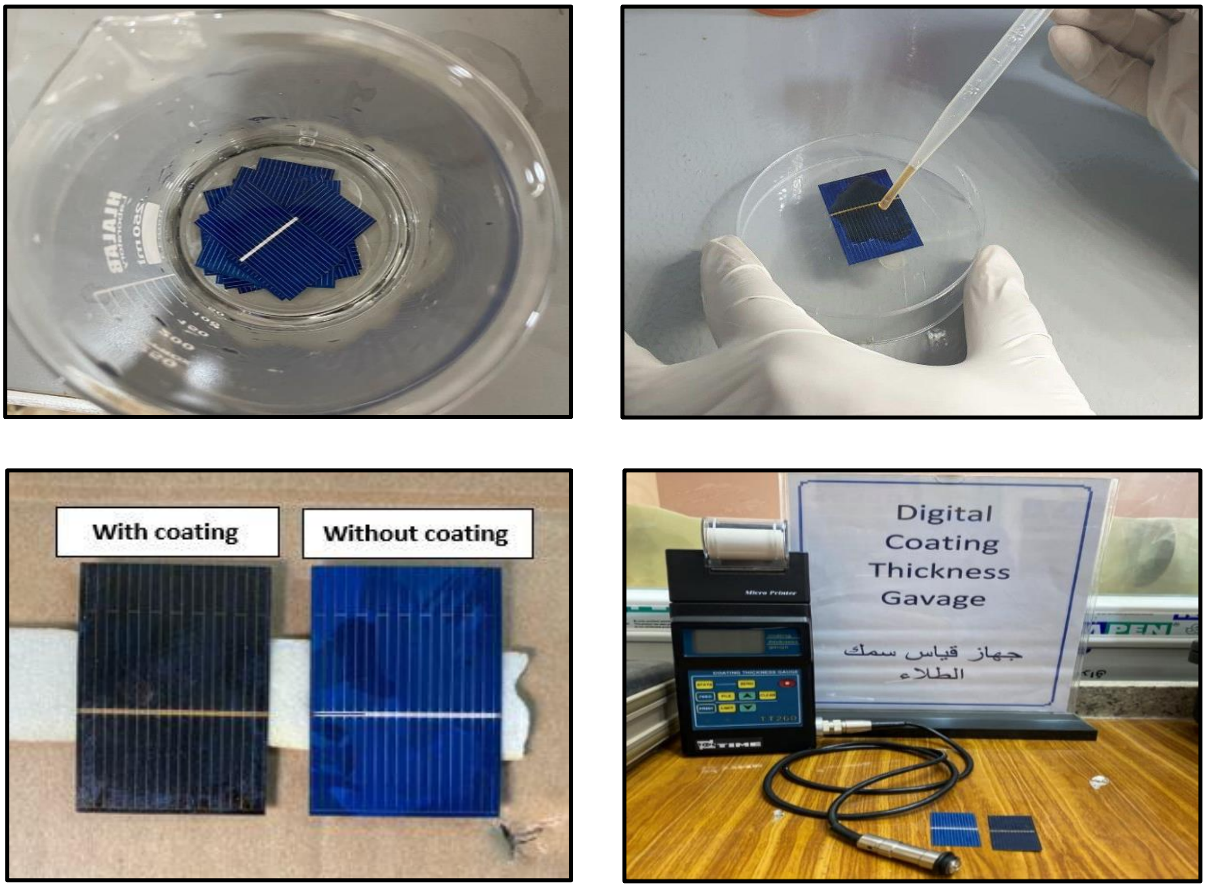

Figure 4. Coating application process and thickness measurement.

Results and discussion

The results show the performance of the coated and un-coating polycrystalline solar cells which are used in this experiment to test the UV-visible absorbance, surface temperature, Current-Voltage (I-V) curve, power-voltage (P-V) curve, power and efficiency. The quantity of solar irradiation and the surface temperature degree of the solar cell change the value of electric power produced by photovoltage cells. If the solar radiation increases, the short circuit current (I_{SC}) grows linearly, but open circuit voltage (V_{OC}) increases marginally. But the temperature has the greatest impact on the I–

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V characteristics and power efficiency of the PV solar cell unit [20]. The power and efficiency calculations has been calculated by [7]:

$$P_{max} = I_{sc} \times V_{oc} \times FF = I_{mp} \times V_{mp} \quad (1)$$

$$\eta(\%) = \frac{I_{mp} \times V_{mp}}{P_{in}} = \frac{P_{max}}{A \times G} \quad (2)$$

Where, (Pmax) is the maximum power output, (I_{SC}) short circuit current, (V_{OC}) open circuit voltage, (FF) fill factor, (η) electrical efficiency, (G) overall irradiance (w/m^2), and (A) the effectively illuminated region (m^2).

