Enhancement of the Performance of Crystalline Silicon Solar Cells by Using Nano Composite Polyvinyl-Alcohol/Titanium Dioxide with Natural Dyes

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Abstract

Some contemporary techniques have been used to boost the efficiency of crystalline solar cells. These techniques include coating the cells with titanium dioxide (TiO2) nanomaterial that has been mixed with polyvinyl alcohol (PVA) and using natural dyes with PVA that are non-toxic and environmentally friendly while also acting as a good enhancer in solar cell efficiency by utilizing the photosynthesis process to absorb light. In order to create a film of a nanocomposite with a natural dye, the study examined the effects of mixing TiO2/PVA with natural colors taken from Acasia alata leaves and spirulina algae. The silicon solar cells were coated with paint using the deposition method, and the optical characteristics of the paint were examined using ultraviolet spectroscopy. Combining nanocomposites and natural dyes within the layers of solar cells can enhance productivity while minimizing light reflection, leading to a higher electricity output. TiO2/PVA, TiO2/PVA with algae dye (Spirulina), algae dye, and Acasia alata dye had energy gap differences of 1.5 eV, 1.9 eV, 2 eV, and 1.87 eV, in that order. Nanocomposites and natural dyes cover solar cells more effectively and reduce light reflection. Acasia alata dye increases effectiveness by 75%, while spirulina dye boosts it by 85.9%.

Keywords: Efficiency, Silicon Solar Cells, Nano-Composite, Natural Dyes.

All nations use renewable energy sources like solar and wind power. These sources demand minimal maintenance but a large initial investment. We can get uninterrupted electricity from these sources (Garche et al., 2013). Solar energy is renewable and cheaper than other renewable energy sources. Much of the sun's thermonuclear fusion process, which converts hydrogen into helium and creates heat and electromagnetic radiation, reaches Earth's surface, where solar cells can use it to generate electricity (Yang et al., 2020). Polymer matrices in nanocomposites have been extensively studied for diverse applications. Polymers form the matrix, and nanoparticles fill it. Unlike normal compounds, these materials have unequal particle dispersion and surface-to-volume ratios. Nanocomposites have 1–100 nm fillers. Different from normal materials with greater fillers (Sharma et al., 2021). PANi, polyamide, and polyvinyl alcohol are combined with TiO2, GO, and nanoparticles to make nanocomposites (Ma et al., 2006; Nguyen-Tri et al., 2018). According to Nosrati et al., nano-sized titanium dioxide was mixed with organic binders to study how these groups affect solar cell performance and efficiency (Nosrati et al., 2018). Nosrati et al. found that a nanocomposite of 2% and 3% titanium dioxide (TiO2) in polypyrrole was the most effective coating. This study sampled photocatalytic coatings detected by spectroscopy (Nosrati et al., 2020). Kumar et al. found the modified coating effective in dye removal (Chandar Shekar et al., 1999; Kumar & Chandramani, 2009). Polyvinyl alcohol (PVA) is adaptable and has low electric charge and heat conductivity, while titanium dioxide's phase and particle size affect nanocomposites' properties, making it suited for solution casting (Mutsak Ahmed & Hasan, 2023; Stribeck & Smarsly, 2005). Using natural colors is disadvantageous. Unfortunately, natural dye-sensitized solar cells (NDSSCs) are less efficient than silicon-based competitors (Alim et al., 2022). Natural dyes reduce crystalline silicon solar cell efficiency, according to multiple studies. Beet, spinach, turmeric, pomegranate, cassava, black sticky rice, and mint leaf pigments have been used as dye-sensitized solar cell (DSSC) sensitizers (Aziza et al., 2023; Kamarulzaman et al., 2023; Karmakar et al., 2022). The study investigates how nanocomposite polyvinyl alcohol and titanium dioxide can boost crystalline silicon solar cell efficiency. The utilization of spirulina and acacia alata colors is also examined. The study examines nanocomposites' characteristics and the relationship between solar cell surface temperature and electricity production using automatic data recorders, solar module analyzers, deposition coating methods, and UV spectroscopy.

