The Effect of Titanium Dioxide Nanoparticles on the Surface Properties of Photovoltaic Solar Panels

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Abstract

The hydrophilic and photocatalytic properties of titanium dioxide (TiO_2) nanoparticles offer a cost effective solution for self-cleaning solar panels. In this study TiO_2 nanocolloids were prepared using a mixture of tetraethylene glycol (TEG), titanium (IV) oxysulfate ($TiOSO_4$), and sodium hydroxide (NaOH). The solar panels were cleaned with ethanol and a Piranha solution to eliminate any organic residue on the glass before applying TiO_2 nanoparticles. The solar panels were tested with three iterations of various debris applied to the glass surface. The panel with the TiO_2 nanoparticles coating showed much lower rates of debris retention over the control panel. This directly affected the measured current and voltage when tested in an enclosed light box. The control panel was found to have the lowest values. It is of interest to conduct a different method of debris exposure to also test for sustained durability of the applied solutions over a marked period of time.

I Introduction

By the end of 2018, the total solar photovoltaic installation in the United States reached 64.2GW capacity, and it is expected to double over the next five years [1]. It is important to know that this capacity is highly dependent on the surface condition of the solar panels. When photovoltaic (PV) panels are mounted in exposed environments, the surface can be contaminated. If not cleaned effectively and often, light energy can be reflected off of the surface or blocked [2]. The accumulation of organic materials (i.e. dust, pollen, dirt, snow, etc.) on PV panels can greatly reduce the generated power [3]. Different methods have been proposed to clean the surface of the solar panels. These include mechanical, electrostatic, and coating methods. The mechanical methods can vary from brushing, air-blowing, ultrasonic, and vibration. These methods can require significant amounts of human labor in order to maintain large solar farms [4]. Both electrostatic and coating methods are considered as self-cleaning since they do not require manual labor and moving mechanical parts. The electrostatic method works well in space where there is no moisture and poses a problem when used in the earth atmosphere. In addition, it needs to embed transparent electrodes in solar panels and are not suitable for field application [4]. Surface coating methods coat a thin film to modify the surface energy or photolysis process. Three types of coatings have been researched: superhydrophobic, superhydrophilic, and photocatalytic coatings.

It was of interest to take advantage of photocatalytic and hydrophilic properties found in Titanium Dioxide (TiO_2) nanoparticles. The photocatalytic properties of TiO_2 allow for the split of organic dirt in the presence of ultraviolet (UV) light. This reduces the sticky characteristic that attracts particulates to the surface of the PV panel [5]. The hydrophilic properties are of importance to the self-cleaning of a solar panel because water will not bead up and roll off, but rather diffuse on the surface of the glass, spreading over a larger area, and allowing for cleaning evenly in the lightest rainfall [5]. Also, it is possible to apply to the already installed solar panels. In this study, TiO_2 nanoparticles were synthesized, the methods of applying the nanoparticles on the solar panels were explored, and their effects on the surface properties of solar panels were investigated.

II Experimental Method

A. Synthesis

The TiO_2 nanoparticles were synthesized in a 125mL tetraethylene glycol (TEG) (Sigma-Aldrich 110175-1KG) solvent. 2.702g of titanium (IV) oxysulfate (Sigma-Aldrich 14023-100G) was added to the solvent and stirred for 30 minutes using a magnetic plate stirrer at room temperature. During this time, 3.024g sodium hydroxide pellets (Sigma-Aldrich 567530-250GM) dissolved in deionized water were gradually added to the solution. This solution then underwent a reflux process for 180 minutes at 440K resulting in a TiO_2 nanocolloid solution [6].

B. Application and Test

The solar panel surfaces were cleaned with ethanol and deionized water. A Piranha solution (H_2SO_5) was then applied to the surface for 30 minutes to eliminate any remaining organic matter and hydroxylate the surface [6]. The coating was then applied by pouring the nanocolloid solution (spreading evenly with a stir rod) directly on the cleaned surface. This solution was left to sit on the surface for 120 minutes to allow for the nanoparticles to adhere. To validate the application of the coatings, an enclosed light box with a 300W ELH lamp/filters was used to test the solar panels. The coated panels were tested against a non-coated control with varying amount and types of debris applied to the surfaces.

III Results and Discussion

To determine the effectiveness of the self-cleaning coating on the panels, the following four conditions of debris were tested:

- Nominal conditions (no debris)
- Wet conditions (20g H_2O retention)
- Dust conditions (1g $MgCO_3$ retention)
- Wet with dust conditions (20g H_2O with 1g $MgCO_3$ retention)

After the panels were applied with debris, they were tilted at a 45° angle for 30 minutes in order to observe the debris retention. Figure 1 shows two solar panels, one with and the other without coating, at the wet condition. The panel on the left is coated, and is shown prior to being tilted for the allotted time. The panel on the right is not coated, and is shown prior to being tilted as well. Tilting provided a way to determine which panel was most effective in deterring organic build-up. After 30 minutes, the panels were rotated back to 0° and were placed in the enclosed light box for testing.