UV-visible absorbance analysis

Four samples with different concentrations of the ZnO/PMMA nanocomposite coating were used (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%). An absorbance test UV-Vis was conducted to find out the effect of adding the ZnO nanomaterial to the PMMA polymer on the absorption of UV rays. The examination was carried out by the UV-visible spectrophotometer device (Mega-2100) at the University of Kufa, Science College.

The results show that the absorbance intensities (1.9 A.U, 2.2 A.U, 2.7 A.U, and 2.4 A.U) for the investigated concentrations (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%), respectively. Indicating that the nanomaterial increased the absorption area within the UV wavelength range (200-400) nm, with the higher concentration of the nanomaterial, the greater the ultraviolet ray absorption area, as shown in table 4 and figure 5.

Table 4. The Absorption values with the ZnO/PMMA nanocomposite concentrations.

ZnO/PMMA nanocomposite concentrations (weight percent)	**Absorbance (A.U)**	**Peak Absorption point (nm)**
Without coating (WOC)	Full-transmittance	-
3.375 wt%	1.9	205
3.625 wt%	2.2	208
3.875 wt%	2.7	203
4.125 wt%	2.4	210

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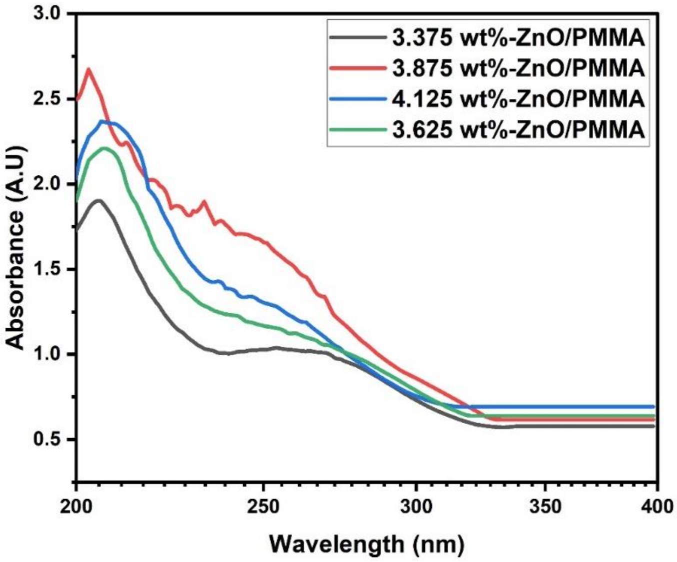

Figure 5. Comparison of the Absorption for ZnO/PMMA coating concentrations used (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%)

Energy bandgap analysis

The band gap (energy gap E_g) is the energy difference between the conduction and valence (P-region), commonly given in electron volts (eV). The band gap is particularly important in insulation materials and semiconductors, where even a small gap value controls several of the material body's electrical and optical characteristics[21]. Therefore, the bandgap energy of polymethyl methacrylate (PMMA) and ZnO/PMMA nanocomposite was measured using the Tauc plot relation through the absorbance data that were extracted when examining the UV-Visible absorbance. The results shown in figure 6 showed that the examined PMMA polymer at a concentration of 3.125 wt% obtained a band gap of 4.55 eV, while the examined ZnO/PMMA nanocomposite concentrations (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) recorded higher results (5.16 eV, 5.23 eV, 5.60 eV, and 5.50 eV) respectively.

As it is mentioned earlier, the value of the energy bandgap has increased by increasing the concentration of the ZnO nano-material until it reaches the steady state point. Compared with the value of the band gap of silicon (Si), the main component of the polycrystalline solar cell, at 1.1 eV, it is low, as raising the band-gap value of the nanocomposite coating works to reduce the reflection light experienced by the silicon cell, so it works as an antireflective coating.