Experimental Setup Design Geometry Description of Solar Cell

Figure 1 shows the dimensions of the multi-crystalline silicon solar cell that was used in this investigation, which were 19mm × 52mm, and its specifications used in this research under certain conditions at a temperature of 25 °C are shown in Table 1 below:

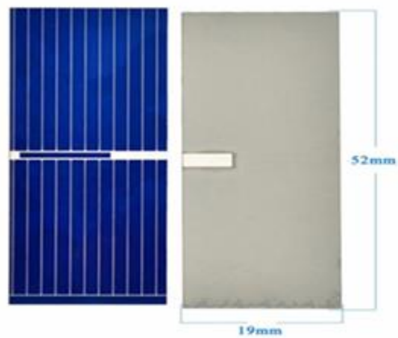

Figure 1. Polycrystalline silicon solar cell.

Table 1. Specifications of A Multi-crystalline Silicon solar cell.

Size (mm)	Maximum power (P_{max})	The voltage at P_{max} (V_{mp})	Current at P_{max} (I_{mp})	Open circuit voltage (V_{OC})	Short circuit current (I_{SC})	Efficiency (%)	Standard test conditions
19 × 52 mm2	0.1 W	0.48 V	0.2 A	0.5 V	0.313A	10	1000 W/m^2, 25ºC

2.1 Preparation of Polyvinyl Alcohol (PVA)

We dissolved one gram of polyvinyl alcohol (PVA) in 50 milliliters of distilled water. We agitated the solution at 300 RPM at room temperature until it became transparent. After filtration with 45µm paper, the solution was left undisturbed until no longer visible in the foam. The liquid was sealed to prevent bacterial growth. To prepare all samples consistently, this method was repeated four times.

2.2 Prepare the Polyvinyl Alcohol/Titanium Dioxide Nanocomposites

TiO2 nanoparticles weighing 0.017g were dissolved in 80 ml of distilled water to make solutions. This created weight-based titanium dioxide solutions. The TiO2 solution was sonicated for four hours. We also made a polyvinyl alcohol (PVA) solution by dissolving 50 milliliters of distilled water in 1 gram and then leaving it at room temperatureThe TiO2 solutions were continually sonicated, added dropwise to the PVA solution, and well mixed. This method was performed for all nanocomposite film concentrations. Figures 2 and 3 illustrate that polyvinyl alcohol in a titanium dioxide solution has various benefits. First, PVA absorbs UV light (300–900 nm). Encasing titanium dioxide nanoparticles in polyvinyl alcohol chains prevents stickiness. Encapsulated particles travel slower at higher PVA concentrations due to solution viscosity. Because PVA makes films well, the TiO2/PVA nanocomposite and TiO2 solution are supposed to form a film on the solar cell. We performed the following procedures during TiO2 dispersion to illustrate the preparation process: After two hours of thorough dispersion, we added 50 ml of PVA to the TiO2 solution at 12.5 ml per 30 minutes. A solar module analyzer and UV-Vis spectroscopy were utilized to assess the produced nanocomposites' optical characteristics and solar cell parameters. K-type thermocouples with data loggers were used to test the film's thermal insulation.

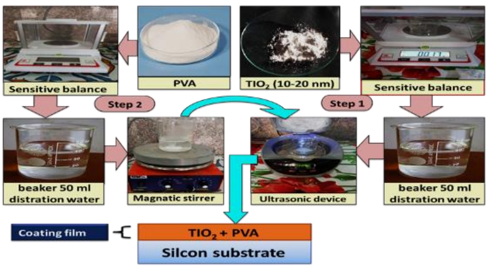

Figure 2. Schematic Diagram of PVA+TiO2 Coating Film Preparation.

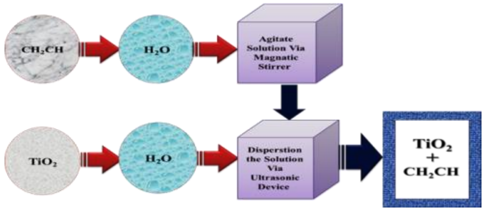

Figure 3. Flow Chart Nanocomposite Preparing.

