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Fabrication of Antireflection Structures as a Protective Layer of Solar Cells with Nanoporous Silica Films and Nanoimprinted Moth-Eye Structure

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The antireflection structures are fabricated by sol–gel process as a protective layer of solar cells and by hot embossing process with anodized aluminum oxide membrane template on polycarbonate film. The optical properties and morphology of the antireflection structures are analyzed by UV-visible spectroscopy and field emission scanning electron microscopy, respectively. The total conversion efficiency of a polycrystalline Si solar cell module with the protective layer, sol–gel-derived nanoporous antireflection structure, is increased by 2.6% and 5.7% for one-side antireflection coated prismatic matt glass and both-side antireflection coated prismatic matt glass, respectively.

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1. Introduction

Si-based solar cells need a protective layer, in order to protect them from external shocks and corrosion. But this protective layer causes the reflection of sunlight, which reduces the conversion efficiency. The antireflection (AR) can be fundamentally achieved by multi-stacked layers with various refractive indices. Two kinds of approaches are available for fabricating AR structures. One is coating porous or multilayered films on the surface of devices, and the other is fabricating subwavelength AR structures (moth-eye structures) on the surface devices. The sol–gel-derived nanoporous silica films have unusual properties such as an adjustable refractive index, a high porosity, a low thermal conductivity and a low dielectric constant [1]. Several authors have reported the properties and synthesis method of nanoporous silica films based on sol–gel process [1–3]. The periodic microstructures with a size of a few hundred nanometers change the effective refractive index gradually. The AR moth-eye structures have been fabricated with template which contains submicron-sized synthetic moth-eye features, which were used to transfer the nanopatterns to thermoplastic polymer films, such as polyethylene terephthalate (PET) substrate [4] and polyvinyl chloride (PVC) substrate [5]. The anodized aluminum oxide (AAO) membrane has been used to template to fabricate the AR structures [6].

In this study, the AR structures are fabricated by sol–gel-derived silica films as a protective layer of solar cells and by hot embossing process with AAO membrane template on polycarbonate film. The optical properties and morphology of the fabricated AR structures are analyzed by UV-visible spectroscopy and field emission scanning electron microscopy (FE-SEM), respectively. The effect of AR structures is examined by solar simulator with a polycrystalline Si solar cell module.

2. Experimental details

The precursor sol solutions of silica were prepared by hydrolysis and polymerization reactions of tetraethylorthosilicate (abbreviated as TEOS, Aldrich, 99%) in the presence of acid catalyzer. The acid pre-treated silica nanoparticles (Nalco 1060) were added to TEOS, (3-glycidoxypropyl)trimethoxysilane (GPTMS, Aldrich, 98%), C_2H_5OH, and H_2O solution. The reaction was performed at room temperature for 3 h. Then, isopropyl alcohol (IPA), methyl cellosolve, and acid pre-treated silica nanoparticles (Nalco 1050) were added to precursor sol with stirring at room temperature for 1 h. The AR structures of nanoporous silica films were coated by flowing or dipping method with the silica sol on the low iron prismatic matt (LIPM) glass which has 3.2 mm thickness. The /coated AR glass was dried at 200 °C for 2 min and cured at 740 °C for 20 s.

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The nanoimprinted moth-eye structures were fabricated by hot embossing method (Obducat, Nanoimprinter) on polycarbonate (PC) substrate which has 500 μm thickness with AAO membrane template (Whatman, $\phi = 2$ inch, pore diameter = 200 nm) which was pre-treated by an antisticking for detaching. The hot embossing process was performed at 160 °C for 300 s with a pressure of 8 bar and the sample was cooled to room temperature. The PC film was carefully detached from the AAO template.

The optical properties and morphology of the AR structures were analyzed by UV-visible spectroscopy (Hitachi, U-4100 Spectrophotometer) and FE-SEM (Hitachi, S-4800), respectively. To estimate the effect of AR structures, the total conversion efficiency of a polycrystalline Si solar cell module (Shinsung solar energy) with a cover glass, sol–gel-derived nanoporous AR structures, was measured by solar simulator (HSPV, HS-M2, grade: class AAA).

3. Results and discussion

The optical properties of the AR structures are shown in Fig. 1. The transmittance of the bare LIPM glass (no AR coating), one-side AR coated LIPM glass, and both--side AR coated LIPM glass are 92.6% (92.4%), 94.5% (94.5%), and 96.4% (96.1%) in the wavelength range of 380 nm to 1100 nm (800 nm), respectively. This result is quite good, compared with previous report of Kesmez et al. [2]. The average reflectance of the bare PC film and moth-eye structure patterned PC film are 15% and 5% in the wavelength range of 380 nm to 1100 nm, respectively. According to the previous report of Han et al. [5], the transmittance of AR structure on PVC film by hot embossing method was 90% (one-side patterned PVC), and 93% (both-side patterned PVC). The transmittance of one-side patterned PC film is comparable to both-side patterned PVC film.