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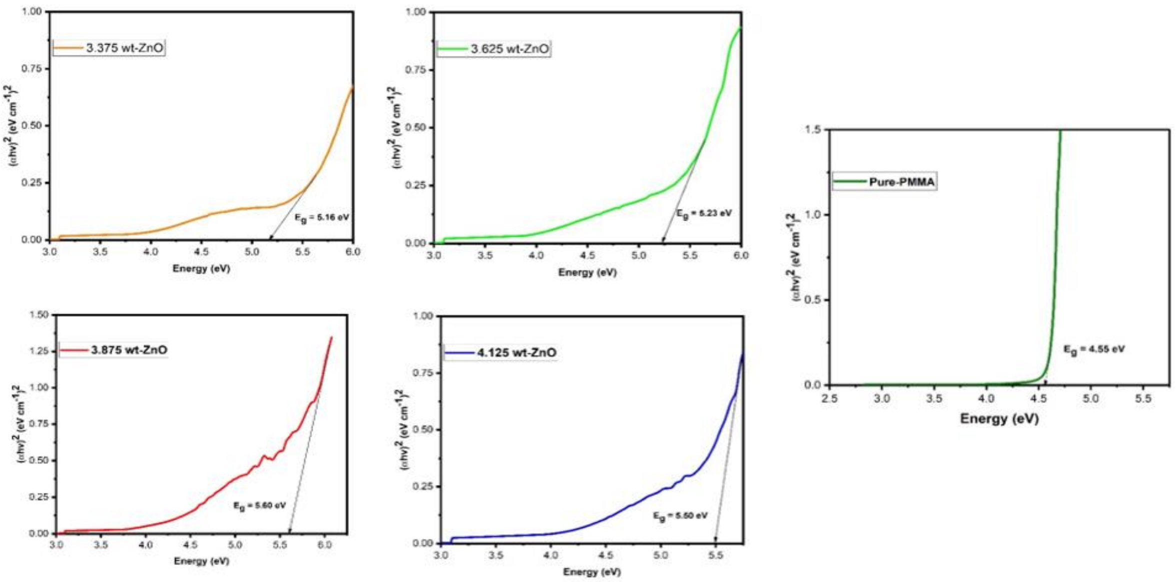

Figure 6. The energy band gap (E_g) of the ZnO/PMMA nanocomposite, Tauc plot relation.

Reflection losses analysis

The reflection test was carry out by using the UV-Visible spectrometer, type (UV-1800) double beam device for the coated polycrystalline solar cells and compared with the reflectance on the uncoated polycrystalline solar cell that has reflected light 35%, where the results of visible light reflection ratio showed in figure 7 was (13.2%, 10.3%, 5.6%, 8.7%) at 600 nm wavelength for the tested ZnO/PMMA concentrations (3.375wt%, 3.625wt%, 3.875wt%, and 4.125wt%) respectively, the best result was obtained for visible light transmission and low reflection (5.6%) at 3.875 wt% of ZnO/PMMA concentrations. Depending on the above, the light reflection is reduced from 35% to 5.6% for the polycrystalline solar cell coated with ZnO/PMMA nanocomposite coating, 3.875 wt% concentration.

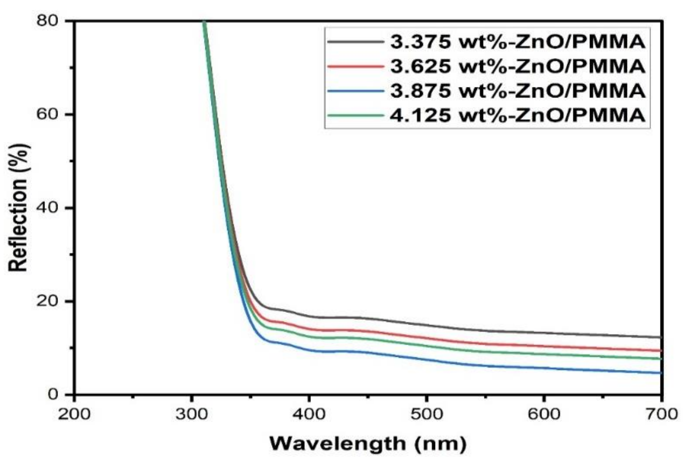

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Figure 7. Comparison of the reflections for ZnO/PMMA coating concentrations used (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%)

