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Suppression of dust adhesion on a concentrator photovoltaic module using an anti-soiling photocatalytic coating

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Abstract

An anti-soiling layer was coated on the surface of polymethylmethacrylate (PMMA), which is the primary material of Fresnel lenses for concentrator photovoltaics. The layer was prepared by coating the photocatalytic surface layer with modified WO_3 and partially hydrolyzed tetraethyl orthosilicate. When sand was discharged onto the PMMA samples, the mass of adherent sand was more than 0.010 g for the sample without the coating and approximately 0.005 g for the sample with the coating. The electrostatic potential of the sample without the coating increased with increasing amount of incident sand, reaching a maximum value of 0.25 kV. On the other hand, the electrostatic potential of the sample with the coating was suppressed to 0.10 kV. The presence of electrostatic charges on the surface of the samples was a main factor for the adhesion of sand, and it could be suppressed by the anti-soiling photocatalytic layer.

Keywords: Concentrator photovoltaic; Anti-soiling; Fresnel lens; Photocatalyst; Electrostatic potential

1. Introduction

Multijunction solar cells have attracted increasing attention for applications in concentrator photovoltaic (CPV) systems owing to their high conversion efficiencies (Yamaguchi, 2003; Yamaguchi et al., 2006; Takamoto et al., 2005; Nishioka et al., 2004; Guter et al., 2009). Light concentration is one of the important issues for the development of an advanced PV system using high-efficiency solar cells. In particular, high-efficiency multijunction cells under high light concentration have been investigated for terrestrial applications (Jaus et al., 2011; Nishioka et al., 2006; Araki et al., 2006, 2010).

The radiation received by the cells inside a PV module is lower than the radiation arriving at the module surface. The causes of this energy loss are soiling on the surface of the module and losses owing to light reflection and absorption by the materials covering the cells (Garcia et al., 2011; Haeberlin and Graf; 1998; Elminir et al., 2006). A CPV system uses an optical system to collect sunlight and focus it onto the solar cells. Since the CPV system can only use the direct-beam component of sunlight, a significant proportion of the light is scattered and lost when the collector surfaces are soiled because the optical system cannot focus the scattered light onto the solar cells. By contrast, conventional non-concentrating panels can use both direct and indirect light, which means flat-panel PV systems are much less sensitive to soiling than CPV systems (Hammond et al., 1997; Vivar et al., 2010). For the development of high-efficiency CPV systems, we must therefore consider the impact of dust accumulation on the Fresnel lenses in CPV modules. PV systems must be introduced on a very large scale to generate large quantities of power because solar energy is low density by nature. Hence, their enormous potential can be fully exploited if the world's deserts can be made available (Ito et al., 2003, 2008; Adiyabat et al., 2006). When installing CPV systems in desert

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areas, we must, however, take into account the effect of collision and adhesion of sand on the modules' Fresnel lens. When sand remains attached to the lens surface, it can become firmly fixed in place by moisture such as dew and the transmittance of light through the lens is interrupted. Therefore, it is very important to avoid this type of surface adhesion on CPV optics.

In our previous work (Nabemoto et al., 2012), an anti-soiling layer consisting of a WO_3 photocatalyst was coated on a polymethylmethacrylate (PMMA) substrate. The samples with and without the anti-soiling coating were exposed outdoors on the roof of a building at the University of Miyazaki (Miyazaki, Japan). The effect of the anti-soiling layer was remarkable: after 8 months of exposure to the elements, the reduction rate of the photocurrent was 9.6% in the CPV without the anti-soiling coating, but it was suppressed to 3.3% in the CPV with the anti-soiling coating.

In this study, we coated the anti-soiling layer on the surface of PMMA, which is a primary acrylic material used for the manufacture of Fresnel lenses for CPV modules. The relationship between the electrostatic potential and adhesion of sand on a Fresnel lens was evaluated, and the effect of the anti-soiling layer was assessed.

2. Experimental procedure

In this study, an acrylic PMMA (size = 3 cm × 3 cm, thickness = 2 mm; SUMIPEX-E000, Sumitomo Chemical Co., Ltd., Japan) plate was used as the substrate and an anti-soiling layer was coated on its surface.

