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ENGINEERING TECHNICAL COLLEGE- NAJAF

APPLICATION OF NANOTECHNOLOGY (TiO_2/PVA) TO IMPROVE THE SOLAR CELL EFFICIENCY

A Thesis
Submitted to the Department of Mechanical
Engineering Techniques of Power in Partial Fulfillment of the
Requirements for Master of Thermal Technologies Degree in Mechanical
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(M.Tech.)

BY
Ali Kadhim Naser
B.Tch. Refrigeration and Air Condition. Eng.
2012

Supervised by:
Prof.
Dr. Dhafer Manea Hachim
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بســــــــــــــــم الله

الرحمن الرحيم

هُوَ الِّذي جَعَلَ الشِّمسَ ضِياءً وَالقَمَرَ نورًا
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صدق الله العلي العظي

DISCLAIMER

I confirm that the work submitted in this thesis is my own work and has not been submitted to another organization or for any other degree.

Ali Kadhim Naser

Signature:

Date:

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Ali Kadhim Naser

2021

SUPERVISORS CERTIFICATION

We certify that this thesis titled **“Application of Nanotechnology (PVA-TiO2) To Improve The Solar Cell Efficiency ’’** which is being submitted by **Ali Kadhim Naser** was prepared under our supervision at the Power Mechanical Engineering Techniques Department, Engineering Technical College/Najaf, AL-Furat Al-Awsat Technical University, as partial fulfillment of the requirements for the degree of Master in thermal-mechanical engineering.

Signature:

Name:Prof. Dr. Dhafer Manea Hacim
(Supervisor)

Date: / / 2021

In view of the available recommendation, we forward this thesis for debate by the examining committee.

Signature:

Name: Prof. Dr. Dhafer Manea Hachim

Head Mechanics Eng Tech of power Department Dept.

Date: / / 2021

THE EXAMING COMMITTEE CERTIFICATION

We certify that we have read the thesis entitled **“Application of Nanotechnology (PVA-TiO2) To Improve The Solar Cell Efficiency’’** which is being submitted by **Ali Kadhim Naser** and as an examining committee, examined the student’s thesis in its contents. And that, in our opinion, it is adequate as a thesis for a master of thermal-mechanical engineering techniques degree.

Signature:

Name: Prof. Dr. Dhafer Manea Hachim

(Supervisor)

Date: / / 2021

Abstract

Photovoltaics (often abbreviated as PV) is a simple and elegant method of harnessing the sun's energy. PV devices (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. Thus, Solar cells are the best choice for clean energy in the world.

One of the most important difficulties in using photovoltaic systems is the low energy conversion efficiency of PV cells and this efficiency decreases further during the operational period by increasing the temperature of the cell above a certain limit. However, the Photovoltaic panel's efficiency suffers from a noticeable decrease with the rise of the surface temperature by 0.5% for each degree rise in its working temperature. In addition, the reflection of the sun’s irradiance from the panel typically reduces the electrical efficiency of PV modules by 35%.

During this study, reducing the effect of rising temperature and reflection losses on the Polycrystalline silicon solar cell have been investigated. Nanocomposite coating thin-films - Polymer- Polyvinyl Alcohol (PVA), Titanium Dioxide (TiO_2) with Nano size (10nm) on the top side of the solar cell was the method used for that purpose. Different concentrations of (TiO_2) and (PVA) have been used (0.05gram, 0.1gram, 0.2gram, 0.3gram) and (0.25gram, 0.5gram, 0.75gram, 1gram, 1.3gram) respectively.

Based on the fabricated Rig solar cell test and through the laborites tests (Ultraviolet-Visible-Spectrometer device), the results observed that the PVA affect as Ultraviolet blocking system and thus decreasing the solar cell surface temperature & the TiO_2 as an anti-reflection coating and reducing the reflection losses. The best concentration of the PVA was (1 gram) in terms of its ability to absorb the greatest intensity of Ultraviolet solar radiation. The (0.2 gram) of the $TiO2$ was the best concentration was chosen in terms of its capability to reducing the reflection losses. 9.7 ^{0} C was the maximum temperature difference yielded as compared to without coating solar cell, and 3.9% reflection losses was the minimum reflection losses obtained as compared to 35% reflection losses to without coating solar cell. The solar cell efficiency has been improved (14.2% to 16.5%).

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NOMENCLATURE

Symbol	**Definition**	**Unit**
TiO_2	Titanium Dioxide	--
PVA	PolyVinyl Alcohol	--
A	Absorption broadened	Nanometers (nm)
R	Reflection	%
I	Absorption Intensity	(Absorption .Unit) A.U
I_{SC}	Short Circuit Current	Amper (A)
V_{OC}	Open Circuit Voltage	Volt (V)
I_{mp}	Maximum power current	Amper (A)
V_{mp}	Maximum power voltage	Volt (V)
FF	Fill Factor	--
η	Electrical Efficiency	%
η_{TR}	Electrical Efficiency at Temperature Reference	%
λ	Wavelength	Nanometers (nm)
n	Refractive Index	--
E	Photon Energy	Joule (J)
ν	Frequency	Hertz (HZ)
I_{ph}	photocurrent	Amper (A)
I_s	Diode saturation Current	Amper (A)
β_R	Temperature Coefficient	0.004-0.005/^{0} C
T_R	Refrence Temperature	(25) ^{0} C
T_C	Cell Temperature	^{0} C
K	Boltzmann constant	1.38×10^{-23} m^2 kg s^{-2} K^{-1}
h	$Planck\ constant$	$(6.63 * 10^{-34} JS)$
q	Electronic charge	1.602×10^{-19} coulombs
Eg	Energy Bandgap	electron.volt (e.v)
Mono-Si	Monocrystalline silicon	/

1

Chapter

Introduction

Introduction

1.1 Introduction

The population of humanity is rising every day, as is their energy demand. Over the years, so many different forms of fuel have been used as a source of energy. For several years, wood, coal, and fossil fuels have been the primary sources of energy. Because of pollution and global warming caused by carbon dioxide emitted by these fuel forms, the earth's atmosphere began to change in the last century. In recent years, humanity has begun to search for a new source of energy that is both efficient and sustainable, as well as renewable. Many different forms of alternative fuels have been used, with solar energy being the most common. Solar energy can be used in both indirect and direct ways, such as by wind or geothermal energy[1]. Solar energy is used in a variety of ways, including heating water in solar collectors and generating electricity in concentrated thermal collectors such as heliostats, Fresnel collectors, and parabolic collectors (Figures. 1.1, and 1.2)[2]. Furthermore, direct photovoltaic panels transform light photons in solar radiation directly into electrons in a semiconductor, resulting in the generation of electrical power. Due to the fabricated materials and the issue of the surface working temperature increasing, the power conversion in all forms of these panels varies from 15% to 20% of the total fallen radiation when the solar radiation exceeds more than 1250 W/m^2[2]. Monocrystalline and polycrystalline photovoltaic panels are the two most popular types of photovoltaic panels used in homes and businesses.

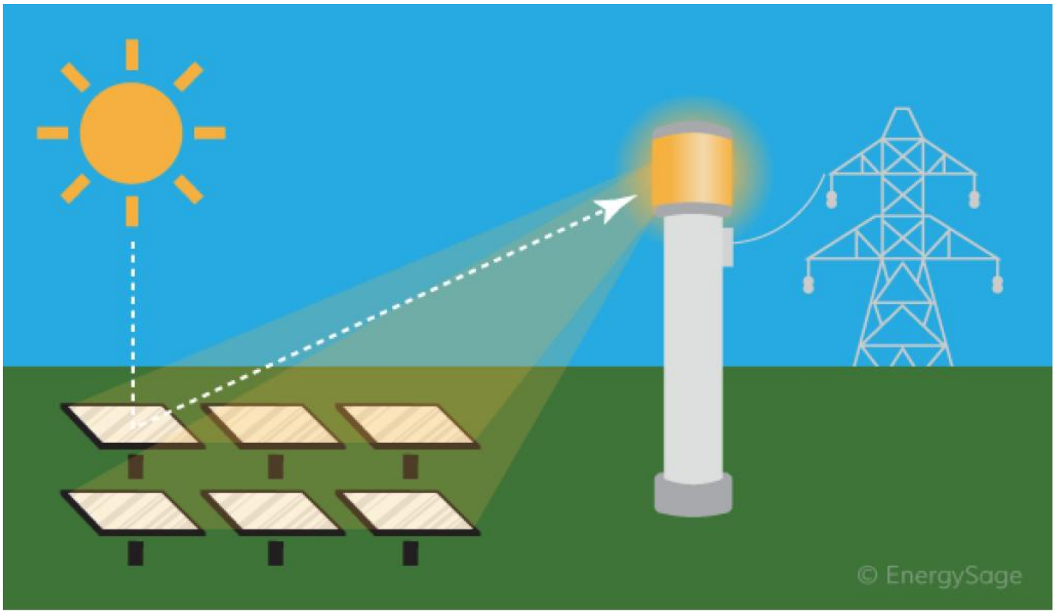

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Figure 1.1. heliostat solar collector [1]

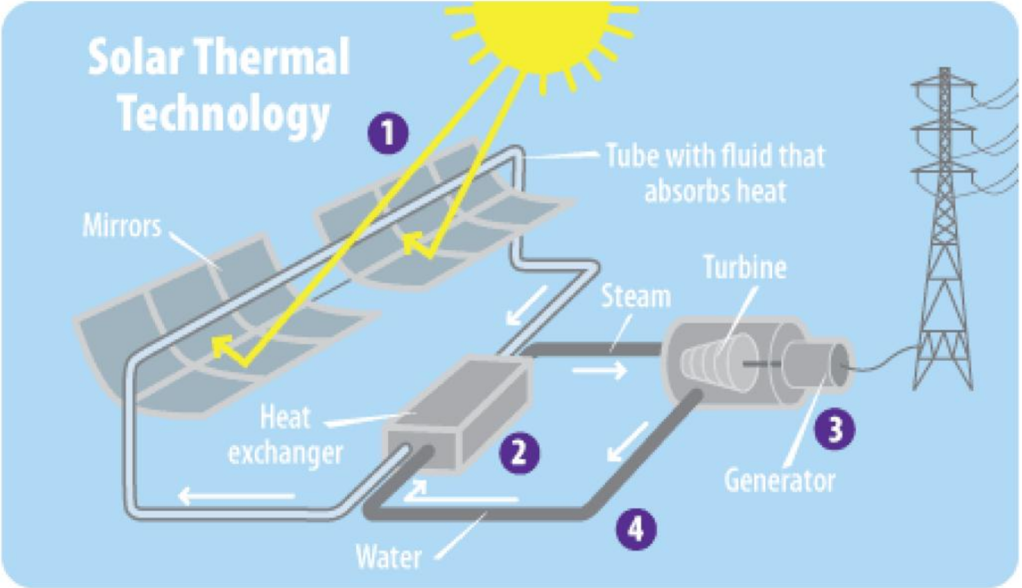


Figure 1.2 parabolic collector [1]

1.2 Photovoltaic panels (PV Cell)

The photovoltaic panel is a system that uses a phenomenon called the photovoltaic effect to transform solar radiation into light directly. Edmond Becquerel, a French physicist, was the first to discover the photovoltaic effect in 1839. However, it was not used in satellite applications until the 1960s, where it was the first used. Photovoltaic panels come in various shapes and sizes, but they all use a semiconductor to generate electricity.

The photovoltaic panel is made up of many layers, each of which serves a particular function. The semiconductor layers are the most critical, with two semiconductors (P-type and N-type) connected in a junction field.

Photovoltaic panels are becoming more popular as domestic and global power sources due to the availability of silicon semiconductors. Furthermore, since photovoltaic cells are solid units (Figure. 1.3), they can be easily connected to other groups of cells with no moving parts, allowing them to be used in domestic and industrial settings.

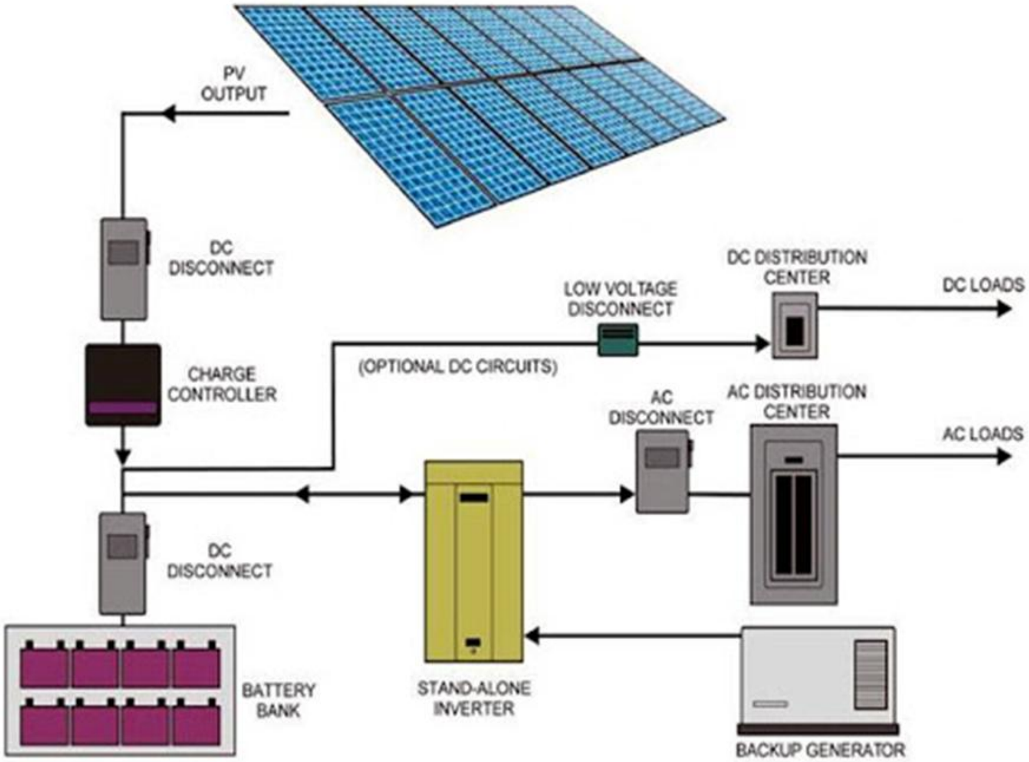


Figure.1.3 photovoltaic panel installation[3]

In the 1980s, photovoltaic panels were first used in industry, and installed capacities began to grow from 77 MW in 1996 in the United States. China's installed capacity rose to 100 GW in 2016, and installed capacities around the world were rapidly increasing, with global power output reaching 653 GW at the time of this report. According to the International Energy Agency, by 2050, global photovoltaic power would be about 4.7 TW (4674 GW)[3]. In industrial applications, photovoltaic panel technology has achieved a maximum power conversion (solar radiation to electricity) efficiency of 20%. Furthermore, as the working temperature of the panel surface rises, the conversion efficiency decreases. And for every 1^0 C over the 25^0 C , performance decreases by around 0.5 %[4]. As a result, a significant portion of the energy was lost due to overheating of the panel surface. As a result, a plethora of techniques have been employed to lower the surface working temperature of the panels.

1.3 Photovoltaic panels types

Photovoltaic cells are made up of two thin layers of semiconductors, most commonly silicon. When a semiconductor is exposed to sunlight (light), electrical changes in the molecules produce electrons, which conductors can collect as a direct current (DC). Since the power generated by a single cell is insufficient to be used, multiple cells are connected to form a (string) that generates a direct current.

To form a photovoltaic panel, the cells are connected and coated with a glass layer, and then the PV panels are connected in parallel or series to produce the suitable voltage and current.

Photovoltaic panels come in various shapes and sizes, depending on the materials used in their construction and the technology used in their operation. In general, researchers have divided the development of photovoltaic systems into three technological generations, but there are three types of photovoltaic panels for both residential and commercial are commonly used. As shown in Figure.1.4.

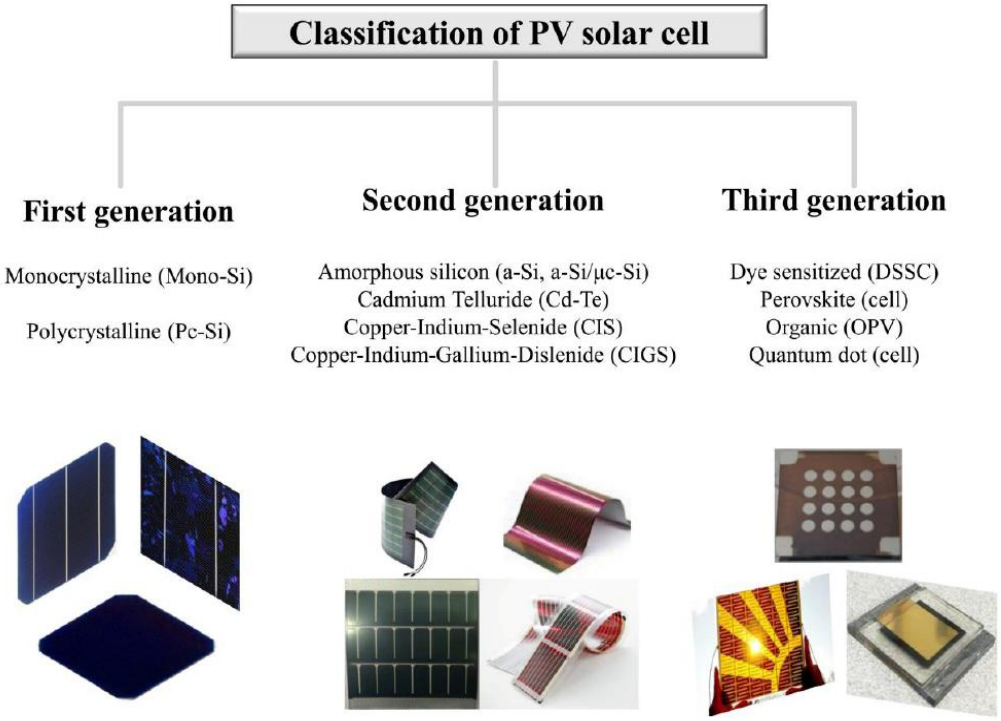


Figure 1.4. classification of photovoltaic panels generations types[5]

1.3.1 Monocrystalline silicon solar cells

Monocrystalline silicon, also known as single-crystal silicon, is the most common form of silicon chip used in today's electronics. Mono-Si is also used in the production of solar cells as a photovoltaic, light-absorbing material. Mono-Si can be rendered intrinsically, with only very small amounts of other elements added to change its semiconducting properties, or doped, with very small amounts of other elements added to change its semiconducting properties. The Czochralski method is used to develop silicon monocrystals into ingots up to 2 meters long and weighing several hundred kilograms. For further processing, these cylinders are cut into thin wafers of a few hundred microns. Single-crystal silicon is probably the most significant technological material of the last few decades[6]—the "silicon era"—because its inexpensive availability has been critical for the production of electronic devices, which are the foundation of today's electronic and informatics revolution. Other allotropic types of silicon include non-crystalline amorphous silicon, which is used in thin-film solar cells, and polycrystalline silicon, which is made up of small crystals called crystallites. Around 15-17 % of the solar radiation energy is converted into electricity by monocrystalline PV panels[7].

1.3.2 Polycrystalline silicon solar cells

Polycrystalline PV modules are generally composed of a number of different crystals, coupled to one another in a single cell. The processing of polycrystalline Si solar cells is more economical, which are produced by cooling a graphite mold filled containing molten silicon. Polycrystalline Si solar cells are currently the most popular solar cells. They are believed to occupy most up to 48% of the solar cell production worldwide during 2008 [8]. During the solidification of the molten silicon, various crystal structures are formed. Though they are slightly cheaper to fabricate compared to monocrystalline silicon solar panels, yet are less efficient ~12% - 14% [4].

1.3.3 Thin-Film Solar Cell (TFSC)

A thin-film solar cell (TFSC), also known as a thin-film photovoltaic cell (TFPV), is a second-generation solar cell, manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production[9]. They are also flexible—which opens a lot of opportunities for alternative applications—and is less affected by high temperatures. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations. The thin-film PV frames, on the other hand, have a poor conversion ratio. The conversion efficiency of thin-film PV panels is less than 10% in all forms.

1.4 Photovoltaic solar cell operating principles

The Photovoltaic (PV) effect is the conversion of sunlight energy into electricity. In a PV system, the PV cells exercise this effect. Semi-conducting materials in the PV cell are doped to form P-N structure as an internal electric field. The p-type (positive) silicon has the tendency to give up electrons and acquire holes while the n-type (negative) silicon accepts electrons. When sunlight hit the cell, the photons in light excite some of the electrons in the semiconductors to become electron-hole (negative-positive) pairs (as seen in Figure 1.5). Since there is an internal electric field, these pairs are induced to separate. As a consequence, the electrons move to the negative electrode while the holes move to the positive electrode. A conducting wire connects the negative electrode, the load, and the positive electrode in series to form a circuit. As a result, an electric current is generated to supply the external load. This is how the PV effect works in a solar cell. [2].

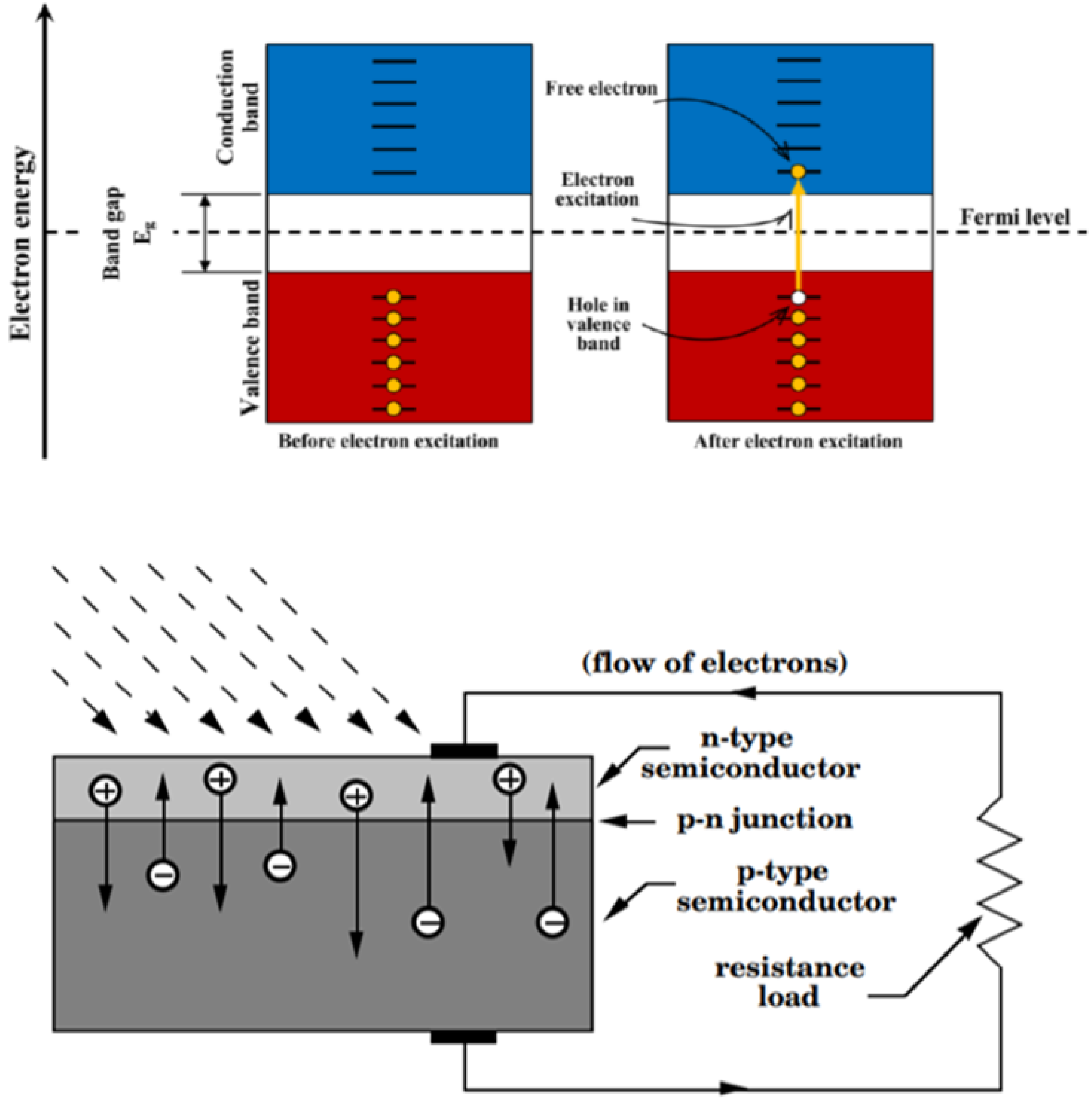


Figure.1.5 schematic operation solar cell[10]

1.5 Nanomaterials

Nanotechnology provides innovative means and techniques to be able to control the atomic arrangement of a substance and develop the pattern of arranging atoms in the sites of crystal networks, which led to the emergence of new materials that differ in their properties from traditional materials, which are the nanomaterials that are known to be materials that can be produced so that at least one of its dimensions is in the range 1-100 nm [11]. The primary materials for the production of nanomaterials are most of the materials available naturally, such as semiconductors, metals, polymers, and others. Materials with dimensions greater than 100 nanometers are called micrometers materials or thin-films, and materials with dimensions greater than 1 micrometer are called thick-films. The uses and applications of nanomaterials are many and enter many fields such as agriculture, engineering, medicine, and space technology.

1.5.1 Classification of Nanomaterials

Nanomaterials are divided into zero-dimensional (0-D), one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) categories based on their dimensions[12]. As shown in figure.1.6.

1.5.1.1 Zero-dimensional (0-D)

All three dimensions of 0-D nanomaterials are nanometers. This type of nanostructure can be found in metal nanoparticles like gold and silver nanoparticles, as well as semiconductors like quantum dots. The majority of these nanoparticles are spherical, but they also come in cubic and polygonal forms[13].

1.5.1.2 One-dimensional (1D)

1-D nanomaterials, such as nanowires, Nano rods, and nanotubes, have one dimension that is beyond the nanometer range and the other two dimensions that are in the nanoscale range [13].

1.5.1.3 Two-Dimensional (2D)

Two dimensions of 2-D nanomaterials are outside the nanometer spectrum, while the other dimension is nanoscale. Nanostructures are thin films with a thickness of fewer than 100 nanometers, such as nanosheets, nanowalls, and nanobelts [13].

1.5.1.4 Three-dimensional (3-D)

They are materials whose dimensions are outside the range of nanoscale dimensions and are called bulk-nanomaterials. The reason for their classification within the nanomaterials is that they have a nanocrystalline structure.

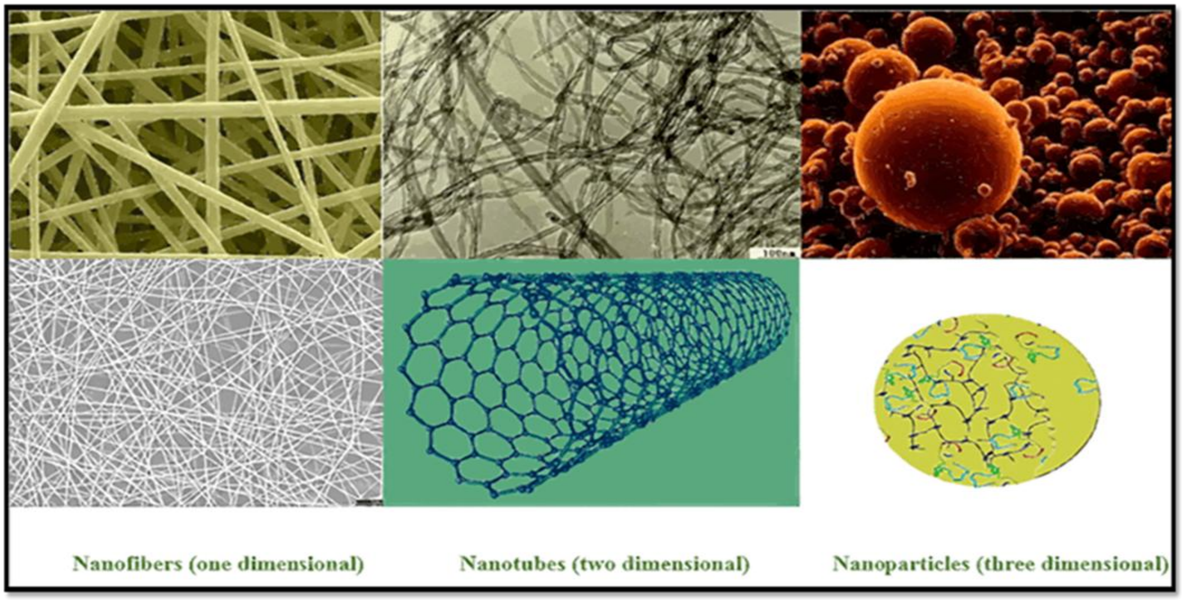


Figure.1.4 types of nanostructure[13]

1.6 Organic-Inorganic Nanocomposites

Hybrid nanocomposites of inorganic nanocrystals and conjugated polymers are complex materials whose properties are influenced by molecular parameters of the polymeric constituent (microstructure of polymer chain) and on its macromolecular parameters (mass of molecular and its distribution). Size, Shape, and distribution in addition to the stoichiometry of the nanocrystal must also be taken into account. The important properties, that have revealed enhancement after the nanoparticles integration in a matrix of polymer, are[14]:

- Optical properties.
- Mechanical properties.
- Thermal properties like stability and temperature of heat distortion.
- Electrical conductivity.
- Chemical resistance.

Beneficial optical properties of hybrid nanocomposite materials, including high wide absorption light which extended from the IR to UV region, great refractive index, and the reduction of photoluminescence, have made hybrid nanocomposite materials a significant material in different optoelectronic applications. The optical properties of these materials are influenced by the size and spatial dispersal of inorganic nanoparticles in the matrix of the polymer[15].

1.7 Problem Statement

Recently, a lot of scientific research and manufacturers have been concerned about developing solar panel technologies that have focused on increasing the efficiency of the solar panel. The different types of photovoltaic panels have different conversion ratios. However, the most efficient is the silicon-based cells with a conversion ratio of up to 20% of the radiation energy. The rest will either be reflected or converted into heat inside the panel itself.

There are many parameters are affect the solar cell's efficiency and consequence of its power output. The operating temperature and the reflection losses are playing the main role to affect the solar cell's efficiency. All photovoltaics were designed to perform under normal test conditions of 1000W/m^2 incident radiation and 25^{o}C ambient temperature. The overall efficiency of the solar panel is reduced by 0.4-0.5% for every 1^{o}C above 25^{o}C as the temperature rises. solar cells are suffering from high reflection, resulting in a loss of almost 35% of incident energy, which caused reducing the power output and thus the performance of the solar cell. Many methods are used to improve the performance of the solar cell, one of them is applying photo-filters (Nanocomposite-coating –Thin-film) on the top of the surface solar cell to reduce the losses of reflection of light falling on the solar cell, as well as to control the temperature of the surface of the solar cell. Where this Nano-coating makes as an anti-reflection, and thermal regulation thin-films respectively.

1.8 The Objective of the Study

The main goal of this study is to investigate the influences of temperature variation and reflection losses on the solar cell parameters. Thus, The goal of this work is to increase the efficiency of the solar cell and consequently the power output via reducing the factors that negatively affect the work of the solar cell. The following points are the most important goals that we have aimed to achieve during this study.

1- Reduce the surface temperature of the polycrystalline silicon solar cell as low as possible.

2- Blocking the Ultraviolet wavelength (200-400nm) which has high photon energy (10,000 times more than the infrared ray's energy), where this extra energy is dissipated in the form of heat and negatively affects the solar cell efficiency.

3- Reduce the reflection losses of the polycrystalline silicon solar cell as little as possible.

4- Create a Novel Thin-Film Nanocomposite material TiO_2/PVA.

5- Deposition the Nanocomposite on the top side of the solar cell and investigate its effect on the solar cell's performance.

6- Increase the polycrystalline silicon solar cell's efficiency.

1.9 The Scope of the Study

1- Decrease the impact of the temperature on the polycrystalline silicon solar cell performance.
2- Reducing the light reflection losses problem of the polycrystalline silicon solar cell, which is estimated at about 35% of the total incident solar radiation.
3- Investigate the effect of the applying organic semiconductors material- (Polymer-Polyvinyl Alcohol -PVA) as a coating film on the surface temperature of polycrystalline silicon solar cells.
4- Inspect the influences of the inorganic semiconductor material (Titanium Dioxide –TiO_2) with Nano-size grain (10nm) as a coating film on the reflection losses of the polycrystalline silicon solar cell.
5- Research the best concentration of the Polymer-PVA which gave the maximum temperature variation on the top side of the polycrystalline silicon solar cell.
6- Determine the optimum concentration of Nanocomposite material- TiO_2/PVA Which reduces the reflection losses as a minimum value.
7- Evaluate the maximum efficiency and power output of the polycrystalline silicon solar cell that is achieved by the Nano-coating film's method.

1.10 Thesis Outline

Chapter I Provides the introduction (summary discussion of the importance of solar energy and some solar photovoltaic technologies) followed by the problem statement, objective, and the scope of the study.

Chapter II Provides the background on the methods was used to improve the solar cell active and passive techniques. In addition, the literature review for most of the previous studies including with water, and air cooling solar cell, anti-reflection techniques, and self-cleaning methods.

Chapter III Theoretical concept and the physical meaning of the reflection phenomena and how the high photon energy spectrum rising the surface temperature of the solar cell. Also, this chapter mainly concentrated on the mathematical relation dealing with the solar cell parameters.

Chapter IV provides an overview of the experimental setup of this study, material, and Measurement devices are including UV-Visible spectroscopy, reflectometer, film thickness measurement device, and solar module analyzer are perform in this study.

Chapter V Presents the analysis of the experimental results that consist of data used to predict the optimum performance of the solar cell by using the best Nanocomposite concentration as a coating film with fewer reflection losses and lower temperature effect.

Chapter VI Introduces, the objective and conclusions of this Study, It also offered ideas and guidelines for future research. At the end of this thesis the lists of references and appendixes are also included.

2

Chapter

Literature Review

Literature Review

2.1 Introduction

Solar cells are made of semiconductor materials that use the sun radiation photons to the excitement a wave of electrons as a direct electric current and consequence to turn sunlight into electricity. When a photovoltaic cell is exposed to light, it produces current and voltage. The relationship between the absorbed radiation and the generated power output is linear; however, there are many parameters are affect the solar cell’s efficiency and consequence of its power output. The operating temperature and the reflection losses are playing the main role to affect the solar cell’s efficiency[16]. where the factor which affects raising the solar cell’s surface temperature is the absorption of the high energy photons (ultraviolet spectrum)[17]. solar cells are suffering from high reflection, resulting in a loss of almost 35% of incident energy, which caused reducing the power output and thus the performance of the solar cell[18].

May methods were used to improve the solar cell's power output. Thus, this chapter deals with many previous studies concerned with improving the efficiency of the solar cell by controlling and reducing the temperature of the cell surface and decreasing the reflection of incident light.

2.2 Techniques Used To Improve The Performance Of Solar Cells

Many papers have been published in recent years to investigate the various methods and techniques for improving photovoltaic panels. Many experiments had been used both active and passive approaches to boost the solar cell’s efficiency and electrical power production by decreasing the effect of high temperature and reflection losses.

This review will classify the techniques according to:-

1- Active Approaches (water and air cooling systems)
2- Passive Approaches (Nanocoating Thin-films).

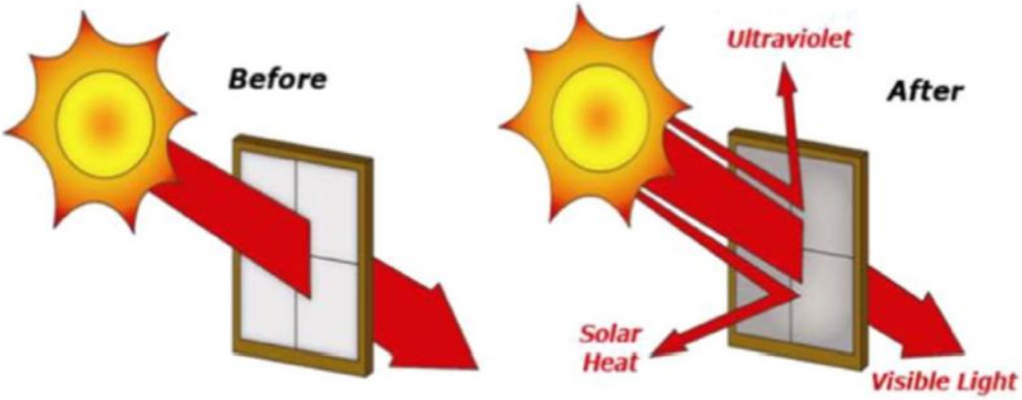


Figure 2.1 passive approach (nanocoating thin-film)[19].

2.2.1 Active Approaches (Water and Air Cooling Systems)

2.2.1.1 Water Cooling System

M. Abdolzadeh and M. Ameri.2009[20] Investigate the effect of the water pumping cooling system on the solar cell electrical characteristics. Reducing the surface temperature and light reflection losses was the goal of using this technique. The maximum efficiency achieved was 12.5% as a result of cooling.

M. Rosa-clot, et al.2010[21] Enhance the single crystalline silicon solar cell's power output by reducing the surface temperature. Submerge the solar panel in water was the major objective to dissipate the heat from the top surface of the solar cell. 4cm was the perfect depth to immerse the panel in water in this study and achieve the higher efficiency of 11%.

R. Hosseini, et al.2011[22] Improve the photovoltaic panel efficiency by extracting the surface's heat via a water cooling system. Create the thin film of water on the top surface of the solar cell was the aim to reduce the surface temperature and increase efficiency.

A. Yadav and F. Grubišic. 2015[23] Present the water cooling spray technique to improve the crystalline silicon solar cell's performance. Reduce the solar cell surface temperature was the main role. 16.3% it was found the maximum efficiency achieved, and that as a result to decrease the temperature from 54^0 C to 24^0 C due to the top and backside water cooling.

2.2.1.2 Air Cooling System

A. S. Káiser and B. Zamora.2013[24] Improve the solar cell's electrical characteristics by reducing the effect of ambient temperature. Air as a working fluid was used to cool the solar cell in this study via a forced-air channel cross-section with a certain velocity. $10\text{-}16^0$ C were the temperatures at different fan speeds were obtained lower than the reference temperature before cooling. Due to this action, 2.4% maximum power increased.

Y. M. Irwan et al.2015[25] Present the air cooling technique to increase the power output of the crystalline silicon solar cell. Indoor experimental work with solar simulator design to investigate the effect of reducing the temperature of the solar cell performance. Two PV panels were used to compare. 2-3^0 C was obtained lower than the un-cooling solar cell and consequences 6-14% maximum power output increased.

A. Crăciunescu, et al.2016[26] Investigate the effect of extract and dissipate heat on solar cell performance. Forced circulation air cooling system by used fan used to cool the solar panel.4.37% was the increased of the power output due to cooling the PV panel.