Thermal and temperature reduction

One of the objectives of this work is to reduce the surface temperature of polycrystalline silicon solar cells by applying ZnO/PMMA nanocomposite coatings with different concentrations on the top surface of commercial polycrystalline silicon solar cells, in order to increase their efficiency. The thermocouples (K-type) were used to measure the temperature of the solar cells by fixing them on the back surface of the cells, and the thermocouples were connected to the thermometer data logger device to display the temperature results. The test was done in the laboratory by exposing solar cells to solar radiation using halogen light, the test has been done under a standard test condition STC (1000 w/m^2 and 25 °C) and the test duration lasted for an hour. The experiment was carried out for four polycrystalline silicon solar cells coated with four different concentrations of ZnO/PMMA nanocomposite (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) and compared to the uncoated polycrystalline cell.

The results showed that the temperature of solar cells at the end of the test time, after 1-hour, was (75.4 °C, 74.3 °C, 72.9 °C, and 73.7 °C) for the concentrations used in a respectively, while the uncoated solar cell recorded (81.5 °C), where the decrease in temperature for each concentration was (6.1 °C, 7.2 °C, 8.6 °C, and 7.8 °C) compared to the uncoated solar cell, respectively, as shown in figure 8 and table 5. According to the results, it can be concluded that the solar cell surface temperature decreases as the concentration of nanomaterials in the nanocomposite coating increases, which leads to an increase in the amount of UV photons absorption in the wavelength range (200-400) nm, And this is one of the causes that make the temperature of solar cells rises, and thus its effect on the efficiency of solar cells increases. The highest decrease in temperature was recorded (8.6 °C) when using a concentration (3.875 wt%) of ZnO/PMMA nanocomposite coating.

Table 5. The temperature variations of solar cell with the ZnO/PMMA nanocomposite concentrations.

ZnO/PMMA nanocomposite concentrations	Variations in temperature values
Without coating (WOC)	-
3.375 wt%	6.1 °C
3.625 wt%	7.2 °C
3.875 wt%	8.6 °C
4.125 wt%	7.8 °C

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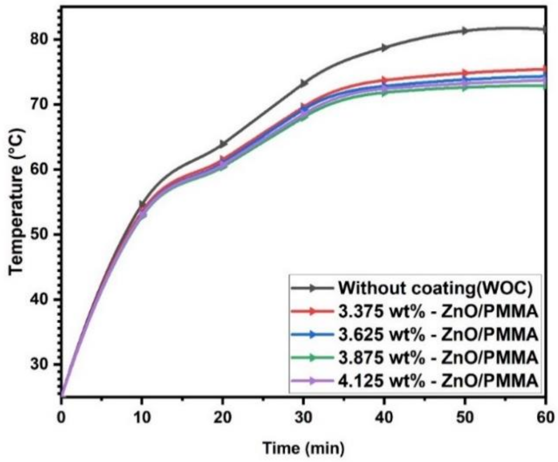

Figure 8. Comparison surface temperatures of coated and uncoated polycrystalline solar cells at (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) concentration.

To validate the findings, a Thermal Imaging Infrared Camera FLIR E-30bx type was used in the current experiment to monitor the temperature of the coated and uncoated polycrystalline solar cells in order to verify the temperature readings obtained by the thermometer Data-Logger device. Figure 9 illustrates that the results that resemble those of thermocouples closely.

