G-2-02 Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp421-422

A PDMS-TiO_2 Composite Anti-Reflection Film for Enhanced Efficiency in Organic Photovoltaic

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Abstract

Suppressing light reflection in organic photovoltaic devices is critical for the enhancement of efficiency. We developed a method of fabricating a flexible anti-reflection thin film using a composite of polydimethylsiloxane and TiO_2 nanoparticles. By integrating this film with the organic photovoltaic devices, we successfully demonstrated an efficiency enhancement of 10.6% at 0° light incidence (vertical incidence) to 54.6% at 80° light incidence.

1. Introduction

Photovoltaic devices, which convert solar energy into electrical energy, are considered one of the most potential clean energy solutions in the future. Beyond the conventional inorganic semiconductor based bulky photovoltaic devices which have already gained a lot of attention and applications, organic photovoltaic (OPV) devices possess merits such as flexibility, light-weight, low-cost, and simple and fast fabrication [1]. These allow OPV to be synthesized on curved and soft substrates, which give advantages of OPV in applications such as portable, textured or on-skin devices.

The solar energy loss from light reflection is always a big issue and has been researched for over decades. Utilizing light diffusing structures have been demonstrated to effectively suppress light reflection and enhance the power conversion efficiency (PCE) [2]. Furthermore, compared with the multi-layered anti-reflection film, the subwavelength structured diffusing anti-reflection usually shows good performance with a wide range of light incidence angle [3]. However, the conventional light diffusing anti-reflection layer is usually fabricated on rigid substrate and patterned by etching methods [4]. This is not compatible with the flexible and simple fabricated OPV applications.

In this work, we made an anti-reflection film by a composite of polydimethylsiloxane (PDMS) and TiO_2 nanoparticles with simple fabrication process. This film shows good flexibility with a thickness of only around 100 μm, which has very little affect on the flexibility and light-weight of OPV devices. Integrating this flexible anti-reflection film with flexible OPV, we succeed to enhance the PCE of solar cell under a wide range of light incidence. Notably, the enhancement reaches 54.6% at a large light incidence angle of 80°.

2. PDMS-TiO_2 Composite Film Fabrication

Nanoparticles with high refractive index dispersed in a transparent substrate is a common structure of light diffuser. One of the common high refractive index materials for this purpose is TiO_2 [5]. To achieve good visible light diffusing ability while maintain high transmittance, TiO_2 nanoparticles with a diameter around 300 nm are selected.

The fabrication process of the PDMS-TiO_2 composite film is depicted in Fig. 1. First, TiO_2 nano powder with an average diameter of 300nm (rutile, US Research Nanomaterials) is mixed with ethanol in a weight ratio of 1:14 to form a TiO_2 paste. Several drops of Triton™ X-100 (Sigma-Aldrich) were also added to stabilize the TiO_2 dispersion. The TiO_2 paste is blade coated onto a glass substrate which is prior treated by O_2 plasma for 15min. The TiO_2 layer is then annealed in an oven at 370 °C for 3 hours to remove the solvent and form a porous TiO_2 nanoparticle structure. Subsequently, a thin layer of PDMS (SYLGARD™ 184) is spin coated onto the TiO_2 layer at a speed of 1000 rpm for 1 min. After the PDMS is cured at 120 °C, the top surface TiO_2 nanoparticles embedded into PDMS will be peeled off together with PDMS, forming an antireflection film with both good light diffusing and transmitting ability.

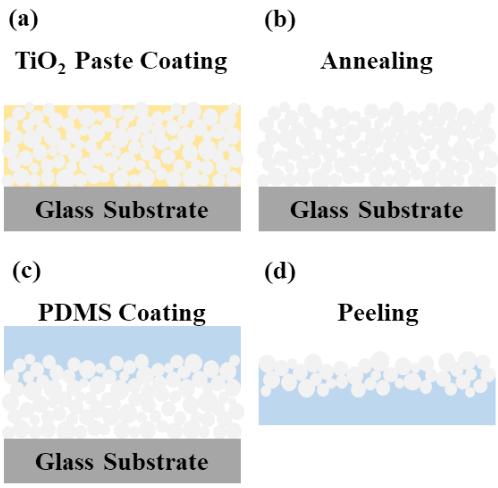

Fig. 1 Fabrication process of the PDMS-TiO_2 composite film. (a) Blade coat TiO_2 paste onto a glass substrate. (b) Anneal the TiO_2 paste. (c) Spin coat PDMS onto the porous TiO_2 layer. (d) Peel off the PDMS-TiO_2 composite film.