2.2.2 Passive Approaches (Nanocoating Thin-Film).

2.2.2.1 Thermal Regulation Film Nanocoating Materials

Solar spectrum losses are an important factor in reducing the efficiency of the solar cell. As it is known that the energy of the incident solar radiation's photon contributes to stimulating the electron of the solar cell and producing electric current. the specific energy of the photon should be fit with the bandgap of the solar cell. The higher the photon energy (for example, the photons of the ultraviolet spectrum) will participate to excitement the electron's of the solar cell but the excess energy will dissipate as heat over the solar cell surface and cause raising its temperature. Lower photon energy (for example, the infrared photon energy) does not have enough energy to elevate the electron of the solar cell. Fit photon energy (for example, visible spectrum photon energy) has satisfying energy to elevate the electron without excess energy. Therefore, ultraviolet (UV) and infrared (IR) rays may function as important roles in contributing heat to the solar device system. This study is further confirmed by S. W. Glunz. et al.2012[17], whereby IR and UV caused solar heating, which led to the instability of solar cells and lowering their efficiencies.

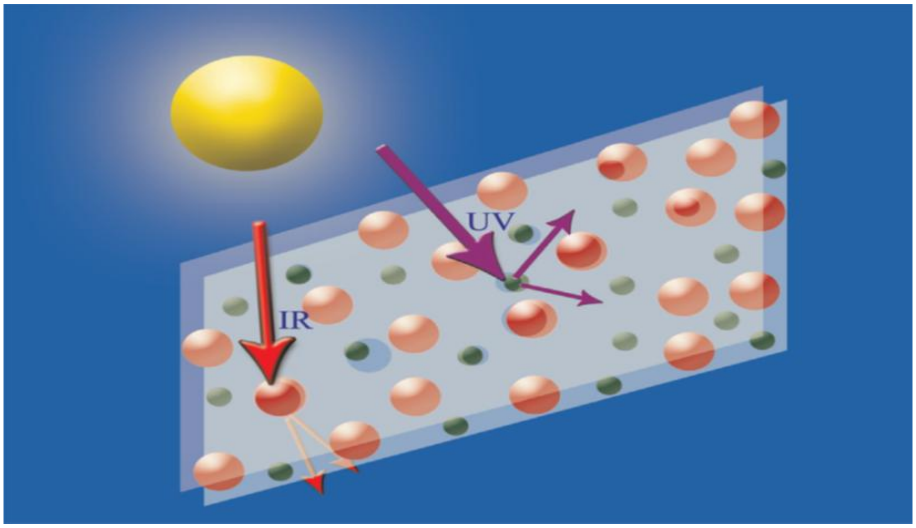


Figure 2.2 Thermal insulation film - Ultraviolet wavelength blocking [27]

I. Gonzalez-valls, Y et al.2011 [28] Investigates the solar cell output parameters as a function of light intensity, UV light, and working temperature. After applying thin-film, nanocoating zinc oxide Nano-rod (ZnO NRs) were grown between 1.6μm and 5.2μm rod length, with 1.2μm optimum thickness, the best photovoltaic response having a power conversion efficiency of 1.02 % and Jsc of 3.72 mA/cm2.

V. Kaler, U et, al.2018[29] Investigated the effect of Nanocomposite-Coating [Titanium Dioxide (TiO2) doping with Polymer-Polyvinyl Alcohol (PVA)] with different concentrations to coating the crystalline silicon solar cell. The result has obtained, that the Nanocomposite coating played as an ultraviolet(UV) spectrum blocking system and the ability of the Nanocoating to mask the UV depends upon the concentration of the Nanocomposite. As the concentration increases the ability to mask the UV increase. The UV wavelengths were blocking in this study were 338, 370, 390, 360, 365 nm from the UV wavelength (which broadened from 200nm to 400nm).

A. Manasrah, A. et al.2019[30] Improve the solar cell performance in terms of solar intensity, which was the main objective of this study. Nano coatings as the thermal insulation films were the main roles to enhance the solar cell's characteristics. A mixture of ceramic and carbon with particles size 25nm was the Nano coating material applying in this study. Blocking the visible spectrum solar cell intensity by an average of 20%, 60%, 80 of the radiation reached to solar cells has a major effect to reduce the solar cell surface temperature and consequence its efficiency. indoor test records 59^0 C (solar cell without coating) and 49^0 C for Nano coating with 80% solar intensity blocking with 20.3% maximum efficiency obtained.

F. K. Mohd Zaini et al.2020[31] Improved the polycrystalline silicon solar cells' efficiency via decreasing the solar cell surface temperature was the main goal. Nanocoating [Titanium Dioxide (TiO_2) with nanosize doping with Polymer- 3-aminopropyl triethoxysilane] to coating the top side of the solar cell with different concentrations was the technique used to reduce the solar cell temperature. where the TiO_2 plays as an Ultraviolet spectrum blocking system and prevents the Ultraviolet wavelength from transmittance to the solar cell. The solar cell was tested indoors, the test conditions were $1000W/m^2$, and one hour the total test time. The result was reducing the temperature from 55.74^0 C (without coating) to 46.81^0 C (with Nano coating) and consequently increasing the solar cell's fill factor by 33.3%.

D. M. Hachim et al.2020[32] Improves solar cell performance as a function of infrared absorption. The Polycrystalline solar cell was coated with Nanocoating via casting technique to deposition Titanium Dioxide (TiO_2) and Polymer- Nitro Cellulose with different concentrations on the top of the polycrystalline silicon solar cell. to improve the electron excitation process and reduce infrared radiation (IR) absorption at low frequencies. According to the results of the tests, increase the efficiency by 1.11 and 2.71 % for one-layer and two layers of the Nanocoating respectively, and reduce the solar cell's surface temperature by 10^0 C as comparison without coating solar cell.

2.2.2.2 Anti-Reflection Coating Thin-Film

Because the bare silicon cell has a high reflective index, more than 35 % of incident light is reflected away from the panel surface and causes decreasing the solar cell power output. The reflection is reduced by applying an anti-reflective coating on the surface of the solar cell. A thin layer of dielectric material with appropriate thickness is used as an anti-reflection layer on the top side of the solar cell and reduces the light reflected. The anti-reflective coating helps the solar surface to capture more light and thus boost its efficiency.

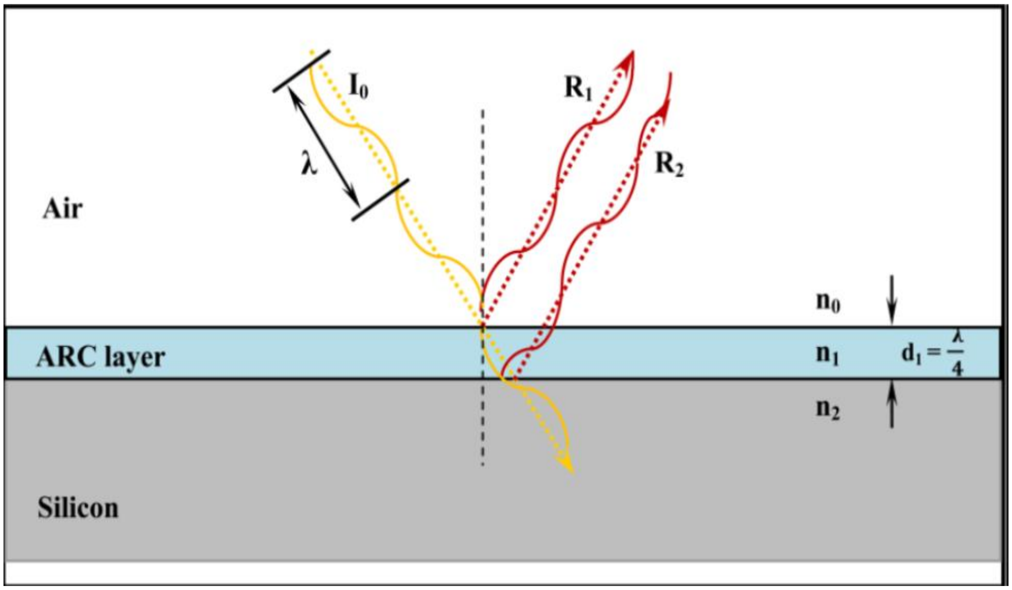


Figure 2.3 anti-reflection coating silicon solar cell[33]

D. Hocine, et al.2013[34] Improve the multi-crystalline silicon solar cell performance via applying Titanium Dioxide (TiO_2) nanoparticles as an anti-reflection coating. Chemical vapor deposition (CVD) technique used to paint the solar cell's surface with Nanocoating. As a result of this paint, the reflection losses reducing from 35% for solar cells without Nanocoating to 8.6% for solar cells with TiO_2 coating, and consequence maximum efficiency obtained 14.26% with gain +3% as compared with reference solar cell (without coating).

A. Jannat, W. et al.2016 [35] Enhanced the crystalline silicon solar cell performance by applying the Nano coating on the solar cell's surface and play as an anti-reflection layer. Spin coater device with 2000RPM was used to deposition the solar cell with $SiC–SiO_2$ nanocomposite. The Nanocoating played as an excellent film to reduce the reflection from 35% for the bare silicon solar cell to be 7.08% at wavelengths ranging from 400-1000nm, thus increasing the efficiency from 16.99% without anti-reflection layer to 18.24% with Nanocomposite anti-reflection coating.

D. Karthik et al.2017 [36] Applying material with high transmittance, low cost, and durable against the weather conditions like MgF_2 on the top side of the crystalline silicon solar cell to reduce the reflection losses was the goal of this study. The dip-coating technique is used to form a single-layer anti-reflection coating (ARC) on the glass substrate of the solar cell. as a result due to this coating, the reflection loss was 100% transmittance (R: 0%) in the visible region (615-660nm) and 99% transmittance (R:1%) in the region (400-800nm) and thus, 6% maximum efficiency enhancement.

J. Jung, A. Jannat, et al.2018[37] Applying the spin coating method to deposition double layer anti-reflection coating, were deposition Al_20_3 layer and then TiO_2 on the crystalline silicon solar cell's surface. due to reducing the reflection from 35% to 4.74% in the visible region 400-1000nm, the conversion efficiency obtained 13.95% with 35.27 mA/cm2 (JSC) short circuit current, and 593.35 mV (VOC) open-circuit voltage.

B. Ashok, G. Sivasankar 2018[38] reducing the photon reflection from the silicon solar cell surface via anti-reflection coatings (CNT, ZnS, Aluminium isopropoxide) deposition on the top side of the solar cell and improve its performance. The result shows that the carbon nanotube (CNT) has the maximum efficiency enhanced with a range of 31.25% higher than the solar cell without coating.

H. Dhasmana, et al.2020[39] Investigate the effect of Zinc Oxide (ZnO) Nano-Rod deposition on the surface of the crystalline silicon solar cell as an anti-reflection. the result was reducing the texturing silicon reflection from 25% before applying the anti-reflection layer and be 2.5% with the Nano-Rod coating layer along the visible region (450-750nm).

A. A. Ahmad et al.2020 [40] Applying the multi-layer Nanocoating as an anti-reflection to coating the solar cell was the aim to enhance the solar cell efficiency. $ZnO/TiO_2/SiO_2$ layers were the nanomaterials that were deposition on the solar cell's glass surface to reduce the reflection losses. The result decreasing the reflection from 8.62% for glass substrate down to 4.445% for ZnO and 4.021% for ZnO/SiO_2 and further reducing with applying TiO_2 down to be 1.433%.

A. Jalali, M. R et al.2020[41] Investigate the effect of deposition of a Zinc Oxide (ZnO) with Nanoparticles size (30-50nm) via spin-coating method on the solar cell performance. It was found the applying thin-film of ZnO on the silicon increases the absorption of the incident light, enhances the electron generated, reduces the light reflection, and consequently improves the solar cell efficiency.9.19% and 5.29% were the efficiencies for present and absent the anti-reflection (ZnO-layer) respectively.

2.2.2.3 Self-Cleaning –Nanocoating Thin Film

investigate the effect of using different materials with Nano-size particles such as ZnO, TiO_2, Silica, MgFe, CuO, and MnO_2 by using various methods (dip coating, spin coating, sol-gel, chemical vapor deposition, and spray coating) to casting the Nano coating on the glass of the PV panel to play as an anti-dust material to remove the dust and soil and prevent it to adhesion on the surface. This technique is called the self-cleaning approach. It is a less expensive and less time-consuming method.

The self-cleaning technique is based on two concepts. To begin with **Super- hydrophobic**, which permits the droplets of water to rolling off the surface and carrying the contaminations away from the surface with a water contact angle (WCA) $> 150^0$. in addition **Super- hydrophilic** surface, which made a water film on the surface to detach dust particles and move them away from the surface with a water contact angle of small or even zero. Figures 2.3-2.4 depict the super-hydrophobic, hydrophilic surfaces.

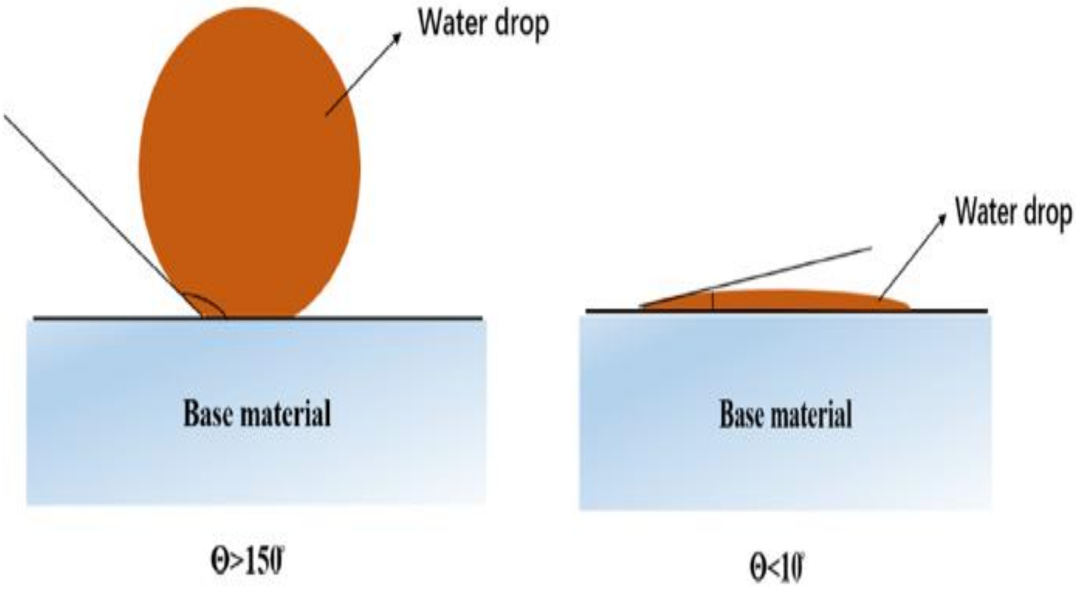


Figure 2.3 Super-hydrophobic, Super- hydrophilic surfaces [42]

Figure 2.4 water droplets rolling down carrying the dust particles on the superhydrophobic surface[43].

C. S. Thompson et al.2013[44] Self-cleaning and antifogging silica nanoparticle Nanocoatings thin -film are presented in this study. The main purpose of this coating, which is applied to the cover glass of solar panels, is to eliminate pollutants when wet with rainwater and to transmittance more sunlight in foggy weather. As a result, the coated glass eliminated 90% of surface pollutants, compared to only 48% for bare glass. Furthermore, the Nano-coating film increased the solar transmittance of glass substrates by 4.3 % over the bare glass in the wavelength range of 350–1100 nm.

D. H. Kim, et.al.2016[45] Improve the thin-film solar cell's performance via applying Nano coating material. Al doping with ZnO Nano rod to get layer has the self- cleanable and anti-reflection properties deposition on the glass of the solar cell. as a result, reduce the glass reflection from 8.6% to 2.9% and made the surface less rough and easy to remove the contaminations.

H. Zhong et al.2017 [42] Improve the self-cleaning coating properties of the surface of the solar cell to make it high stability and corrosion-resistant. composite the coating with 3-triethoxysilylpropylamine (KH550) and TiO_2.By using the scanning electron microscope (SEM) and water contact instruments. The surface structure and water contact angle have been investigating and found excellent super hydrophobic surface properties. And show lower water contact angle (WCA) and good transmittance. Thus, increased the energy production of PV panels by 4.3%.

S. Sutha, et al .2017[46] Enhance the self-cleaning characteristics of the glass surface of the solar cell by deposition the glass with aluminum oxide coatings. The super hydrophobic surface property was obtained with water contact angle (WCA) 161^0 , and 300nm thick the coating. The Investigating process of the Nano coating effect was done by comparing the two glasses with and without coating as a term of dust contaminations it was found 67% and 91% respectively. The solar cell's performance had improved to 1.32 percent.

P. P. Self-maintenance et al.2018 [47] This study looks at how an anti-fouling Nano-coating affects the electrical energy produced by a string of photovoltaic modules. The coating is made of silica, tin oxide, titanium oxide, platinum, methanol, and water and has a thickness of 100–200 nm, allowing for high light transmission. The coating effect was measured by comparing the energy provided by two PV panels: it was found to raise the energy output on the PV panel by around 1.82 % as compared to the uncoating one.

A. Pan, H. Lu, and L. Zhang .2019[48] Investigate the effect of various materials to be used as anti-dust coating and deposition on the top glass surface of the solar cell. Four different glasses were used to compare, glass A (pure glass), glass B (Silica gel), glass C (ethanol with SiO_2), glass D (silica gel with SiO_2). Indoor experimental work with tilt angle 30^0 , 60 min (time for exposure for dust). The result shows the dust deposition for samples B, C, and D was 51.4%, 38.6%, and 36.1% as compared to bare glass sample A. thus sample D show higher transmittance and lower power losses after deposition.

A. Mishra and N. Bhatt.2019[49] Super hydrophobic coatings based on Nano-silica can improve solar panel performance by reducing reflection and increasing cleaning efficiency. The Nano coating thin-film was made by combining silica Nano size with the polymer polymethylmethacrylate (PMMA) and then spinning the solution onto a glass side of the solar cell. The properties of the coating were investigated, including water repellency, anti-dust, transparency, and contact angle measurements. The coating's temperature stability was also investigated. found that the Super hydrophobic surfaces have a high water contact angle of greater than 150^{0} , which is one of the most significant properties of the surface with strong water repellence and is mostly used to protect a substrate's property from environmental factors such as icing, dust, and other contaminants through the coating. stable in a wide variety of environmental conditions, and various temperatures. These coatings may be appropriate for solar panels to avoid various weathering effects**.**

M. Z. Al-badra. et al.2020 [50] This research explores the antistatic and hydrophilic thin film properties of the Nano-coating materials tin oxide and silicon oxide Nano sizes. An automatically vibrator is used to coat the glass substrate of a crystalline silicon solar cell. The vibrator's job is to shake the PV panel, allowing dust to fall off by gravity. This method is particularly useful in arid and desert areas. The PV panels with coating and mechanical vibrator's average electrical efficiency dropped by 12.94% after six weeks of service, while the reference panel's efficiency dropped by 33%.

2.3 Summary of Previously Studies

After reviewing most of the previous studies related to improving the performance of solar cells as a function of temperature and reflection losses. passive approaches -Nano coating thin-film, its was the most efficient, less expensive, and less time-consuming method. Where the some of Nano-coatings make as thermal regulation to reduce the solar cell’s surface temperature and others as anti-reflection coatings to decrease the sunlight reflection and as a result enhancement the solar cell efficiency and consequently its power output. The challenge in this study focuses on the choice of a Nanomaterial (Titanium Dioxide and doping with Polymer-Polyvinyl Alcohol) and makes it as thermal regulation and anti-reflection coating at the same time to be more efficient and less cost Nano coating thin film. Since the different concentrations of Nano coating used have affected the coating's ability to reduce the temperature and refection loess, thus the choice of the fit concentration of the Titanium Dioxide and Polymer also will be the main role in this study.

3

Theoretical Concept

Chapter

Theoretical Concept

3.1 Introduction

In this chapter, the main concept of the effect of temperature variations and reflection losses on the polycrystalline silicon solar cell parameters is present here. that is useful to understand the influences of reflection loss and temperature variation on the polycrystalline silicon solar cells, to estimate their performance under various conditions. All mathematical relationships that deal with the parameters of solar cells are present here.

3.2 Light Properties

The light we see daily 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. as depicted in figure 3.1[51].

The sunlight reaches the ground level consists of, around 49% of the radiation is in the infrared region solar spectrum ($\lambda >$700 nm), 45% is in the visible range (400 nm 700 nm), and the remaining 6% is ultraviolet light ($\lambda <$400 nm)[52]. Since light is electromagnetic waves, it is necessary to distinguish between these waves. The wavelength (λ), photon energy(E), and frequency $(\nu)$are the most important characteristics of electromagnetic waves to distinguish between them. where the wavelength and energy of photons are inversely proportioning to each other[51].

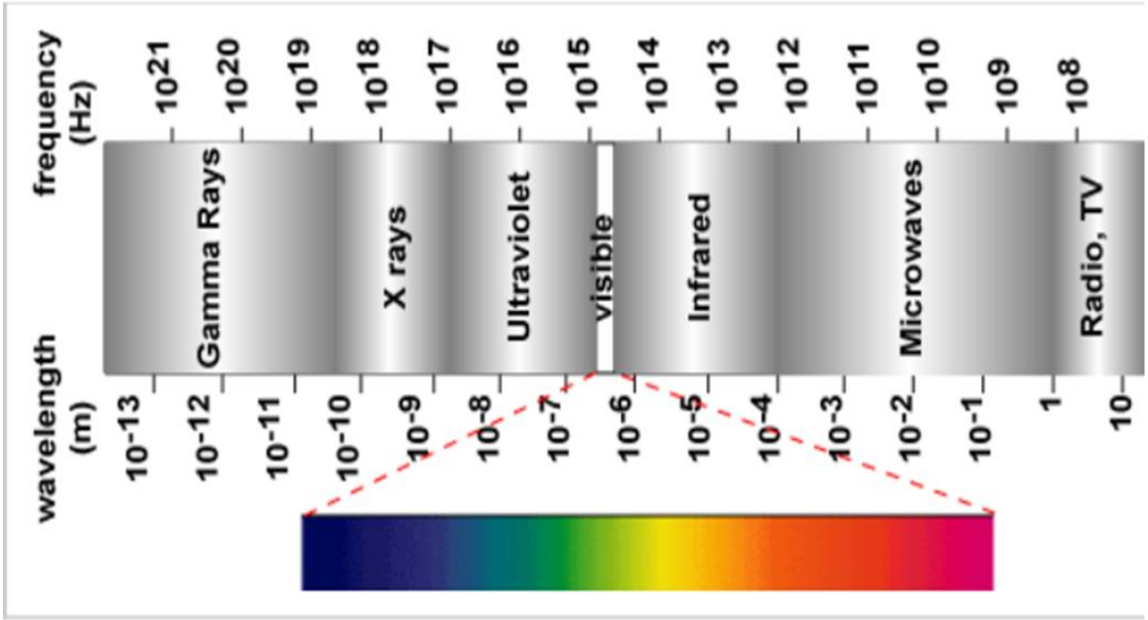


Figure 3.1 Spectrum wavelength[17]

3.3 Light's Interaction with Matter

Because electromagnetic radiation is light and has energy. It is affected by matter and affects it. We note the effect of matter on light through its ability to radiate, absorb and reflect light. This means when the light incident of the matter, part of it is **reflected** from the top side of the matter, while the rest enter and **absorption** through the matter. if any other part of light reaches the backside of matter it may reflect again or **transmittance** through it[51]. Figure 3.2 depicts these activities.

Where :

Reflection (R): Changing the path of the incident radiation and return it to the medium coming from it. When moving between two media with different refractive indexes, this property is called reflection.

Transmittance (T): passes the radiation through the matter without affecting it(without made excitation to electrons of that matter).

Absorption: If the atoms of the matter are exposed to some energy, they absorb a quantity of this energy, which causes the excitement of these atoms and thus stimulates their electrons to move to higher energy levels. This phenomenon is called the absorption of the incident energy by the material which represents by the incident light energy[53].

$A = \mathcal{E}bC$ ……………………………………..……………………...(3.1)

A: absorbance (A.U), $\mathcal{E}$:Molar absorptivity (L/(mol cm))

b : path length(cm) ,C: concentration (mol/L)

When the rays fall on the material, the intensity of the incident radiation is stronger than the transmitted radiation and the difference between them is the absorbed rays[53].

$R = 1 - A - T$ ………….……………………………………………(3.2)

$I_{(X)} = I_O e^{-\propto x}$ ……………………………………….………….....(3.3)

$I_{(X)}$:light intensity at distance (x) passed through material

$I_{(0)}$: initial light intensity, ∝: absorption coefficient

Since electromagnetic radiation is a bundle of photons, each photon has certain energy depending on the frequency of the radiation. The energy of a photon can be calculated according to the following equation.

$E = h\upsilon$ ……………………………………………………...…………..(3.4)

Where, E: photon energy

$h: Planck\ constant (6.63 * 10^{-34} JS) \quad , v: frequency\ (HZ)$

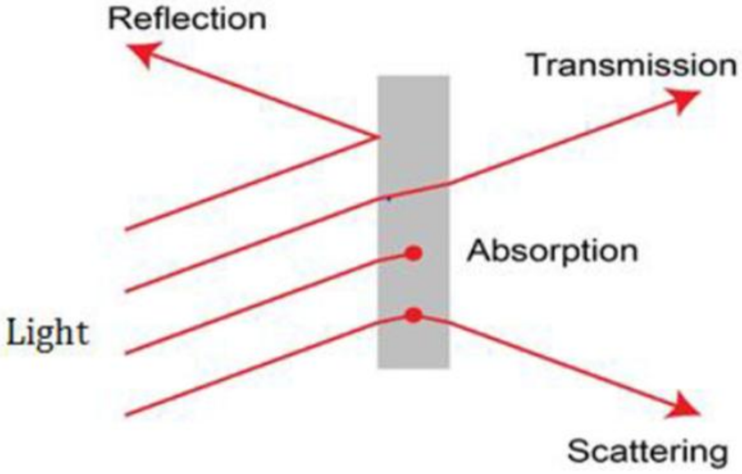


Figure 3.2: Light-material interaction[54]

3.4 The Influence of The Surface Temperature on The Solar Cell Performance

Solar cells, like all semiconductor materials, are temperature-sensitive devices. temperature raising decreases the semiconductor's bandgap, thereby influencing the parameters of the semiconductor material. The decrease in the bandgap of a semiconductor as temperature rises can be interpreted as an increase in electron energy in the material. as the operating temperature of the PV module rises the PV parameters influence by reducing the voltage with slightly increasing the short circuit current and thereby reducing the power output. With standard test conditions 1000W/m^2 incidence radiation and 25^0 C ambient temperature, all photovoltaic were designed to optimum performance. Rising the temperature, reducing the overall efficiency of the photovoltaic panel at a rating of 0.4-0.5 % for every 1^0 C above 25 ^{0} C [55].

Furthermore, increased temperatures increase strains associated with thermal expansion and also increase deterioration rates by a factor of around two for each 10°C increase in temperature[56], implicating temperature in numerous failure or degradation mechanisms of PV modules. figure 3.3 shows the effect of the surface temperature of the solar cell performance [41].

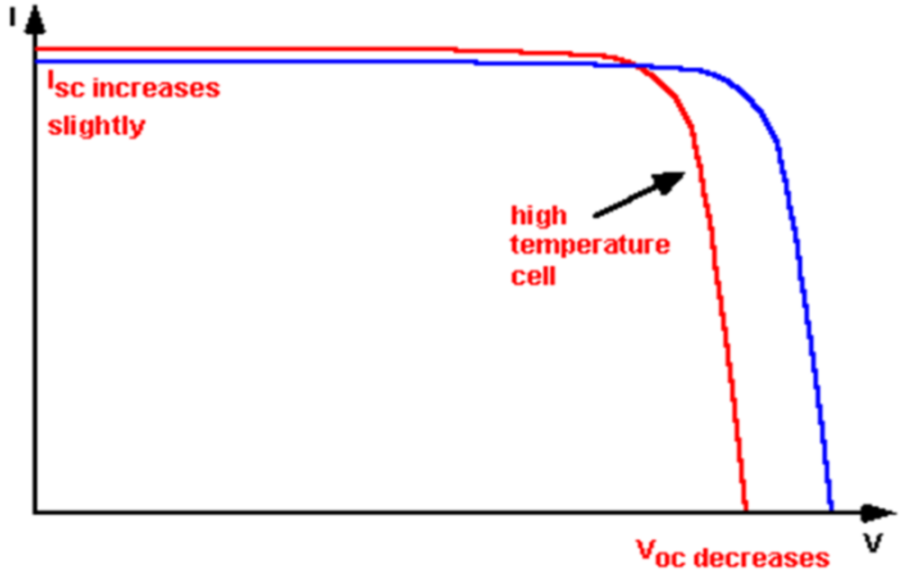


Figure 3.3 I-V curve as a function of the solar cell temperature[41]

3.5 Electrical Analysis of Photovoltaic Cell

Several parameters are used to characterize solar cells, such as short circuit current (I_{SC}), open-circuit voltage (V_{OC}), fill factor (FF), and Efficiency (η), all of which can be estimated from the I-V characteristics of the solar cell under illumination, as shown in Figure.3.4 [40].

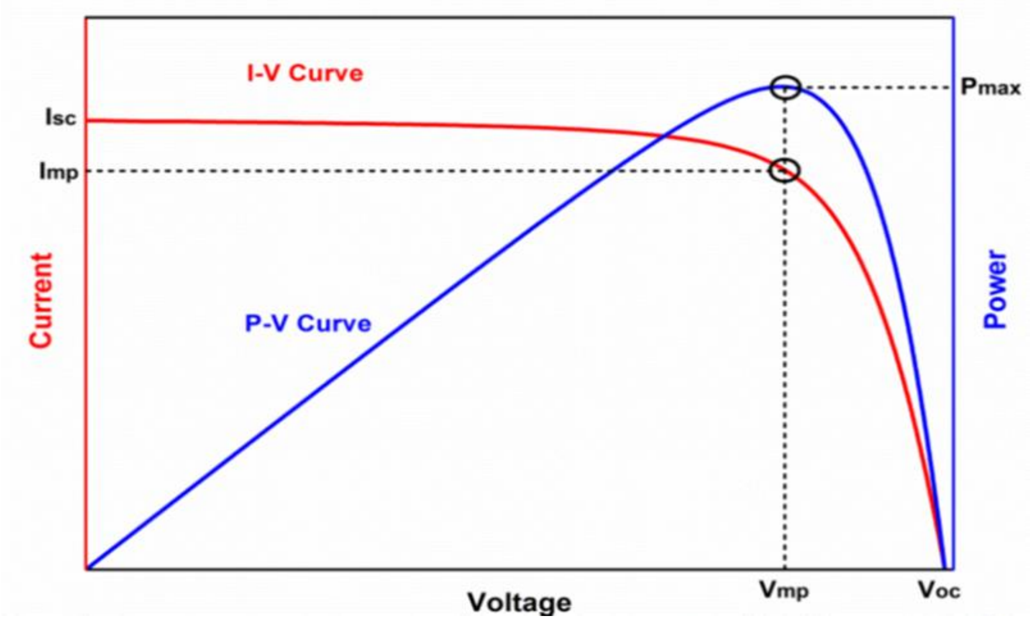


Figure 3.4 The standard current-voltage (I-V) and power-voltage (P-V) curves of a solar cell[40]

3.5.1 Open Circuit Voltage

The open-circuit voltage, or V_{OC}, is the greatest voltage a solar cell can produce while the current is zero. The forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current is represented by the open-circuit voltage. On the IV curve below, the open-circuit voltage is displayed. the open circuit voltage is strongly dependent on temperature as shown in the below relation [57].

$$V_{oc} = \frac{KT}{q} In\left[\frac{I_{ph}}{I_s}\right] + 1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.5)$$

3.5.2 Short Circuit Current

If the output voltage is zero, the cell is said to be short-circuited. The short circuit current is equal to the absolute number of photons converted to hole-electron pairs. The short circuit current (Isc) was found to be dependent on the temperature. ISC of the solar cell can be determined using the relationship[57].

$$I_{SC} = I_S \left[exp \frac{q * V_{OC}}{KT} - 1 \right] - I_{ph} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

Where(K) is Boltzmann constant, (T) is the temperature, (q) is the electronic charge, (I_{ph}) is the photocurrent, and (Is) is the diode saturation current.

3.5.3 Fill Factor

The measure of the quality of a solar cell refers to the ratio between the maximum power of the cell Pmax to the theoretical power $P_{Theoritical}$. The fill factor is an important parameter that affects the solar cell's conversion efficiency. However, with a low FF value, the Efficiency will be below. The fill factor of a solar cell can be estimated using the relationship[58].

$$F.F = \frac{I_m * V_m}{I_{SC} * V_{OC}} = \frac{P_{max}}{I_{SC} * V_{OC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.7)$$

Where Im is the maximum current and Vm is the maximum voltage.

3.5.4 Electrical Efficiency

The ratio of the output electrical energy to the input solar radiation (Radiation incident on the solar cell) is defined as the efficiency value. It depends on the type of cell, given irradiance, and temperature. which can be expressed as[56].

$\eta(\%) = \frac{V_{OC}*I_{SC}*FF}{P_{in}} = \frac{P_{max}}{A*G}$ ……………………………………..…… (3.8)

Where, (G) denotes overall irradiance (W/m^2), and (A) denotes the effectively illuminated region (m^2)

The expression of electrical efficiency (η_{el}) according to the temperature for PV panel is given by[59].

Raising the ambient temperature and the solar cell's surface temperature has a crucial impact on the PV performance, as shown in the following mathematical relations.

$\eta_{PV} = \eta_{TR}[1 - \beta_R(T_C - T_R) + \gamma log_{10} I_{PV}]$ …………………...……….(3.9)

Where:$\eta_{PV,}$ is the PV efficiency at reference temperatures. T_R: Reference cell temperature (25^0 C),β_R: temperature coefficient (typically equal to 0.004-0.005/^{0} C)[60]. I_{PV}: irradiation incident on the photovoltaic panel at NOT (nominal operating temperature). T_C: PV temperature.

Since, γ : intensity coefficient of the radiation is mostly equal to zero[61][62], thus the equation reduces to the following relationship.

$\eta_{PV} = \eta_{TR}[1 - \beta_R(T_C - T_R)]$ …………………………………... (3.10)

3.6 Energy Bandgap Calculations

The bandgap is the minimum amount of energy required for an electron to break free of its bound state. The band gaps can be calculated via UV-Vis spectroscopy using Tauc Plots. Tauc used an equation in 1968 to calculate the absorption edges (bandgaps) of amorphous Ge and Si from their absorption data. Where Tauc's relation is given as:

$\alpha h\nu = A\sqrt{h\nu - Eg}$ ………………………………………………..(3.11)

$\alpha = 2.303\log(\frac{T}{d})$ ……………………………...…………………(3.12)

Whereas; d=thickness of the sample

T=transmission

hυ=photon energy

The above equation can also be written as:

$(\alpha h\,\nu)2 = A2(h\,\upsilon - Eg).$

…………………………………….…..(3.13)

Thus, By plotting the graph between $(\alpha h\nu)^2$ on the y-axis, versus photon energy (hν) on the x-axis where the energy bandgap value was obtained by choosing a straight line vertically downward to X-axis.

α: is the absorption coefficient, h is Planck’s constant, υ is the frequency of the incident photon, A is a proportionality constant, it is usually taken as 1 for amorphous materials, and Eg is the bandgap energy [10].

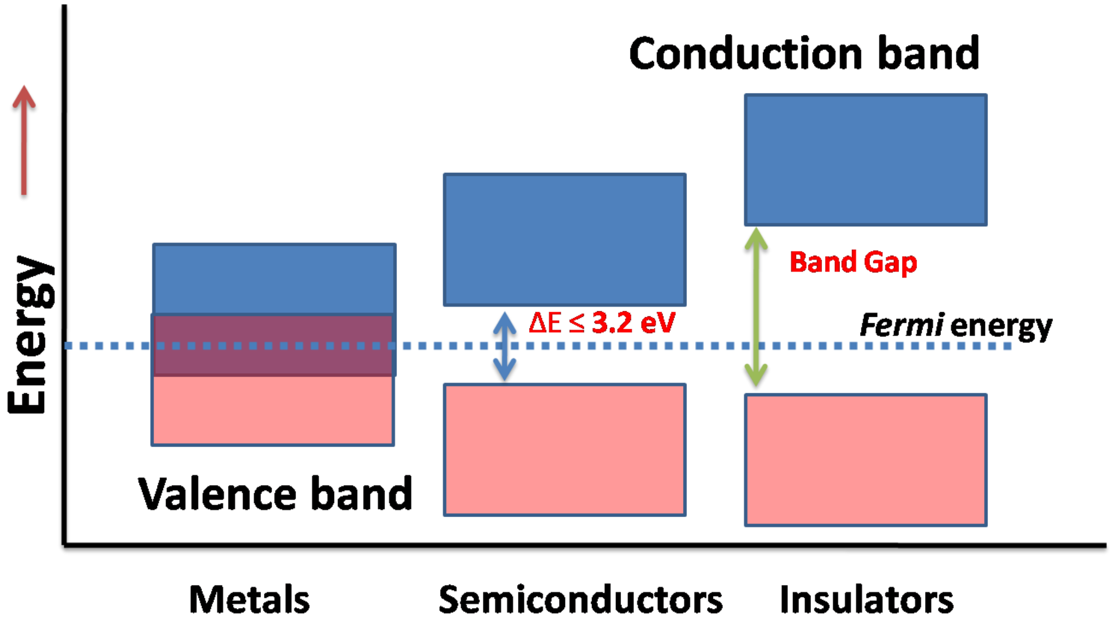


Figure 3.5 Energy Bandgap for metal, semiconductors, and insulators[10]

3.7 The Effect of the Reflection Losses on the Solar Cell Performance

Because of the difference in refractive indices (n) between the two mediums(air, solar cell surface (silicon)), the light would be partially reflected at the interface. around 35 percent of the incident sunlight spectrum on the bare silicon solar cell with refractive index (n silicon = 3.4) is reflected in the air and is to be lost [63].

applying a thin coating of dielectrically material which have, low coefficient absorption, high transparency, and an intermediate refractive index value on the front side of the bare silicon solar cell to reduce the refraction loss. Anti-reflection coating (ARC) is a type of coating that has been widely employed in the field of high-accuracy optical systems, solar cells, scanners, and camera lenses to increase optical transmittance[64]. figure 3.5 shows the anti-reflection coating single-layer.