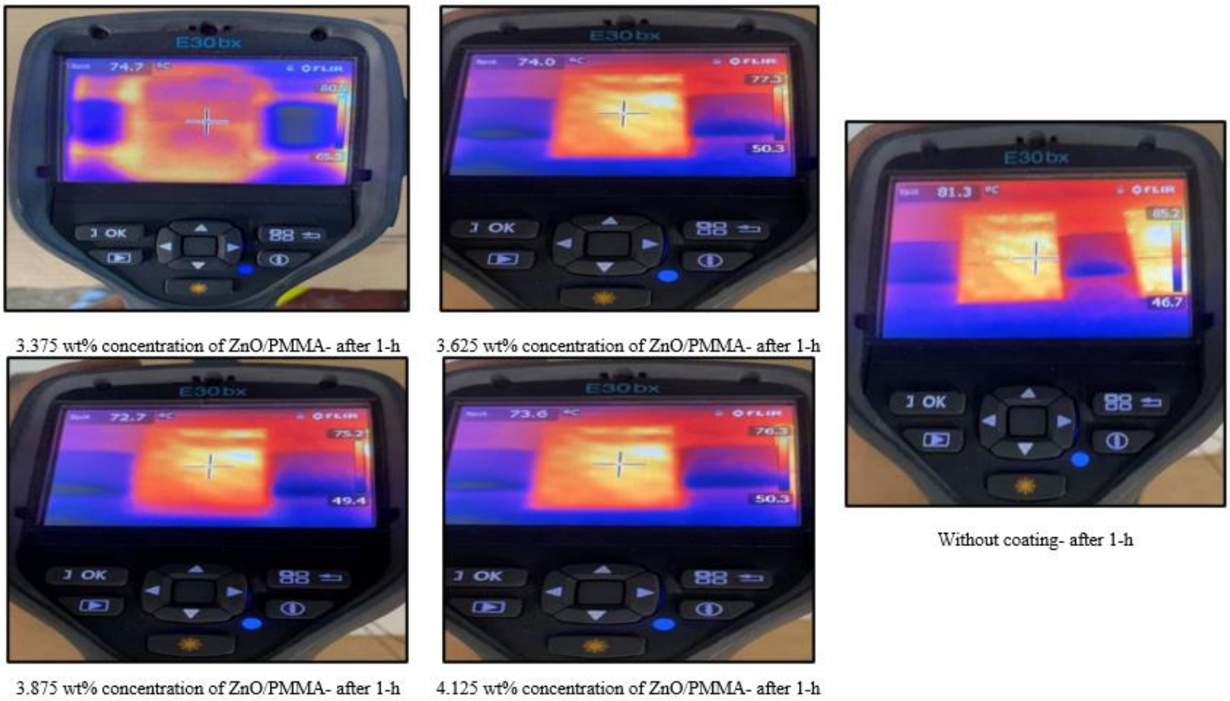

Figure 9. Thermal imaging of coated and uncoated polycrystalline solar cells at (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) concentrations.

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(I-V) and (P-V) curves

The optimal increase in the electrical characteristics of solar cell was attained at zero time, where the reflection losses are carried out. The results were shown by using the PROVA-200A solar module analyzer, the short circuit current (Isc), open-circuit voltage (Voc), maximum power current (Imp), and maximum power voltage ($V_{mp)}$ for polycrystalline solar cells with ZnO/PMMA nanocomposite coating were: (I_{SC}=0.331A, Voc=0.526V, I_{mp}=0.285A, and V_{mp}=0.508V), (I_{sc}=0.338A, V_{oc}=0.531V, I_{mp}=0.292A, and V_{mp}=0.511V), (I_{SC}=0.350A, V_{oc}=0.542V, I_{mp}=0.310A, and V_{mp}=0.520V) , and (I_{sc}=0.343A, V_{oc}=0.538V, I_{mp}=0.304A, and V_{mp}=0.515V) for the concentrations of ZnO/PMMA nanocomposite coating (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) respectively, and compared to the polycrystalline solar cell without coating that had (I_{sc}=0.320A, V_{oc}=0.520V, I_{mp}=0.280A, and V_{mp}=0.500V). According to the data presented above, the maximum effect of antireflection coating when used at the (3.875 wt%) concentration reduces reflection from 35% for polycrystalline solar cells without coating to only 5.6%.