2.3 X-Ray Diffraction Analysis

X-ray diffraction (XRD) is utilized for the assessment of phase purity and crystallinity in inorganic substances. The XRD spectrum of TiO2 nanoparticles produced electrochemically in a 1100 ml cell solution is illustrated in Figure 4. The nanoparticles were created using a Shimadzu 6000 diffractometer under conditions of 50 kV, 40 mA, and a Cu-K α of 1.540598 A within the 2 Theta range of 10 to 80 , the x-ray diffraction peaks at 2 Theta = 24.208, 36.792, 46.983, 52.982, 61.607, 69.205, and 74.195 are indicative of specific crystallographic planes. It is stated in JCPDS 21-1272 that these reflection peaks are in agreement with the anatase phase of TiO2.

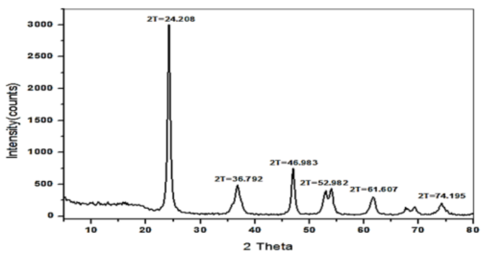

Figure 4. XRD spectrum of TiO2 nanoparticle.

2.4 Preparation of Dye Sensitizer

The colors were obtained from both Acasia alata and algae (Spirulina) using a consistent process. After harvesting, we first rinsed the lush foliage of acacia alata and the spirulina with distilled water. Next, we exposed the leaves to room temperature air in a dimly lit setting to dry them. We crushed the leaves separately using an electric grinder after they were fully dry. Next, we mixed 25 grams of dehydrated leaves from each plant kind with 60 milliliters of acetone. The resultant mixture was sealed and stored in complete darkness for a period of 24 hours. Following this time frame, the solution was filtered using filter sheets to remove any significant debris, resulting in a pure extract free from contaminants. The resulting dye solution was kept in a light-free environment until it was needed; after that, we mixed the natural dye with PVA in equal amounts for coating solar cells. Figure 5 clearly depicts the sequential phases of this procedure.

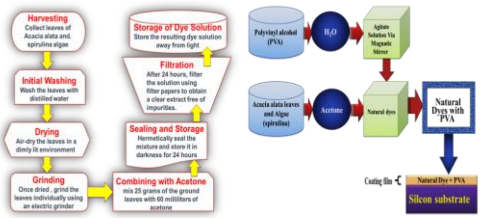

Figure 5. Extraction Steps for Acacia alata Leaves and Algae (Spirulina) Via Acetone and coating for solar cell.

2.5 Testing Rig of Solar Cell and Measurements Devices

The experimental apparatus illustrated in Figure 6 is used as a visual tool to demonstrate the technique used to evaluate the effectiveness of solar cells, both with and without a coating. The system indicated above consists of several components, each of which has a vital function in the entire testing process. Firstly, a halogen lamp serves as the primary source of solar radiation, allowing for the evaluation of the solar cell's performance. Furthermore, a solar power meter is utilized to precisely gauge the magnitude of the solar energy. To thoroughly assess the electrical performance of the solar cell, a solar cell module analyzer is employed, yielding significant insights into its operation. In addition, a data logger device is utilized to accurately measure the temperature of the solar cell and its surroundings using K-type thermocouples. Finally, a laptop is used to carefully store and document all the data gathered from the many measuring devices, guaranteeing a thorough and structured approach to data analysis.

Figure 6. Experimental setup design (rig solar cell test) (1) data logger (2) solar cell module analyzer (3) halogen lamp (4) pyrometer/solar power meter device (5) coated solar cells (6) personal laptop

Results and Discussions

3.1 Ultraviolet-Visible Absorption Analysis

The UV-Vis absorption properties of the prepared nanocomposite and natural dyes were examined by analyzing the UV-Vis spectra of native PVA and TiO_2/PVA nanocomposite and natural dyes across the wavelength range of 300 to 900 nm, as depicted in Figure 7 below. The absorption wavelength of pure PVA was found to be 275 nm. Conversely, the TiO_2/PVA nanocomposite specimens demonstrated the greatest absorption at a wavelength of 359 nm, while the acacia alata dye. exhibited the highest absorption at 423 nm, and the Spirulina algae exhibited the highest absorption at 407nm. Additionally, the nanocomposite with algae dye revealed a peak absorption at 389 nm. It is noteworthy that the results indicated that the dye extracted from Spirulina algae exhibited the highest light energy density among ultraviolet rays. This suggests that nanocomposite films possess the potential to serve as effective UV filters due to their selective absorption capabilities. These findings underscore the prospective applications of these nanocomposite films and the extracted pigments in UV protection.