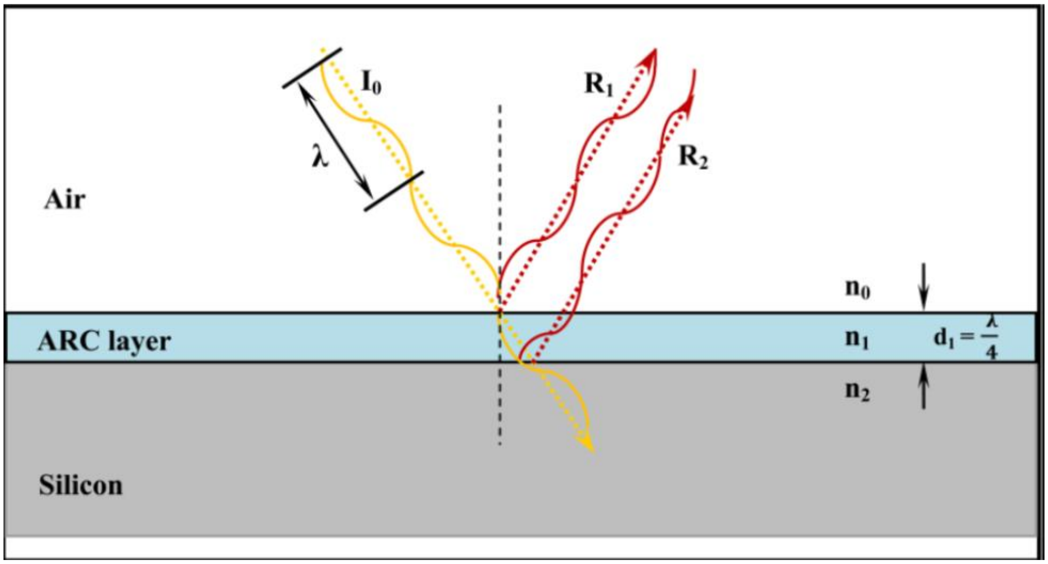


Figure 3.6 Anti-reflection coating silicon solar cell[47]

The ARC thickness "d1" equal to 1/4 of the incident light wavelength "λ", the top and bottom refraction loss "R1"," R2" respectively are destructively interface and as a result the light refracted into the solar cell which contributes to zero reflection loss. Fresnel's formula gives the reflection coefficient (R), as shown in equation (6)[65].

$$R_\lambda = \left(\frac{n_{air}-n_{silicon}}{n_{air}-n_{silicon}}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.14)$$

where n_{air} and $n_{silicon}$ are the refractive indices of air and silicon respectively, λ represents the wavelength of incoming light.

for a quarter-wave anti-reflection coating with, (n1) refractive index and (λ) wavelength; the thickness for zero reflection loss is given as follows[65].

$$d1 = \frac{\lambda_0}{4n_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

$$n_1 = \sqrt[2]{n_0 n_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.16)$$

d1: optical thin film ARC thickness

λ_0 : designed wavelength

n_0, n_1, n_2 : air, Nanocoating, and silicon refractive indexes

4

Chapter

Experimental Work

Experimental Work

4.1 Introduction

This chapter focuses on the method to produce Nanocomposite materials-Titanium Dioxide (TiO_2) doped with Polymer- Polyvinyl Alcohol (PVA), and what the mechanism produced to deposition the Nanocomposite on the front side of the solar cell.

This study has been done on Polycrystalline silicon solar cells, the solar cells were tested indoors in the laboratories of the Technical Engineering College in Najaf with controlled room temperature 25^0 C and under 1000W/m^2 fixed radiant flux with a light that is perpendicular to the surface of the solar cell. Measurement devices are including: UV-Visible spectroscopy, reflectometer, film thickness measurement device, and solar module analyzer to perform the investigations and the effect of coating on the solar cell performance.

The main purpose of using the Nanocomposite as coating films were, to reduce the solar cell surface temperature, and to decreasing the light reflection losses. Thus, enhancing the solar cell efficiency and its power output via played the Nano coating as an Ultraviolet-blocking, and anti-reflection coatings.

4.2 Materials

4.2.1 Polycrystalline Silicon Solar Cell

Figure 4.1 &. Table 4.1. depict the dimensions, and specific properties of the solar cell was employed in this study.

Table4.1. Polycrystalline Silicon Solar Cell Properties.

NO.	Item	Description
1	Type	Polycrystalline
2	Size (mm)	26mm*39mm
3	Maximum power (P_{max})	0.144 W
4	The voltage at P_{max} (V_{mp})	0.48 V
5	Current at P_{max} (I_{mp})	0.3 A
6	Open circuit voltage (V_{OC})	0.5 V
7	Short circuit current (I_{SC})	0.34 A
8	Standard test conditions	$1000 W/m^2$, 25^0 C

Figure 4.1. Polycrystalline Silicon Solar Cell.

4.2.2 Titanium Dioxide (TiO_2)

Titanium dioxide is a white, highly stable, and unreactive metal oxide found in three crystalline forms in nature: anatase, rutile, and brookite[66], as pictured in figure 4.2.

Figure 4.2 Crystalline Forms of Titanium Dioxide, Anatase, Rutile, and Brookite[49]

Unlike brookite, and rutile which are rarely used, anatase has been used in a variety of industrial fields since the 1920s. Titanium dioxide is naturally occurring, where the titanium is never found pure. Titanium Dioxide anatase crystalline form (TiO_2) is an indirect semiconductor with an energy gap of about 3.2 eV and a refractive index of about (n=2.52)[67]. In the case of rutile, and brookite the energy gaps are 3.0 eV, and 3.1 eV respectively and they have a refractive index (n=2.76) [68]. Appendix A, show the Titanium Dioxide properties and Scanning Electron Microscope (SEM) test to certify the Nano size by an equipped company for the TiO_2 anatase crystalline form which has been used in this work.

Table 4.2. General Properties of Titanium Dioxide[69]

Properties	value
Chemical formula	TiO2
Molar mass	79.86 g/mol
Density	3.78 g/cm^3
Appearance	White
Melting point	1843 ^{0} C
Refraction index (n)	2.52
Energy bandgap	3.2 e.v

4.2.3 Polyvinyl Alcohol (PVA)

PVA (Polyvinyl Alcohol)) is a non-toxic white-yellowish solid material with a melting point of 228°C and a molecular weight of 78,000 g/mol. It is a widely used polymer due to its semi-crystalline nature, water-solubility, excellent film-forming ability, and adhesive properties, as well as its transparency and thermal stability properties[70]. Figure 4.3 shows the polyvinyl alcohol.

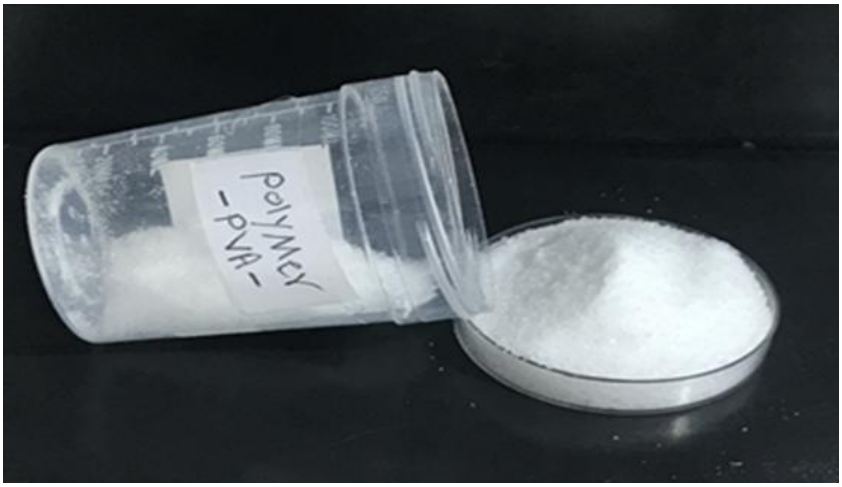


Figure 4.3 Polyvinyl Alcohol (PVA)

4.3 Preparation of PVA and TiO_2 Nanocomposite.

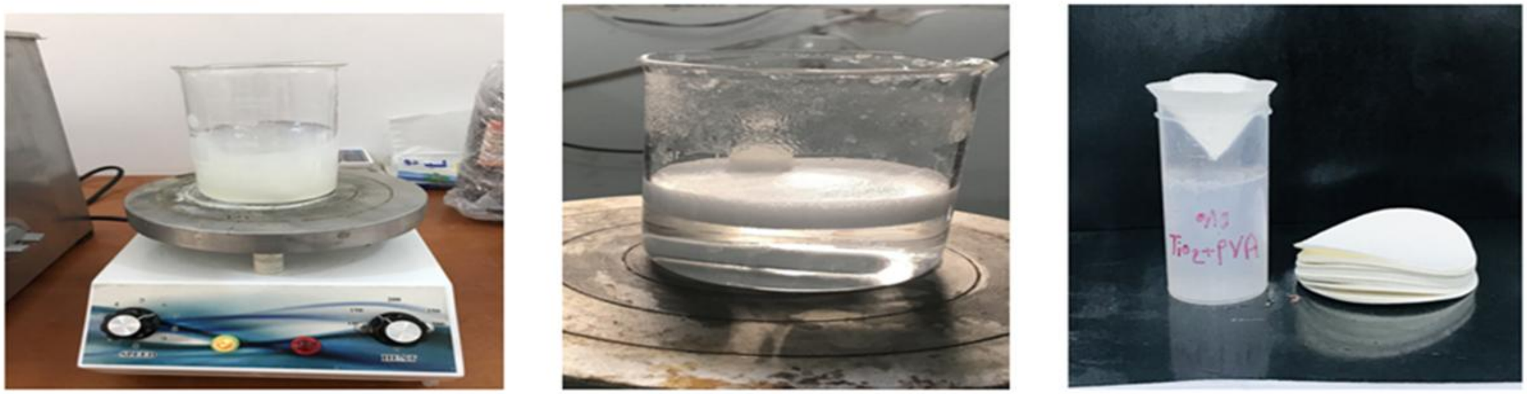
4.3.1 PVA Prepared Procedure

The Solutions of Polyvinyl Alcohol (PVA) were prepared by adding the PVA's concentrations in distilled water. Five different concentrations of PVA in powder form were used, C1: 0.25gram, C2:0.5gram, C3:0.75gram, C4: 1gram and C5:1.3gram, and by adding each concentration of PVA in 50 ml of distilled water. As the following weight percentages (wt. %).

- 0.25gram PVA powder form /50 ml (distillation water) : 0.5Wt%
- 0.5gram PVA powder form /50ml(distillation water) :1Wt%
- 0.75gramPVA powder form/50ml(distillation water) :1.5Wt%
- 1gram PVA powder form /50ml (distillation water): 2Wt%
- 1.3gram PVA powder form /50ml(distillation water) : 2.6Wt%

Via a magnetic stirrer device, the mixture of PVA and distilled water was agitated at 300 RPM and 60^0 C for one –hour, where the maxing at the end time becomes transparent, and all the polymer particles were melted. The solutions were filtered by a filter paper size of 45 μm. Leave the solutions enough time until the solution's foam was finished and sealed tightly to avoid bacteria formation. Figure 4.4 shows the PVA processing.

Polymer –polyvinyl-Alcohol 50ml distilled water Magnetic stirrer



PVA melting process PVA solution form PVA filtration process

Figure 4.4 Polyvinyl Alcohol prepared procedure

4.3.2 TiO_2 prepared procedure

The solutions of TiO_2 were prepared by taking four different concentrations C1:0.05gram, C2:0.1gram, C3:0.2gram, and C4:0.3gram, of TiO2 in powder form with nanoparticles size (10nm) each concentration was added to 50 ml of distilled water, As the following weight percentage (wt%).

- 0.05 gram of TiO2/50ml of distillation water:0.1wt%
- 0.1 gram of TiO2/50ml of distillation water:0.2wt%
- 0.2 gram of TiO2/50ml of distillation water:0.4wt%
- 0.3 gram of TiO2/50ml of distillation water:0.6wt%

The TiO_2 powder form was dispersion in distilled water Via the Ultrasonic device, the dispersion process takes four-hour as a period to make all the Nanoparticles suspension in water. Repeat the procedure four times to prepare all samples. Figure 4.5 depicts the TiO_2 prepared procedure.

TiO2 (10-20nm) 50ml distilled water Ultrasonic device

Figure 4.5 TiO_2 prepared procedure.

4.3.3 TiO_2/PVA Nanocomposite prepared producer

There are many objectives to doping the Polyvinyl Alcohol in Titanium Dioxide solution, to begin with, the PVA has an excellent film-forming ability, and in addition, it prevents the Titanium dioxide Nanoparticles to be an agglomeration and that because the TiO_2 particles are entrapped and encapsulated by the Polyvinyl Alcohol chains. by increase, the solution viscosity (increase the PVA concentration) the motion of the encapsulation particles slows down[71]. In conclusion, the existing of the PVA in TiO_2 solution and create Nanocomposite TiO_2/PVA aimed to form a film has two goals, the first one it make as UV-Blocking, and as an anti-reflection coating. Where the PVA has the absorption property of the wavelength spectrum with the Ultraviolet region (200-400nm), and the TiO_2 has the refractive index lower than the silicon thus it has the ability to reducing the reflection of light.

The Nanocomposite prepared process was done related to the best PVA concentrations. PVA concentrations tests were done via an Ultraviolet-Visible device where (1-gram) of PVA was the high viscosity and highest Ultraviolet absorption intensity and that means that the best PVA concentration. Thus, four different concentrations of TiO_2 were doping with 1-gram, As the following weight percentage.

- 1gram (PVA) doping with 0.05 gram (TiO_2)/50 ml (distillation water):2.1wt %.
- 1gram (PVA) doping with 0.1gram (TiO_2)/50 ml(distillation water): 2.2 wt.%.
- 1 gram (PVA) doping with 0.2gram (TiO_2)/50ml (distillation water): 2.4wt%.

- 1 gram (PVA) doping with 0.3gram (TiO_2)/50 ml (distillation water): 2.6wt. %.

Through the TiO_2 dispersion process (dispersion of the Nanoparticles by the Ultrasonic device). The 50 ml of the PVA solution was dropped into the TiO_2 solution at the range of 12.5 ml for every 30minute after the first two hours from the total dispersion period (four hours). Figure 4.6 &4.7, depicts the Nanocomposite prepared procedure.

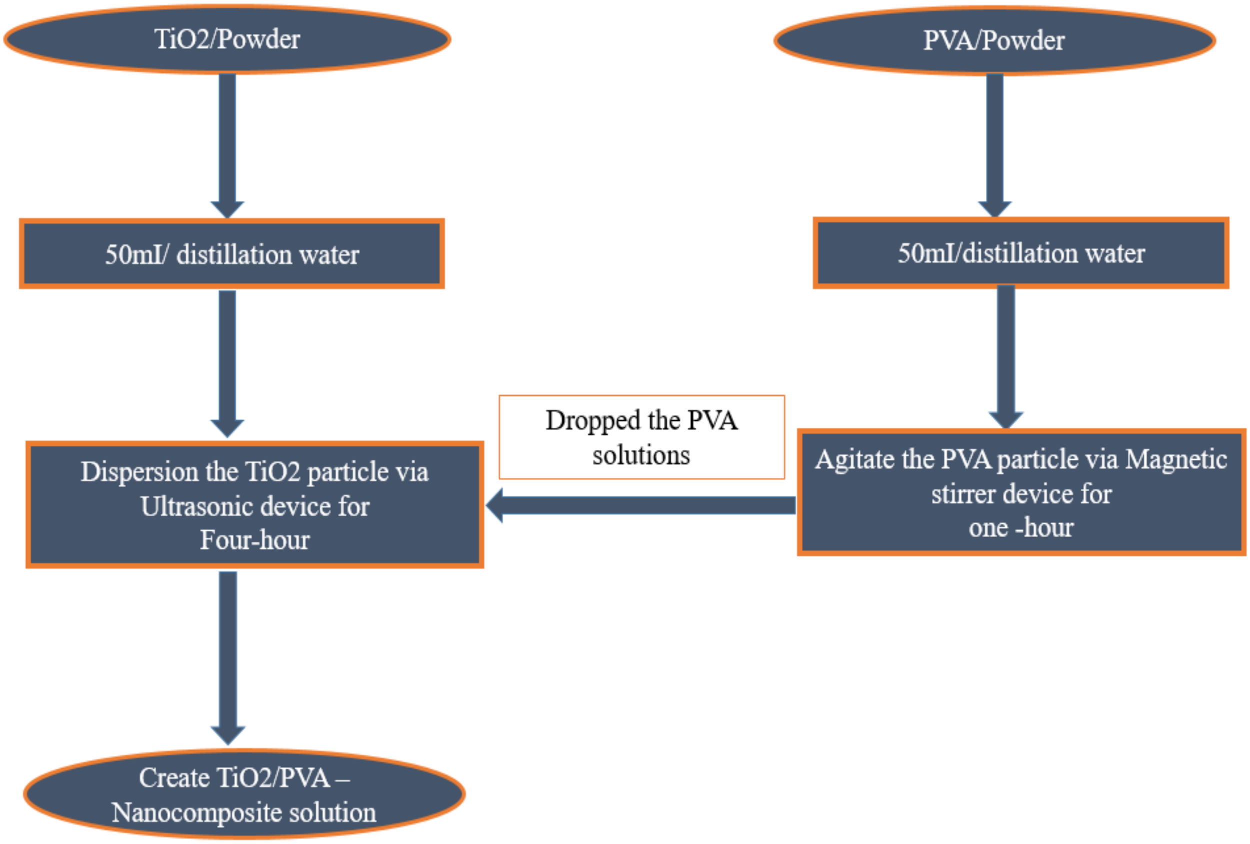


Figure 4.6 flowchart Nanocomposite preparation procedure.

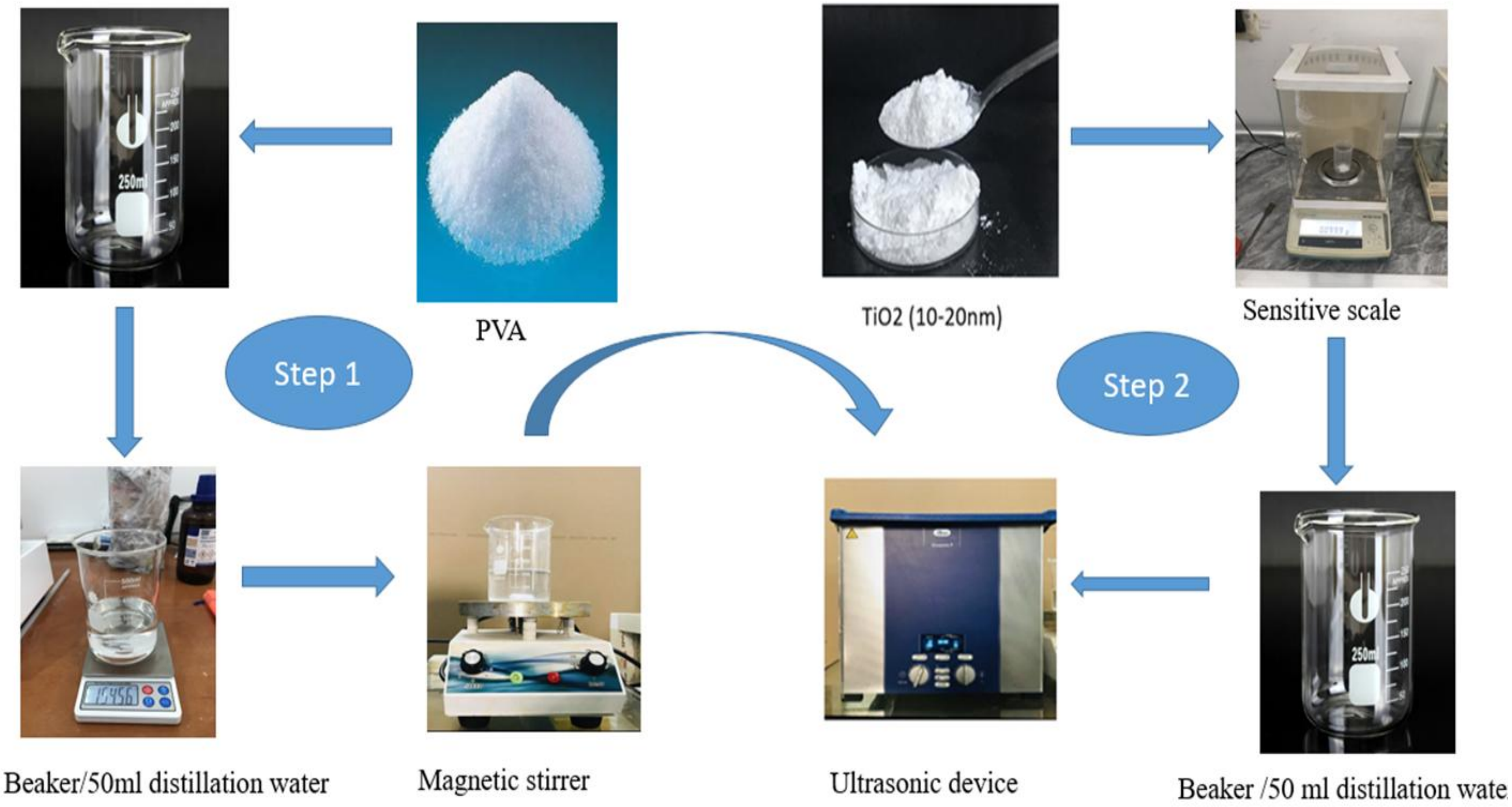


Figure 4.7 Nanocomposite prepared procedure.

4.4 Coating Process

4.4.1 Clean the Polycrystalline Silicon Solar Cell

Before the coating process, the substrate (solar cell) should be cleaning very well to remove the pollution and plankton from the surface of the solar cell. The steps taken to clean the surface of the solar cell are approved in previous sources and researches[54]. The cleaning process is summarized as follows.

1- Put the solar cell in the beaker filled with detergent and placed it in the ultrasonic device for 15 minutes.
2- Wash the solar cell very well several times with water.
3- Repeat the first step by replacing the detergent with acetone.
4- Left the solar cell to dry at room temperature.

4.4.2 Casting Method

There were different methods applied to coating the solar cell one of them was the Casting method was the best and simplest technique [29]. It summarized as dropped a Nanocomposite solution (TiO_2/PVA) with different concentrations on the front side of the polycrystalline silicon solar cell and move the drops to full all the solar cell’s surface. Left the solar cell two hours to permeation the solution to dry on the solar cell.

To ensure that the Nano coating thin-film on the solar cell was coating with the same thickness on all the solar cells. The coating procedure was following.

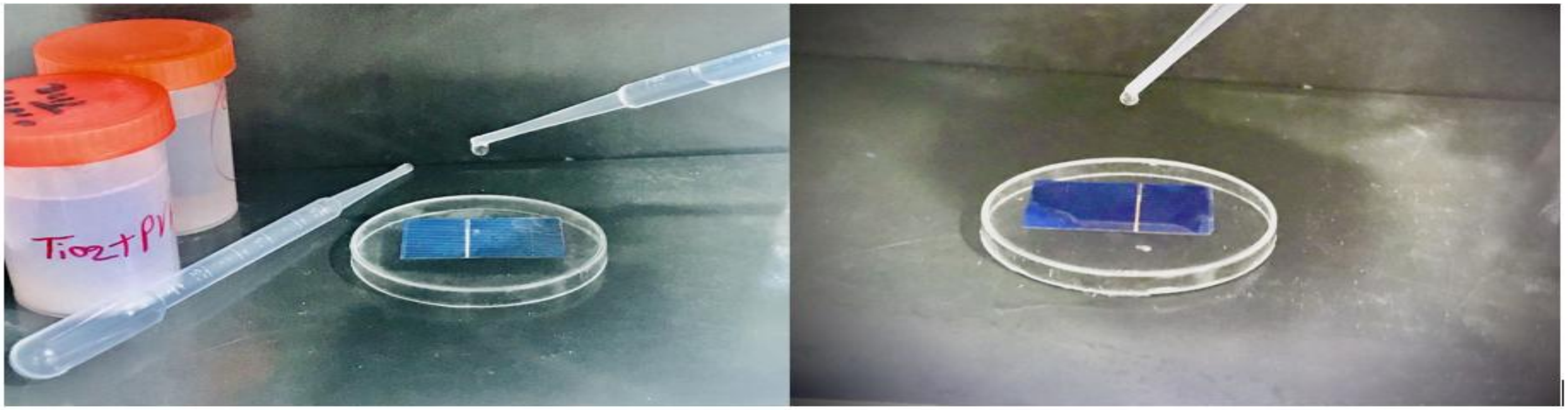
1- The amount of the solution was dropped on the solar cell surface was controlled by a pipette with an amount of 0.5 ml.

2- After drying the Nanocomposite solution, the thickness of the coating thin-film was measured via coating thickness gauge, and to ensure that the coating was uniform on the solar cell surface, several readings were taken on several positions on the cell‘s surface. Figures 4.8-4.9 show the Nanocomposite coating deposition process.

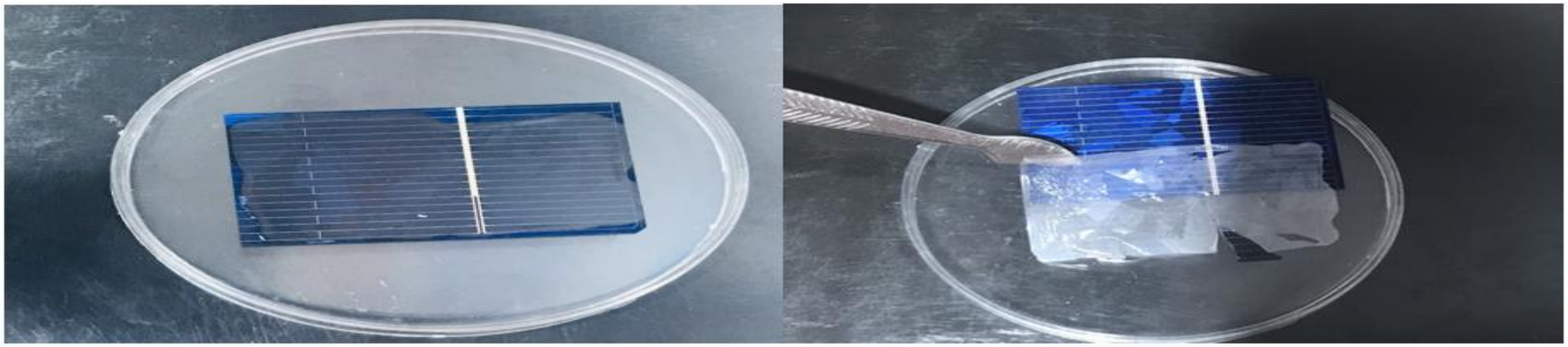
Tube pipes (samples)

Pipette

Figure 4.8 Tube pipes, and pipette



Casting the solar cell via dropping process



Solar cell with Nano-coating Nanocoating film

Figure 4.9 Nanocomposite Coating process.

4.5 Experimental Rig Setup

Indoor experimental work in the laboratories of the Engineering Technical College in Najaf was performed. Figure 4.10, and figure 4.11 show the experimental and schematic rig solar cell test. The experiment including the electrical properties of solar cells test after and before Nano coating layers, also including the thermal insulation test for the solar cells to study the effect of Nanocoatings on the surface of solar cell's temperature.

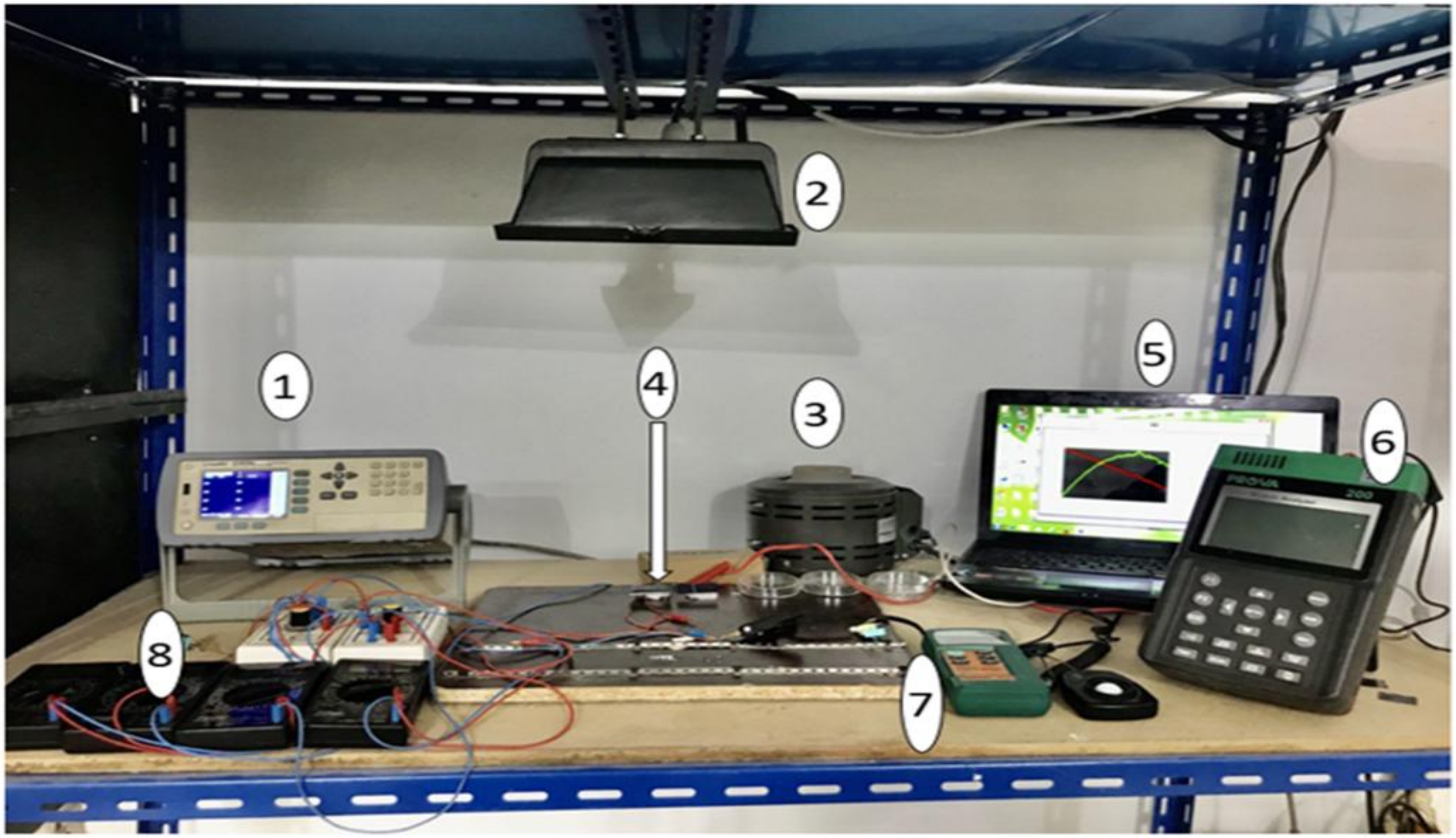


Figure 4.10 Rig Solar cell Test.

Table 4.3 Define The Items of The Rig Solar Cell Test

Item	Description
1	Data-logger
2	Halogen Lamp / 1000W/m^2
3	Variac light intensity
4	Polycrystalline silicon solar cell/coating – un-coating
5	Personal laptop
6	Solar cell module analyzer
7	Pyrometer/ solar intensity Device
8	Widerstander/resistor

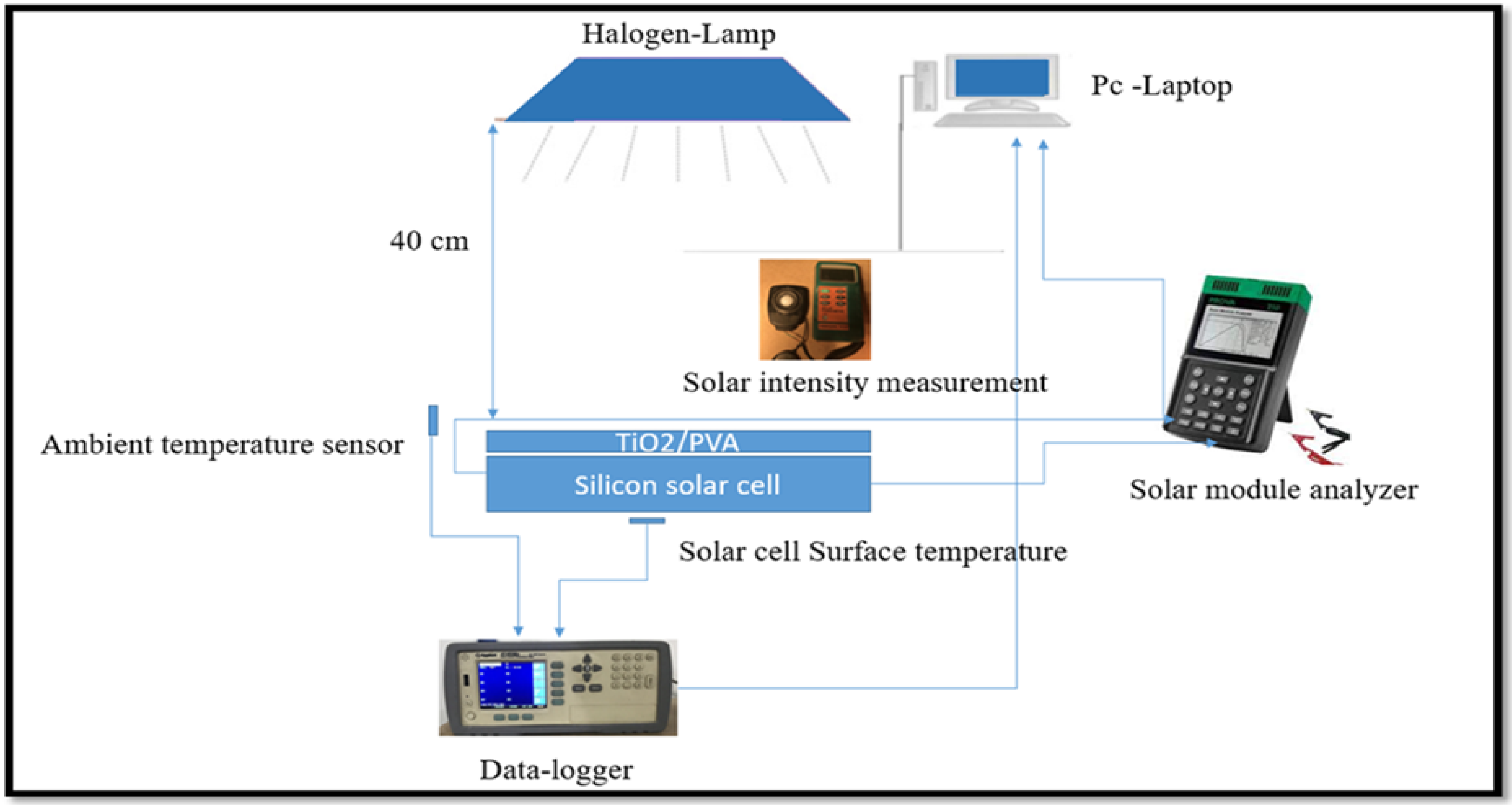


Figure 4.11 schematic Rig Solar Cell Test.

4.6 Measurement Devices

4.6.1 Sensitive Electronic Scale

To know the true Nanomaterial weight with high precision. The four-digit sensitive electronic balance model **ACS 200-4**, manufactured **by KERN and Sohn Gmbh,** was used.

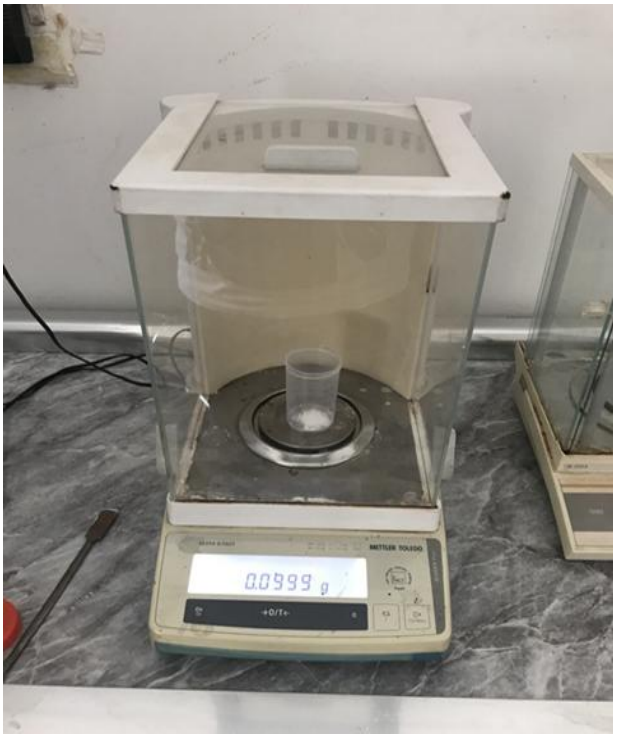


Figure 4.12 Sensitive Electronic Scale

4.6.2 Magnetic Stirrer

Figure 4.13. Shows the magnetic stirrer device, which contains hot plates and speed selectors. The magnetic field was the basis of its work .two magnetic poles, one of them was installed at the bottom plate of the device and the second as a bar put inside the beaker, and due to a magnetic repulsion,

the bar rotates and agitate the solution. This process aimed in this work to solvent the polymer-PVA in the distilled water.

Figure 4.13 Magnetic Stirrer Device

4.6.3 Ultrasonic Device

The device was used to disperse the Nanoparticles and make them suspension in the basic fluid and break particle agglomerates.

Principle work, The basis work of the device is an emission of Ultrasound waves at certain frequencies that hit the basic fluid to dispersion the Nanoparticles in it. In this work, The Nanoparticles prepared process was done via the Ultrasonic device- type **NT-628,** manufacturing company **GUANGZHOU HENWEI ELECTRONICS TECHNOLOGY,** in Engineer Technique College of Najaf. As shown in figure 4.14. It was as a basin filled with water to a certain level, putting the beaker filled with the mixture of (Nanoparticle and distillation water) inside the basin, and by emission of ultrasound waves at certain frequencies hit the basic fluid and work to dispersion the particles in it. Appendix.B, shows the more specification of that device.

Figure 4.14 Ultrasonic Device.

4.6.4 Coating Thickness Gauge

To measuring the Nanocomposite Coating thickness, the **coating thickness gauge Type: TT -260** was used as shown in figure 4.15. Measuring principle, The probe, and the magnetic metal substrate will form a closed magnetic circuit when the probe contacts the coating; the magnetic resistance of the closed magnetic circuit varies due to the existence of a nonmagnetic coating. The thickness of the coating can be measured through the variation of magnetic resistance.

The device is calibrated before Initiation to measure the thickness of the layer. By knowing the difference between the two measurements before and after the coating process, the coating thickness was measured. To obtain a more accurate thickness, several readings of several positions are taken on the surface of the solar cell and take the average readings, the average thin-film thickness obtained (1.156 μm). More detail is found in Appendix. C.

Figure 4.15 Coating Thickness Gauge.

4.6.5 Ultraviolet-Visible Spectrometer (UV-Vis)

To study the absorption, transmittance, and reflection properties of the light falling on the solar cell. An **Ultraviolet-Visible Spectrometer (UV-Vis)** –Type- **Shimadzu 1800** was used. The principle work of the device is to emit light with wavelengths similar to that of incoming solar radiation, by measuring the intensity of the incident radiation and transmittance radiation, and by knowing the difference between them the absorbed radiation was measured. The same device is also used to measure the reflectivity of light, with the reflection measurement option. Where the emitted and received light ratios are read using a lens, and by knowing the difference between them the transmitted and reflected light are reading. Figure 4.16 shows the **UV-Vis spectrometer device**. This apparatus was used in this study to investigate the Polycrystalline silicon solar cell properties before and after Nanocomposite coating. The test process was done in Kufa-University-Engineering College.