Figure 2 shows FE-SEM images of the AR structures. The surface morphology of the sol–gel-derived silica films exhibits nanoporous structure. The film thickness of the nanoporous AR structure is round 220 nm. The nanoimprinted structure is comparatively regular shape like moth-eye patterns. The average pillar diameter and height of patterned moth-eye structure is about 170 nm and 300 nm, respectively. The area of nanoimprinted moth-eye patterns is 2 inch diameter. Solar simulator results of a polycrystalline Si solar cell module with a cover glass are presented in Table. The used polycrystalline Si solar cell module is a commercial product (Shinsung Solar Energy, 2 bus bar type, 20 W grade). The dimension of used polycrystalline Si solar cell module is 156 mm × 156 mm. Therefore, the protective layer was prepared with a dimension of 200 mm × 200 mm by one--step flow coating or dip coating with the silica sol solution. The total conversion efficiency of a polycrystalline Si solar cell module is increased by 2.6% and 5.7% for one-side AR coated LIPM glass and both-side AR coated LIPM glass, respectively. The surface hardness of the nanoporous AR structure is measured 3H with the pencil hardness tester. This value is not bad for commercial protective layer of Si-based solar cells.

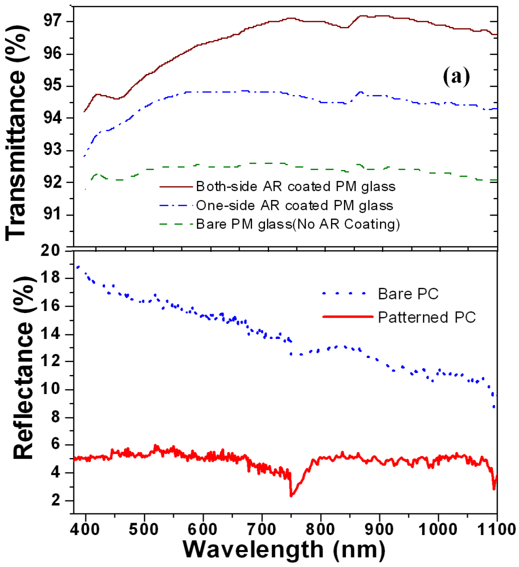

Fig. 1. Optical properties of the antireflection structures: (a) sol–gel-derived nanoporous silica films, and (b) nanoimprinted moth-eye polycarbonate film.

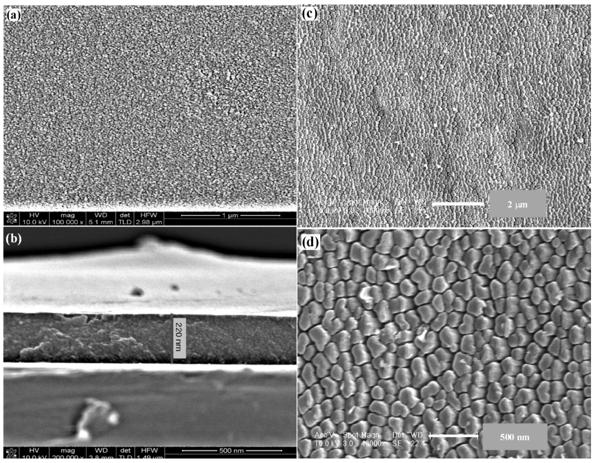

Fig. 2. FE-SEM images: (a) surface morphology of the sol–gel-derived silica film, (b) cross-sectional image of the sol–gel-derived silica film, (c) surface morphology of the nanoimprinted moth-eye polycarbonate film, and (d) magnified image of (c).

TABLE

Solar simulator results of a polycrystalline Si solar cell module with the protective layer which is sol–gel-derived nanoporous antireflection structure. The parameters denote: $V_{\rm oc}$ — open-circuit voltage, $I_{\rm sc}$ — short-circuit current, $P_{\max}$ — maximum power, $V_{\rm m}$ — voltage at Pmax, $I_{\rm m}$ — current at $P_{\max}$, FF — fill factor, $E_{\rm ff\_Cell}$ — cell efficiency, $E_{\rm ff\_mod}$ — module efficiency, $R_{\rm sh}$ — shunt resistance, respectively.

Cover glass	$V_{\rm oc}$ [V]	$I_{\rm sc}$ [A]	$P_{\max}$ [W]	$V_{\rm m}$ [V]	$I_{\rm m}$ [A]	FF [%]	$E_{\rm ff\_Cell}$ [%]	$E_{\rm ff\_mod}$ [%]	$R_{\rm sh}$ [Ω]	$\Delta P_{\max}$ [W]	Increment of cell efficiency [%]
bare PM	2.441	9.341	17.919	2.034	8.811	78.6	18.408	11.99	3.341	–	–
one-side AR coated PM	2.513	9.523	18.387	2.074	8.867	76.83	18.888	11.492	2.919	+0.468	2.61
both-side AR coated PM	2.519	9.722	18.935	2.078	9.114	77.33	19.451	11.834	6.278	+1.016	5.67

4. Conclusion

According to the UV-visible spectroscopy analysis, the increase of transmittance of AR structures by sol–gel-derived nanoporous silica films is 1.9% per AR coating in the wavelength range of 380 nm to 1100 nm. The total conversion efficiency of a polycrystalline Si solar cell module with the protective layer which is fabricated by sol–gel-derived nanoporous AR structure is increased by 2.6% and 5.7% for one-side AR coated LIPM glass and both-side AR coated LIPM glass, respectively. The sol–gel-derived protective layer is fabricated by one-step flow coating or dip coating with the silica sol solution. This process is a low cost, fast, and suitable for mass production.

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