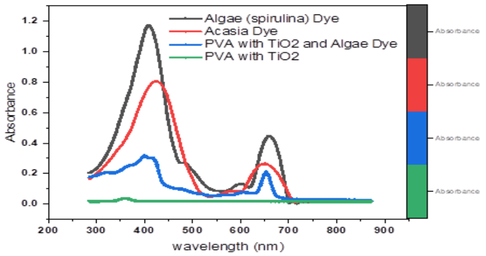

Figure 7. Shows the absorbance and wavelength (nm) for all dyes used in the experimental test.

3.2 Energy Gap Calculations

We calculated energy gaps, specifically the band gap, using the Tauc relationship. This approach checked the band gap of nanocomposite films, polyvinyl alcohol films, and natural dyes (PVA with Acasia alata dye, PVA with Algae dye, TiO2/PVA with Algae dye, and TiO2/PVA nanocomposite). In disordered or amorphous semiconductors, the optical band gap (Tauc bandgap) can be determined using the Tauc diagram. In a tauc plot, the x-axis shows photon energy (hv), and the y-axis shows the quantity (α hv) 1/2, where α is the material's absorption coefficient. The following graph shows the link between (αħ)2 on the y-axis and (ħ) on the x-axis. The band gap values were calculated from the linear extrapolation curves. We used the same method for the remaining forms. The energy band gap for Acasia alata dye (Figure 8) combined with the polyvinyl alcohol was determined to be 1.87 eV. Figure 9 of ALgae (Spirulina) dye paired with polyvinyl alcohol had a 2 eV energy gap, whereas Figure 10 combined titanium dioxide and polyvinyl alcohol with ALgae (Spirulina) dye had a 1.9 eV. Finally, Figure 11 shows the 1.5 eV energy gap for titanium dioxide-polyvinyl alcohol. The algal dye has a 2 eV band gap. However, TiO2 nanoparticles reduced the nanocomposite's band gap when we mixed it with algae. In a predictable fashion, adding TiO2 nanoparticles to nanocomposites reduces or increases natural dye band gaps. Thus, we could coat photovoltaic (PV) panels with TiO2/PVA films and natural pigments with good band gaps to reduce light reflection. These bandgap materials are low-cost, sustainable, and environmentally friendly, yet they also have high electrical efficiency.

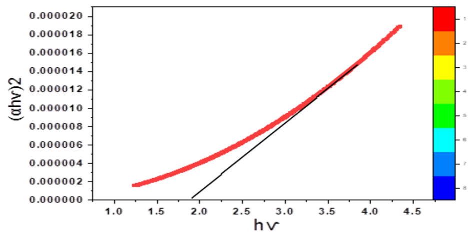

Figure 8. shows the Energy gap of Acasia alata dye.

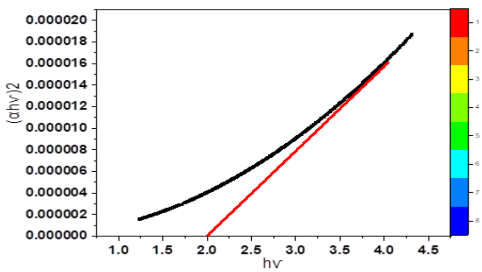

Figure 9. shows the Energy gap of Algae dye

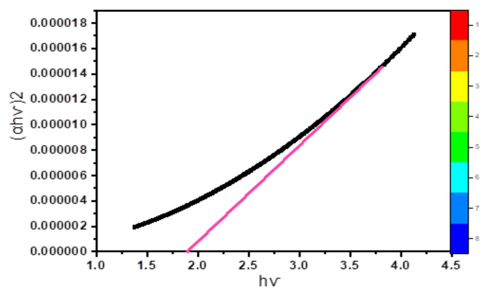

Figure 10. shows energy gap of titanium dioxide-polyvinyl alcohol (Tio2/PVA) and Algae dye.