Figure 2 shows the images of the anti-reflection film. Figure 2 (a) shows the SEM image of the porous structure of TiO_2 nanoparticles formed after annealed at 370 °C. The porous structure helps PDMS to be sunk in and maintains the TiO_2 nanoparticles to be not too dense to cause too much light back scattering. During the peeling off step, TiO_2 particles with PDMS sunk around will be peeled off together, resulting to a TiO_2 nanoparticles randomly embedded PDMS surface with high roughness, as shown in Fig. 2 (b). This rough surface with TiO_2 nanoparticles gives a strong interaction with visible light and helps light diffuse through the film. The cross-sectional image of the PDMS-TiO_2 film under laser microscopy is shown in Fig. 2 (c). According to the cross-sectional image, the TiO_2 nanoparticles on the film surface are not completely continuous. The average thickness of the TiO_2 embedded area is around 1-2 µm, which provides the film with high visible light diffusing ability while maintaining enough light transmittance. The total thickness of the PDMS-TiO_2 composite film is around 100 µm. It exhibits good flexibility and stretchability due to the PDMS layer.

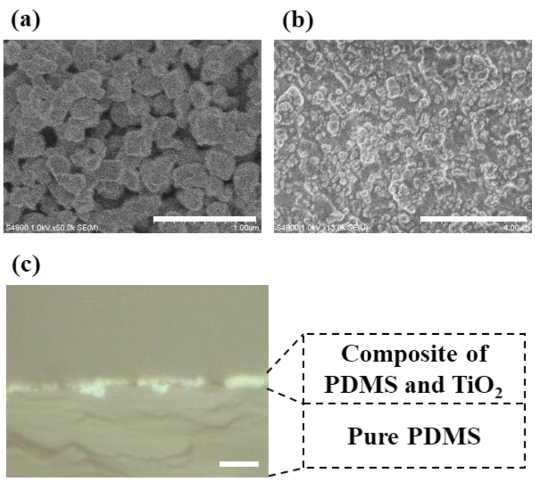

Fig. 2 (a) SEM image of porous TiO_2 nanoparticles on glass substrate after annealed at 370°C. (Scale bar: 1 µm) (b) SEM image of the fabricated PDMS-TiO_2 film showing TiO_2 nanoparticles are randomly embedded on the PDMS surface. (Scale bar: 4 µm) (c) Optical microscopic cross-sectional image of the anti-reflection film. (Scale bar: 5 µm)

3. Results

To demonstrate the ability of PCE enhancement in OPV owing to the introduction of the anti-reflection film, the characteristics of an OPV device attached with this PDMS-TiO_2 composite film was investigated using a solar simulator. In addition, PCE enhancement was measured under various light incidence angles. The experiment setup is shown in Fig. 3.

The experiment results are shown in Fig. 4. The left axis is the PCE of the OPV under different light incidence angles with or without the PDMS-TiO_2 film attached, and the right axis is the enhancement percentage after the antireflection film attached. At 0° light incidence (vertical incidence), owing to the suppression of light reflection, the PCE is increased from 9.9% to 10.9%, which gives an enhancement of 10.6%. Furthermore, the effect of anti-reflection is more significant when the incidence angle becomes larger. At a large incidence angle of 80°, the PCE is significantly increased from 1.4% to 2.4%, with the enhancement percentage reaches 54.6%.

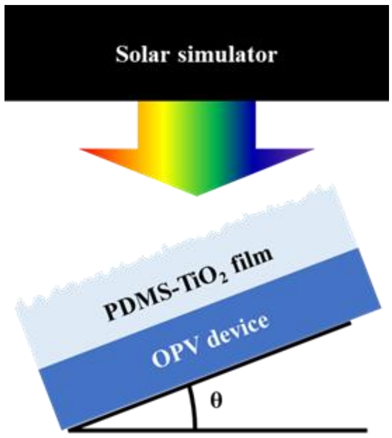

Fig. 3 Experiment setup of measuring the PDMS-TiO_2 film assisted OPV efficiency enhancement at different light incidence angles.

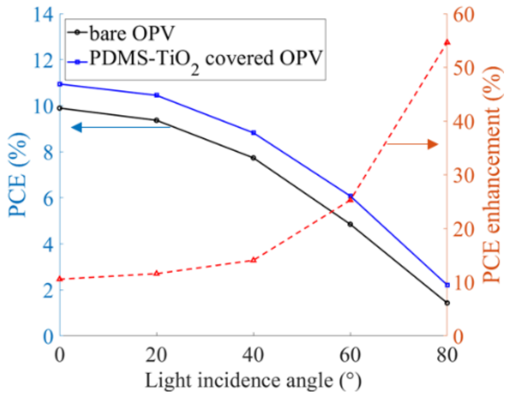

Fig. 4 The OPV efficiency and the enhancement with the PDMS-TiO_2 anti-reflection film at different light incidence angles.

4. Conclusions

In summary, we developed a simple and effective method of fabricating flexible and light-weighted anti-reflection film. This film is composed with TiO_2 nanoparticles as the light diffusing material and PDMS as the transparent and flexible substrate. Experiments showed this anti-reflection film can give an enhancement to the OPV efficiency significantly, especially when the light incidence angle is large.

Acknowledgements

This research was supported by the New Energy and Industrial Technology Development Organization (NEDO) through the Project of Cross-ministerial Strategic Innovation Promotion Program (SIP).

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