After one hour, the second test was performed where the temperature and anti-reflection effects (increased surface temperature of the tested solar cells). The electrical performance results of polycrystalline solar cells were (I_{sc}=0.341A, V_{oc}=0.395V, I_{mp}=0.292A, and V_{mp}=0.372V), (I_{sc}=0.348A, V_{oc}=0.408V, I_{mp}=0.308A, and V_{mp}=0.390V) , (I_{sc}=0.355A, V_{oc}=0.430V, I_{mp}=0.317A, and V_{mp}=0.412V) and (I_{sc}=0.352A, V_{oc}=0.418V, I_{mp}=0.310A, and V_{mp}=0.400V) for the concentrations of ZnO/PMMA nanocomposite coating (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%), respectively, and compared to the polycrystalline solar cell without coating that had (I_{sc}=0.330A, V_{oc}=0.380V, I_{mp}=0.270A, and V_{mp}=0.360V). According to the data presented above, the maximum effect of ZnO/PMMA coating when used the 3.875 wt% concentration, has reduced the surface temperature from 81.5 °C for polycrystalline solar cells without coating to 72.9 °C, in a way tha leads to the maximum current and voltage (I_{mp} = 0.317 A, V_{mp} = 0.412 V). Figure 10 shows the I-V and P-V curves, while Table 6 shows the results of studies for all polycrystalline solar cells with various nanocomposite coatings and without coating.

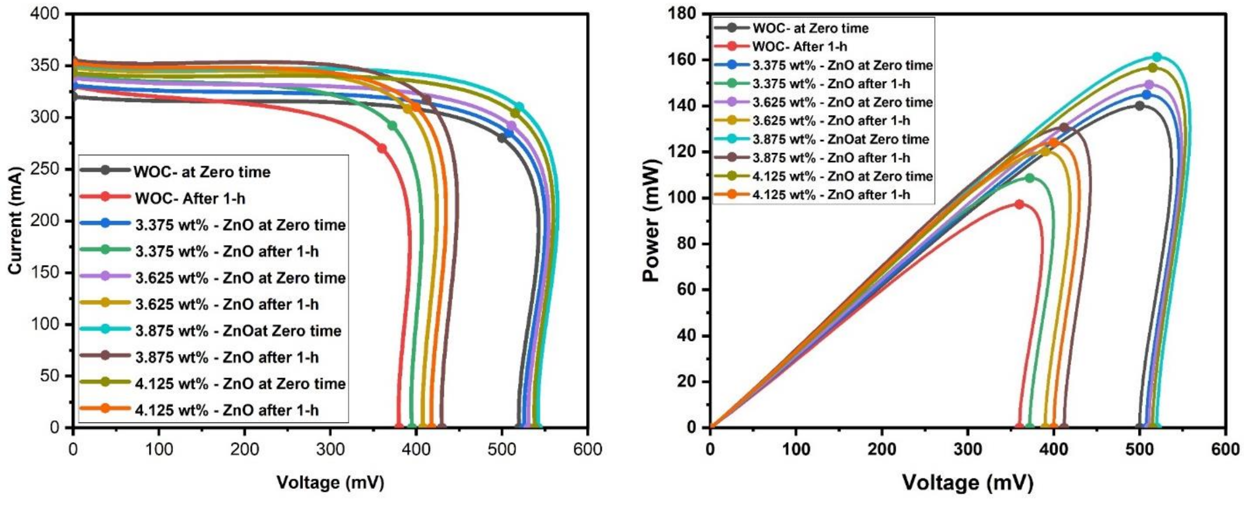

Figure 10. Comparison of I-V & P-V curves for polycrystalline solar cells with and without coating for all concentrations.

Power and efficiency of polycrystalline solar cell.

To study the effect of ZnO/PMMA nano-coating on the power and efficiency, the polycrystalline coated solar cells were tested as mentioned previously to find the I-V curve, where the power and efficiency were measured and calculated for each of the solar cells coated with different concentrations of the ZnO/PMMA (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%) and compared with the uncoated cells to see the amplitude of the effect of adding nano coating to the top surface of the polycrystalline solar cells. Where the results showed the power (145mW, 149mW, 161mW, and 157mW) and efficiency (16.87%, 17.4%, 18.78%, and 18.25%) at the beginning of the test(at zero time) and power (109 mW, 120 mW, 131mW, and 124mW), and efficiency (12.66%, 14%, 15.22%, and 14.25%) at the end of the test (after one hour) for each of ZnO/PMMA concentration (3.375 wt%, 3.625 wt%, 3.875 wt%, and 4.125 wt%), respectively, while the power and efficiency of the polycrystalline solar cells which were without coating (140mW, and 97.2mW), (16.32%, and 11.33%) at zero time and after one hour, respectively.