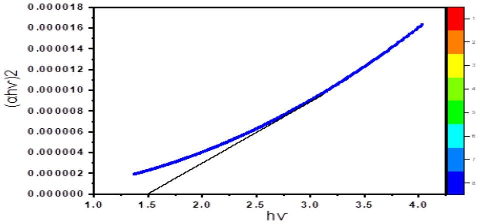

Figure 11. shows energy gap of titanium dioxide-polyvinyl alcohol (Tio2/PVA)

3.3 TiO2/PVA Nanocomposite and Natural Pigment as an Anti-Reflection Thin Layer

X-ray diffraction A high level of reflectance presents a significant challenge for polycrystalline silicon solar cells, resulting in a loss of about 30% of incident energy. This decline in energy absorption consequently diminishes energy generation and thus impacts the overall functioning of the solar cell. To solve this problem, the current study uses a nanocomposite coating made of titanium dioxide (TiO_2) at a concentration of 0.017 grams mixed with polyvinyl alcohol (PVA) at a concentration of 1 gram. This nanocoating is administered to the frontal surface of the solar cell. Regarding the natural dye, it consists of the extract obtained from dried and ground leaves of the acacia tree and algae. 25 grams of dried leaves were combined with 60 milliliters of acetone mixed with polyvinyl alcohol (PVA). UV reflectance spectroscopy was used to look at the reflective properties of the nanocomposite and the natural pigments that were Extracted. As a result, applying coatings using nanocomposites and extracted natural dyes to solar cells contributes to improving their efficiency and reducing light reflection. This coating reduces the temperature of the solar cell and thus improves its efficiency. It also reduces light reflection and increases light absorption, resulting in increased energy production.

3.4 The Effect of (TiO2/PVA) Nanocomposite and Natural Dyes on Solar Cell Temperature

Figure 12 shows the surface temperature of the solar cells after 1-hour exposure to 1000 W/m2 radiation. Initially, all cell surfaces show a uniform temperature of about 25 °C. After that, the temperatures applied to the surfaces of the solar cells gradually increase, reaching high temperatures at the conclusion of the examination, which takes about an hour. We notice that temperatures rise with a direct change over time as the cell heats up to reach high temperatures, and the cells continue to provide good efficiency and capacity. Figure 13 clearly illustrates the distinction between uncoated and coated cells. The test results on the uncoated solar cell showed a higher temperature. According to our observations in Table 3, there is a clear correlation between temperature and maximum power. At 81 °C, we obtained a Pmax of about 70 mW. At a lower temperature of 41 °C, we obtained a Pmax of about 95 mW. We observed that PVA/TiO2-coated cells heated to 73 °C exhibited a Pmax of approximately 107 mW, outperforming cells coated with varying amounts of dye. At a lower temperature of 41 °C., we obtained a Pmax of about 130.2 Mw. The Pmax for cells dyed with acacia dye was about 93 Mw at 77 °C and about 122.6 Mw. at 43 °C. The Pmax for cells dyed with Spirulina algae dye mixed with PVA/TiO2, or nanocomposite, was about 112 mW at 80 °C and about 122.6 mW at 41 °C. We also conducted the same dye for algae but without the nanocomposite, i.e., the algae type Spirulina with PVA. At a temperature of 77 °C, we obtained a Pmax of about 104 mW, and at a lower temperature of 41 °C, we obtained a Pmax of up to 127.7 mW. These results have sparked discussions about the effect of ultraviolet radiation on these temperature outcomes. UV radiation is known to contribute to the degradation of solar devices (Chen et al., 2017; Lee et al., 2010). In the solar cell industry, previous investigations have identified titanium dioxide nanoparticles as effective UV filters in many cases (Perrakis et al., 2020). The natural colors derived from Acasia alata and Spirulina algae were advantageous. This study is unique because it focuses specifically on polyvinyl alcohol with natural dyes, which is a crucial ingredient for producing nanocomposites because of its film-forming properties. These films are very important for figuring out how well PVA/TiO2 works with the natural algae strain Spirulina when the temperature of the solar panel changes. Among the concentrations examined, this filtering coating exhibits the highest UV efficiency at the lowest solar cell surface temperature.