Fig. 1 shows the schematic diagram of the sample examined in this study. The acrylic urethane capping layer and the inorganic/organic nanograded intermediate layer (Ube-Nitto Kasei Co., Ltd., Japan) were first coated on the PMMA surface. The anti-soiling layer was prepared by using modified WO_3 (ILUMIO®, Sumitomo Chemical Co., Ltd., Japan) and partially hydrolyzed tetraethyl orthosilicate (Wako Pure Chemical Industries, Ltd., Japan) in the photocatalytic surface layer. The three layers were deposited by the spin-coating method. The acrylic urethane capping layer improved the adhesion of the upper layers as it shielded them from the oligomers exuding from the PMMA substrate. By depositing the inorganic/organic nanograded intermediate layer, local variations in the layer components and the refractive index were introduced. The PMMA substrate could be protected from the photocatalyst, and the reflectance could be reduced. The anti-soiling photocatalytic surface showed a self-cleaning property driven by both photo-reactivity under the sun and super-hydrophilicity in the rain.

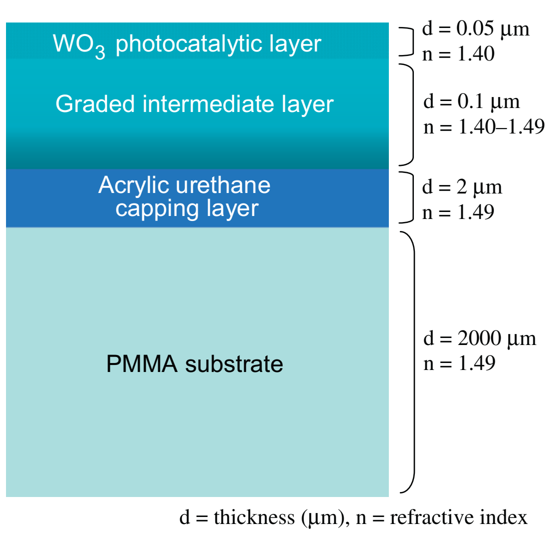

Fig. 1. Schematic diagram of the sample with an anti-soiling coat that was examined in this study.

Since the main component of desert sand is silica, silica sand (No. 6-3, Toyo Matelan Co., Ltd., Japan) was discharged onto the substrate using a sand-falling system (velocity = 1.9 m/s). The distribution in the particle size of the silica sand was 63–250 µm, which was similar to that of desert sand. The incident angle was 45° and the experiment was carried out at room temperature.

The electrostatic potential of the sample was measured with a digital static meter (KSD-2000, Kasuga Electric Works Ltd., Japan), and the mass of the sample was measured with an electronic balance.

3. Results and discussion

Fig. 2 shows photographs of the samples with and without the anti-soiling coating after the sand impingement (velocity = 1.9 m/s, sand content = 15 g). The incident sand adhered on the surface of the sample without the anti-soiling coating. On the other hand, there was much lower adhesion of sand on the sample with the anti-soiling coating, proving the effectiveness of the anti-soiling coating.

Every time 1 g of sand had been discharged onto the sample, we measured the electrostatic potential and the amount of adherent sand for the samples with and without the anti-soiling coating. Fig. 3 (a) and (b) shows the mass of the adherent sand and the electrostatic potential of the samples with and without the anti-soiling coating.

The mass of the adherent sand was more than 0.010 g for the sample without the coating and approximately 0.005 g for the sample with the coating, suggesting that sand adhesion was suppressed by the anti-soiling coating.

The electrostatic potential of the sample without the coating increased with increasing amount of incident sand, reaching a maximum value of 0.25 kV. On the other hand, the electrostatic potential of the sample with the coating was suppressed to 0.10 kV.

We determined that the electrostatic charges on the surface of a sample were the main facilitators of sand adhesion, and their presence could be suppressed by the anti-soiling photocatalytic layer. The layer with WO_3 contained many hydroxyl groups (–OH) that adsorbed water