Where the effect of reducing the reflection by ZnO/PMMA nano-coating has increased the power and efficiency of the solar cell at the zero time of the test and according to the ZnO/PMMA concentration value of the coating used. And after one hour, according to the additional nano coating, the impact of raising the surface temperature of the solar cell and the action of the nano-coating on decreasing the solar cell temperature was obvious in enhancing the power and efficiency of the solar cell. From the results shown above, it was found that the best concentration that was used was (3.875 wt%) as the power and efficiency increased from (140 mW, 16.32%) for the uncoated cell to (161 mW, 18.78%) at the beginning of the test (at zero time), and from (97.2 mW, 11.33%) for the uncoated cell to (131 mW, 15.22%) after one hour at the end of the test, and the amount of the increased power and efficiency was (+33.8 mW) and (+3.8%) at the end of the test. This increase came as a result of reducing the visible light reflection from (35%) for the uncoated polycrystalline solar cell to (5.6%) for the solar cell coated with nano-coating at a concentration of (3.875 wt%), as well as reducing the surface temperature of the polycrystalline solar cell from (81.5 ºC) to (72.9 ºC). Figure (11) show the power and efficiency graphs, while Table (6) shows the results of studies for all polycrystalline solar cells with various nanocomposite coatings and without coatings.

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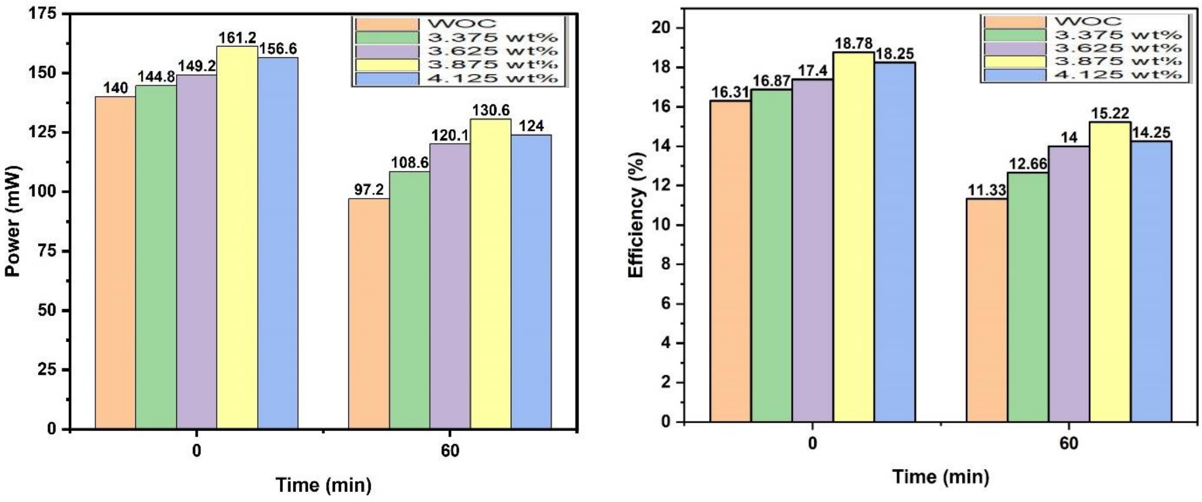

Figure 11. Comparison the power & efficiency of polycrystalline solar cells with and without coating for all concentrations.

Table 6. Electrical properties and efficiency of polycrystalline silicon solar cells coated with different concentrations of ZnO/PMMA nanocomposite coating and without coating.