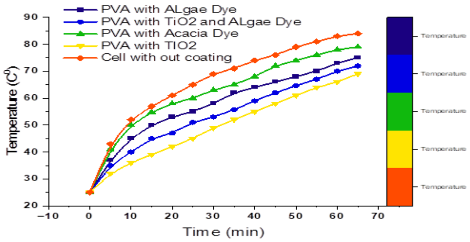

Figure 12. Temperature vs. time nanocomposite PVA/TiO2 and natural dye coating for silicon solar cells

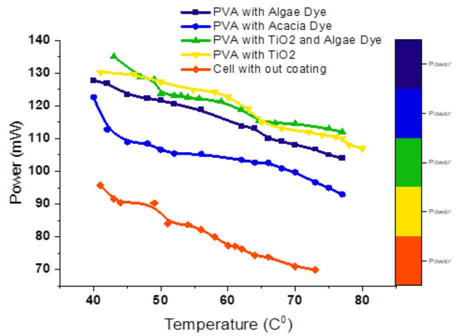

Figure 13. Temperature vs. Power max of nanocomposite PVA/ TiO2 and natural dyes coating for silicon solar cell

Table 2. Show us The PMAX with Temperature at Zero Time and after One Hour from the Test

Samples	P_{MAX} (mW)	Temperature zero time	P_{MAX} (mW)	Temperature after 1-h
Cell without coating	95.8	41 ºC	70	81 ºC
PVA with Acassia alata dye	122.6	43 ºC	93	77 ºC
PVA with Algae (spirulina) dye	127.7	41 ºC	104	77 ºC
PVA/TiO_2 with Algae (spirulina) dye	135	41 ºC	112	80 ºC
PVA with TiO_2	130.2	41 ºC	107	73 ºC

3.5 I-V and P-V Curves Characteristics

Figures 14 and 15 display the electrical properties of a polycrystalline silicon solar cell, specifically its current and power voltage characteristics. Temperature fluctuations and reflection loss might affect these parameters. The effects of dyes on acacia alata, spirulina algae, and a titanium oxide nanocomposite with vinyl alcohol polymer were investigated using a solar module analyzer called PRAVO-200. The testing was performed indoors, with a controlled room temperature of 25°C and a steady radiant flux of 1000 W/m2, while typical lighting conditions were maintained. Each model was subjected to a one-hour test, primarily assessing the anti-reflective impact while disregarding the temperature effect. It was noted that all solar cells with various coatings exhibited a beneficial impact in comparison to the solar cells lacking the nanocomposite or covered with a natural dye. According to the findings, Figure 7 shows that the acasia alata dye had the greatest an absorption peak of 0.80476 at a wavelength of 423 nm and a light reflection of 0.195242.The resulting values obtained were as follows: The maximum power output is 122.6 mw, the open circuit voltage is 0.59 volts, and the short circuit current is 0.28 amperes. On the other hand, the algae (Spirulina) dye showed its maximum absorption peak in Figure 7, reaching a value of 1.16618 at a wavelength of 412 nm. No light reflection was observed,The resulting values obtained were as follows: The maximum power output of the system is 130.2 mw, the open circuit voltage is 0.581 volts, and the short circuit current is 0.313 amperes. Regarding the algae (Spirulina) dye combined with the nanocomposite PVA/TiO2 (Figure 7), the absorption peak reached its maximum value of 0.31678 at a wavelength of 400 nm,The light reflection was measured to be 0.68322, and the resulting values obtained were as follows: The maximum power output is 128.7 mw, the open circuit voltage is 0.593 volts, and the short circuit current is 0.258 amperes. Regarding the nanocomposite PVA/TiO2 in same Figure 7 the maximum absorbance peak of 0.0379 observed at a wavelength of 359 nm, and the light reflectivity was measured to be 0.9621, and the values obtained were as follows: The maximum power output of the system is 130.3 mw, the open circuit voltage is 0.59 volts, and the short circuit current is 0.259 amperes. From the data described above, it can be concluded that there is a direct relationship between nanocomposites and natural dyes upon coating, which led to improved power output in contrast to the solar cell without coating. The reflectivity and absorbance were calculated following the mathematical relationship:

Reflectance = 1 - Absorbance (1)