General specifications:

- Wavelength range: 190 – 1100 nm
- Wavelength accuracy: ±0.3 nm (190 to 1100 nm)
- Wavelength repeatability: ±0.1 nm
- Dimensions (W x H x D): 450 x 270 x 490 mm

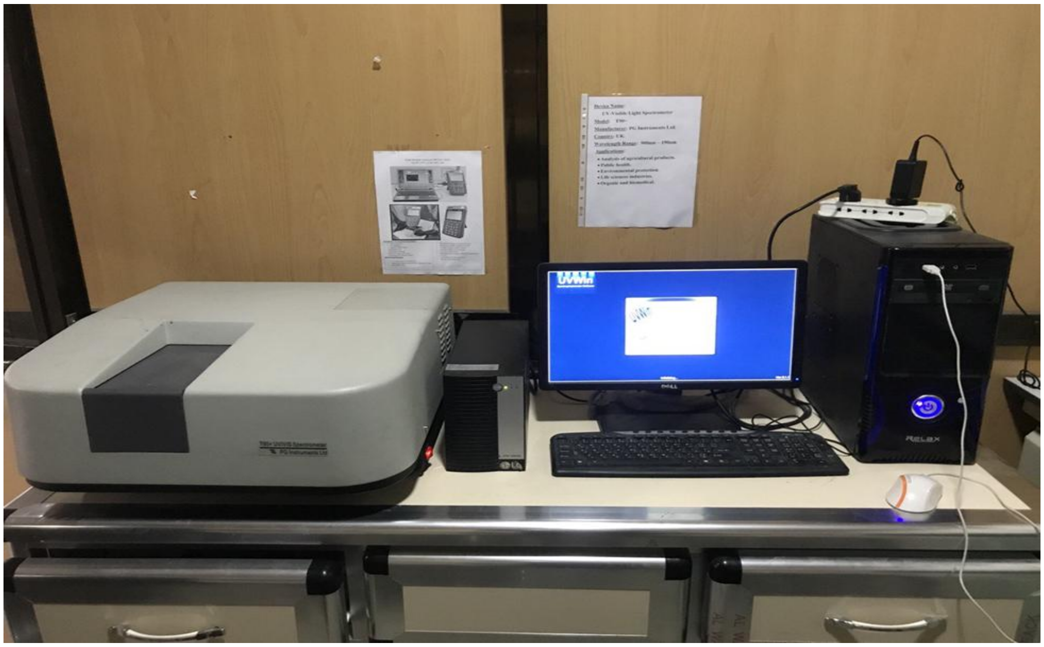


Figure 4.16 UV-Vis spectrometer.

4.6.6 Solar Power Meter

A device that measures the intensity of radiation reaching the solar cell.it called a solar power meter or (Pyrometer). This device was used in this thesis to fit the height between the halogen light source and the solar cell, to controlling the radiant flux at 1000W/m2. Indoor experimental work in the laboratories of the Engineering Technical College of Najaf was performed where the solar radiation intensity was constant as a function of time. the solar power meter (Pyrometer) is shown in figure 4.17. Before using, the calibration process should be done, and it was performed by taken the reading of intensity light at dark, which record (0 W/m^2). Several readings were taken to ensure the appropriate height between the halogen light source and the solar cell surface which gave the light intensity $1000W/m^2$. The device contains a sensing lens, control buttons, LCD monitor. Its specifications and calibration were listed in Table 4.4, and appendix D.

Figure 4.17. Solar Power Meter.

Table 4.4 specification of Solar Power Meter.

Specifications	Details
Type	Tenmars TM-207
Reading range	0-2000 W /m^2
Accuracy	± 10 W/m^2
Reading time	0.25 second

4.6.7 Temperature Measurement

To study the effect of the Nanocomposite with a different concentration on the polycrystalline silicon solar cell's surface temperature . Indoor experimental work was done in the laboratories of the Engineering Technical College in Najaf. The experiments were performed under the condition (1000W/m^2, controlling room temperature 25^0 C, total test time 1-hour). K- Types thermocouples were fixed on the solar cell surface and connected to data-logger type - **Anpat (AT4532)** to record the solar cell surface temperature with and without Nanocomposite coating.

4.6.7.1 Data-Logger

A data logger is a temperature measuring device with multiple channels, as depicted in Figure 4.18.it was very important to study the effect of Nanocoating on the solar cell's surface temperature. **Anpat (AT4532)** with (32) channels was chosen as the data logger in this thesis. Type K and Type T thermocouples can be used with this instrument, and the read accuracy is 0.2 percent ∓1^0 C.

Figure 4.18 Data-Logger

4.6.7.2 Thermocouples

K-Types thermocouples as shown in figure 4.19 were used to investigate the effect of Nano-coating on the solar cell surface temperature. Three thermocouples type-k were fixed, two of them fixed on the back surface of the solar cells (coating and without coating solar cell) at the same time to record and compared the temperature between them, the third one fixed to record the room temperature. To obtain actual thermocouples reading, a calibration process was achieved. Where the thermocouples reading were compared to mercury thermometer reading at freezing and boiling readings (0^0 C, and100^0 C) respectively, and different readings between ($100-0^0$ C). More details of the calibration process are shown in appending E.

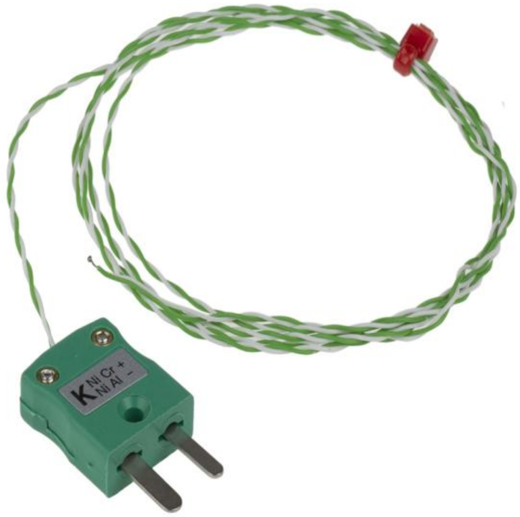


Figure 4.19 Thermocouples K-types

4.6.8 Electrical Properties Measurement

4.6.8.1 Solar Module Analyzer

To calculate the solar cell’s electrical properties (ISC, VOC, η, and I-V Curve) before and after applying the Nanocomposite coating. Solar Module Analyzer –Type- **PROVA-200A**, equipped by **PROVA** instruments-**INC** Company. Data saved and download to PC (laptop) for more analysis with software application was supplied with the apparatus.

General specifications:

- AC Adaptor : AC 110 V or 220 V input , DC 12V / 3 A output
- Dimension : 257 mm × 155 mm × 57 mm (L×W×H)
- Weight: 1160 g (battery included)

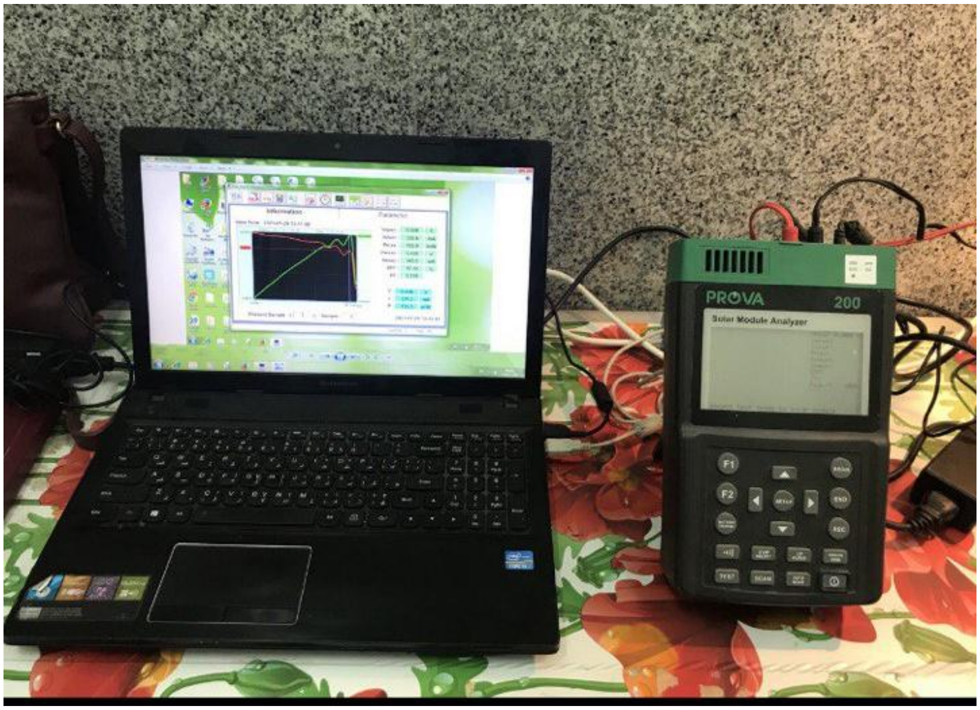


Figure 4.20 Solar Module Analyzer.

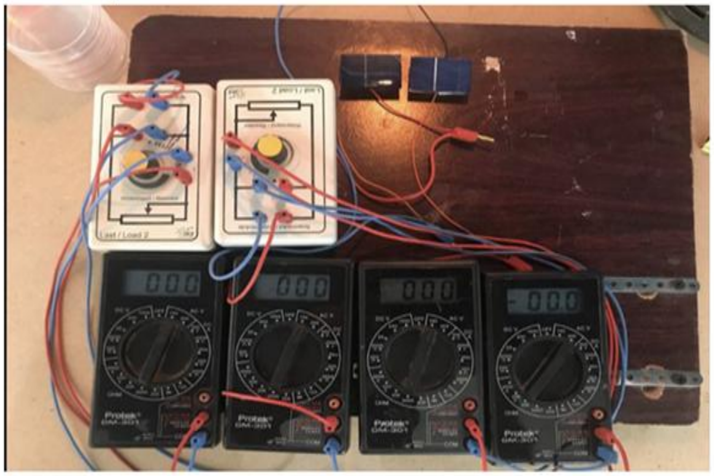
Figure 4.21 shows the I-V Characteristics Measurement system, indoor experimental work was done in the laboratories of the Engineering Technical College of in Najaf .under halogen light source power 1000W/m^2, perpendicular to the solar cell surface, total test time 1-hour. Solar module analyzer-module **PROVA-200A** was to calculate the solar cell electrical properties (I_{SC}, V_{OC}, η, I-V Curve) before and after applying the Nanocomposite coating, all of the electrical properties were taken as software data and downloaded to PC.

ammeter, voltmeter, and variable resistance to vary the load as shown in figure 4.21, which were utilized on the solar cell to find the solar cell characteristics, was the second way to measure the solar cell electrical properties. The solar cell was measured under the simulated solar spectrum, before and after the applied Nano coating. Voltage and current caused by the solar cell at the variable load from zero ohms to the highest possible value of the resistance to know the maximum electrical power. Load is connected in the parallel position for voltage measurement at open-circuit state, while, solar cell load was connected in the series position for current measurement at close circuit state.

Notes: the I-V curves characteristic were taken for several solar cell coating with different Nanocomposite concentrations and without coating solar cells. The readings were recorded at zero time, To study the effect of the Nano-coating in reducing the reflection losses on the electrical properties of the solar cell, while after 1- hour test record was to study the effect of Nanocoating in reducing the solar cell surface temperature on the solar cell electrical properties.

Solar module analyzer

light halogen-lamp



Solar cell's test panel

Figure 4.21 I-V Characteristics Measurement system.

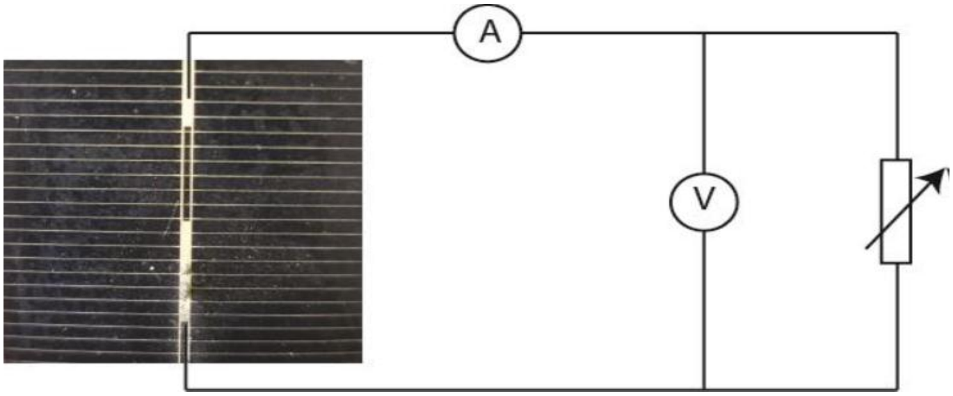


Figure 4.22 Solar Cell Equivalent Circuit.

5

Chapter

Result and Discussion

Results and Discussion

5.1 Introduction

In the present chapter, the effect of Nanotechnology coating thin-film on polycrystalline silicon solar cell performance and its power output were discussed. Reducing the reflection losses and the temperature effect on the solar cell performance were the main roles of this study.

Indoor experimental work in the Engineering Technical College of Najaf was performed. The study focuses on the impact of organic and inorganic semiconductors on solar cell performance. Polymer type – PolyVinyl Alcohol (PVA) and Titanium Dioxide (TiO2) with Nano size (10-20nm) were the main materials where used as Nano-coating thin-films on the solar cells in this study.

Polyvinyl Alcohol (PVA) and the Nanocomposite style -Titanium Dioxide doping with Polyvinyl Alcohol (TiO2/PVA) with different concentrations, were performed as films to coating the front side of polycrystalline silicon solar cell dimensions (26mm*39mm). Ultraviolet-Visible spectrometers device (UV-Vis) to study the reflection losses and the effect of the ultraviolet wavelength on the solar cell, solar module analyzer to test the electrical characteristics of the solar cell, and finally, thermocouples system connected to data-logger to record the temperature surface of the solar cell, where the main instruments were used in this thesis.

5.2 Comparison of the Result

To ensure the behavior, validity, and logicality of the results obtained during the practical side of this study. The results were obtained during this study were compared with the results from other researchers as shown in the following paragraphs.

5.2.1 Comparison the Results of Polyvinyl Alcohol (PVA) Absorbance.

To demonstrate the validity and the behavior of the experimental results, a comparison was performed between the results of the present work and the result of A. Barman et al. [71]. By comparing the behavior of the Ultraviolet absorption intensity curve, we note the same behavior for the two workers. the two works (present and Ref [71]) their absorption in the Ultraviolet wavelength region (200-400nm) with peak absorption (300nm) for both studies (present and Ref [71]). The intensity absorption were (2.3 A.u)for the present work and (2.1 A.u)for the ref.[71] with a maximum error was 9.5%, and there wasn't absorption in the visible region (400-700nm).

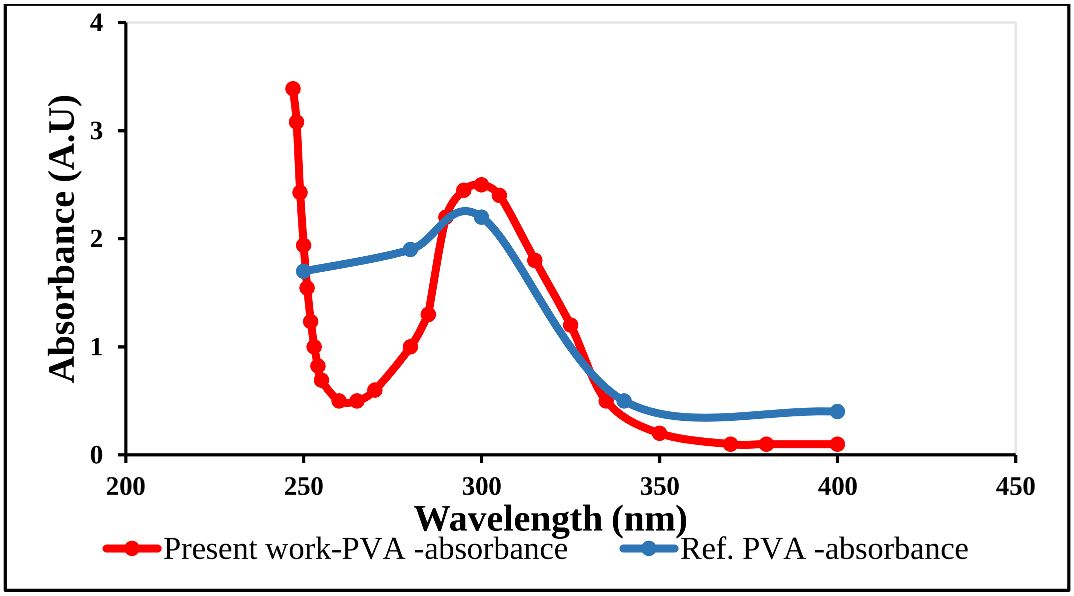


Figure 5.1 Comparison of the polyvinyl alcohol (PVA) ability to absorption the ultraviolet wavelength between present work and ref[71].

5.2.2 Comparison the Result of the Temperature Effect for Nanocomposite-material

To demonstrate the validity of the experimental results, a comparison was performed between the results of the present work and the result of F. K. Mohd Zaini et al. [31]. The maximum temperature difference obtained in the present work was (9.7^{0} C), while in the reference, the maximum temperature difference was (8.6^{0} C). Maximum error was found between the two works was 12.8%.

The two works (present work and reference[31])were performed in the same conditions.

- Polycrystalline silicon solar cell.
- Same Nano-material (Titanium dioxide- Nanoparticles coating films).
- 1000W/m^{2}.
- Total test- time one hour.

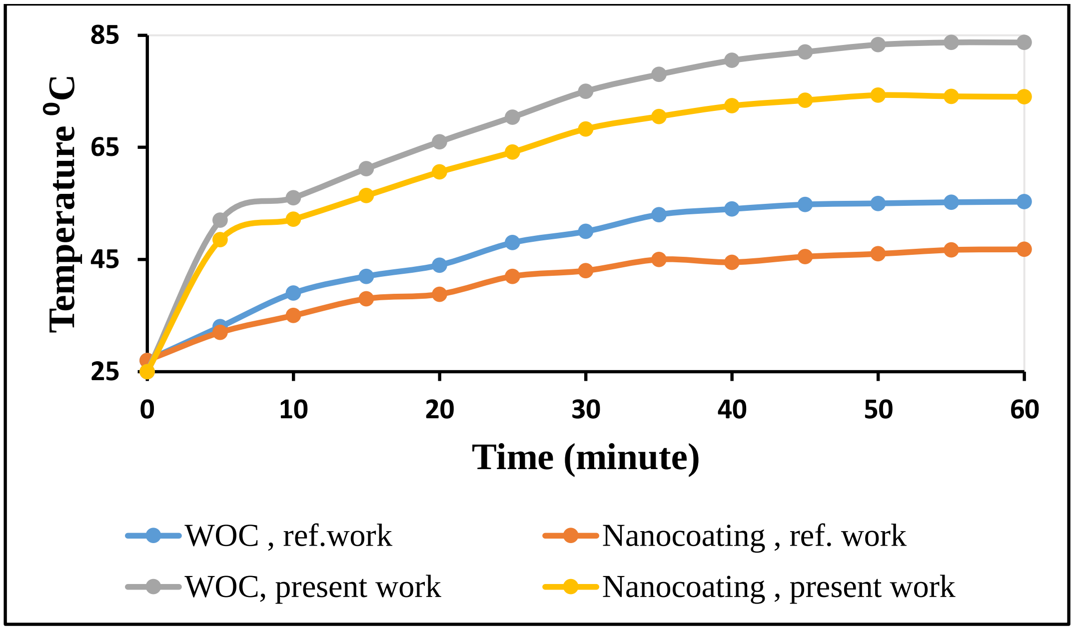


Figure 5.2 comparison of solar cell temperature between present work and ref[31].

5.2.3 Comparison the Result of Ultraviolet Absorption for Nanocomposite

To demonstrate the validity and the behavior of the experimental results. A comparison was performed between the results of the present work and the result of Kaler et al.[29]. The present work observed maximum Ultraviolet absorption was obtained 380nm, while in the reference the absorption ability was 390nm. The same concentration was used and the same Nano-coating material. maximum error obtained between the two works was 2.6%.

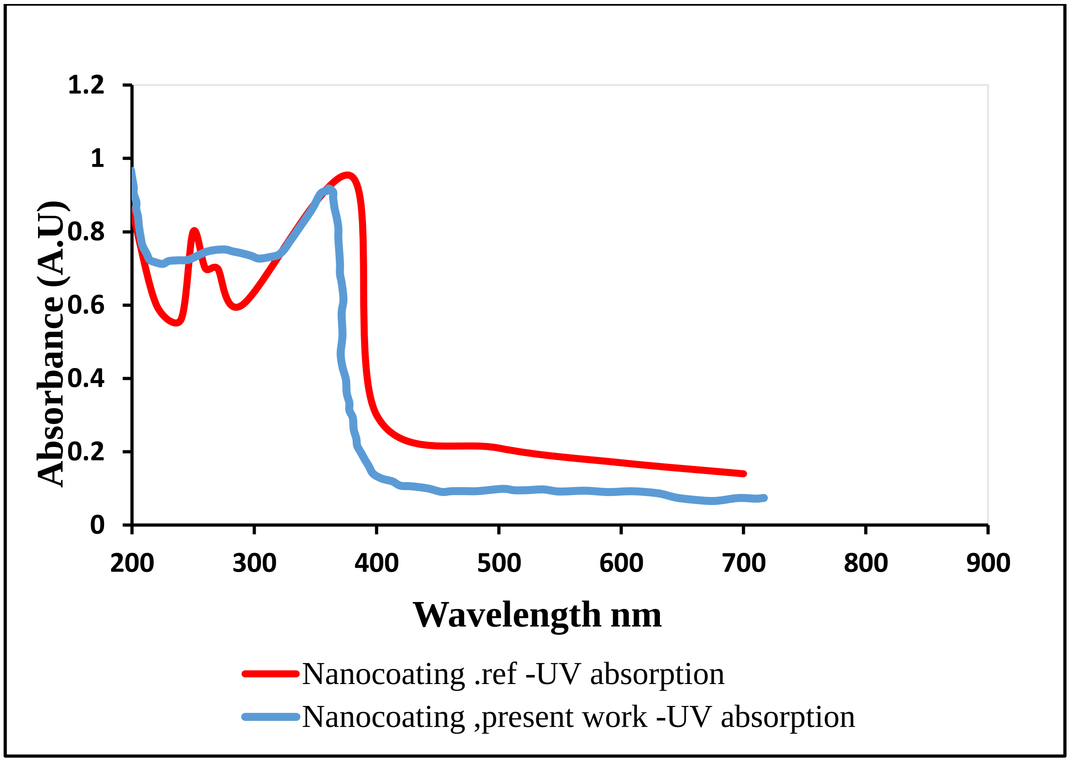


Figure 5.3 comparison the ultraviolet absorption ability for the present work and the result obtained by ref[29].

5.2.4 Comparison the Result of Reflection Losses for Nanocomposite material

To demonstrate the validity of the results, a comparison between the present work and other authors should be done. the result of the present study was compared with the result of the researcher Dhafer Manea et al.[32] in terms of the reflectivity of the surface solar cell. The result was reducing the reflection from 35% to be 8.45% in Ref.[32] , while in the present work the reflection reducing from 35% to be 8.3 %. The test conditions are the same in both the present work and the authors' works. The test was done on the same solar cell type which was polycrystalline silicon solar cell, the same Nano-material coating was used (Titanium Dioxide), and the same concentration. The maximum error was found as a comparison between the two works was 1.8%.

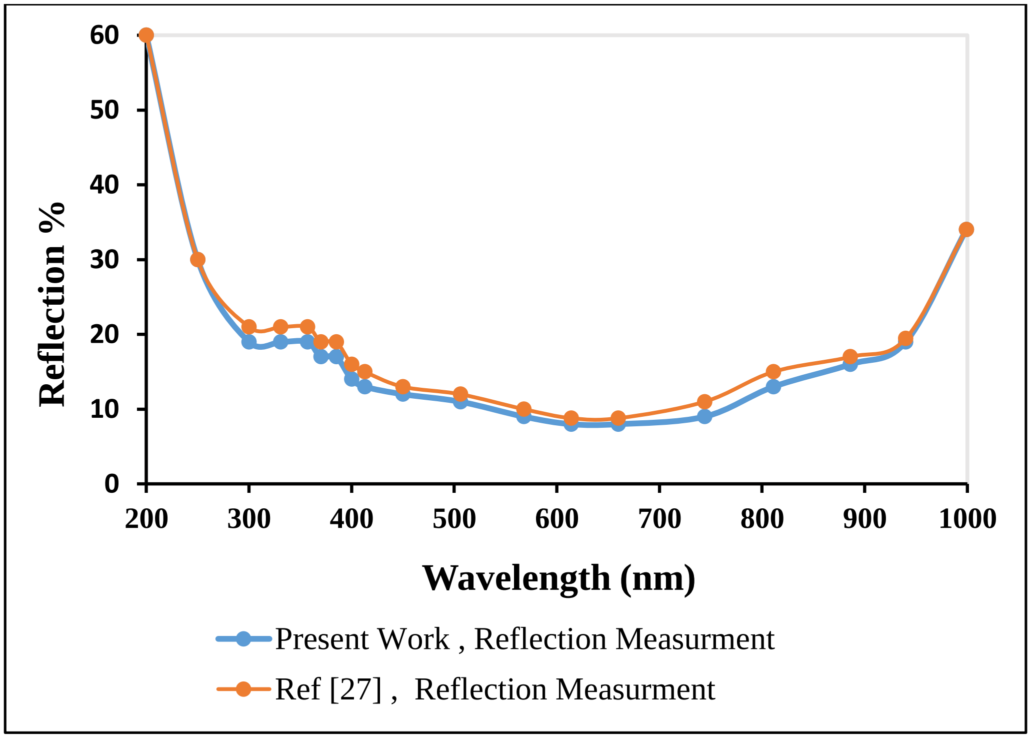


Figure 5.4 Comparison of the reflection measurement losses between present work and ref.[30]

5.3 Study the Effect of Polyvinyl alcohol (PVA) on Solar Cell Performance.

Indoor experimental work was done to investigate the effect of Polymer-Polyvinyl Alcohol (PVA) with different concentrations on the Polycrystalline silicon solar's performance. To study the effect of the polymer on the performance of the solar cell, it is necessary to study the ability of the polymer to absorb the Ultraviolet wavelength of the solar radiation, and its effect on the temperature of the surface of the solar cell. Thus, how the PVA affected the efficiency and the power output of the solar cell.

In this study, the tests were done in the laboratories of the Engineering Technical College of Najaf. Rig solar cell was manufactured to do the test. The solar cells were tested indoors with controlled room temperature (25^0 C) and under 1000 W/m^2 fixed radiant flux with a halogen light that is perpendicular to the surface of the solar cell. The total period test was one – hour (1-h).

The solar cells tests were in two stages. The first test was to study the effect of PVA coatings on the performance of the solar cell when it was at zero time where the solar cells were under the room temperature about (25^0 C). While the second test, it was to study the effect of PVA coatings on the performance of the solar cells after one -hour of light effect where the solar cell's surface temperature raising with time (the effect of temperature was present).

5.3.1 The Effect of Polyvinyl Alcohol (PVA) on Ultraviolet Absorption.

Solar cells can directly convert the sunlight energy to electrical energy through photovoltaic processes. That is why solar cells are also known as photovoltaic cells. In photovoltaic cells, semi-conductors convert light to electricity. In fact, when the utilized semiconductor material absorbs photons of light with appropriate energy, the absorbed energy helps to excite and move an electron from its valance band to the conduction band resulting in the production of electron–hole pairs (excitons). After collecting and separating the charge carriers produced, the generated load transmits the electrical current through a P–N junction in the solar cell. Accordingly, only the photons whose energies are equal to or greater than the bandgap energy of the semiconductor material participate in the process of energy conversion. If the photon’s energy is greater than the bandgap energy of the utilized semi-conductor, then electron release will happen and the excess energy will be wasted as heat, which will increase the temperature of the solar cell.

The present work concern blocking Ultraviolet wavelength (UV) which has high photon energy 10,000 times greater than infrared radiation [15]. Thus when the UV sharing to elevate the electron of the solar cell, the excess of the photon energy will be dissipated on the top side of the solar cell as heat and thus rising its temperature.

In this work, Polymer-Polyvinyl Alcohol (PVA) was used to filtration the Ultraviolet wavelength (UV) and prevent it from transmittance to the solar cell. By applying the PVA on the front side of the solar cell. An Ultraviolet-Visible spectrometer device was used to investigate the ability of PVA to blocking the UV-ray, the test was done in Kufa-university-Engineering College laboratories. Different concentrations of PVA were used (C1:0.25gram, C2:0.5gram, C3:0.75gram, C4:1gram, and C5:1.3gram).

Figure 5.5 shown the ability of the PVA to absorbance the UV- ray within the region 200-400 nm (the ultraviolet wavelength region), and don’t exceed to the visible region (400-800nm). The absorption intensities of PVA were (I_1:0.8A.U, I_2: 1A.U, I_3: 1.3A.U, I_4: 2.5A.U, and I_5: 2.2A.U) according to the PVA concentrations (C1:0.25gram, C2:0.5gram, C3:0.75gram, C4: 1gram, and C5: 1.3gram) respectively. It is clear the PVA absorption varying at different intensities (A.U) according to varying the concentrations and, as noted the intensity of ultraviolet absorption is increased with the concentration of the polymer increases, where the increase in the concentration increasing the number of atoms of the PVA that absorbing the ultraviolet photons, thus the intensity of absorption increases. This relationship is not absolute and showed opposite results at a concentration (C5:1.3gram) where its intensity to absorption was (I_5:2.2A.U) which was less than that at (C4:1gram) (I_4:2.5A.U), the reason for that variation was because of the accumulation of the atoms on top of each other with increasing the concentration over a certain quantity and creating a state of destructive interference with the substance. That is what happened in the concentration (C5:1.3gram) where it gave less absorption intensity, so the concentration (C5:1.3gram) consider the turning point of the result and the C4:1-gram was the maximum ability to absorption (2.5A.U).

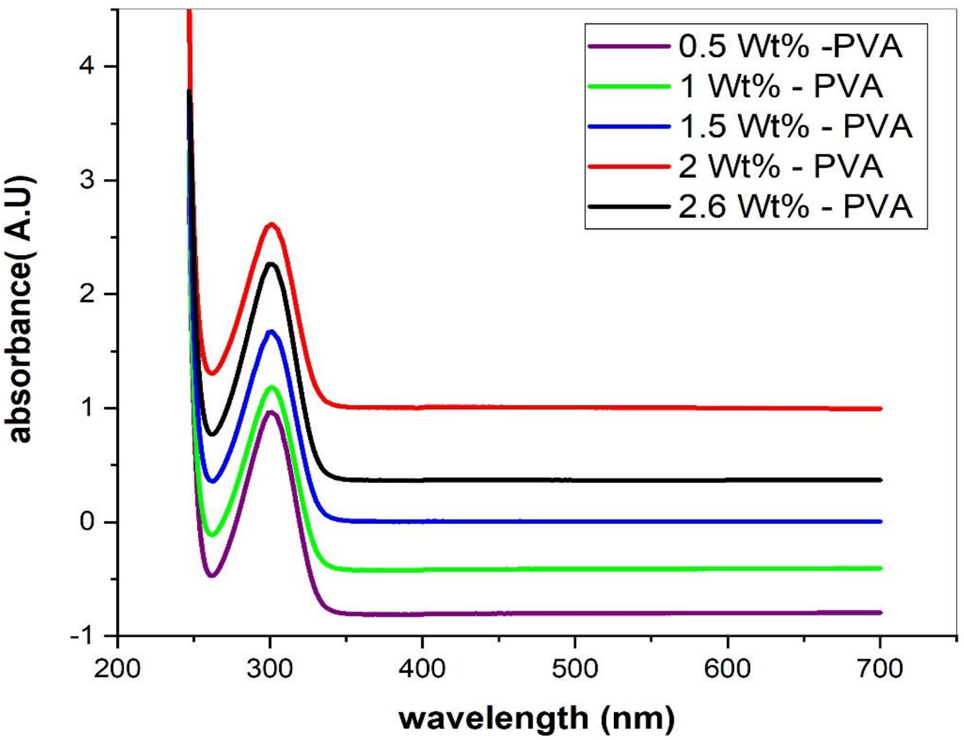


Figure 5.5 Polyvinyl-Alcohol Concentrations Vs. Ultraviolet Absorption Intensity

5.3.2 The Effect of Polyvinyl Alcohol (PVA) on Solar Cell's Surface Temperature and Thus its Efficiency

The purpose of implementing the PVA coatings system with varying amounts on the top side of polycrystalline silicon solar cells is to study the coating effects on the performance of solar cells in terms of temperature and efficiency.

Figures 5.6 - 5.7 depict the effect of PVA on the surface temperature of the solar cell and solar cell's efficiency respectively. K-Type thermocouples system attached to the back surface of the solar cells and connected to data-logger were the main tools to investing the effect of PVA on the solar cell temperature. An indoor experimental test with the following limitations, halogen light source 1000W/m^2 perpendicular to solar cells, 25^0 C controlling room temperature, and one-hour total period test time were the conditions of the test. Data-logger via thermocouples system (K-types) record the solar cell's temperatures. It was clear from the results that the solar cell without coating (WOC) recorded (T_O: 83.7^0 C) after one hour of light effect, while the other cells record less than this value and gradient depends upon the PVA concentrations. The temperature values were (T1:81.3^0 C, T2: 80.5^0 C, T3: 79.7^0 C, T4: 77.5^0 C, and T5: 78.8^0 C) according to the PVA concentrations (C1:0.25gram, C2:0.5gram, C3:0.75gram, C4:1gram, and C5:1.3gram) respectively. Figure 5.7, shows the effect of the PVA coating system on the polycrystalline silicon solar cells' efficiency. A solar module analyzer (**PROVA-200A**) was used for this purpose. From the results, the solar cell efficiency without coating was (η:14.2%) at zero time-under room temperature 25^0 C (before the temperature rising effect), while it was deteriorated to be (η: 10.4%) after one hour of effect light (under the effect of raising temperature). The test excluding all the solar cells with PVA coating and at different concentrations to investigate the deterioration in its efficiencies after one hour of light effect, and compared to without coating solar cell. Thus the efficiencies of the solar cells with PVA coatings were (10.6%, 10.7%, 10.74%, 11%, and 10.8%) according to the PVA's concentrations (C1:0.25gram, C2:0.5gram, C3: 0.75gram, C4:1gram, and C5:1.3gram) respectively. To explain the effect of PVA on the solar cell in terms of temperature and efficiency the following physical reason is demonstrated. The main reason for the lowering of the surface temperature of the solar cell was the blocking of ultraviolet rays. The electron of the solar cell is in a stable state unless it is acted upon by an external force, this force is represented by the energy of the photon of the solar radiation. Ultraviolet waves have short wavelengths and high energy. Thus the high energy of the photon is dissipated in the form of heat and increases the temperature of the surface of the solar cell and thus negatively affects the efficiency of the solar cell. The temperatures of the solar cells recorded different values according to the concentration of the PVA, and according to the difference in the ability of the PVA material to absorb ultraviolet rays which were dependent upon the PVA amount. Where the highest absorption intensity of UV radiation (2.5 A.u) was for PVA concentration (C4:1-gram) recorded the lowest solar cell's surface temperature (77.5^0 C) and consequence, the lowest deterioration with time which was recorded (11%) represent the higher efficiency after one hour of light effect. Table 5.1, represents the relation between the PVA concentration & the UV absorption intensity, and the temperature difference of the solar cell.

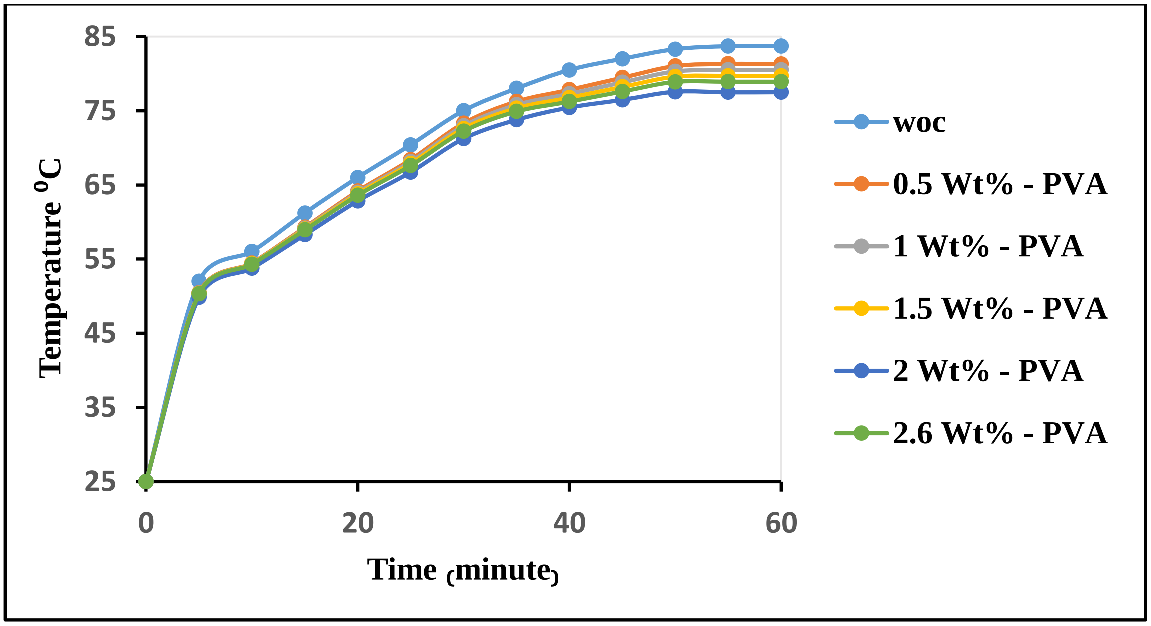


Figure 5.6 Comparison of the solar cell surface temperature, with and without PVA coating

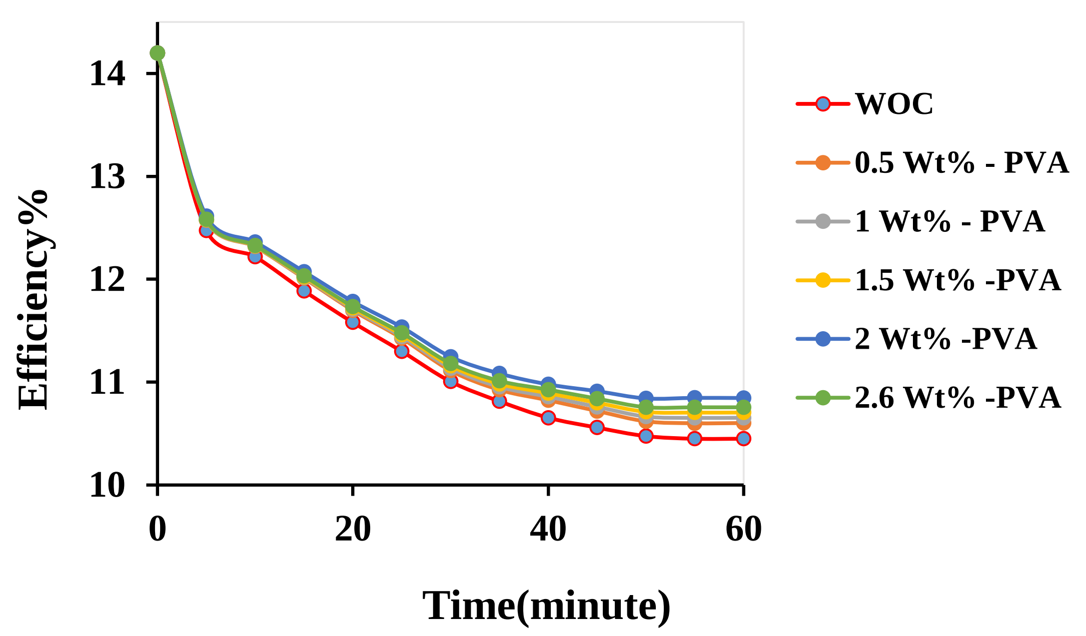


Figure 5.7 Comparison of the solar cell efficiency, with and without PVA coating

Table 5.1 The relation between PVA concentrations and temperature variation

PVA (concentration) (Gram)	**Absorption intensity (A.U)**	**Temperature difference (^{0} C)**
0.25	0.8	2.4
0.5	1	3.2
0.75	1.3	4
1	2.5	6.2
1.3	2.2	5

5.3.3 Study the Effect of PVA on the Solar Cell Electrical Characteristics

Figures 5.8, A. - 5.8, B. show the Current-Voltage, Power-Voltage relation for polycrystalline silicon solar cells with and without PVA coating. Solar module analyzer type **PRAVO-200A** was used to investigate the effect of Polyvinyl Alcohol (PVA) with different concentrations on the solar cell's electrical characteristics. The test was indoor with controlling room temperature at (25^0 C) and fixed radiant flux ($1000W/m^2$) with a perpendicular halogen light to the solar cells. The test for each model took an hour. Where the solar cell's test was done twice, the first one at zero time, at room temperature (before the temperature rising effect), and the second one after 1-h of exposure to solar radiation (halogen light source) under the effect of rising temperature. Table 5.2 show the solar cell electrical characteristic.