	Polycrystalline silicon solar cell without coating (WOC)		**Polycrystalline silicon solar cell – Coated with 3.375 wt%-ZnO/PMMA**		**Polycrystalline silicon solar cell – Coated with 3.625 wt%-ZnO/PMMA**		**Polycrystalline silicon solar cell – Coated with 3.875 wt%-ZnO/PMMA**		**Polycrystalline silicon solar cell – Coated with 4.125 wt%-ZnO/PMMA**	
Time test	Zero-time	After 1-h	Zero-time	After 1-h	Zero-time	After 1-h	Zero-time	After 1-h	Zero-time	After 1-h
Open-circuit voltage V_{OC} (V)	0.52	0.38	0.526	0.395	0.531	0.408	0.542	0.430	0.538	0.418
Short-circuit current I_{SC} (A)	0.32	0.33	0.331	0.341	0.338	0.348	0.350	0.355	0.343	0.352
Maximum power voltage V_{mp}(V)	0.5	0.36	0.508	0.372	0.511	0.390	0.520	0.412	0.515	0.40
Maximum power current I_{mp} (A)	0.28	0.27	0.285	0.292	0.292	0.308	0.310	0.317	0.304	0.31
Maximum power P_{max} (W)	0.140	0.097	0.145	0.108	0.149	0.120	0.161	0.130	0.156	0.124
Electrical efficiency (η)%	16.32	11.33	16.87	12.66	17.39	14	18.78	15.22	18.25	14.45

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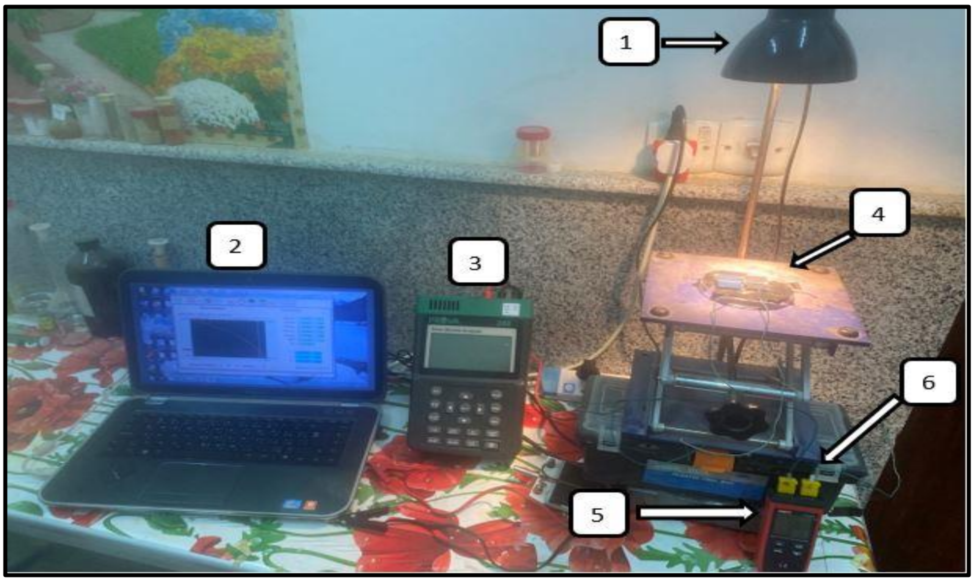

Figure 12. Rig Solar cell Test.

1. Halogen Lamp.
2. Personal laptop.
3. Solar cell module analyzer
4. Polycrystalline silicon solar cell/coating – un-coating
5. Thermometer (Data-logger)
6. K-type thermocouples.

Conclusion

A nanocomposite ZnO/PMMA was made by doping 3.125 wt% PMMA with four specific concentrations of ZnO (0.25wt %, 0.5wt %, 0.75wt %, and 1wt %). The nanocomposite was applied to the front surface of the commercial polycrystalline silicon solar cell by using a casting coating method. Testing the effectiveness of the nanocomposite coating to absorb the ultraviolet rays at various wavelengths in order to reduce PV solar cell surface temperature and the ability of the coating thin film to reduce light reflection based on the ZnO weight percent in ZnO/PMMA, as demonstrated by a UV-Vis spectrophotometer. The study found that the greatest temperature impact when utilizing a concentration of 3.875 wt% ZnO/PMMA coating has reducing the solar cell temperature from 81.5 °C for uncoated polycrystalline solar cells to 72.9 °C for coated solar cells, and the reflection has decreased by about 29.4%, which was reduced up to only 5.6%. The PROVA-200A solar module analyzer device was used to examine its efficiency. The results indicated that the coated solar cell had an improvement in efficiency of +3.8% when compared to the uncoated cell. It is recommended to investigate the effects of applying multiple thin layers of nanocoating on the performance of the solar cell, or it can be utilizing different kinds of nano-coatings and researching their effectiveness with the solar cell.

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