As is known, after an hour, the temperature will rise and thus affect the work of the solar cells. According to the data shown in Table 4, the solar cell's power production was least affected by temperature when it reached 80 °C for both PVA/TiO2 and algal dye. The increase in temperature resulted in a decrease in power output percentage. Specifically, the maximum power output (Pmax) was 128.7 mW, the open-circuit voltage (VOC) was 0.581 V, the short-circuit current (ISC) was 0.258 A, and the overall efficiency was 13.03%. In contrast, the uncoated solar cell was exposed to same circumstances. The solar cell exhibited the least significant decrease in power production when exposed to a temperature of 81 °C. At this temperature, the power output loss was measured to be Pmax: 70 mW, VOC: 0.489 V, and ISC: 0.315 A, resulting in an efficiency of 7.09%. The data displayed a significant disparity in the impact of temperatures on these cells. The coated cells demonstrated a distinct ability to generate high power output at elevated temperatures, whereas the uncoated cells exhibited lower power output. This discrepancy can be attributed to the influence of concentrations on the absorption of ultraviolet rays.

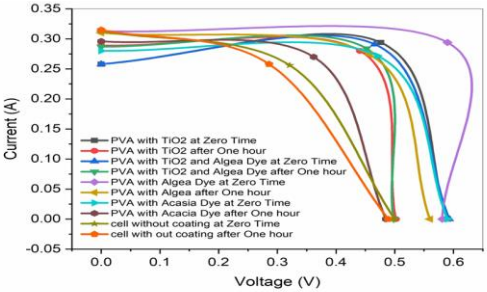

Figure 14. Current vs. Voltage Nano-composite PVA/ TiO2 and PVA / natural dyes coating and un-coating to crystalline Si solar cell

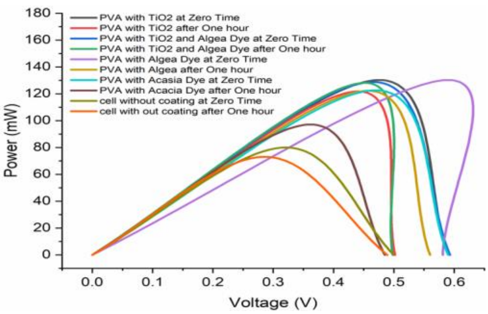

Figure 15. Power vs. Voltage to coating and un-coating mc-si solar cells

Table 3. Data Extracted from Solar Module Analyzer (PROVA- 200A) for Coating and without Coating (WOC) Polycrystalline Silicon Solar Cell

Samples	**V_{OC} (V)**	**I_{SC} (A)**	**P_{MAX} (mW)**	**Temperature after 1-h**	**Reflection**	**η (%)**
Cell without coating	0.489	0.315	70	81 ºC	0.36	7.09%
Acasia alata dye	0.59	0.2	122.6	77 ºC	0.195242	12.41%
Algae (spirulina) dye	0.581	0.313	130.2	77 ºC	No light reflection	13.18%
PVA/TiO_2 with Algae (spirulina) dye	0.593	0.258	128.7	80 ºC	0.68322	13.03%
PVA / TiO_2	0.59	0.259	130.3	73 ºC	0.9621	13.19%

Conclusion

Using different TiO2/PVA nanocomposites and natural dye coatings has greatly impacted the efficiency of silicon solar cells. Compared to uncoated solar cells, the results showed higher efficiency for silicon solar cells coated with natural dye from Acaia dye, Spirulina algae, and titanium dioxide nanocomposite, as the results showed the energy gap between natural dyes and nanocomposites. The energy gap of Acacia alata pigment was 1.87 eV. In comparison, the energy gap of algae pigment (Spirulina) was 2 eV, the energy gap of TiO2/PVA pigment was 1.5 eV, and TiO2/PVA with algae. It was found that the spirulina dye reached 1.9 volts. Furthermore, the study used a solar module analyzer to examine the nanocomposite's effect on solar cells' efficiency. The results clearly showed the positive effect of the nanocomposite with natural dyes on solar cells. Furthermore, the study investigated the effect of temperature on solar cell energy production. The nanocomposite with natural dyes was observed to have mitigated temperature-induced power loss, in contrast to uncoated solar cells, this study tells us a lot about how a TiO2/PVA nanocomposite with natural dyes can improve the performance of polycrystalline silicon solar cells when temperatures change.

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