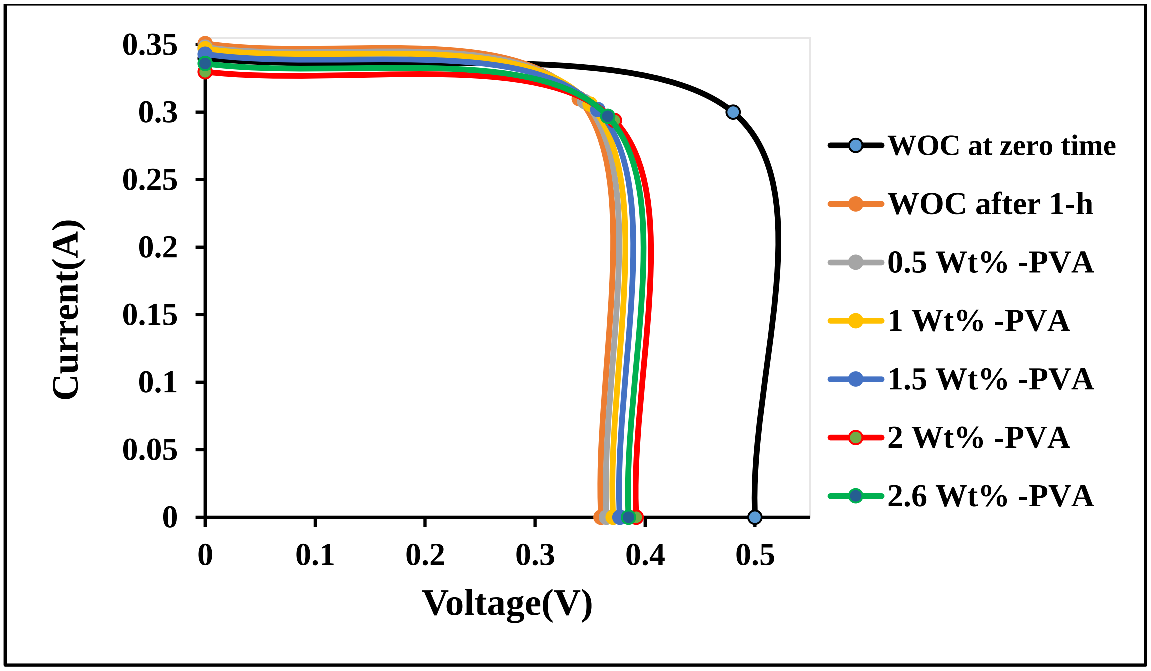


Figure 5.8, A. Comparison of the solar cell's Current-Voltage curves, with and without PVA coating.

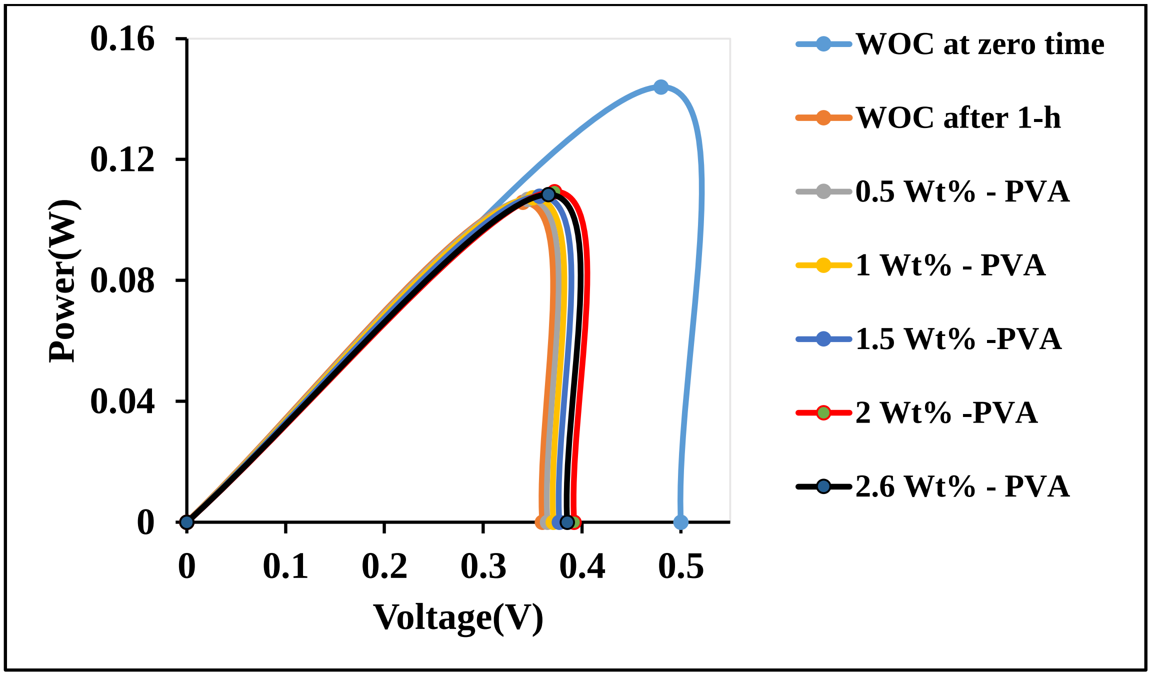


Figure 5.8, B. Comparison of the solar cell's Power-Voltage curves, with and without PVA coating

Table 5.2 Solar Cell electrical characteristic, with and without PVA coating

PVA/concentration	**V_{OC} (V)**	**I_{SC} (A)**	**P_{MAX} (W)**	**η%**
WOC/at zero time	**0.5**	**0.34**	**0.144**	**14.2**
WOC/after1-h	0.36	0.3509	0.1059	10.4%
0.25g/after 1-h	0.365	0.3482	0.1068	10.6%
0.5g/after 1-h	0.371	0.347	0.1075	10.7%
0.75g/after 1-h	0.377	0.343	0.108	10.74%
1g/after 1-h	0.392	0.33	0.112	11%
1.3g/after 1-h	0.385	0.336	0.109	10.8%

5.4 Study the Effect of Nanocomposite TiO_2/PVA on Solar Cell Performance

To check the effect of Nanocomposite on the polycrystalline silicon solar cell performance. Different concentrations of Titanium Dioxide (TiO_2) doping with the Polymer- Polyvinyl Alcohol (PVA) were applying on the top side of the solar cells. study the effect of the Nanocomposite coating on the performance of the solar, required the reflection losses test, solar cell surface temperature test, Ultraviolet- absorption test, and solar cells' electrical characters test should be performed and consequently their effects on solar cells power output, and efficiencies.

The test was done on the Rig solar cell test in the laboratories of the Engineering Technical College of Najaf, under the influence of 1000W/m^2 of halogen light radiation perpendicular to the solar cell, with the total period test one –hour (1-h). The test was in two stages, the first one at zero time (under room temperature (25^0 C) - no rising temperature effect - reflection losses effect only), while the second after (1-h) where the effect of temperature rising under the light effect was present. Four different concentrations of TiO2 (C1:0.05gram, C2:0.1gram, C3: 0.2gram, C4:0.3gram) were used and doping with (1- gram) of the PVA.

5.4.1 Energy bandgap calculations

The bandgap of the Polymer –PVA and prepared TiO_2/PVA Nanocomposite films were calculated by Tauc's relation. a Tauc plot was created by shows hν (the photon energy) plotted on the x-axis and by taking the quantity $(\alpha h\upsilon)^2$ on the y-axis, where α is the absorption coefficient of the material as shown in figure 5.9. Where the energy bandgap value was obtained by choosing a straight line vertically downward to X-axis. Bandgap for pure PVA was obtained as (3eV) and it was increased by loading of TiO_2 Nanoparticles in TiO_2/PVA Nanocomposites.

For TiO_2/PVA Nanocomposites the bandgaps values were obtained as (Eg1: 4.25eV, Eg2: 4.44eV, Eg3: 5.27eV, and Eg4: 4.6eV) with respect to the concentrations C1:0.05gram, C2:0.1gram, C3:0.2gram, and C4:0.3gram respectively. It is clear from the results that is the bandgap increase with an increase wt% of TiO_2 Nanoparticles in TiO_2/PVA Nanocomposites. Thus, because the silicon has a low energy bandgap (1.1 ev) so the silicon solar cell suffers from high reflection light losses. Based on that, these high bandgaps of TiO2/PVA Nanocomposite films can be used as anti-reflection coating in solar cells.

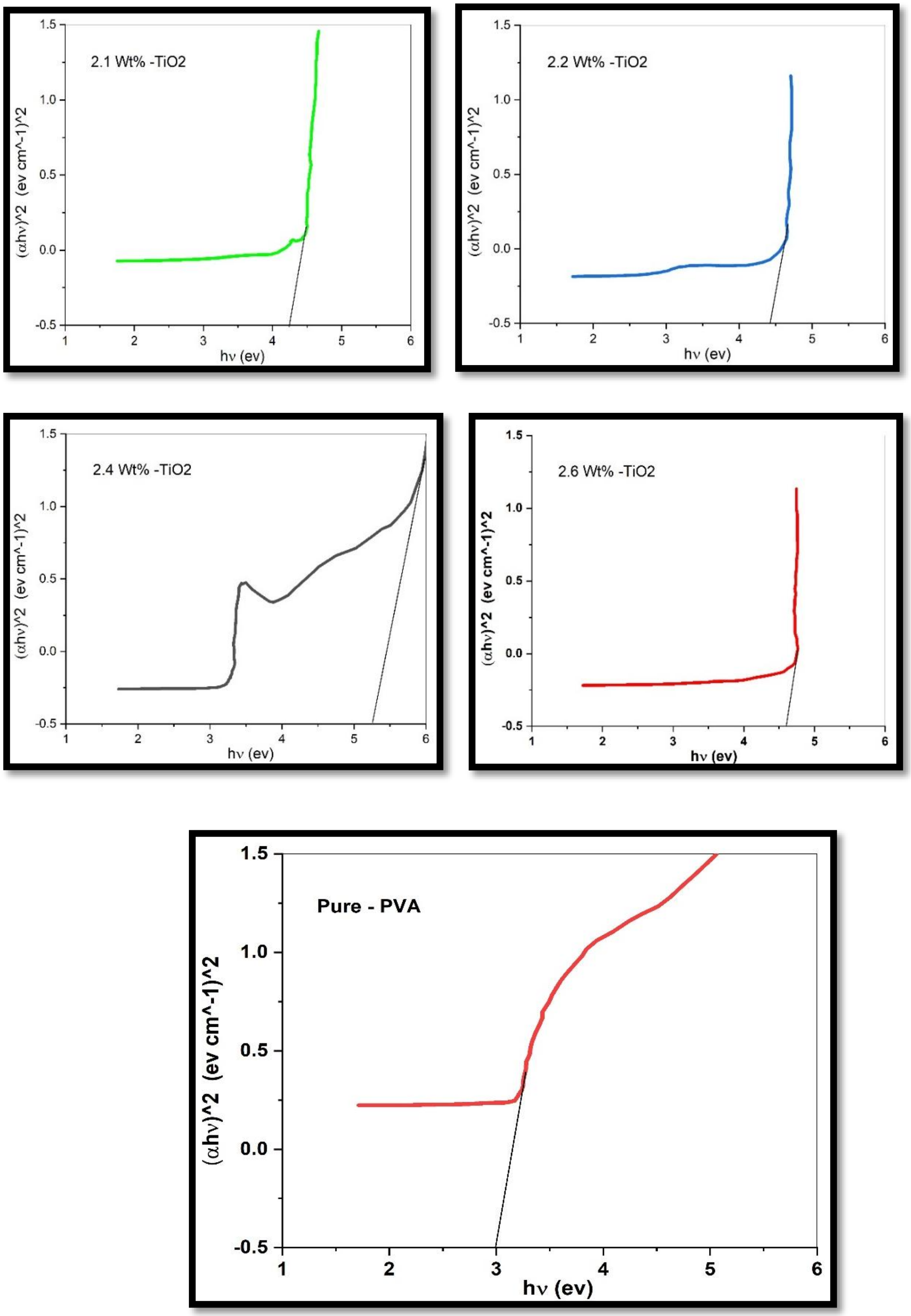


Figure.5.9. Tauc plots, Energy Bandgap Calculations.

5.4.2 Study the Effect of Nanocomposite TiO_2/PVA on Reflection Losses

The silicon has high surface reflection characteristics hence, reflects nearly 35% of the incident light. This reflection affects the PV panel efficiency. Thus, reducing this reflection by applying anti-reflection coating to the solar cell surface helps in dragging power effectively. The anti-reflective coating reduces the photons reflected to the atmosphere and hence, increases the solar cell performance [38][72].

Using the Nanocomposite coating Titanium Dioxide (TiO2) and doping with a Polymer - Polyvinyl Alcohol (PVA) on the front surface of the solar cell was very interested in reducing the power loss due to reflection. Using Ultraviolet-Visible spectrometers device (UV-Vis) (type- Shimadzu-1800), with reflection measurement option was the efficient way to investigate the reduction of the reflection losses of the silicon solar cells after depositing the anti-reflection coating (Nanocomposite TiO2/PVA). The test was done in Kufa-university- Engineering College. A significant reduction was obtained, and its gradient depends upon the different concentrations of the Nanocomposite. The result decreased the reflection from 35 % for the polycrystalline silicon solar cell without coating (WOC), to be (R1:10.25%, R2:8.3%, R3:3.9%, and R4: 6.1%) for Nanocomposite coatings-polycrystalline silicon solar cells with the concentrations (C1:0.05 gram, C2: 0.1 gram, C3: 0.2 gram, and C4: 0.3 gram) respectively. The main reasons for these reductions can be summarized in the following steps, first; the main reason for the light reflection is the transmittance of the sun rays through two media which have a different refractive index (from the surrounding (air) to the surface of the solar cells (silicon)), where the air refractive index (n_{air}=1) and silicon refractive index ($n_{silicon} = 3.5$), thus applying TiO2 with refractive index ($n = 2.52$) as an intermediate layer was the main reason to reducing the light reflection. Second; varying the ability of the Nano coatings to decreasing the reflection losses was because of the different Bandgap values of the coatings. Where the coating's bandgaps were (Eg1: 4.25ev, Eg2: 4.44ev, Eg3: 5.27ev, and Eg4: 4.6ev) relative to the varying concentrations (C1:0.05 gram, C2: 0.1 gram, C3: 0.2 gram, and C4: 0.3 gram) respectively. Where the bandgap is a window to allow the solar radiation to be pass and prevent it from being reflected away. The higher the gap value, the greater the ability to prevent light reflection. In addition, the difference in the coating capacity to decreasing the light reflect was because, whereas the concentration of TiO2 increases, the number of atoms of TiO_2 on the silicon surface increases and forms a layer that allows to the passing most possible amount of incident radiation and prevents its reflection. An increase in the number of atoms greater than a certain quantity; leads to the accumulation of atoms on each other and thus forms a destructive interference of light with matter, this is what we notice when increasing the concentration of TiO_2 to (C4:0.3 gram) where the reflection (R4:6.1%) which was higher than (R3:3.9%) at the concentration (C3:0.2gram). Finally, the C4:0.3gram concentration was to be the inflection point of TiO2 in TiO2/PVA Nanocomposite. Table 5.3 and figures (5.10, 5.10, 5.11, 5.12, and 5.14) show the reducing the reflection values according to the concentration of TiO2 and comparing it to without Nanocomposite –coating (WOC) silicon solar cell.

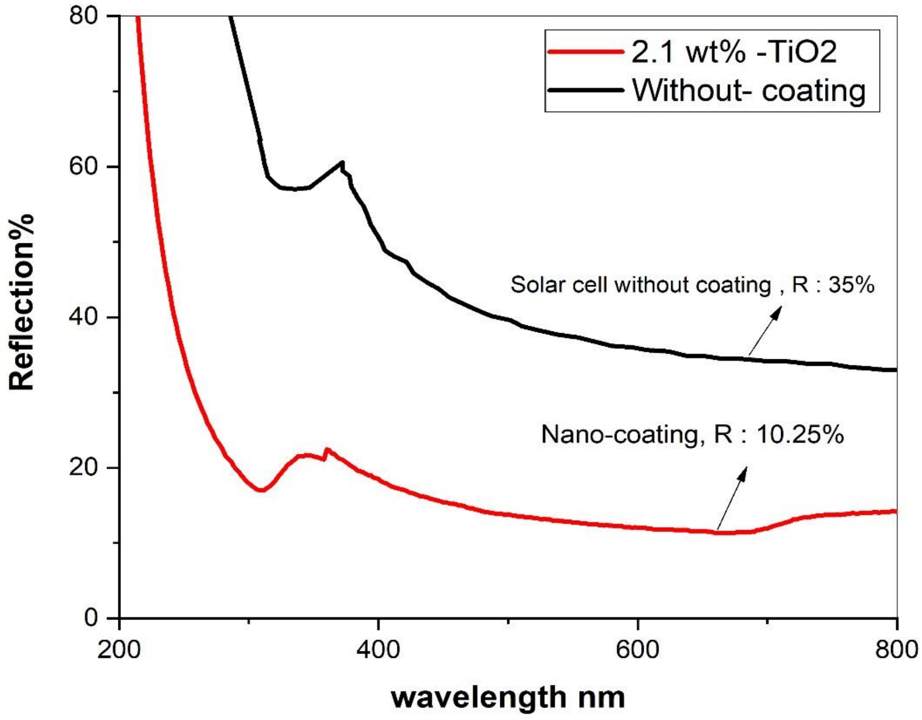


Figure 5.10 Reflection measurement for both coating and without coating solar cell with concentration: 0.05 gram

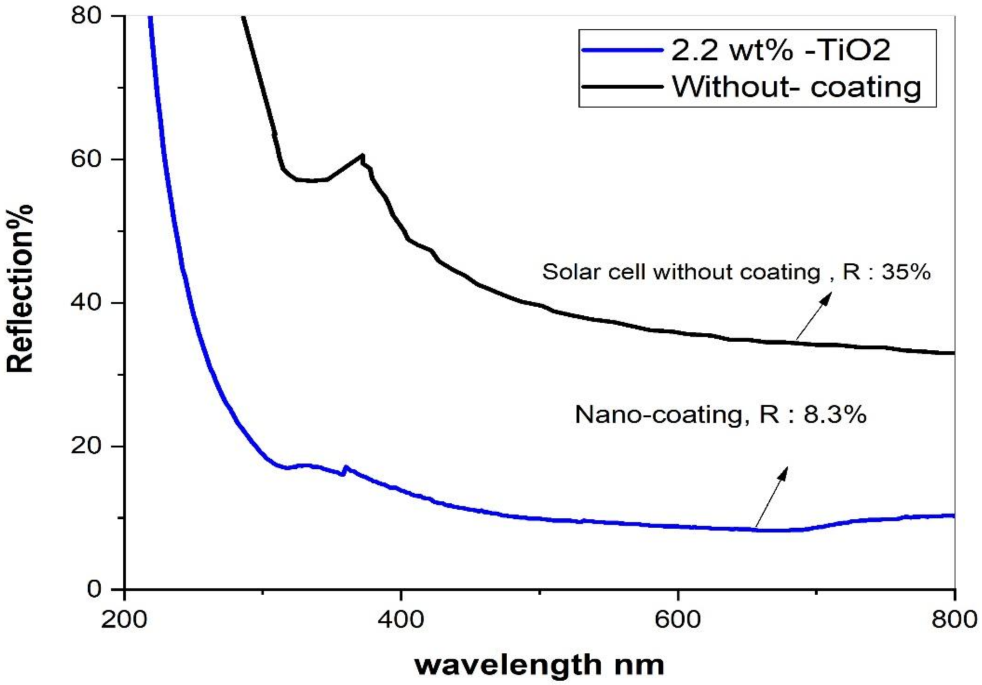


Figure 5.11 Reflection measurement for both coating and without coating solar cell with concentration: 0.1 gram.

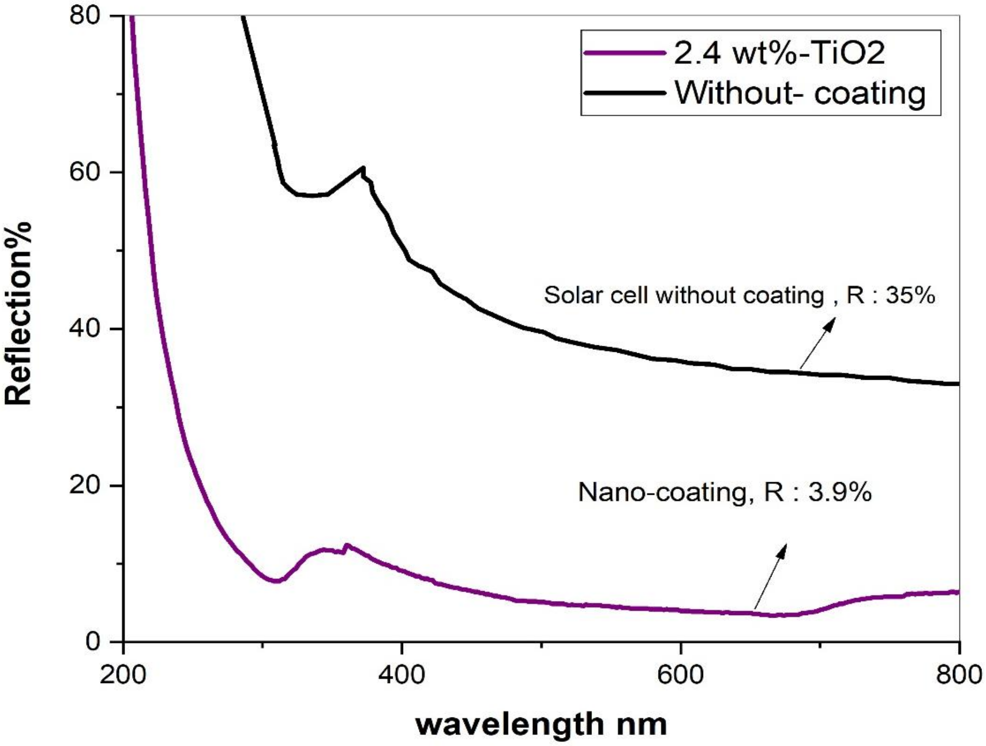


Figure 5.12 Reflection measurement for both coating and without coating solar cell with concentration: 0.2 gram.

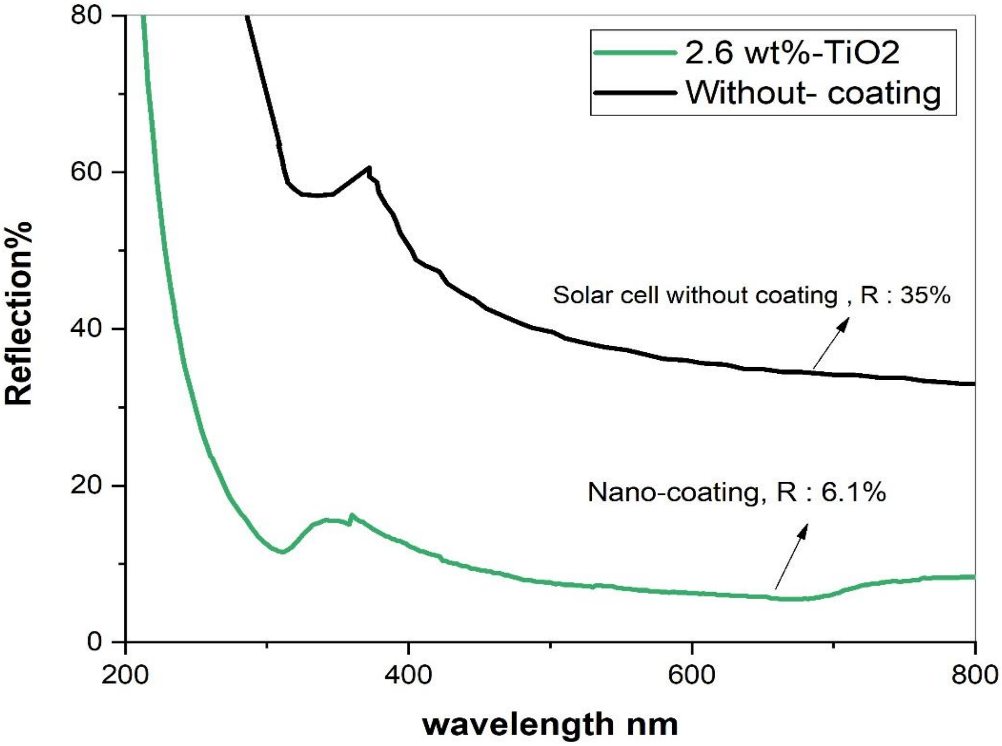


Figure 5.13 Reflection measurement for both coating and without coating solar cell with concentration: 0.3 gram.

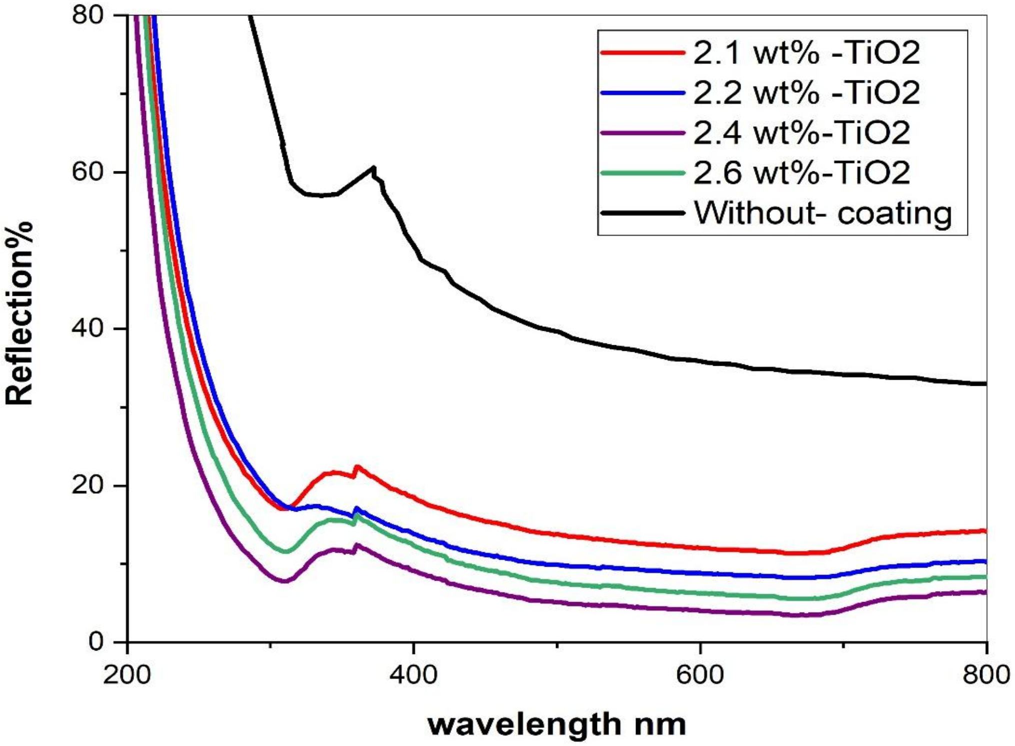


Figure 5.14 Comparison of the reflection measurement for both coating and without coating solar cells.

Table 5.3 The relation between the Nanocomposite concentration & reflection loss

TiO_2/PVA Concentration	**Bandgap**	**Reflection losses %**
WOC	1.1 ev	35%
0.05g-TiO2/1g-PVA	4.25 ev	10.25%
0.1g-TiO2/1g-PVA	4.44 ev	8.3%
0.2g-TiO2/1g-PVA	5.27 ev	3.9%
0.3g-TiO2/1g-PVA	4.6 ev	6.1%

5.4.3 Study the Effect of Nanocomposite TiO2/PVA on the Ultraviolet Absorption

One of the most important purposes of using Nano-coating on the front side of solar cells is to absorb the Ultraviolet wavelength (UV) which extended from 200nm to 400nm and prevent it from reaching the solar cell. Because the Ultraviolet wavelength (UV) of solar radiation has high photon's energy [17]. The ability of the coating to absorb Ultraviolet rays varies according to the type of nanomaterial used and the amount of its concentration.

Four solar cells type- polycrystalline silicon solar cells were used with different concentrations of Nanocomposite coating (TiO_2/PVA) casting on their front side to investigate the ability of Nano-material, and its concentrations to absorb the Ultraviolet wavelength. Ultraviolet-visible spectrometer (UV-Vis) type-(Shimadzu-1800) was used for this purpose. Table 5.4 and the figures (5.15- 5.19) shown the relation between the Nanocomposite concentrations and the absorption's broadened & intensity of the Ultraviolet wavelength, where they were denoted by (A), with the unit (nm) and by (I), with the unit (A.U) respectively. The absorption's broadened in (nm) were (A1:325nm, A2: 366nm, A3:380nm, A4: 375nm) respected to the concentration ratios (C1:0.05gram, C2: 0.1gram, C3: 0.2gram, and C4: 0.3gram) respectively. As noted, the limiting factor to the ability of the Nano coating to absorb ultraviolet rays was the concentration, where the number of atoms that absorbing the ultraviolet rays increases with increase the concentration of TiO_2, The absorption bands were broadened in all the TiO_2/PVA Nanocomposites concentrations and extended over 300nm as compared to the absorption ability of PVA coatings. An increase in the number of atoms greater than a certain quantity, which leads to the accumulation of atoms on each other and thus forms a destructive interference of light with matter. This is what we notice when increasing the concentration of TiO_2 to (C4:0.3 gram), where the absorption (375nm) which lower than (380nm) at a concentration (C3:0.2gram). Finally, the (0.3gram) concentration was to be as the inflection point of TiO_2 in TiO_2/PVA Nanocomposite.

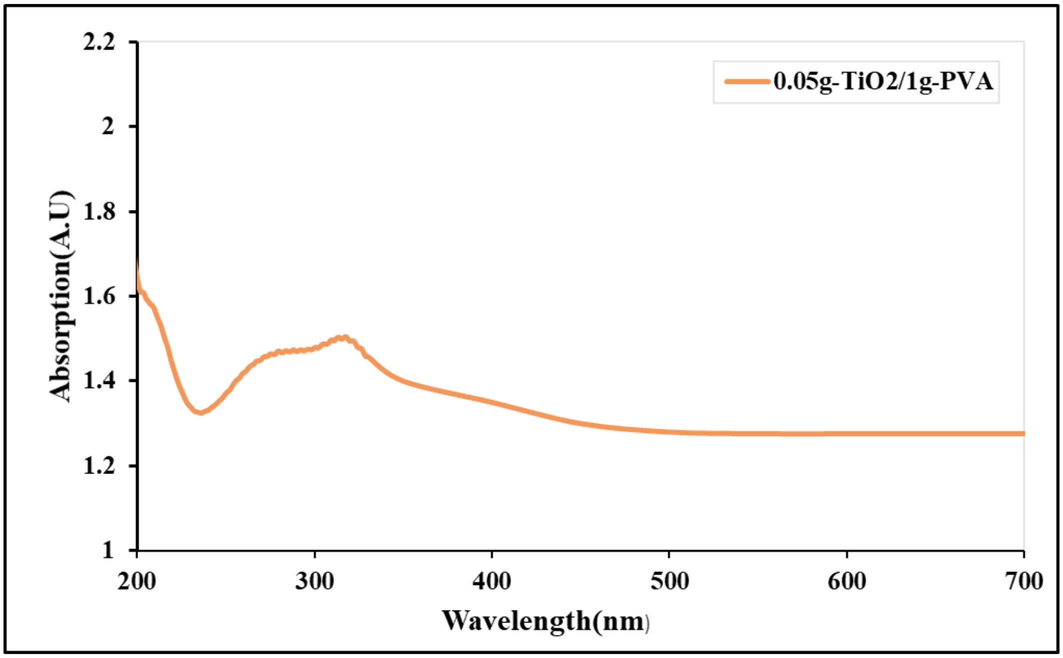


Figure 5.15 Absorption measurement for Nanocomposite TiO_2/PVA ,under concentration 0.05g.

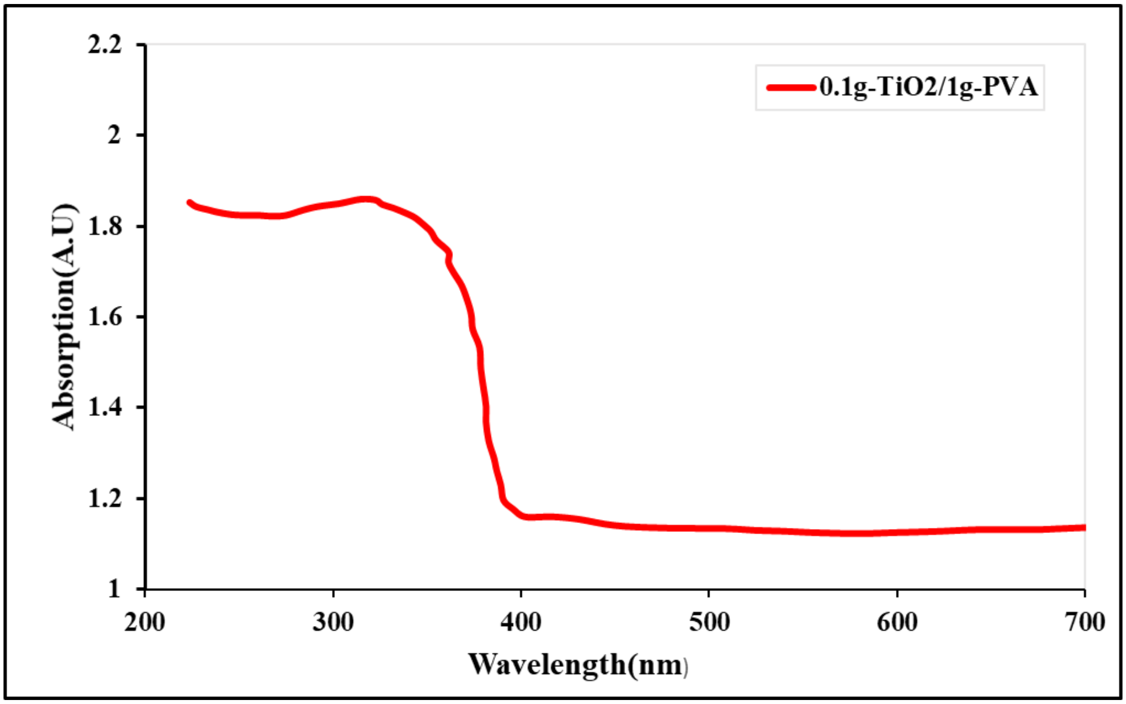


Figure 5.16 Absorption measurement for Nanocomposite TiO2/PVA ,underconcentration 0.1g.

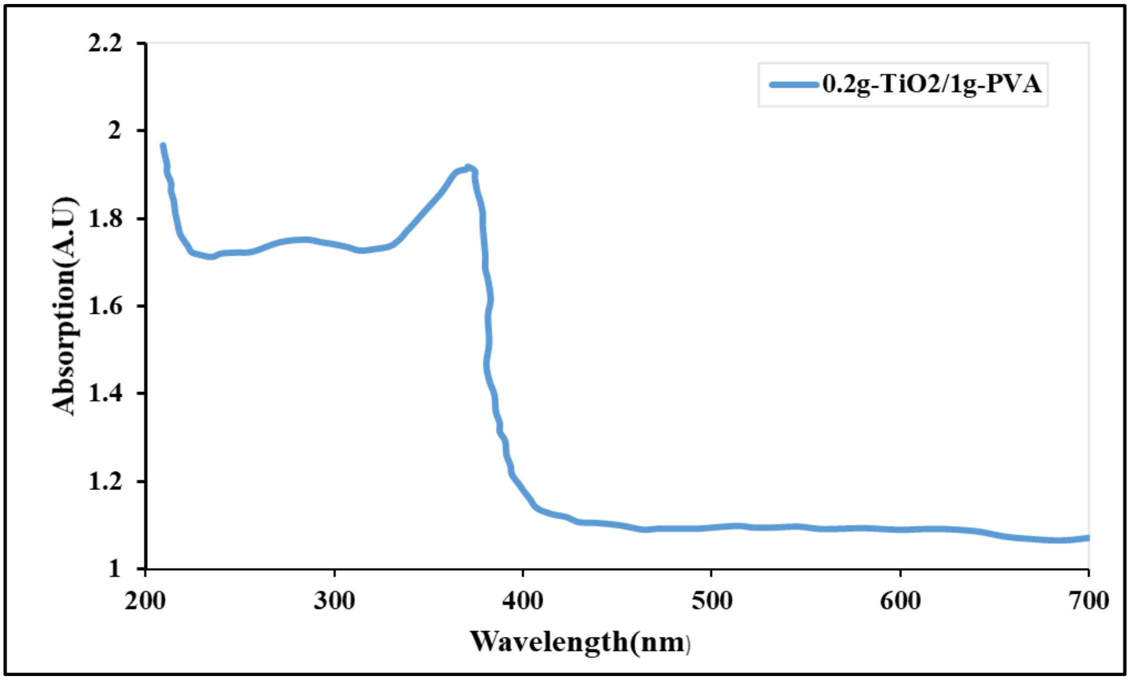


Figure 5.17 Absorption measurement for Nanocomposite TiO2/PVA ,under concentration 0.2g.

