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Reducing the effect of dust deposition on the generating efficiency of solar PV modules by super-hydrophobic films

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ABSTRACT

Dust deposition on photovoltaic (PV) modules is related to environmental and weather conditions and results in a reduction in power generation efficiency over time. The effects of films on the transmittance can be obtained by testing sample glasses coated with silicon and fluorine super-hydrophobic films with a spectrophotometer. Red soil particles with a diameter of 25 μm were selected to simulate the process of natural dust deposition on PV module samples, and an incubator of constant temperature and humidity was used to simulate the condensation process. PV module samples were irradiated by a solar simulator after the aforementioned simulation process, and the effects of different amounts of sediment in unit areas on the photovoltaic properties and spectral characteristics were determined. The experimental results indicate that the influence of dust on the power generation efficiency of PV modules coated with fluorine super-hydrophobic film is smaller than that for PV modules coated with silicon super-hydrophobic film and that the super-hydrophobic films can not only greatly reduce the dust accumulation on the surface of PV modules but also increase the generating efficiency.

1. Introduction

Plateau desert areas are important areas for the development of photovoltaic (PV) power generation due to the long periods of light and large irradiation areas. However, the gales in plateaus make it easy for PV module surfaces to accumulate significant amounts of dust, reducing the power generating efficiency of PV components by 10–25% (Fan et al., 2015). Our research team conducted a practical investigation at the Qinghai, China PV power station and confirmed that dust deposition has a serious direct impact on PV power generation, as shown in Fig. 1.

Mekhilef et al. (2012) confirmed that temperature, humidity and dust in the external environment affected the power generating efficiency of PV modules but did not propose a solution. The influence of sand dust on the shielding of PV modules was analyzed from the spectrum perspective, and Hassan et al. (2014) proved that there is a relation between the dust density and spectral transmittance. By analyzing the force of dust on the plate surface, Meng (2015) designed a mechanical device to remove the dust, but the device installation caused a certain degree of panel sheltering. The cost and maintenance of the device are also significant, which indirectly increases the cost of electricity. Outdoor installation of the PV modules made the dust deposition to be the most immediate problem about the efficiency loss. Paudyal and Shakya (2016) conducted the experiment in Kathmandu for 5 months, the result showed a negative correlation between humidity and dust accumulation. Relative humidity increased the dust particles adhesion force to a surface which increased the difficulty of removing dust. Therefore, a super-hydrophobic film with self-cleaning ability has been widely used in the automotive, construction, aviation, and PV industries among others (Zhang and Lv, 2015). Many experts have investigated improvements in the processing technology of super-hydrophobic films to improve the performance of other aspects and thus increase the range of applications of super-hydrophobic films (Yao et al., 2009; Gwon et al., 2014; Nayak et al., 2012; Strauss et al., 2015). Using nanosilica modified with FAS-17[1] as the filler, Guo et al. (2013) adopted different resins as a matrix to develop a super-hydrophobic coating for protecting the exterior surfaces of aircraft. Gwon et al. (2014) prepared a grass-like porous CaF_2 nanostructure with self-cleaning and antireflective properties on ITO[2] glasses via glancing angle deposition, which can be used for the industrial-scale production of solar cells. Li et al. (2012) formed porous silicon-nanoparticle (Si-NP) films on the solar cell surface to increase the light absorption rate,

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[1] Heptadecafluoro-1,1,2,2-tetradecyl)trimethoxysilane.
[2] Indium Tin Oxide.

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Fig. 1. Dust deposition (Taken from PV power station).

thereby increasing the efficiency of their PV power generation, but did not reduce the impact of the external environment on the power generating efficiency of the panels. Many factors in the natural environment will lead to the reduction of PV power generation efficiency, Lappalainen and Valkealahti (2017) studied the mismatch losses caused by moving clouds, Topić et al. (2017) given out a shading factor which is calculated according to the given ratio of the sunny part and the total module surface that can be calculated using. Dust deposition plays a crucial role in obstructing the solar irradiance reaching solar cells and thus reduces the power generation. Therefore, this study focuses on developing a method to reduce the impact of the external environment, particularly dust deposition, on the efficiency of PV modules.