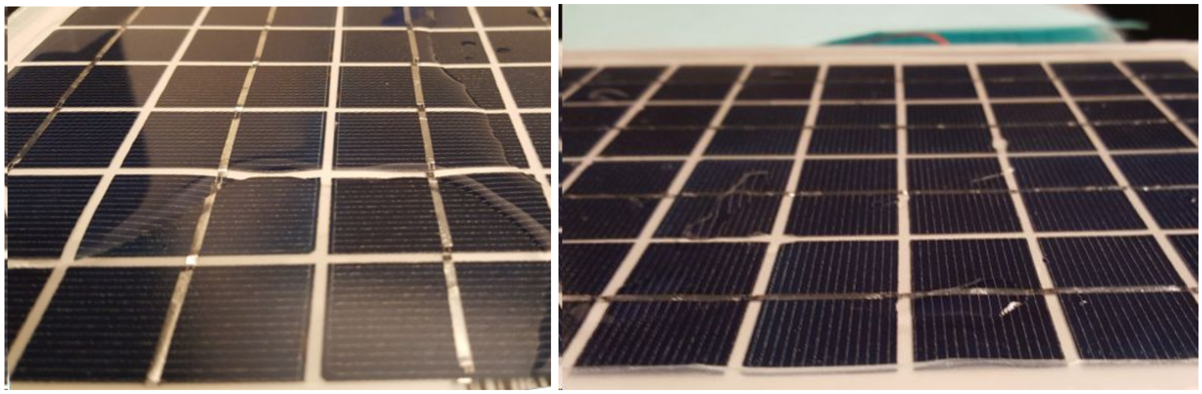

Figure 1. Left: Panel with coating under wet condition
Right: Panel without coating under wet condition

The voltage and current outputs from the panels were measured with a 1kΩ resistor load using digital multimeters. Figure 2 shows the test configuration.

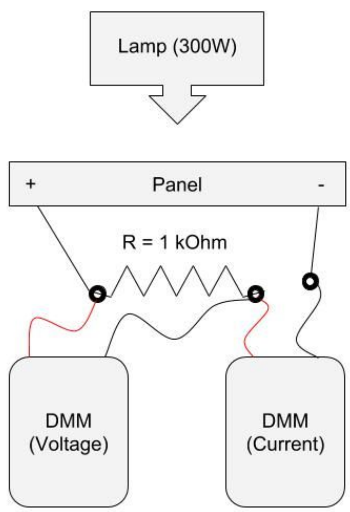

Figure 2. Solar panel test setup with 1 kΩ load

Six solar panels, three with coating and three without, were tested under different conditions. The results are summarized in Tables 1, 2, 3, and 4.

Table 1: Test results for solar panels at nominal conditions

Panel	Voltage (V)	Current (mA)	Power (mW)
Control	11.44	11.60	132.7
Panel with coating	11.63	11.70	136.1

Table 2: Test results for solar panels at wet conditions

Panel	Voltage (V)	Current (mA)	Power (mW)
Control	12.18	12.20	148.6
Panel with coating	12.00	12.10	145.2

Table 3: Test results for solar panels at dust conditions

Panel	Voltage (V)	Current (mA)	Power (mW)
Control	8.77	8.80	77.18
Panel with coating	11.72	11.80	138.3

Table 4: Test results for solar panels at wet with dust conditions

Panel	Voltage (V)	Current (mA)	Power (mW)
Control	11.05	11.10	122.7
Panel with coating	11.88	12.00	142.6

Under nominal conditions, seen in table 1, the panels exhibited similar output power. When subjected to wet conditions on the surface, the panels had higher power outputs as seen in table 2. This may be due to the cooling effects of the tap water used to condition the panel, causing an increase in PV efficiency [7]. The dust condition in table 3 showed a 56% difference in power output between the nominal and experimental panels. In this instance the coated panel reached the nominal conditions output, while the untreated panel decreased in performance. This suggests a significant improvement in panel performance when applied with the nano-coating. Table 4 exhibited a 15% difference in the power output of the panels. In this instance the coated panel had increased efficiency from the nominal condition, similar to the effects seen in table 2. However, due to the presence of the dust in the condition, the output power in table 4 did not exceed the output power seen in table 2. The control panel saw a decrease in efficiency in the wet and dust conditions, again suggesting an increase in panel performance when treated with the nano-coating.

IV Conclusions

The PV panels with nanocolloid coatings applied to their surface were studied to determine the effectiveness of the self-cleaning properties of TiO_2 nanoparticles. When observing the power outputs of each panel, it was seen that the coated panel exceeds the power output of the control panel in three-out-of-four conditions tested which indicates the effectiveness of the application of coating on the solar panels. It is of interest in the future to test the long-term effectiveness of the coatings on the solar panels.

Acknowledgments

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