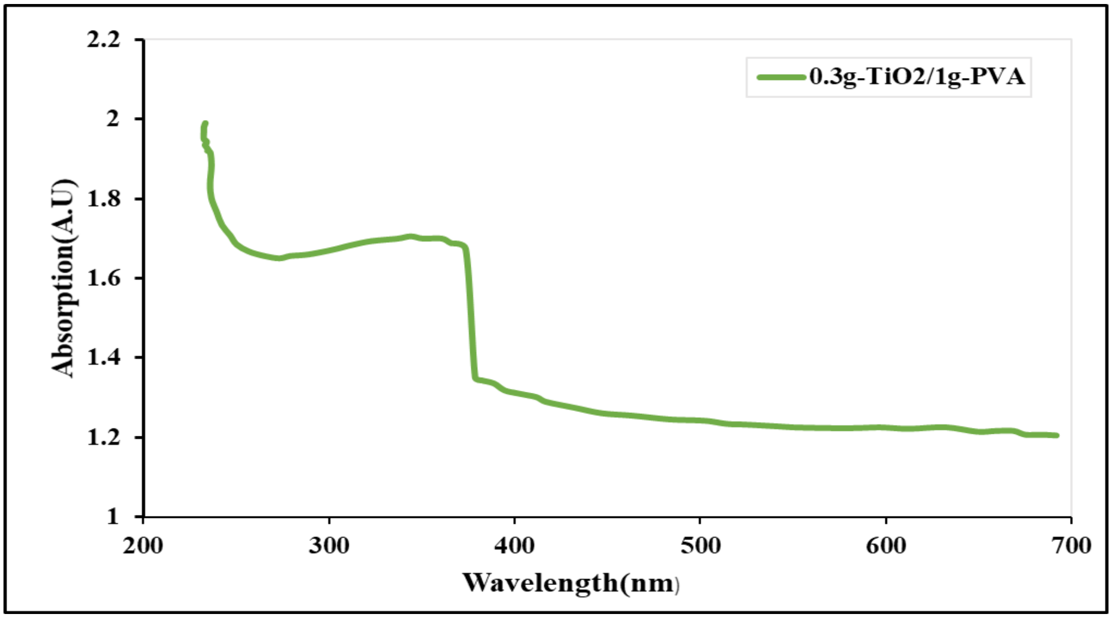


Figure 5.18 Absorption measurement for Nanocomposite TiO_2/PVA ,under concentration 0.3g.

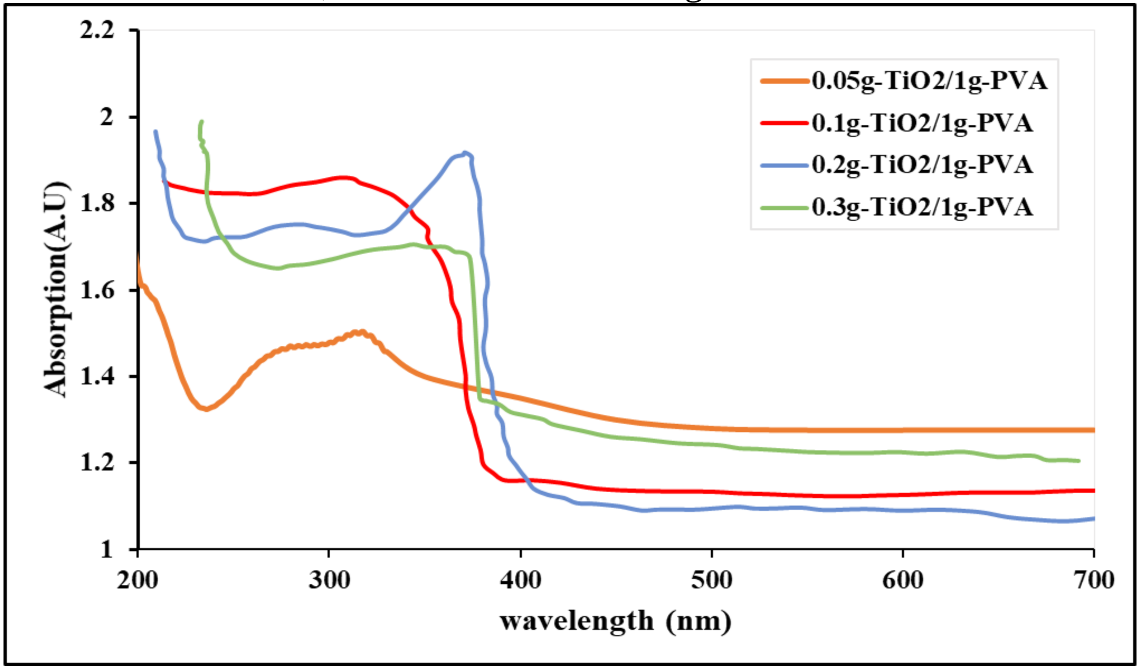


Figure 5.19 Comparison of the absorption measurement for Nanocomposite TiO2/PVA, under different concentrations.

Table 5.4 the relation between Nanocomposite's concentration and ultraviolet Absorption

Concentration	Absorption intensity (A.U)	Absorption broadened(nm)
WOC	Full-Transmittance	Full-Transmittance
0.05g-TiO2/1g-PVA	1.5	325
0.1g-TiO2/1g-PVA	1.7	366
0.2g-TiO2/1g-PVA	1.94	380
0.3g-TiO2/1g-PVA	1.88	375

5.4.4 The Effect of Nanocomposite TiO_2/PVA on the Solar Cell Surface's Temperature

The effect of intelligent Nanocomposite-coating thin-film with different concentrations on the polycrystalline silicon solar cells temperature, and what is the mechanism that the intelligent coating played to affect the solar cell temperature was discussed here.

Table 5.5, and figures (5.20-5.24) show the relation of the temperature of the solar cell with time and its variation according to the Nanocomposite concentrations.

The method to investigate the impact of Nanocomposite coatings on the solar cells surface temperature with different concentrations and compared them to without Nano-coating solar cell was thermocouples K-types system attached to the back surface of the solar cells and connected to a data logger with a laptop –Link, to records the surface temperature of the solar cells over time. The test for each model took an hour under 1000W/m2 of halogen light source perpendicular to the solar cell and 25^0 C controlling room temperature. As shown from the figures, the temperature rises over time for all solar cells, and eventually, stabilizes at different steady-state temperatures by the end of the 1-h test. The physical reason for those varying was as following. Sunlight is electromagnetic waves classified according to the wavelength, frequency, and energy of the photon of that wave. The solar cell, especially the polycrystalline solar cell type interested in the visible solar rays within the range (400-800nm), where the photon energy of these rays is suitable for releasing the electron from the solar cell's surface without producing excess heat. Ultraviolet wavelength (200-400nm) has energy 10,000 times more than the infrared ray’s energy, and this extra energy also works to release the electron from the surface of the solar cell, but that its excess energy is dissipated in the form of heat, thus raising the temperature of the surface of the solar cell and adversely affecting its efficiency. The difference in the concentration of Titanium Dioxide (TiO_2) in (TiO_2/PVA) Nanocomposite made the ability of the coatings to decrease the surface temperature of the solar cells varying at different rang (T1: 78.4^0 C, T2: 76.9^0 C, T3: 74^0 C, T4: 75.4^0 C). The main reason for those varying was the ability of the coating to absorb the Ultraviolet wavelength with different ranges (A1:325nm, A2:366nm, A3:380nm, A4:375nm) according to the concentrations (C1:0.05 g, C2: 0.1 g, C3: 0.2 g, C4: 0.3g) respectively, as compared to without coating solar cell which was recorded (T_o: 83.7^0 C) with full transmittance Ultraviolet ray.

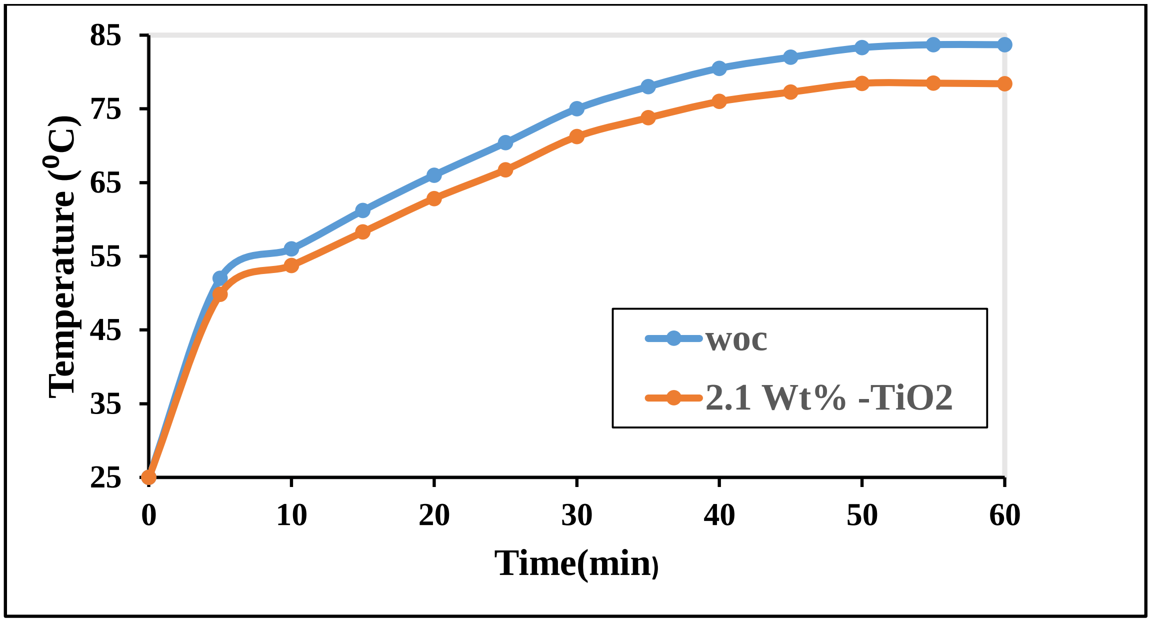


Figure 5.20 Solar cell’s surface temperature for coating and without coating solar cells, under concentration: 0.05gram.

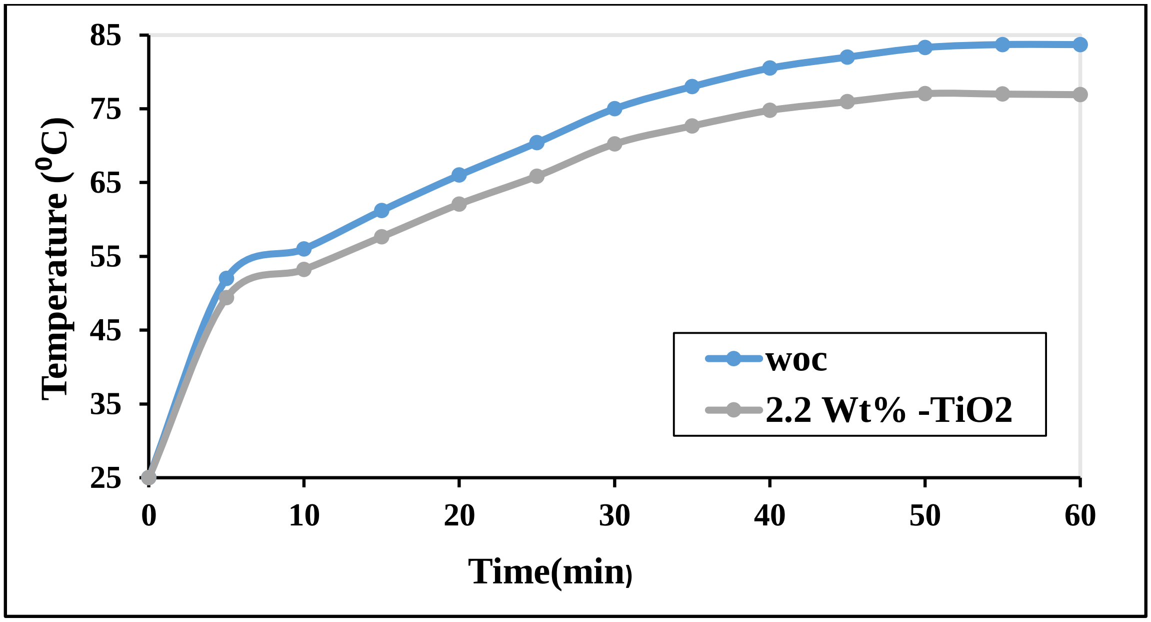


Figure 5.21 Solar cell’s surface temperature for coating and without coating solar cells, under concentration:0.1gram.

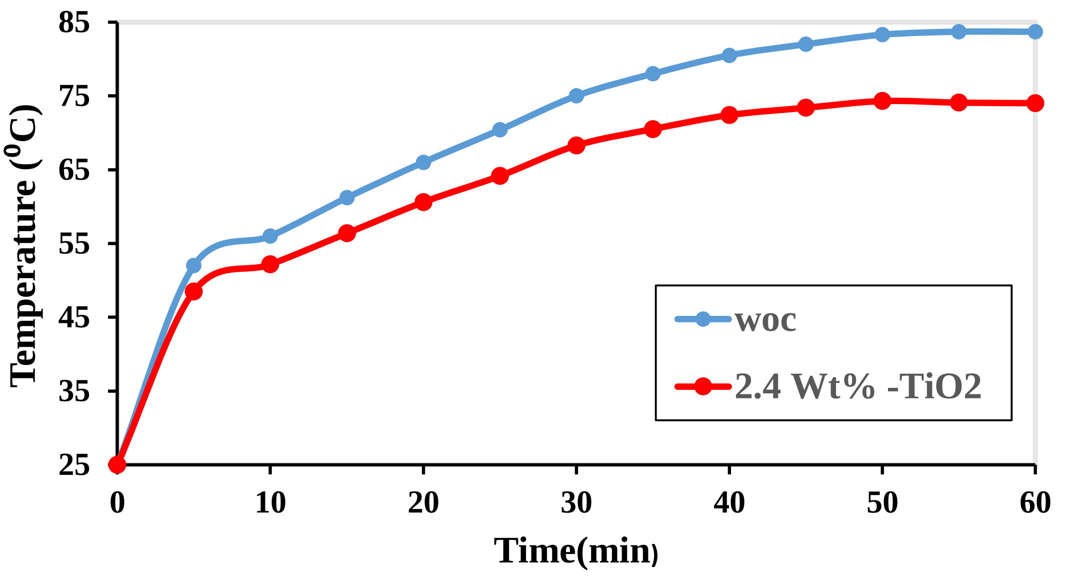


Figure 5.22 Solar cell's surface temperature for coating and without coating solar cells, under concentration:0.2gram.

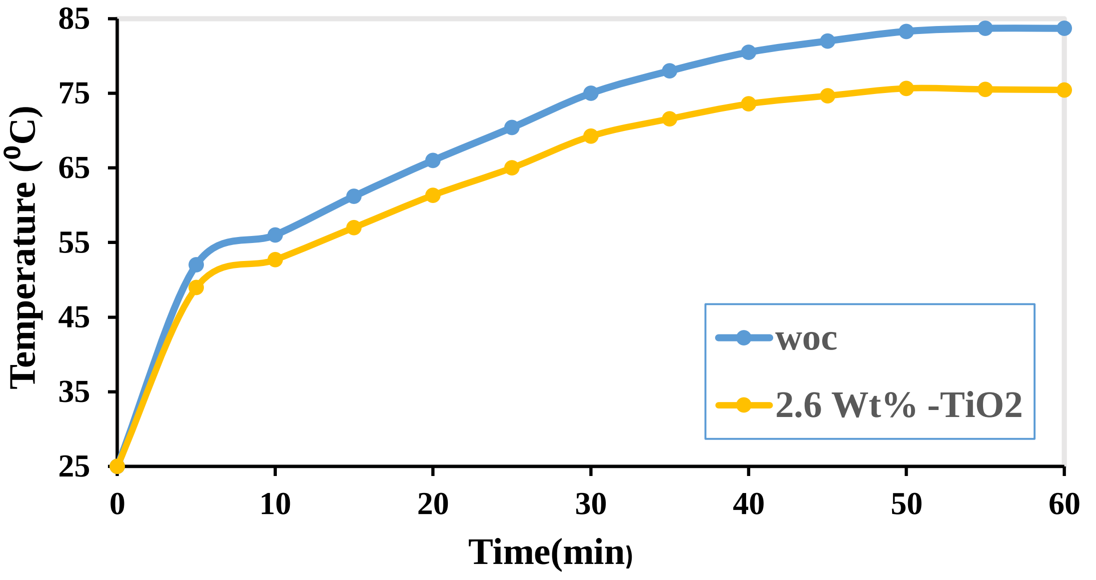


Figure 5.23 Solar cell's surface temperature for coating and without coating solar cells, under concentration:0.3gram.

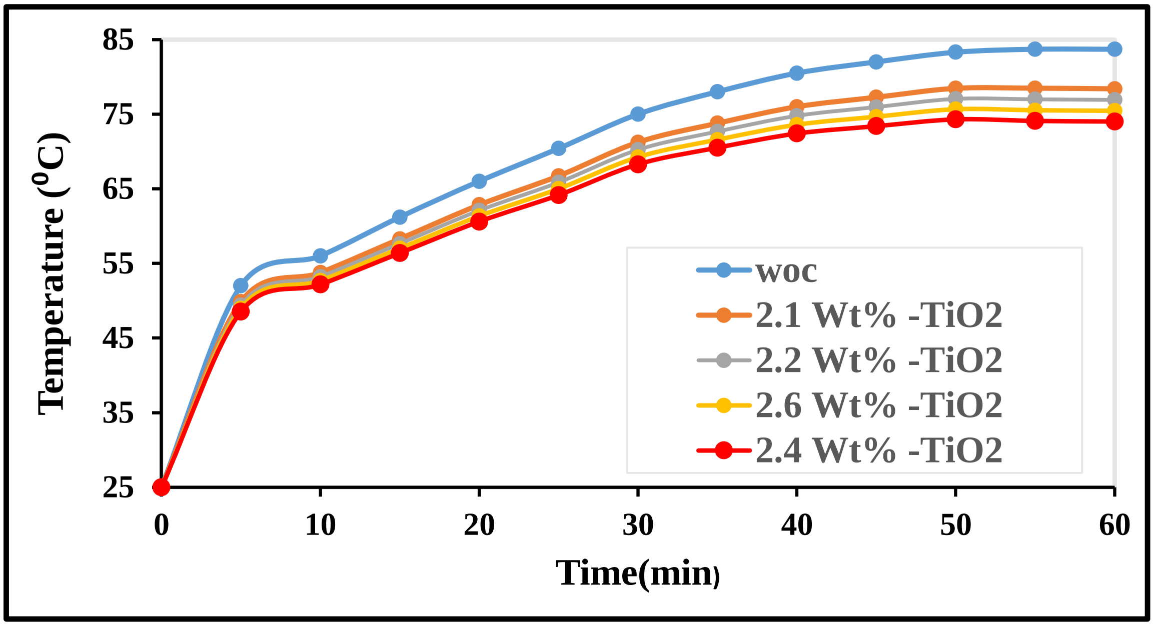


Figure 5.24 comparison the Solar cell's surface temperature for coating and without coating solar cells.

Table 5.5 the relation between Nanocomposite's concentration and temperature difference

Concentration	**Temperature difference**
0.05g-TiO2/1g-PVA	5.3^0 C
0.1g-TiO2/1g-PVA	6.8^0 C
0.2g-TiO2/1g-PVA	9.7^0 C
0.3g-TiO2/1g-PVA	8.3^0 C

5.4.5 Study the Effect of Nanocomposite-Coating TiO2/PVA on the Electrical Characteristics of the Solar Cells

Maximum power output, short-circuit current, and open-circuit voltage, are three significant characteristics in solar photovoltaic (PV) panel performance, Thus the influences of temperature variations and reflection loss on the different solar cell parameters are studied. It is useful to understand the effect of temperature on the solar cell and module performance, in order to estimate their performance under various conditions.

Nanocomposite Titanium Dioxide (TiO_2) doping with Polymer-Polyvinyl Alcohol (PVA) were the Nano-materials choices in this work to coated the top side of polycrystalline silicon solar cells. To investigate the effect of the coating system on the solar cell's electrical characteristics, solar module analyzer **Type-PRAVO-200A** was used for this purpose. Different concentrations of Titanium Dioxide (TiO_2) were used (C1:0.05g, C2:0.1g, C3:0.2g, and C4:0.3g) and doping with (1 g) of Polyvinyl alcohol(PVA). The test was indoor with controlling room temperature at (25^0 C) and a perpendicular halogen light to the solar cells with fixed radiant flux ($1000W/m^2$).

The test for each model took an hour. The first test was at zero time (at room temperature 25^0 C), where the effect of Nano-materials on reducing the reflection losses was investigated and its influences on solar cell's electrical characteristics. The second model test was after one hour of the light effect, where the effect of Nano-material to decreasing the solar cell's surface temperature was investigated and its effect on the deterioration of the solar cell's electrical characteristics.

The following paragraphs show the impact of the Nanocomposite on the solar cell parameters, short circuit current (Isc), open-circuit voltage (Voc), Power output, and efficiency(η). The results show all of the coatings solar cells with different concentrations have a positive effect compared to a solar cell without Nanocomposite coating as a function of electrical characteristics.

5.4.5.1 Study the Effect of Nano-Coating on Current-Voltage, Power-Voltage Relations

The improvement in the solar cell efficiency of Nanocomposite coated with uncoated can be better understood by I-V and P-V studies.

solar module analyzer (**Type – PROVA-200A**) was used to investigate the Polycrystalline silicon solar cell with and without Nanocomposite coating, under the 1000W/m^2, 25^0 C ambient temperature. The current-voltage (I-V) and power-voltage (P-V) curves were calculated twice at zero time and after one hour of incident light to investigate the reflection loss and temperature effect respectively.

At zero time (reflection losses effect) , the optimum enhancement obtained on the solar cell parameters , short circuit current (Isc) , Maximum power current I_{mp}(A), open-circuit voltage(Voc), and Maximum power voltage V_{mp}(V) for the solar cells with Nanocomposite coating were (I_{SC}:0.3507A, I_{mp}:0.306A, V_{oc}: 0.51V, V_{mp} : 0.487V), (I_{SC} :0.355A, I_{mp} : 0.316A, V_{oc}: 0.52V, V_{mp}: 0.498V),(I_{SC}: 0.366A, I_{mp}: 0.326A, V_{oc}: 0.535V, V_{mp}: 0.514 V), and (I_{SC} :0.36 A, I_{mp}: 0.322 A, V_{oc}: 0.53 V ,V_{mp}:0.508) according to the concentrations (C1: 0.05gram, C2:0.1gram, C3:0.2gram, C4:0.3gram) resepectively.As shown the maximum enhancement obtained was at (C3: 0.2gram) where the reflection losses reduced from 35% to 3.9% as comparison to without coating solar cell (35% reflection loss) where the electrical characteristics were (I_{SC}: 0.34 A, I_{mp}: 0.3A, V_{oc}: 0.5V, V_{mp}: 0.48V) . The second test was after one hour (temperature effect present) where rising the temperature play the role. The electrical characteristics of solar cells with Nanocomposite coatings observed less deterioration as compared to without coating solar cell , where the values were (I_{SC}: 0.3603A, I_{mp}: 0.306A, V_{oc}: 0.378V, V_{mp}: 0.355V), (I_{SC}: 0.364A, I_{mp}: 0.324A, V_{oc}: 0.395V, V_{mp}: 0.374V),(I_{SC}: 0.373A, I_{mp}: 0.334A, V_{oc}: 0.418V, V_{mp}: 0.392V), (I_{SC}: 0.368A, I_{mp}: 0.331A, V_{oc}: 0.408V, V_{mp}: 0.382V) according to the concentrations (C1: 0.05gram, C2:0.1gram, C3:0.2gram, C4:0.3gram) respectively. The concentration (C3:0.2gram) was less electrical characteristics deterioration under the temperature effect, where the temperature surface of the solar cell reduced from 83.7^0 C without coating to 74^0 C for the Nanocomposite coating under the concentration C3:0.2gram. as comparison to without coating solar cell (83.7^0 C - solar cell surface temperature) where the electrical characteristics were (I_{SC}: 0.3509A, I_{mp} 0.3108A, V_{oc}: 0.36V, V_{mp}: 0.34V).

Typical experimental results for other Nanocomposite concentrations are summarized in Table 6, and the resulting curves are shown in Figures (5.25-5.34) for optimum conditions.

. All the influences of the solar cell’s electrical characteristics were occurred and were observed after deposited the Nano-coating material can be summarized from the following physical concept.

Firstly, Because all the solar cell designers assess their devices by evaluating the efficiency at standard reporting conditions (SRC: illumination =1000 W/m2, temperature=25°C, and AM1.5 reference spectrum), and thus due to rising temperature reducing the overall efficiency of the photovoltaic panel at a rating of 0.4-0.5 percentage for every degree Celsius above 25 degree Celsius, several parameters are used to characterize solar cells such as (Isc) (Voc) (FF) affected by temperature, thus the solar cell with (C3: 0.2 gram) was the less effected with temperature because it has less surface temperature (74^0 C) as comparison with solar cell without coating (83.7^0 C). Secondly, as it is known, the photovoltaic solar cell is a semiconductor device that generates electricity when light falls on it. Elevate the electron from the Valance band to conduction band of the solar cell and to be sharing to production as a current, required suitable photon's energy for this purpose. if the photon's energy is higher than the energy required to lift the electron; the excess energy will be dissipated as heat and raising the solar cell's surface temperature, that noted with the Ultraviolet (UV) photon energy where blocking this ray gave a positive effect on the solar cell's surface temperature and consequently the solar cell's power output, that clear observed with the solar cell with C3:0.2 gram where its ability to blocking the UV was the maximum value (380nm) as compared with other concentrations. Finally, the Reflected part of the incident radiation from the surface of the polycrystalline silicon solar cell due to the high refractive index of silicon, decreasing the number of electrons that sharing to production the current and the solar cell power output. As noted from the results, as much as reflection losses reduced the solar cell efficiency and its power output increased.

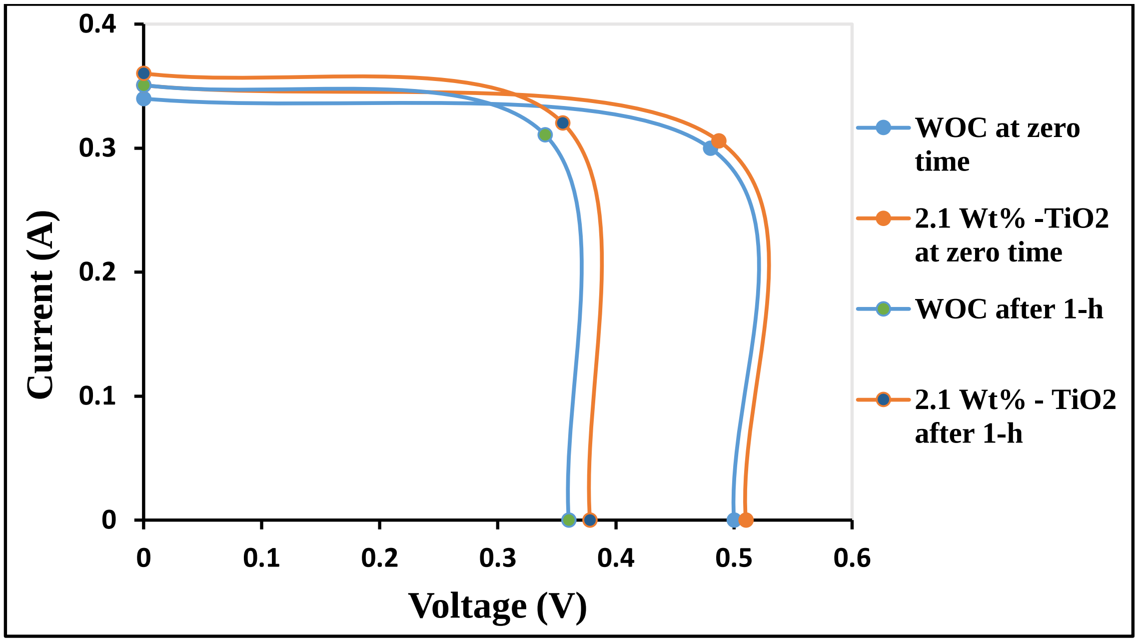


Figure 5.25 current-voltage characteristic for both coating and without coating solar cell, under concentration:0.05gram.

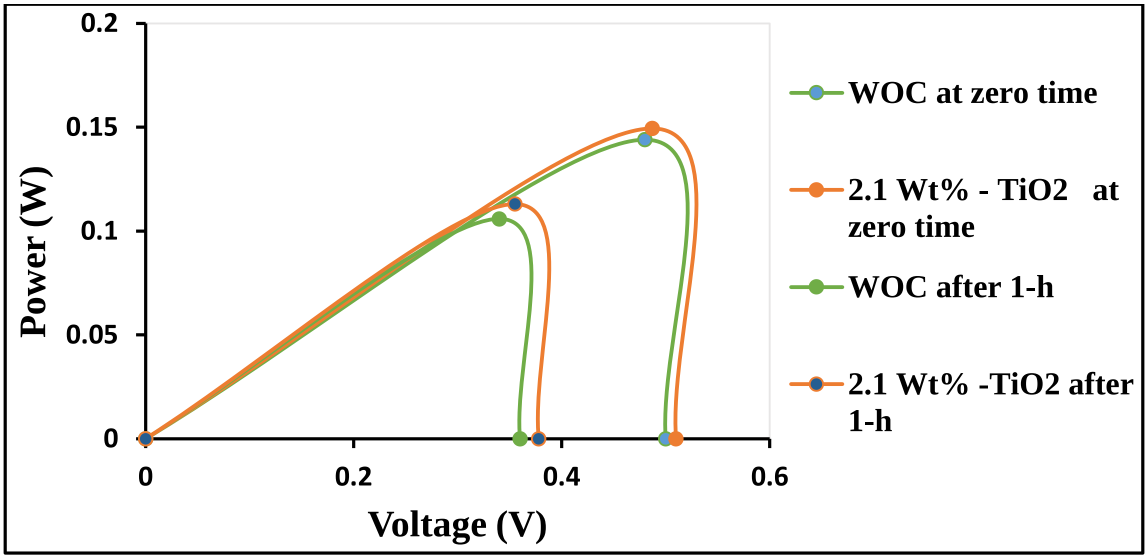


Figure 5.26 power –voltage characteristic for both coating and without coating solar cells, under the concentration:0.05gram.

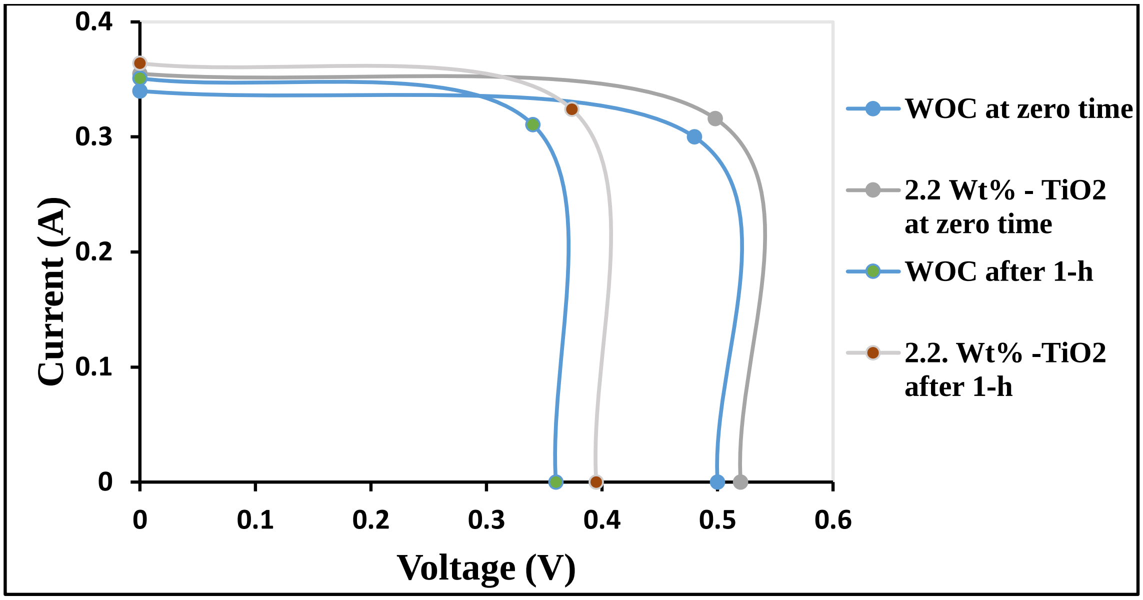


Figure 5.27 current-voltage characteristic for both coating and without coating solar cell, under concentration:0.1gram.

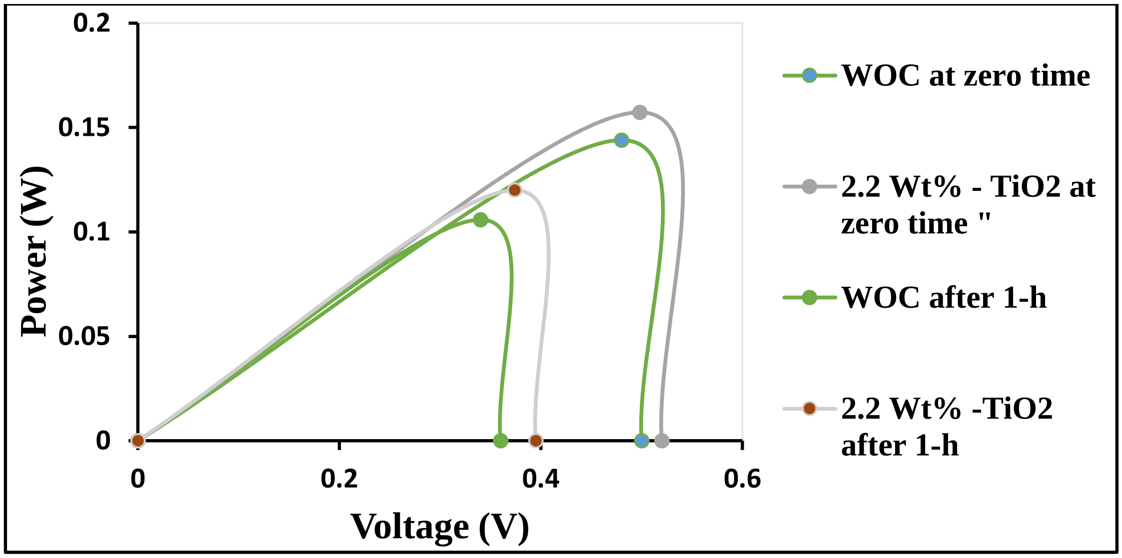


Figure 5.28 power –voltage characteristic for both coating and without coating solar cells, under the concentration:0.1gram.

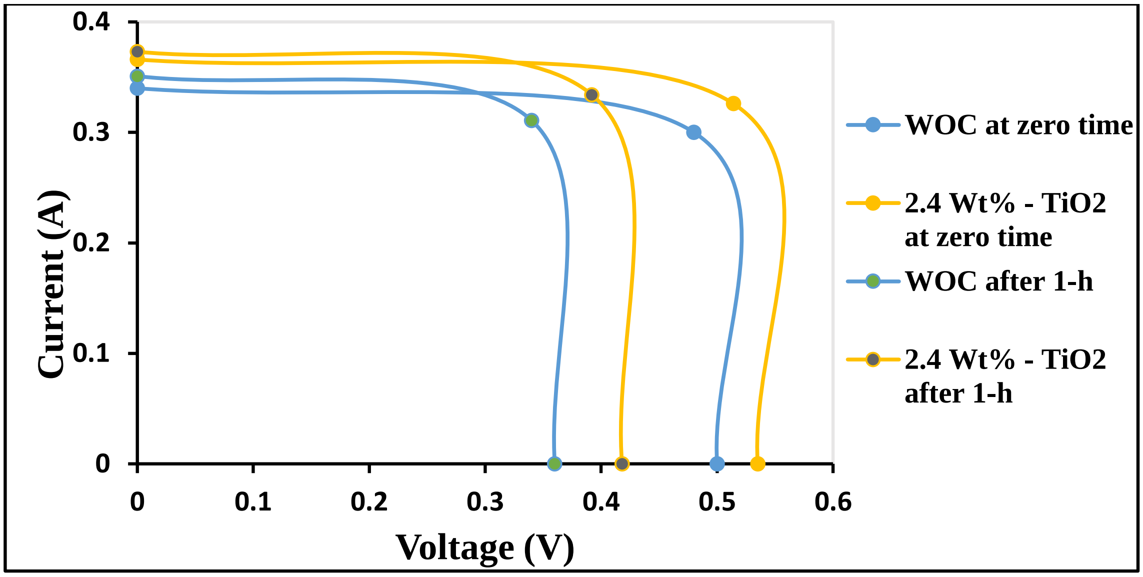


Figure 5.29 current-voltage characteristic for both coating and without coating solar cell, under concentration:0.2gram.

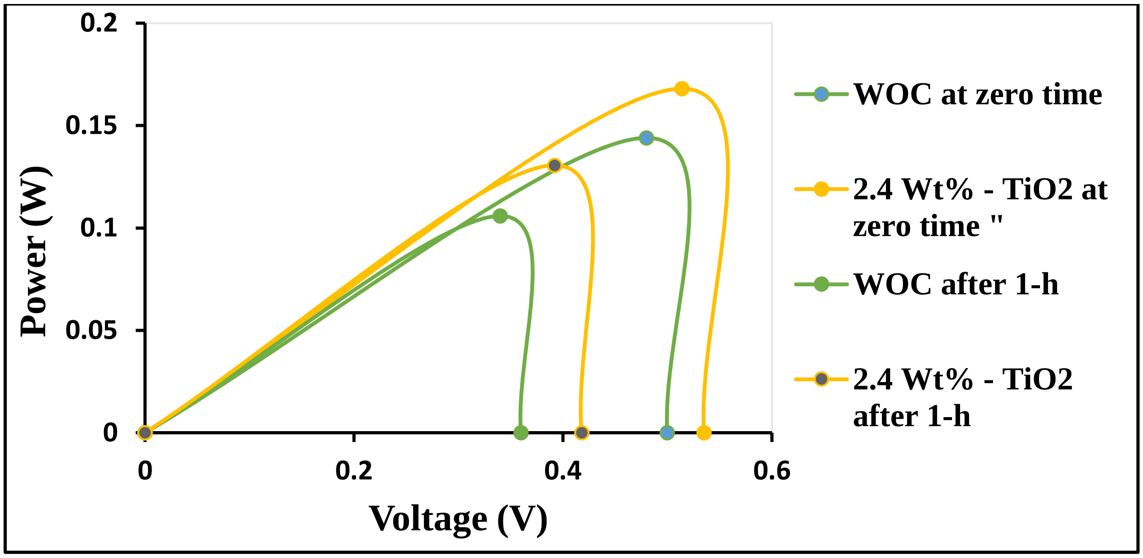


Figure 5.30 power –voltage characteristic for both coating and without coating solar cells, under the concentration:0.2gram.