In the absence of other interference items (e.g., temperature, humidity, dust), this paper selects dedicated packaging glass for the PV module samples, placing plate samples coated with laboratory-prepared silicon, fluorine super-hydrophobic materials and substrates into a spectrophotometer instrument to test the differences in the transmittance. The samples were then placed in a device that simulated dust deposition to study the effects of the surface residual dust of different sand cover ratios on light transmittance after the same condensation process. Preparing three modules of the same type, a spray gun was used to coat silicon and fluorine super-hydrophobic materials on two of the samples, whereas the remaining samples were left uncoated as a reference. First, the sun simulator was used to irradiate the three models, and then, the solar module tester was used to test the PV characteristics of the three models. In this experiment, 25 μm red clay particles were used as a dust source to verify that the super-hydrophobic property can still ensure the efficient power generation of PV modules in such a harsh environment. After the dust deposition and condensation processes were simulated, we investigated the impact of changes in the sand cover ratio on the PV modules coated with super-hydrophobic films by monitoring their output power and I-V characteristic curves.

2. Experiment

2.1. Experimental reagent

The main reagents used in the experiment are shown in Table 1.

Table 1
Main reagents used in the experiment.

Number	Reagent name	Manufacturer
1	Nanometer SiO_2	Hefei Xiang Zheng Chemical Technology Co., Ltd.
2	Butyl Acetate	Hefei Xiang Zheng Chemical Technology Co., Ltd.
3	Fluorinated resin	Shandong Haihua Group Co., Ltd
4	Polydimethylsiloxane	Sichuan Daxing Pohua Chemical Co., Ltd
5	Ethanol	Shanghai Xiang Lan Chemical Co., Ltd.
6	Clean hydrochloric acid	Shanghai Xiang Lan Chemical Co., Ltd.
7	Nano polishing powder	Nanjing Baoning Chemical Co., Ltd

2.2. Experimental instruments

The main experimental equipment required in the experiment is shown in Table 2.

2.3. Coating preparation

2.3.1. Substrate cleaning

The substrate used to prepare the super-hydrophobic films is encapsulation glass measuring 130 mm × 130 mm with a thickness of 3.2 mm, used specially for PV modules. We first placed the glass into a clean hydrochloric acid solvent with a concentration of 10% for a 20-min ultrasonic cleaning to etch the surface oxide and rinse with water. Then, we polished the glass surface with nano polishing powder detergent. Next, we cleaned the glass in an ultrasonic cleaning machine for 20 min. Finally, we rinsed the sample substrate with clean water and performed a drying process in the drying oven.

2.3.2. Preparation of the coating

The transparent nanosilica material liquid was dispersed in butyl acetate solvent at a mass ratio of 11:20 and stirred with a sand mill at room temperature for 24 h to prepare a super-hydrophobic silicon film. It was then mixed with 10% fluorinated resin, 60% polydimethylsiloxane and 30% ethanol, stirred and mixed with a sand mill for 12 h, and the mixture was introduced into the nano-SiO_2 particles at a mass ratio of 55:12 to obtain a fluorine-based super-hydrophobic film.

The spray coating process in this experiment is simple, low cost and easy to operate. The super-hydrophobic material prepared as detailed above is filled into the container of the spray gun, and compressed air is injected to maintain a spraying pressure of 0.7 MPa and a spraying distance of 20 cm. The coating mixture is atomized into small liquid particles under the action of compressed air and deposited onto a clean glass surface. We changed the coating time and flow to control the coating thickness. To reduce the experimental operation error, we produced two samples for each type of super-hydrophobic film and numbered the samples as follows: S_1 and S_2 for the silicon class, S_3 and S_4 for the fluorine class, and S_5 and S_6 for the substrate.

2.4. Environmental simulation

2.4.1. Selection of the dust

The distribution data of dust particle size by volume percentage provided by Jiangsu Feiyang Powder Technology Co., Ltd. indicate that the dust particles that easily remain on the surface of the PV module are smaller and that the majority of the residue comprises small-sized particles (25 μm). The main components of natural dust are SiO_2, Fe_2O_3