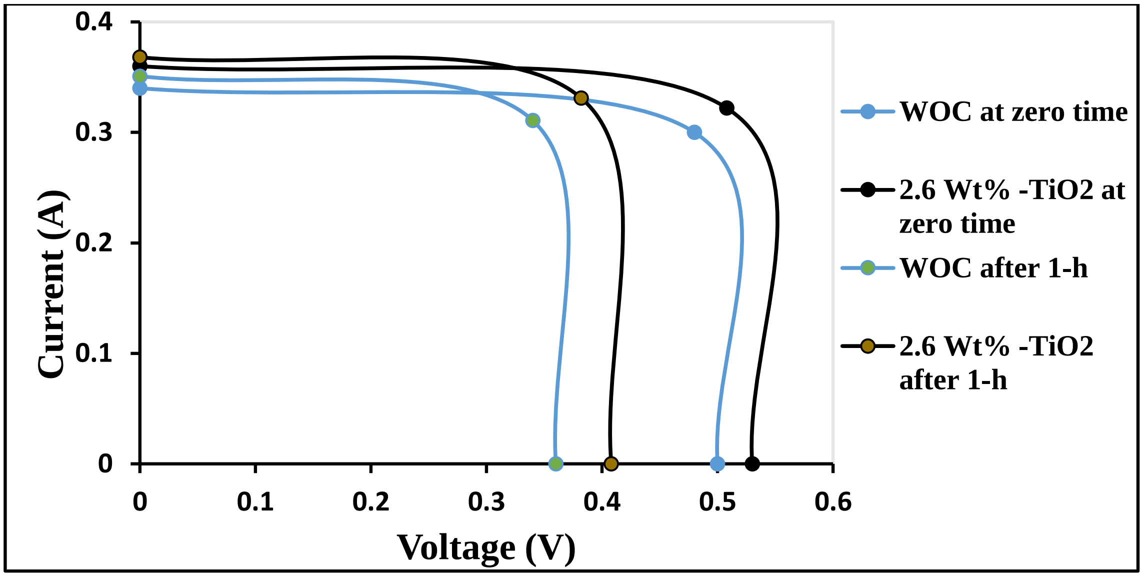


Figure 5.31 current-voltage characteristic for both coating and without coating solar cell, under concentration:0.3gram.

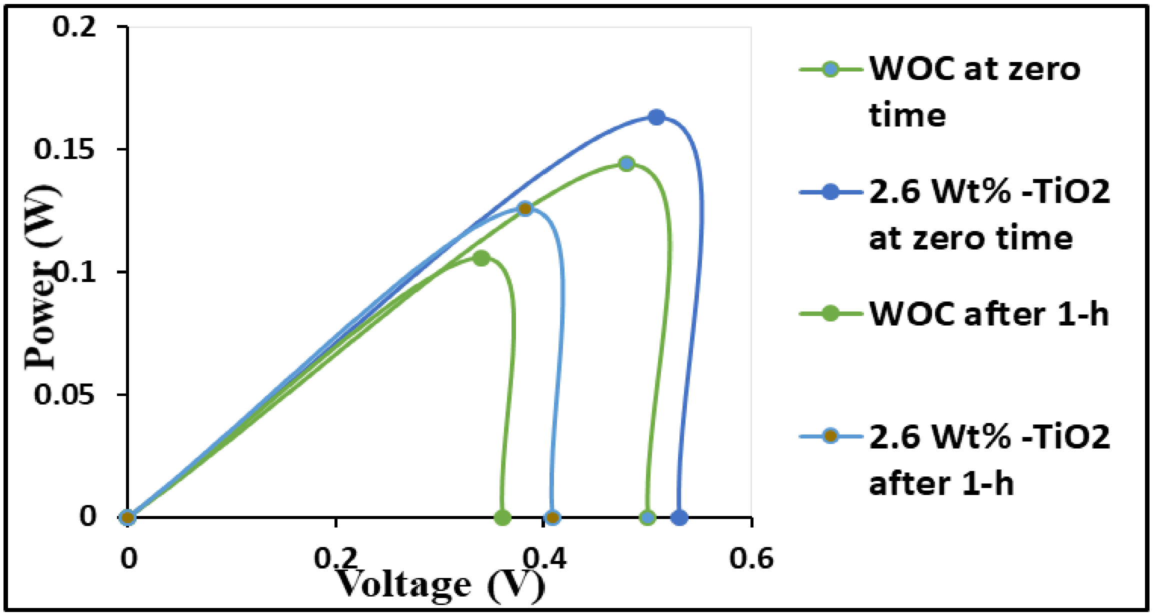


Figure 5.32 power –voltage characteristic for both coating and without coating solar cells, under the concentration:0.3gram.

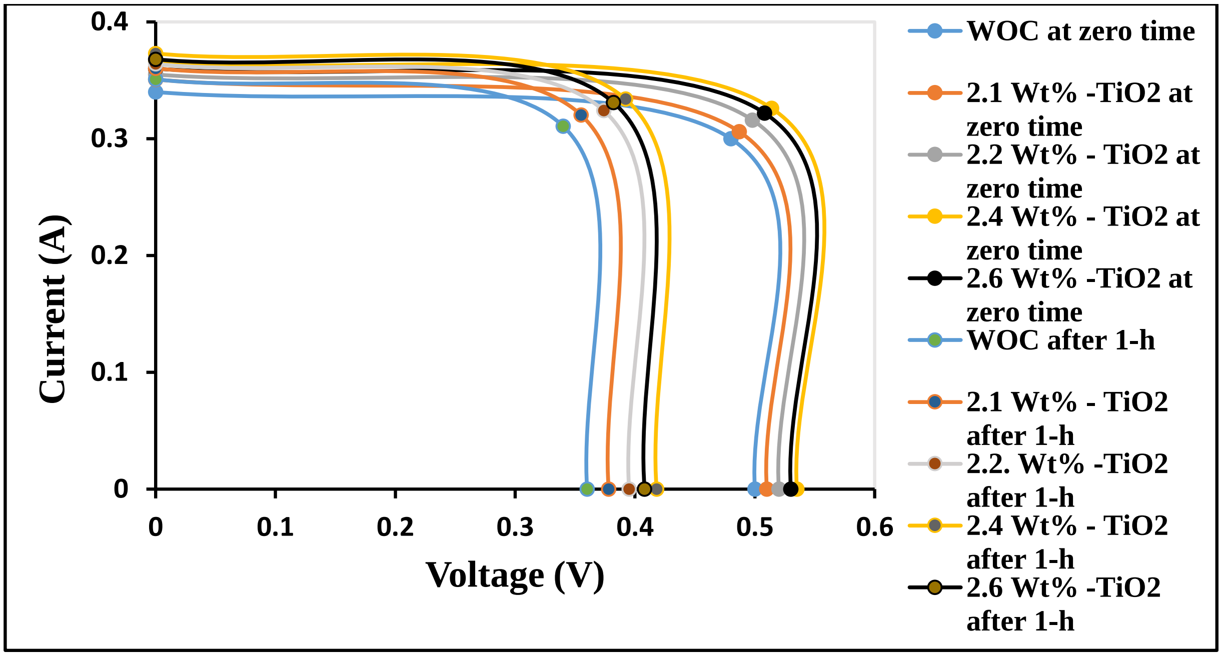


Figure 5.33 comparison the Current-Voltage relations for coating and without coating solar cells.

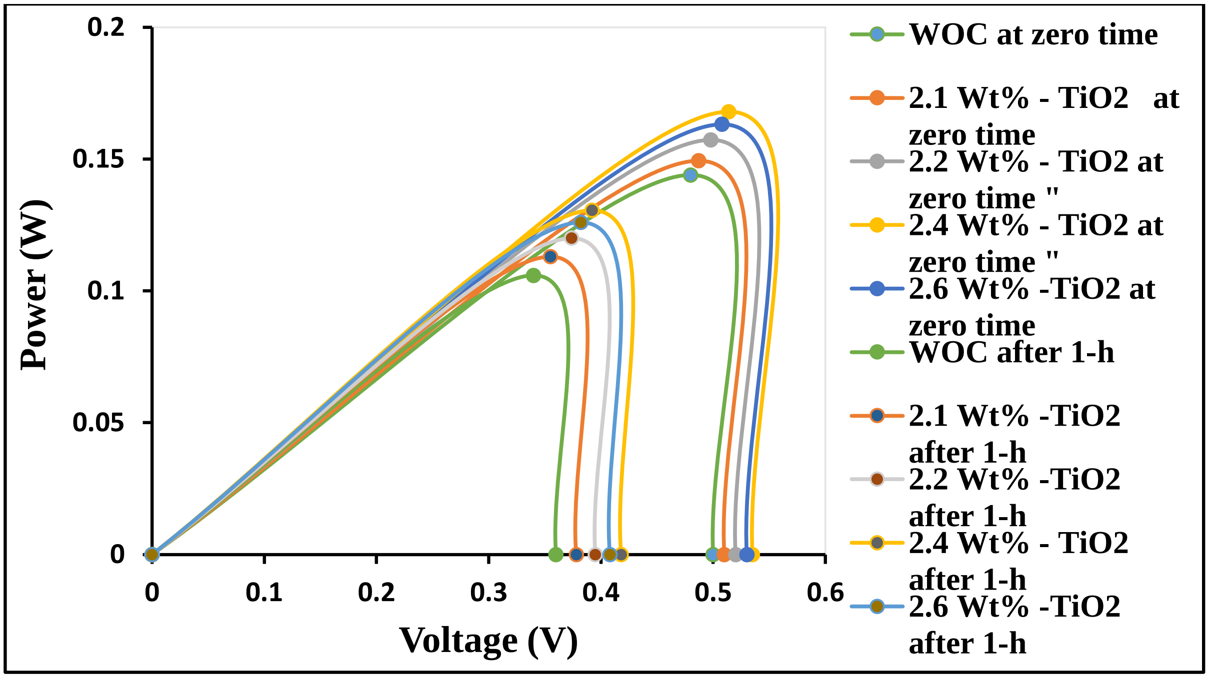


Figure 5.34 comparison the Power-Voltage relations for coating and without coating solar cells.

5.4.5.2 Study The Effect of Nano-Coating on Solar Cell Efficiency and Power output.

This section describes the functioning of a polycrystalline silicon solar cell emphasizing its main parameters (power output, efficiency) and the relation between these parameters and the temperature.

In this work, Nanocomposite TiO2/PVA coatings system was used to coating the top side of the polycrystalline silicon solar cell to keep the solar cell performance high effectively with time. Two solar cells (coating, without coating) were investigated via solar module analyzer (**Type – PROVA-200A**) under 1000W/m^2, 25^0 C ambient temperature to investigate the influences of TiO2/PVA coatings on the solar cell's performance.

The Power-time and Efficiency-time curves were calculated twice. The first test at zero time, at room temperature (25^0 C) to study the effect of reflection loss on the solar cell performance where the TiO2/PVA coatings play anti-reflection function only. The second test after one hour of light effect to study the effect of rising temperature on the solar cell performance where the TiO2/PVA play the insulation function. Table 5.6 and the figures (figure 5.35 - 5.44) show the relations between power, and efficiency with time respectively for solar cells with and without Nanocomposite coating. From the curves, the solar cells with TiO2/PVA coatings show the best results as compared to without coating, where the power output and efficiency values at zero time (at room temperature 25^0 C, and under the effect of anti-reflection losses) were (0.149W, 0.157W, 0.168W, and 0.163W) and (14.7 %, 15.52 %, 16.5%, and 16.1%), according to the TiO2/PVA concentrations (C1:0.05gram, C2:0.1gram, C3:0.2gram, and C4:0.3gram) respectively, while the power and efficiency for the solar cell without coating was (0.1439W, and 14.2%). The values of power &

efficiency after one hour of light effect (under the temperature rising effect) were (0.11W, 0.121W, 0.131W, and 0.126W) and (11.17%, 11.89%, 12.86%, and 12.45%) according to the TiO2/PVA concentrations (C1:0.05gram, C2:0.1gram, C3:0.2gram, and C4:0.3gram) respectively, while the power and efficiency for the solar cell without coating was (0.105W, and 10.44%) In conclusion, the best result obtained for the concentration C3:0.2gram –TiO2/ 1g-PVA, where the highest efficiency obtained (16.5%) at zero time test with higher power output (0.168W) also has the less temperature effect as compared to other concentrations. the main reason for that variation in power and temperature values was according to the two main factors which have a strong effect on the solar cell performance, these are the temperature and reflection loss. and as noted from the result the concentration which has a higher insulation effect and less reflection loss keeps the solar cell to be at a higher performance with time.

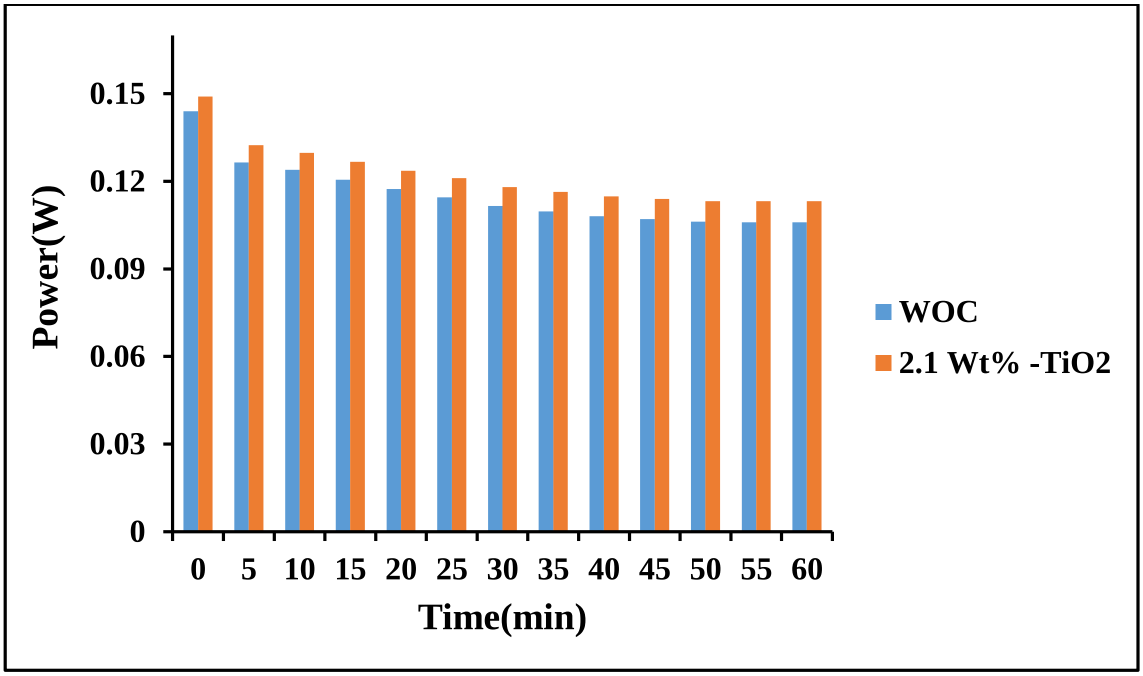


Figure 5.35 The power Vs. time for both coating and without coating solar cells, under concentration 0.05g.

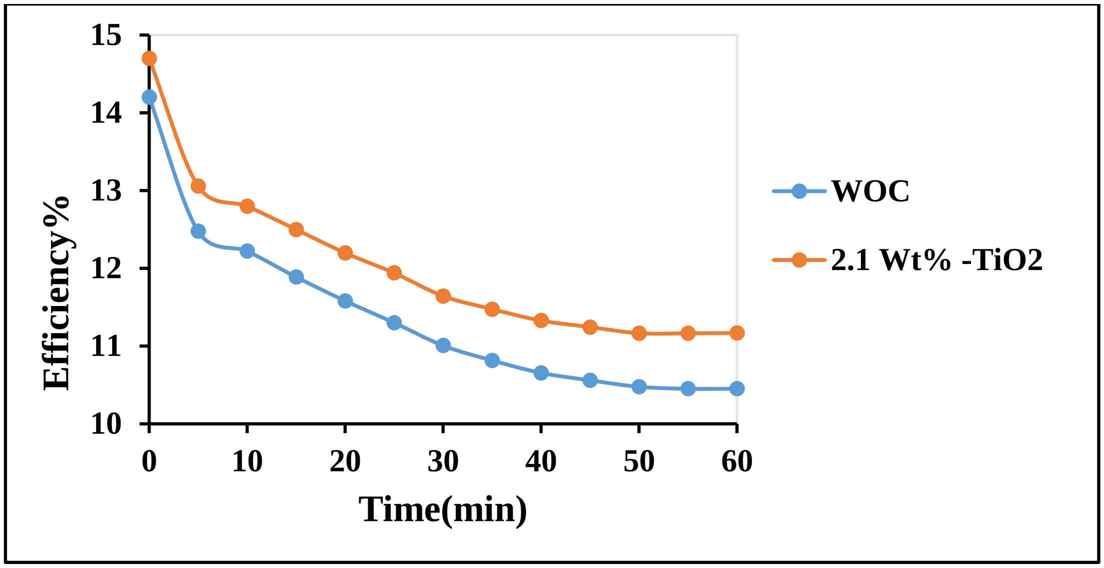


Figure 5.36 The efficiency Vs. time for both coating and without coating solar cells, under concentration 0.05g.

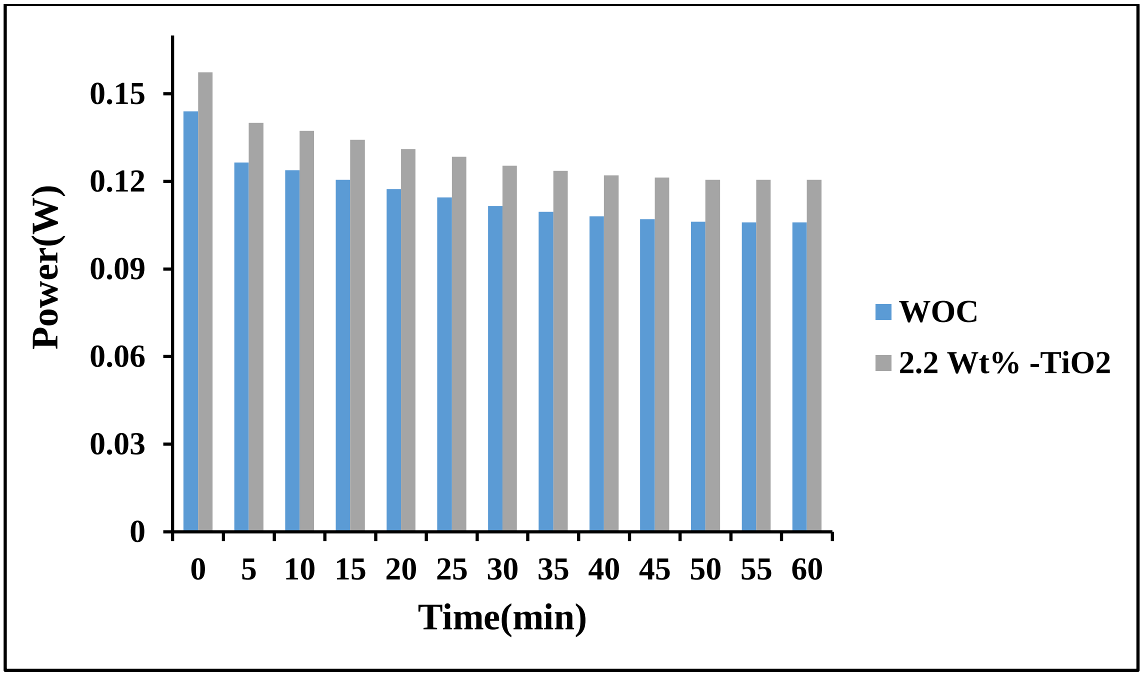


Figure 5.37 The power Vs. time for both coating and without coating solar cells, under concentration 0.1g.

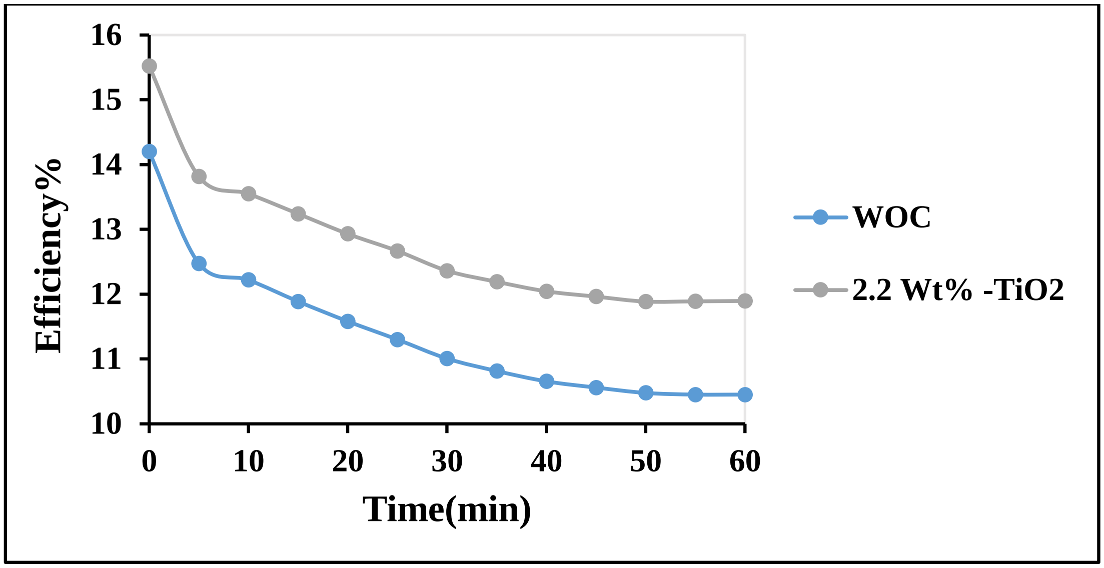


Figure 5.38 The efficiency Vs. time for both coating and without coating solar cells, under concentration 0.1g.

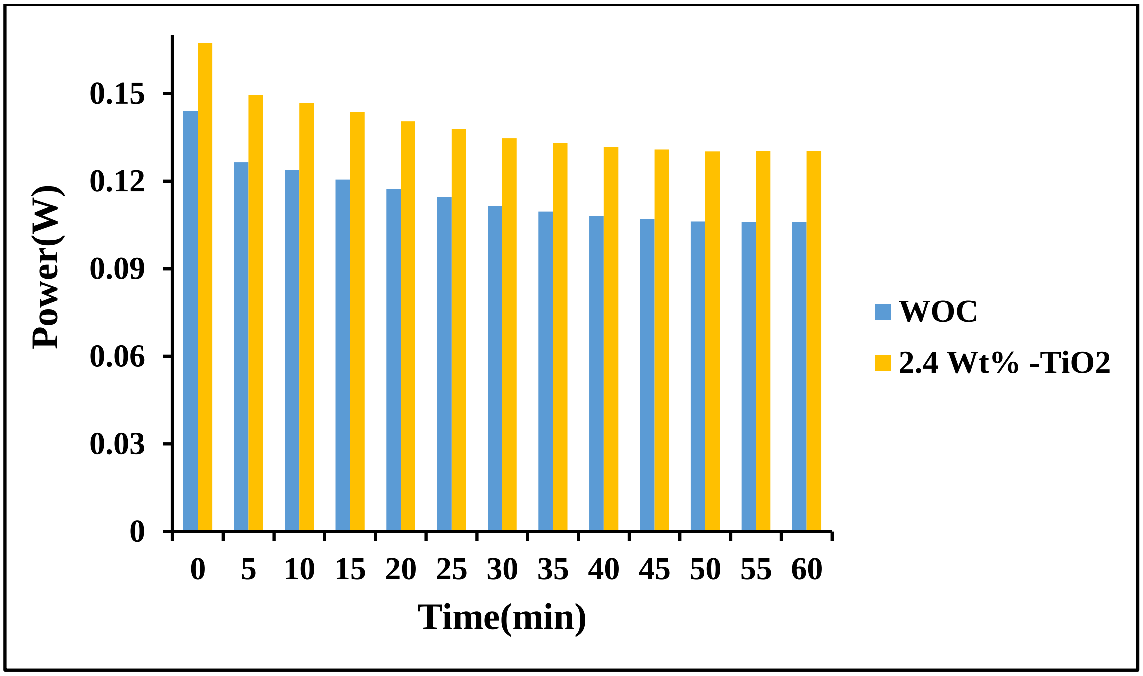


Figure 5.39 The power Vs. time for both coating and without coating solar cells, under concentration 0.2g.

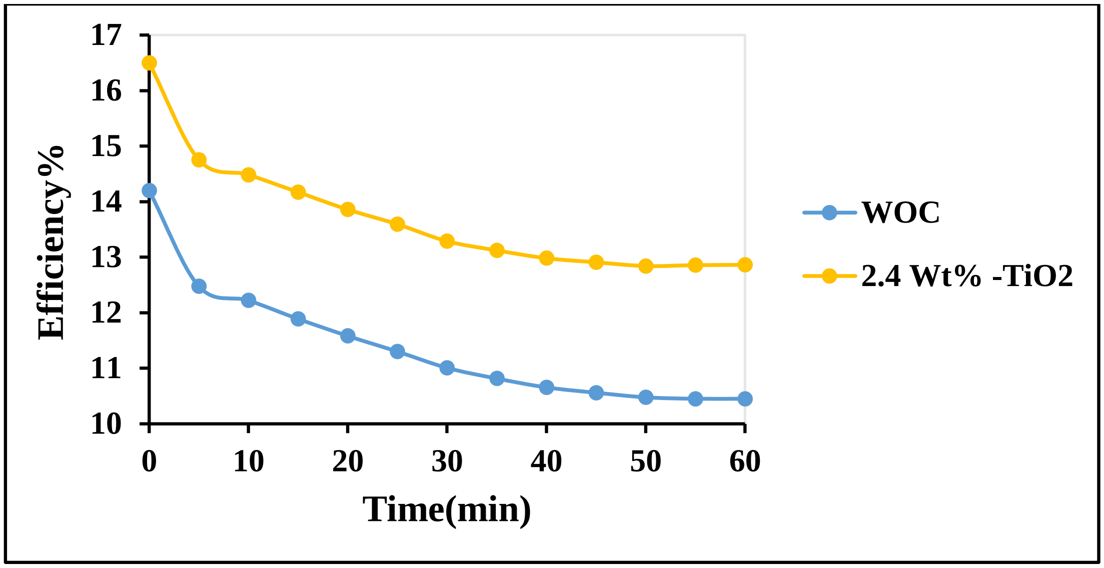


Figure 5.40 The efficiency Vs. time for both coating and without coating solar cells, under concentration 0.2g.

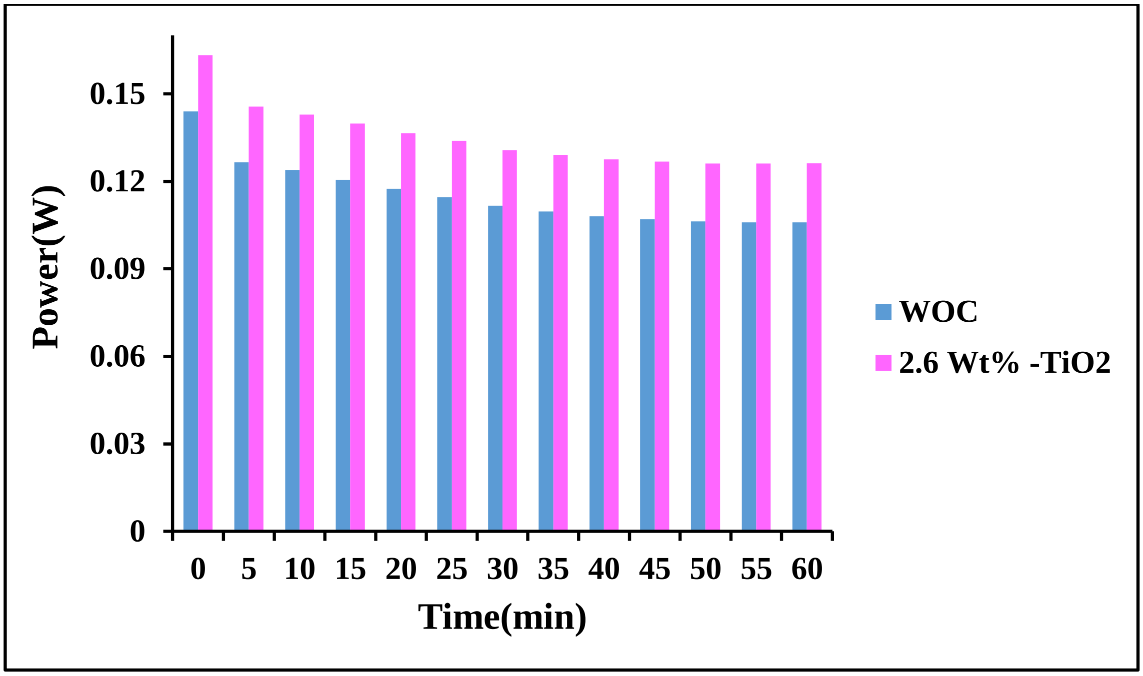


Figure 5.41 The power Vs. time for both coating and without coating solar cells, under concentration 0.3g.

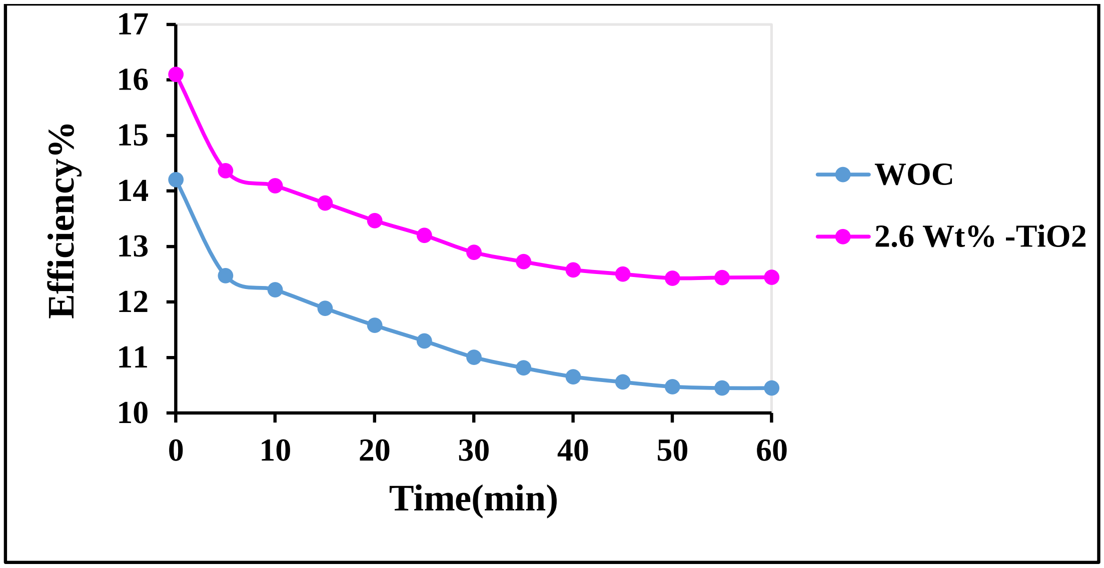


Figure 5.42 The efficiency Vs. time for both coating and without coating solar cells, under concentration 0.3g.

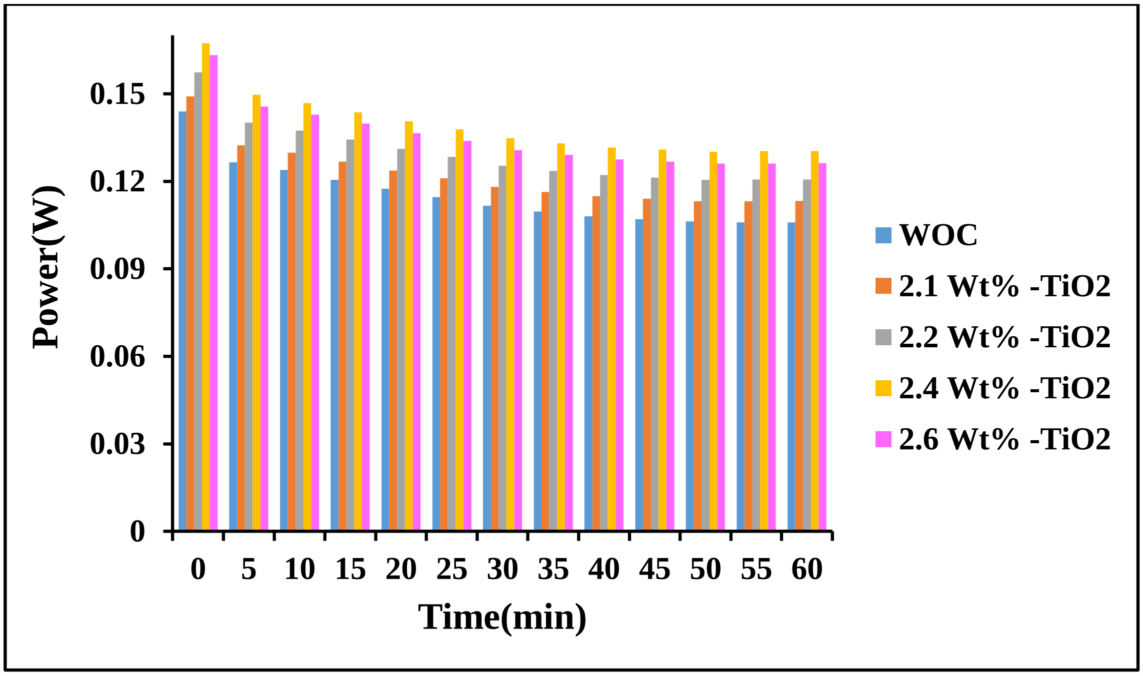


Figure 5.43 Comparison of the power Vs. time for both coating and without coating solar cells, under different concentrations.

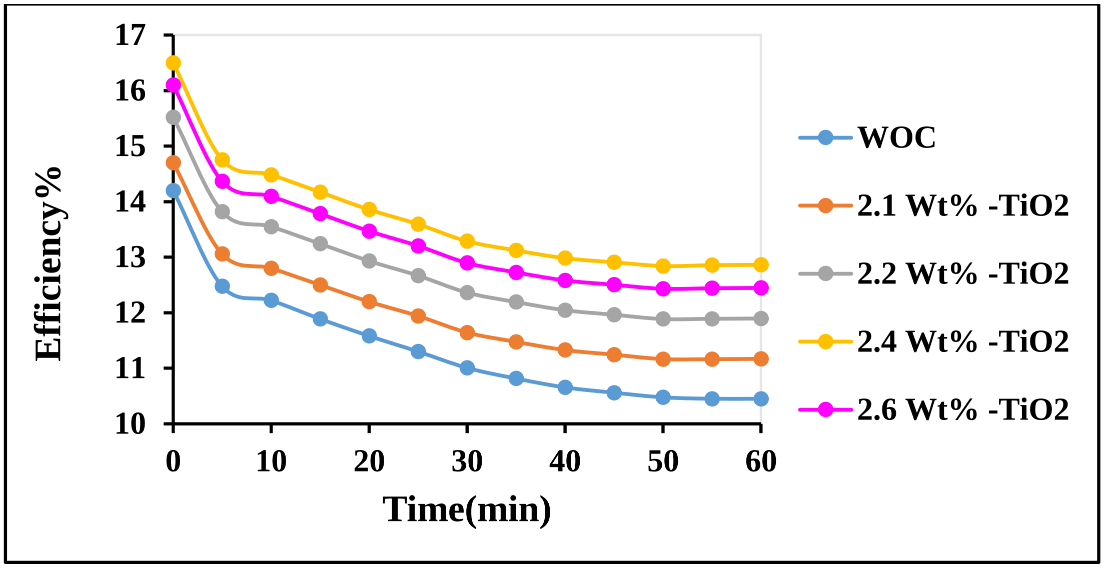


Figure 5.44 Comparison of the power Vs. time for both coating and without coating solar cells, under different concentrations.

Table 5.6 the relation between Nanocomposite's concentrations and electrical characteristics

Test-Time	Electrical efficiency (η) %	Maximium power W_P (W)	Maximum power voltage V_{mp}(V)	Maximum power current I_{mp}(A)	Short-circuit current A (A)	Open-circuit voltage V (V)
Electrical characteristics Polycrystalline silicon solar cell –without coating						
At zero time	14.2	0.144	0.48	0.3	0.34	0.5
After 1-hour	10.45	0.1059	0.34	0.3108	0.3509	0.36
	Electrical characteristics Polycrystalline silicon solar cell –under concentration 0.05g					
At zero time	14.7	0.149	0.482	0.31	0.3507	0.51
After 1-hour	11.17	0.113	0.355	0.3203	0.3603	0.378
	Electrical characteristics Polycrystalline silicon solar cell –under concentration 0.1g					
At zero time	15.52	0.157	0.5	0.315	0.355	0.52
After 1-hour	11.89	0.121	0.374	0.32	0.36	0.395
	Electrical characteristics Polycrystalline silicon solar cell –under concentration 0.2g					
At zero time	16.5	0.167	0.515	0.326	0.366	0.535
After 1-hour	12.86	0.130	0.392	0.334	0.374	0.418
	Electrical characteristics Polycrystalline silicon solar cell –under concentration 0.3g					
At zero time	16.1	0.163	0.51	0.32	0.36	0.53
After 1-hour	12.44	0.126	0.382	0.331	0.372	0.408

5.5 Cost Analysis

Solar energy is the cleanest energy source in the world, Solar energy has many advantages and benefits. For example, it is possible for the sun's energy provided by the earth for one hour to provide global energy requirements for one year. Solar cells suffer from many environmental problems that negatively affect the efficiency of the solar cell, the most important of which are high temperatures and reflection problems.

The Nanocomposite coating thin-film is an efficient and low-cost method to improve the polycrystalline silicon solar cells performance, via reducing the main impact factors which represent reflection loss and decreasing the solar cell surface temperature. Tables 5.7,and 5.8 show the economy analysis for Nano coating method to improve the polycrystalline silicon solar cell efficiency.

Table 5.7 Nanomaterials Cost

<table>
<tr><th>Materials</th><th>Unit</th><th colspan="2">Unit Price</th></tr>
<tr><td>TiO_2
Polymer-PVA</td><td>1-gram
1-gram</td><td colspan="2">0.06 USD
0.015 USD</td></tr>
<tr><td>Nanocomposite/50ml</td><td>50 ml- Price</td><td>Paint Quantity</td><td>Price</td></tr>
<tr><td>1g-PVA/0.05g-TiO_2</td><td>0.018 USD</td><td>0.5ml</td><td>0.00018 USD</td></tr>
<tr><td>1g-PVA/0.1g-TiO_2</td><td>0.021 USD</td><td>0.5 ml</td><td>0.00021 USD</td></tr>
<tr><td>1g-PVA/0.2g-TiO_2</td><td>0.027 USD</td><td>0.5 ml</td><td>0.00027 USD</td></tr>
<tr><td>1g-PVA/0.3g-TiO_2</td><td>0.033 USD</td><td>0.5 ml</td><td>0.00033 USD</td></tr>
</table>

Table 5.8 Comparison of the coating and without coating solar cells price

Solar cell	Cell Price	Power output
Pure solar cell	0.146 USD	0.144 W
2.1Wt –TiO_2 solar cell	0.14618 USD	0.149 W
2.2 Wt- TiO_2 solar cell	0.14621 USD	0.157 W
2.4Wt –TiO_2 solar cell	0.14627 USD	0.167 W
2.6 Wt-TiO_2 solar cell	0.14633 USD	0.163 W

In conclusion, the highest power output was 0.167 W. For 100 cells, 0.167×100 = 167W with a price 14.627 USD. Compared to the pure solar cell, 0.144×100=144W with a price of 14.6 USD. Thus, the gain 23W with a price of 0.027USD / 0.000117 USD per watt

Note: In Iraq, 2021: The kilowatt-hour price is 0.65 USD, and the average price in the world is 0.921 USD per kilowatt-hour.

6

Conclusion and Recommendation

Chapter

Conclusions and Recommendations

6.1 Conclusion

The current study looks at the effect of utilizing the Nano-coating film's method to improving the polycrystalline silicon solar cell performance. Polymer-Polyvinyl Alcohol (PVA) and Titanium Dioxide (TiO_2) with Nano size (10nm) were the main materials used to create the Nanocomposite coatings on the top side of the solar cell.

The thin-films were deposited on the front side of the solar cell via the casting technique. By dropping the solutions of the Polymer-PVA & TiO_2/PVA with different concentrations on the solar cell's surface. Pipette used to control the amount of the solutions.

The following conclusions are drawn from the findings of the experiment works of the thesis.

1- The Nanocomposite coating thin-film is an efficient and low-cost method to improve the polycrystalline silicon solar cell's performance via reducing the main impact factors which represent reflection loss and decreasing the solar cell surface temperature.

2- The surface temperature of the polycrystalline silicon solar cell has been reduced significantly. Maximum temperature variation was obtained (6.2^0 C) by using the PVA and (9.7^0 C) with Nanocomposite TiO_2/PVA as coating films compared to without coating solar cell at the same conditions.

3- Decreasing the light reflection losses of the polycrystalline silicon solar cell as little as possible from (35%) for solar cell without coating to be 10.25 %, 8.3%, 6.1%, and 3.9% with Nanocomposite material TiO_2/PVA at different concentrations (C1:0.05g, C2: 0.1g, C3: 0.2g, and C4: 0.3g) respectively.

4- Polymer-PVA film was made as an Ultraviolet wavelength blocking system, filters the sun radiation and masking the UV- ray from transmittance to the solar cell. Maximum UV-ray intensity blocking were (I_1:0.8A.U, I_2: 1A.U, I_3:1.3A.U, I_4:2.5A.U, and I_5:2.2A.U) according to the PVA concentrations (C1:0.25gram, C2:0.5gram, C3:0.75gram, C4: 1gram, and C5: 1.3gram) respectively.

5- Nanocomposite TiO_2/PVA film was made as an anti-reflection loss layer to reducing the solar cell reflectivity by increasing the bandgap energy of the solar cell’s surface from 1.1ev for without coating solar cell to be Eg1: 4.25eV, Eg2: 4.44eV, Eg3: 5.27eV, and Eg4: 4.6eV) with respect to the concentrations C1:0.05gram, C2:0.1gram, C3:0.2gram, and C4:0.3gram respectively.

6- Optimum Nanocomposite concentrations were, 1-gram for PVA as a higher UV-blocking 2.5A.U and maximum temperature variation of 6.2^{0} C. For Nanocomposite TiO_2/PVA 0.2-gram was the best concentration with lower reflection losses 3.9%, higher energy bandgap 5.27ev, and higher absorption of UV-ray with broadened 380nm.

7- The solar cell efficiency has been improved (14.2% to 16.5%). With Maximum electrical characteristics enhancement were [V_{OC}: 0.535 V, I_{SC}:0.366A, P_{max}:0.167 W] for the typical Nanocomposite concentration (C3:0.2gram of TiO_2 doping with C4:1gram of PVA) as compare to without coating [V_{OC}: 0.5V, I_{SC}: 0.34A, P_{max}: 0.144 W] .

8- Concerning the efficiency of the solar cell and its deterioration with respect to raising the surface temperature. The PVA coatings have less deterioration with time as compared to without PVA. the solar cell's efficiency after one hour of light effect – under temperature raising effect were (10.6%, 10.65%, 10.71%, 11%, and 10.75%) according to the concentrations (C1:0.25g, C2:0.5g, C3:0.75g, C4:1g, and C4:1.3g) respectively, While the efficiency of the solar cell without coating becomes 10.4% at the same time test. as compared to the reference efficiency at zero time 14.2%.

9- The Nanocomposite TiO_2/PVA coatings have less deterioration with time as compared to without coating. The solar cell's efficiency after one hour of light effect – under temperature raising effect were (11.16%, 11.895%, 12.86% and 12.45%) according to the concentrations (C1:0.05g, C2: 0.1g, C3: 0.2g, and C4: 0.3g) doping with (1g) of PVA respectively while without coating was recorded 10.4% as compared to reference efficiency 14.2% at zero time.

6.2 Recommendations

This study focused on Nanocomposite materials used to improve polycrystalline silicon solar cells, and to improve that work, some ideas should be included in future studies.

1. Study the effect of the thickness of Nano-coating thin film on the solar cell’s performance.
2. Study the effect of Nanoparticles size on the efficiency of Nano-coating film.
3. Applying the other types of Nano-coating material and study their effect on the solar cell performance.
4. Used different methods for coating the solar cell such as dip coating, spin coating, electrical vapor deposition.

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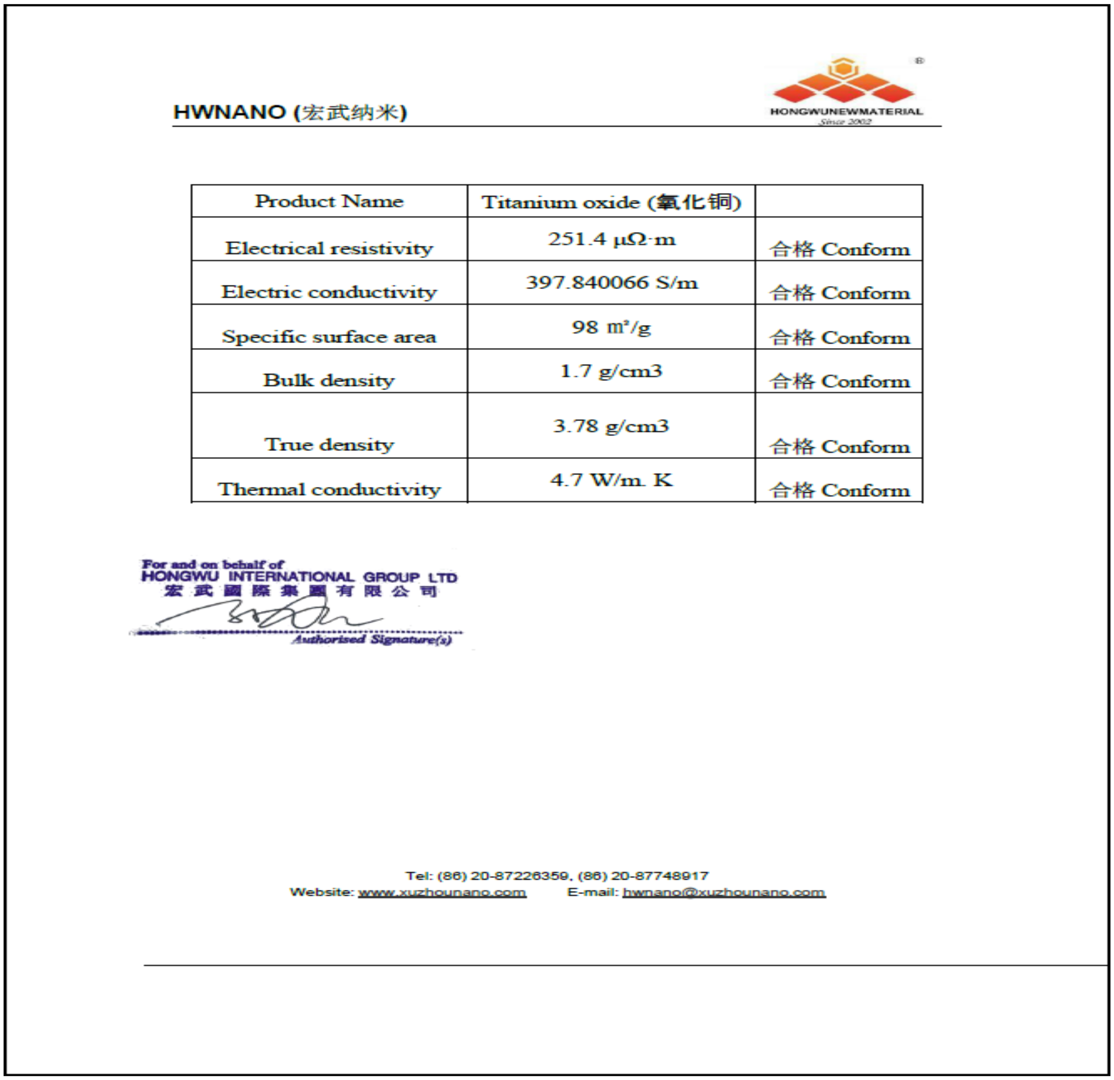
Appendices:

Appendix- A. Titanium Dioxide certificate

This appendix represents the certificate of Titanium Dioxide (TiO2) Nano-particles properties processing from HWNANO-COMPANY. Where, figure.A1 represents the Nanoparticles characteristics, and figure.A2 represents the Nano size verification as a scanning electron microscope test (SEM) to verify the grain Nano-size under the microscope.



HWNANO (宏武纳米)

HONGWUNEWMATERIAL
Since 2002

Product Name	Titanium oxide (氧化铜)	
Electrical resistivity	251.4 μΩ·m	合格 Conform
Electric conductivity	397.840066 S/m	合格 Conform
Specific surface area	98 $\mathrm{m^2}$/g	合格 Conform
Bulk density	1.7 g/cm3	合格 Conform
True density	3.78 g/cm3	合格 Conform
Thermal conductivity	4.7 W/m. K	合格 Conform

For and on behalf of
HONGWU INTERNATIONAL GROUP LTD
宏武國際集團有限公司
Authorised Signature(s)

Tel: (86) 20-87226359, (86) 20-87748917
Website: www.xuzhounano.com E-mail: hwnano@xuzhounano.com

Figure A.1 Titanium Dioxide certificate

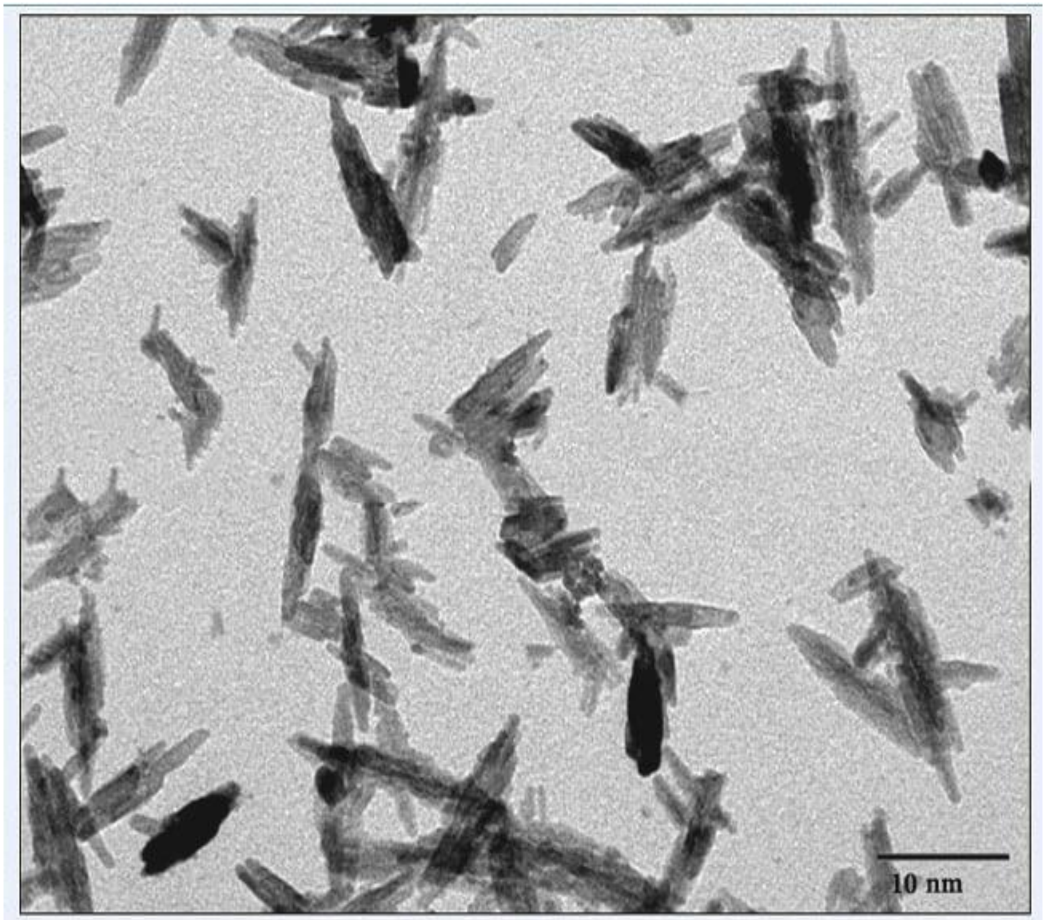


Figure A.2 Titanium Dioxide Scanning electron microscopy (SEM).

Appendix –B: Water Bath Ultrasonic Device (Elmasonic P180H)

This appendix shows the main characteristics of the Water Bath Ultrasonic Device Specifications (Elmasonic P180H) as shown in the table.B1.

Table B.1 Ultrasonic water-bath properties

Property	**Value**
Electrical Characteristics	110/220 VAC
Frequency	37 / 80 kHz
Power consumption	1330W
Unit Dimensions L/W/H	39, 34, 32 cm
Basin dimension L/W/H	32, 30, 20 cm
Wight	8.5 kg
Volume tank	12 liter
Drain size	3/8”
Materials	Stainless steel V2A
sound level (LPZ), (dB)	96 / 87

Appendix. C: Coating Thickness Gauge.

Property	**Value**
Temperature range	0~60°C
Humidity	20%～90%RH
Power source	1.2V, 600mA
Dimensions	270mm×86 mm×47 mm
Weight	530g
Probe-type	N400
Coating thickness-range	0～400μm

Appendix-D. Solar Meter Calibration:

Figure and table c.1. Represent the calibration process for the solar meter (Pyranometer) device which was used in this work.

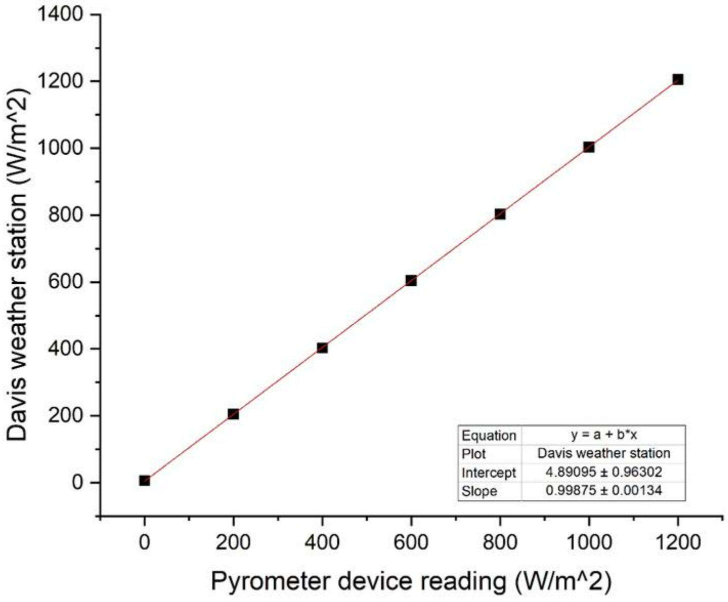


Figure D.1 solar meter calibration(Pyranometer)

Table D.1 solar meter characteristics (Pyranometer).

Property	**Value**
Model	TENMARS TM 207
Temperature error	±0.38℃
Accuracy	±10W/m^2
Sample time	0.25 second
Operating under temperature effect	0^0 C - 50^0 C
Humidity	<80% RH
Dimension L/W/H	22 cm, 15cm, and 4.5cm
Battery	1 pcs 9V

Appendix-E: Thermocouples calibration system

This appendix represents the calibration process for K-Type thermocouples which was used in this work, figure D.1, 2, and 3 show the calibration data.

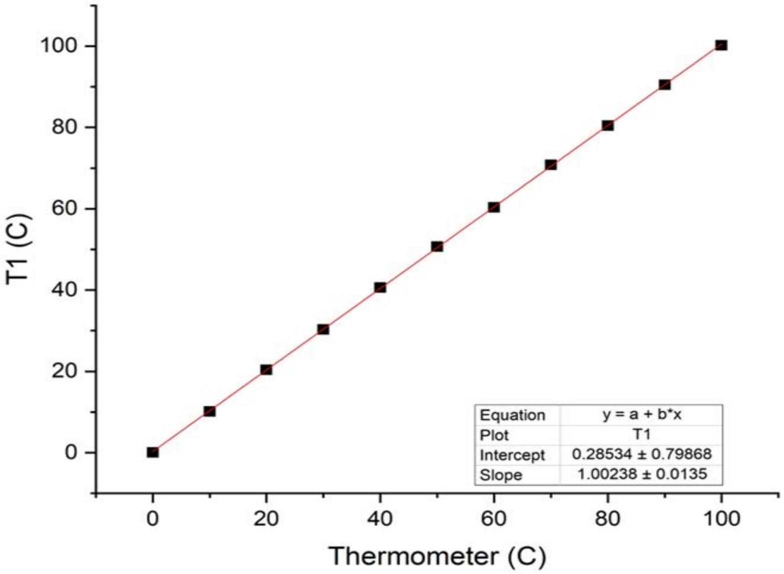


Figure E.1 Temperature calibration T1

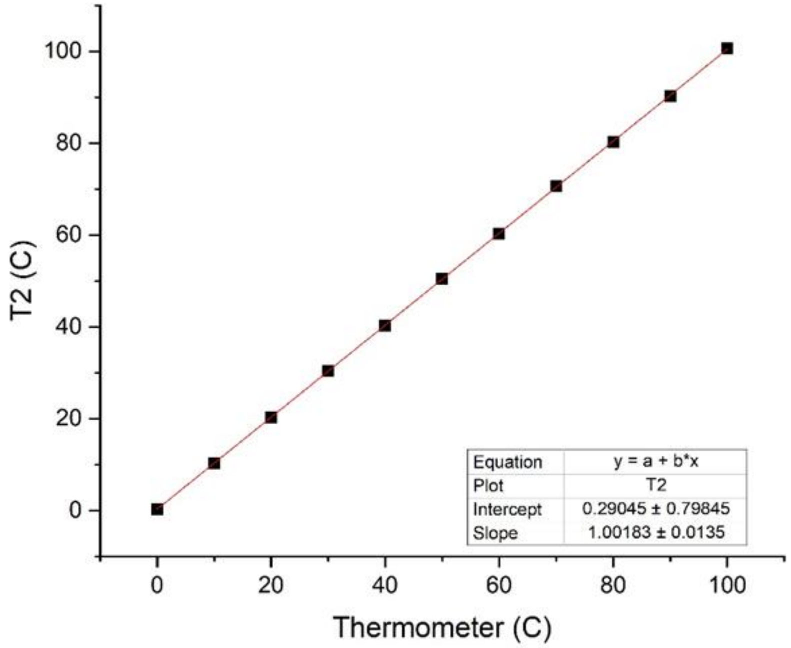


Figure E.2 Temperature calibration T2

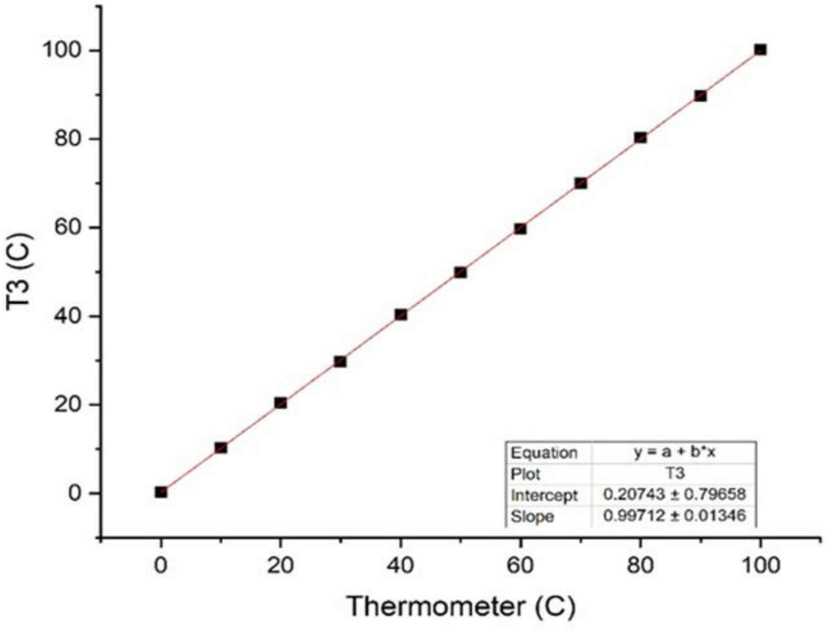
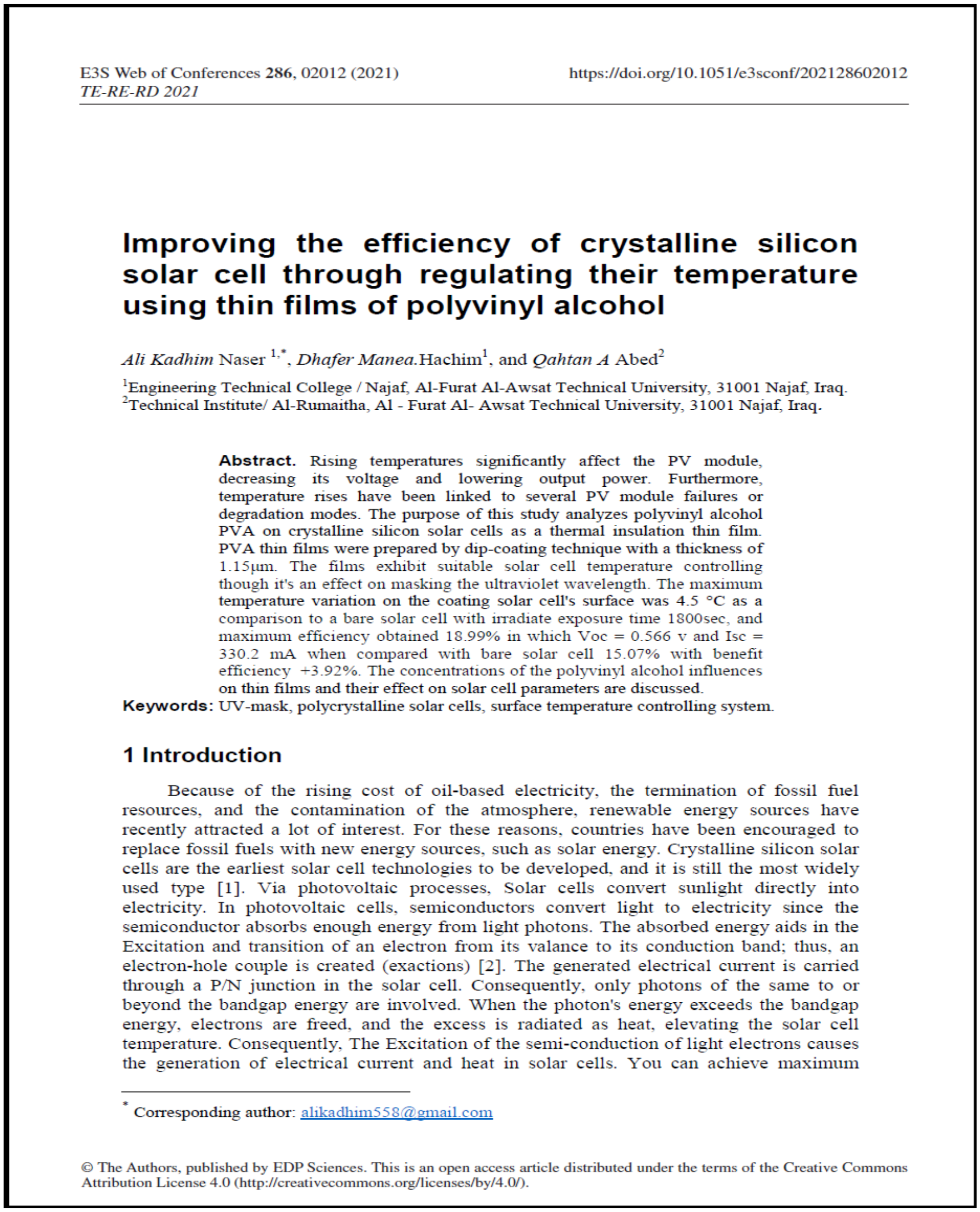


Figure E.3 Temperature calibration T3

Appendix. F-List of publications.

1- Ali Kadhim Naser, Dhafer Manea Hachim, Qahtan Adnan Abed '' Improving the efficiency of crystalline silicon solar cells through regulating their temperature using thin films of polyvinyl alcohol '' 10-Th International Conference on Thermal Equipment, Renewable Energy and Rural Development (TERERD 2021).



E3S Web of Conferences **286**, 02012 (2021) https://doi.org/10.1051/e3sconf/202128602012
TE-RE-RD 2021

Improving the efficiency of crystalline silicon solar cell through regulating their temperature using thin films of polyvinyl alcohol

Ali Kadhim Naser [1,*], *Dhafer Manea.*Hachim[1], and *Qahtan A* Abed[2]

[1]Engineering Technical College / Najaf, Al-Furat Al-Awsat Technical University, 31001 Najaf, Iraq.
[2]Technical Institute/ Al-Rumaitha, Al - Furat Al- Awsat Technical University, 31001 Najaf, Iraq.

Abstract. Rising temperatures significantly affect the PV module, decreasing its voltage and lowering output power. Furthermore, temperature rises have been linked to several PV module failures or degradation modes. The purpose of this study analyzes polyvinyl alcohol PVA on crystalline silicon solar cells as a thermal insulation thin film. PVA thin films were prepared by dip-coating technique with a thickness of 1.15μm. The films exhibit suitable solar cell temperature controlling though it's an effect on masking the ultraviolet wavelength. The maximum temperature variation on the coating solar cell's surface was 4.5 °C as a comparison to a bare solar cell with irradiate exposure time 1800sec, and maximum efficiency obtained 18.99% in which Voc = 0.566 v and Isc = 330.2 mA when compared with bare solar cell 15.07% with benefit efficiency +3.92%. The concentrations of the polyvinyl alcohol influences on thin films and their effect on solar cell parameters are discussed.

Keywords: UV-mask, polycrystalline solar cells, surface temperature controlling system.

1 Introduction

Because of the rising cost of oil-based electricity, the termination of fossil fuel resources, and the contamination of the atmosphere, renewable energy sources have recently attracted a lot of interest. For these reasons, countries have been encouraged to replace fossil fuels with new energy sources, such as solar energy. Crystalline silicon solar cells are the earliest solar cell technologies to be developed, and it is still the most widely used type [1]. Via photovoltaic processes, Solar cells convert sunlight directly into electricity. In photovoltaic cells, semiconductors convert light to electricity since the semiconductor absorbs enough energy from light photons. The absorbed energy aids in the Excitation and transition of an electron from its valance to its conduction band; thus, an electron-hole couple is created (exactions) [2]. The generated electrical current is carried through a P/N junction in the solar cell. Consequently, only photons of the same to or beyond the bandgap energy are involved. When the photon's energy exceeds the bandgap energy, electrons are freed, and the excess is radiated as heat, elevating the solar cell temperature. Consequently, The Excitation of the semi-conduction of light electrons causes the generation of electrical current and heat in solar cells. You can achieve maximum

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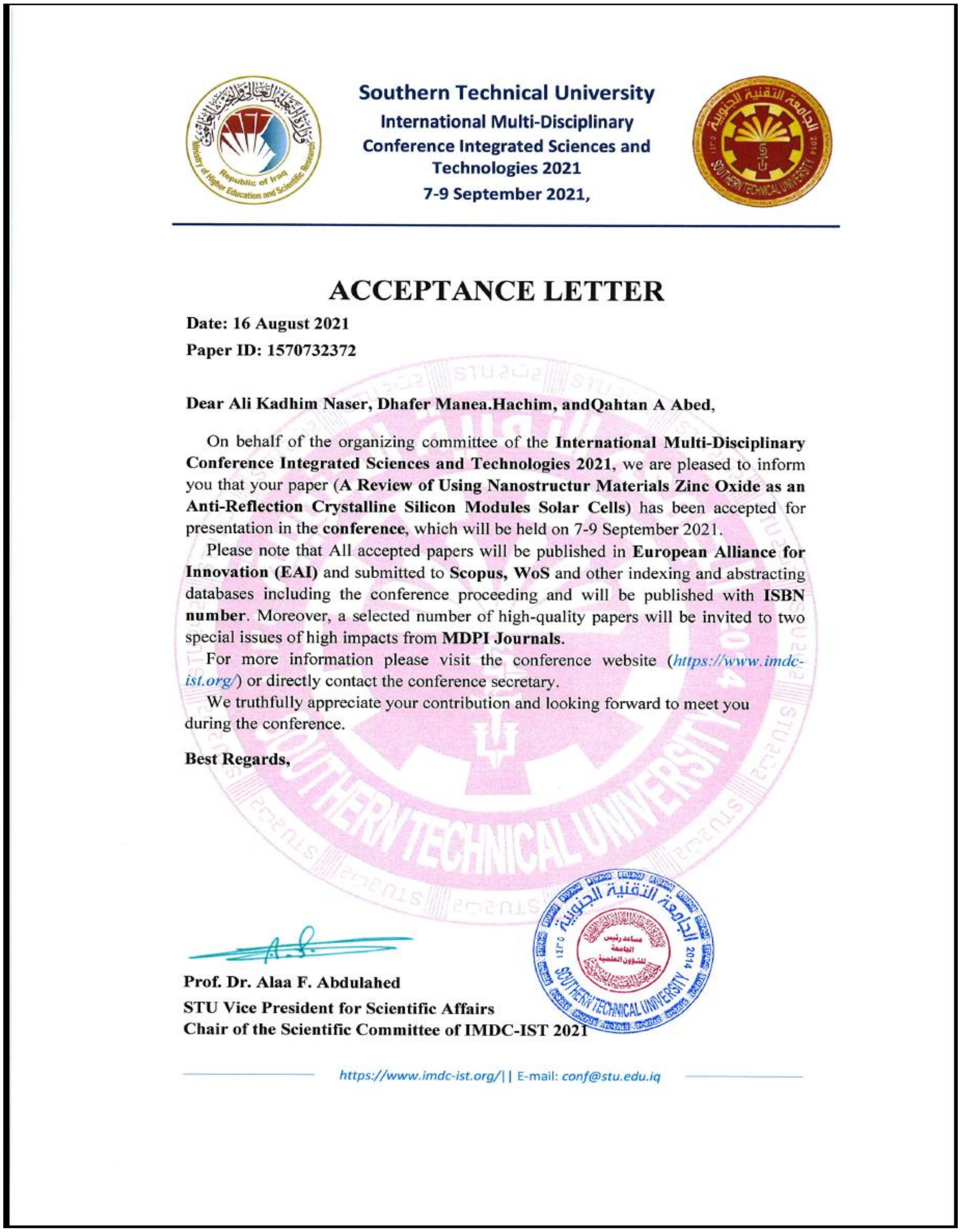
[*] Corresponding author: alikadhim558@gmail.com

2- Ali Kadhim Naser, Dhafer Manea Hachim, Qahtan Adnan Abed '' A Review of Using Nanostructur Materials Zinc Oxide as an Anti-Reflection Crystalline Silicon Modules Solar Cells'' International Multi-Disciplinary Conference (IMDC-IST 2021).



Southern Technical University
International Multi-Disciplinary
Conference Integrated Sciences and
Technologies 2021
7-9 September 2021,

ACCEPTANCE LETTER

Date: 16 August 2021
Paper ID: 1570732372

Dear Ali Kadhim Naser, Dhafer Manea.Hachim, andQahtan A Abed,

On behalf of the organizing committee of the **International Multi-Disciplinary Conference Integrated Sciences and Technologies 2021**, we are pleased to inform you that your paper (**A Review of Using Nanostructur Materials Zinc Oxide as an Anti-Reflection Crystalline Silicon Modules Solar Cells**) has been accepted for presentation in the **conference**, which will be held on 7-9 September 2021.

Please note that All accepted papers will be published in **European Alliance for Innovation (EAI)** and submitted to **Scopus, WoS** and other indexing and abstracting databases including the conference proceeding and will be published with **ISBN number**. Moreover, a selected number of high-quality papers will be invited to two special issues of high impacts from **MDPI Journals.**

For more information please visit the conference website (*https://www.imdc-ist.org/*) or directly contact the conference secretary.

We truthfully appreciate your contribution and looking forward to meet you during the conference.

Best Regards,

Prof. Dr. Alaa F. Abdulahed
STU Vice President for Scientific Affairs
Chair of the Scientific Committee of IMDC-IST 2021

https://www.imdc-ist.org/ | | E-mail: *conf@stu.edu.iq*

1- Ali Kadhim Naser, Dhafer Manea Hachim, Qahtan Adnan Abed ’’ Enhanced electrical property of crystalline silicon solar cell via nano-composite polyvinyl-alcohol/titanium dioxide ’’ International Journal of Design &Nature and Econdynamics (IJDNE).

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International Journal of Design & Nature and Ecodynamics
Vol. 16, No. 5, October, 2021, pp. 557-564
Journal homepage: http://iieta.org/journals/ijdne

Enhanced Electrical Properties of Crystalline Silicon Solar Cells via Nano-Composite Polyvinyl-Alcohol/Titanium Dioxide

Check for updates

Ali Kadhim Naser[1*], Dhafer Manea H. Al-Shamkhee[2], Qahtan Adnan Abed[2]

[1] Engineering Technical College, Najaf, Al-Furat Al-Awsat Technical University, Najaf 31001, Iraq
[2] Technical Institute, Al-Rumaitha, Al - Furat Al- Awsat Technical University, Najaf 31001, Iraq

Corresponding Author Email: alikadhim558@gmail.com

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Accepted: 13 August 2021

Keywords:
TiO_2/PVA nanocomposite, solar cell, thermal regulation thin film, UV- mask, anti-reflection coating

ABSTRACT

Reflection loss and solar cell temperature both have a significant impact on solar cell efficiency and, consequently, on power generation. Herein, the aim is to investigate into the impact of Nanocomposite Titanium Dioxide (TiO_2)/Polyvinyl Alcohol (PVA) on polycrystalline silicon solar cells. The solvent casting method is employed to prepare nanocomposite TiO_2/PVA for deposition on the front side of the solar cell. The Tauc plot is used to investigate the influence of TiO_2 nanoparticle concentration (10-20nm) on the energy bandgap of a nanocomposite. To test the optical properties of the solar cell after depositing the Nanocomposite coating film and to confirm the suspension of TiO_2 in PVA and construct a Nanocomposite, an ultraviolet-visible spectrometer and a Fourier transform infrared spectrometer are provided. The results show that increasing the TiO_2 in the TiO_2/PVA Nanocomposite increases the energy bandgap. The Ultraviolet-Visible spectrometer observes that the Nanocomposite films absorb the Ultraviolet wavelength and transmittance at the visible wavelength. Finally, it found the lowest reflection obtained was 3.9% for 0.2wt% TiO_2 in TiO_2/PVA nanocomposite and the enhancement of the solar cell efficiency was (+2.3%).

الخلاصة

تشكل الخلايا الشمسية (الخلايا الكهروضوئية ؛ غالبا ما يعبر عنها بالرمز PV) الحل الامثل للتخلص من الضوضاء ومشاكل التلوث البيئي الناتجة من عمليات انتاج الطاقة الكهربائيه.تحول الطاقه الشمسية بشكل مباشر الى طاقه كهربائية بفعل خاصية (Photovoltaic Effect) بدون ضوضاء وتلوث بيئي واجزاء متحركة يجعل الخلايا الشمسية الخيار الامثل للطاقة النظيفة بالعالم . الا ان هناك العديد من العوامل البيئية التى تحد من كفاءه الخلايا الشمسية وتجعلها قليلة نسبيا . خلال هذه الدراسة تم التطرق الى الخلايا الشمسية نوع (Polycrystalline silicon solar cell) ودراسة تاثير خاصية انعكاس الضوء الساقط وارتداده من على سطح الخلية الشمسية على كفاءه الخلية الشمسية كذلك تم دراسة التدهور الحاصل بكفاءه الخلية الشمسية نتيجة ارتفاع درجه حراره المحيط . حيث من المعروف ان كفاءه الخلايا الشمسية تقل بمعدل0.5 %-0.4% لكل درجة سيليزية واحده فوق درجة حرارة التصميم . تم استخدام غشاء نانوي (طبقه رقيقه) من مادة (Nanocomposite) المركبة من اشباه الموصلات العضوية (ثاني أكسيد التيتانيوم) (TiO_2) باحجام نانويه (10nm) بتراكيز مختلفة (0.3gram , 0.2gram , 0.1gram , 0.05gram) ممزوجة مع اشباه الموصلات اللاعضوية (بوليمر- كحول بولي فينيل) (PVA) بتراكيز (1.3gram , 1gram 0.5gram , 0.25gram) 0.75gram , .من خلال الفحوصات المختبرية وبأستخدام جهاز(Ultravilote-Visible-) Spectrometer لاحظت النتائج أن مادة البوليمر PVA يعمل على حجب الأشعة الفوق البنفسجية الضارة بعمل الخلايا الشمية وبالتالي تقليل درجة حرارة سطح الخلية الشمسية وان ثاني أكسيد التيتانيوم TiO_2 يعمل كطلاء مضاد للانعكاس وبالتلي تقليل خسائر الانعكاس من على سطح الخلية الشمسية . تم اختيار التركيز (1 gram) كافضل تركيز من ماده ال PVA من حيث قابلية لامتصاص اكبر شده اشعاع شمسي من طيف الاشعة الفوق البنفسجية. كذالك التركيز (0.2gram) من مادة ال TiO_2 بناءا على قابلية على تقليل خسائر الانعكاس الى ادنى حد ممكن .اعلى فرق بدرجات حرارة سطح الخلية الشمسية تم الحصول عليه مقارنة بخلية شمسية بدون طلاء نانوي وتحت نفس الضروف كانت (9.7^0 C). وكذلك اقل خسائر انعكاس تم الحصول عليها هي (3.9%) مقارنة بخسائر الانعكاس الخلية الشمسية السيليكونية بدون طلاء نانوي والتى بلغت (35%) . وكنتجة للمتغيرات اعلاه تم رفع كفاءة الخلية الشمسية السيليكونية من 14.2% الى 16.5% حيث تم الكشف عليها بأستخدام جهاز(Solar-module analyzer) مقارنة مع خلية شمسية بدون طلاء نانوي .

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية

الكية التقنيه الهندسية - النجف

تطبيق تقنية النانو (PVA-TiO2 لتحسين كفاءة الخلايا الشمسية

رسالة مقدمة الى

قسم هندسة تقنيات ميكانيك القوى في الكلية التقنية الهندسة – النجف – جامعة الفرات الاوسط التقنية كجزء من متطلبات نيل شهادة الماجستير في هندسة تقنيات ميكانيك الحراريات

تقدم بها

علي كاظم ناصر عبد الرضا

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اشراف

الأستاذ الدكتور

ظافر مانع حاجم