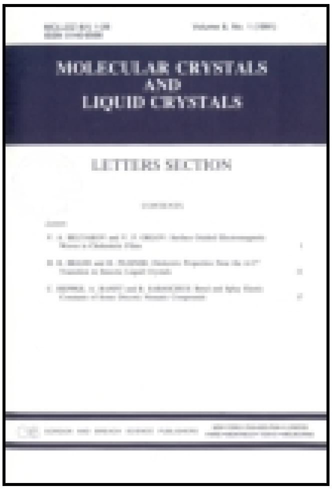

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Published online: 06 Dec 2014.

Mol. Cryst. Liq. Cryst., Vol. 602: pp. 226–233, 2014

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2014.944776

Formation of an Anti-Contamination Layer with Polystyrene Nanobeads over Cover Glass for Solar Cells

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In this study, a colloidal solution was mixed with hydrophobic polymer nanobeads and TEOS (tetra-ethylorthersilicate) for the preparation of an anti-contamination compound, the anti-contaminative properties of which were investigated for its application as an anti-fouling agent for cover glasses used for solar cells. Polystyrene spherical beads of approximately 250 nm were used as the hydrophobic polymer, and were synthesized by the suspension synthesis method. TEOS was used in order to enhance the stability of polymer nanobeads coated over the surface of a cover glass, due to the formation of SiO_2 layer. The ratio of TEOS/PS was controlled to 0/50, 1.2/50, 2.4/50 and 5/50, and the water contact angle on the coated surface of the cover glasses was measured after thermal treatment at 400, 500 and 600°C (Ed note: you mention other temperatures, including 650°C, within the text). The contact angle of glass treated with a TEOS/PS ratio of 1.2/50 at 600°C was approximately 100°, which was about 2.5 times that of the non-coated cover glass, and its transmittance was analyzed and determined to be the same as that of the non-coated cover glass, using a UV-Vis spectrophotometer.

Keywords Anti-contaminant; cover glass for solar cells; polystyrene nanobeads; water contact angle

Introduction

The constantly increasing demand for renewable and nonpolluting energy production methods has resulted in a widespread increase in research interests aimed at improving the efficiency of solar cells. More cost-effective fabrication is one of the key issues in solar cell research [1–3]. In order to enhance an efficiency of solar cells, texturing over the surface of silicon wafers by etching and coating with anti-reflective materials has been investigated by many researches [3]. Furthermore, cover glasses have been applied to enhance the lifetime of solar cells, and to prevent the oxidation of silicon by contact with water and oxygen. Recently, the transmittance of glass for use in the production of solar cells has been improved through the application of a concave lenses, as well as decreases in the reflectance of glass through coating with anti-reflective materials [4–12]. However, the surface of a cover

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glass can be polluted by the deposition of wet dusts, and the efficiency of solar cells can be dramatically reduced due to the consequent decrease of transmittance. Thus, this study developed an anti-contamination solution for application to cover glasses, using nano-sized polymer particles as an anti-fouling ingredient. The nano-sized protrusion, which is created with a coating of polystyrene nanoparticles [13,14], was formed over cover glasses by the spray coating of polystyrene colloidal solutions and thermal treatment. Since polystyrene is a hydrophobic material, the cover glass coated with polystyrene nanoparticles has hydrophobic properties. In order to achieve a good dispersion of polystyrene nanoparticles over the cover glass, polystyrene particles were synthesized along with the colloidal solution by the suspension synthesis method. The mixed solution, which was prepared by mixing TEOS and polystyrene colloidal nanobeads, was used to enhance the anti-contaminative property of cover glasses for solar cells. The anti-contaminative property of the cover glass was then investigated by the measurement of water contact angle.

Experimental

Preparation of Coating Solution for Anti-Contamination

Polystyrene nanobeads were synthesized by the suspension synthesis method, which is used for the polymerization of styrene monomers in water. Distilled water (500 ml) was contained in a round-bottomed flask which was purged with nitrogen gas, after which the styrene monomer (10 g) was injected into the flask using a syringe. The round flask used as the reactor was purged with alternate cycles of nitrogen and vacuum, and a final pure nitrogen atmosphere was attained before the injection of KPS (potassium per-sulfate) (1.5 mmol) which was used as the initiator. The temperature of the solution in the flask was maintained at 80°C using a water bath. The solution was stirred at 800 rpm using a magnetic stirrer. Polymerization of styrene was achieved through the injection of the initiator through the stem, and was carried out for 12 h.

The anti-contaminative coating solutions were prepared by mixing of TEOS and polystyrene nanobeads, resulting in a colloidal solution. TEOS/PS (polystyrene) ratios were controlled to 0/50, 1.2/50, 2.4/50 and 5.0/50.

Coating of Anti-Contamination Solution

The mixed solution was coated over the surface of a cover glass using a spray coating technique (Ed note: we assume there was a spray nozzle – if you wish to provide details of the spray technique then please do so). The cover glass coated with the anti-contamination solution was dried at 150°C for 10 min, and was then thermally treated at 450, 600 and 650°C for 2 min. The thermal treatment process was performed in a quartz tube with an outside diameter of 12.7 cm, in a three-zone horizontal tubular type furnace. The cover glass coated with the anti-contamination solution over the alumina plate was located in the inlet of the quartz tube prior to thermal treatment. When the temperature of the furnace was maintained to the thermal treating temperature, the alumina plate was moved to the center of the quartz tube and thermal treatment was carried out for either 1 or 2 min, in order to determine the effect of varying thermal treatment duration. After thermal treatment, the alumina plate was moved to the inlet of the quartz tube.

The surface morphologies of the cover glasses were analyzed by scanning electron microscopy (SEM, HITACHI S-4800) after coating with the TEOS-PS mixture solution. The anti-contaminative property of the cover glass coated with hydrophobic polymer and

SiO_2 was estimated by determining the water contact angle, and its transmittance was measured in the visible light range of 350–800 nm, using a UV-Vis spectrophotometer (Ocean Optics Inc, USB 4000 optic spectrometer).

Results and Discussion

Surface Morphology of Coated Cover Glass

The mixture solutions, which were prepared with various mixing ratios of TEOS and polystyrene colloidal nanobeads, were coated over the solar cell cover glasses using a spray-coating method. The cover glasses coated with the mixed solutions were thermally treated for 2.0 min at 550°C. The morphology of the coating layer over the tempered glass was observed using SEM analysis, as shown in Fig. 1. The polystyrene nanobeads were observed over the coating area of the tempered cover glass, and various morphologies were determined for the different mixing ratios of TEOS/PS. The size of the polystyrene nanobeads on the silica layer, which is produced by oxidation of TEOS, decreased with increasing addition of TEOS to the mixed solution, because the polystyrene nanobeads became buried in the silica layer deposited over the tempered cover glass. When TEOS was not added to the mixed solution, the polystyrene nanobeads were highly dispersed over the tempered cover glass. However, many areas were observed to be free of polystyrene

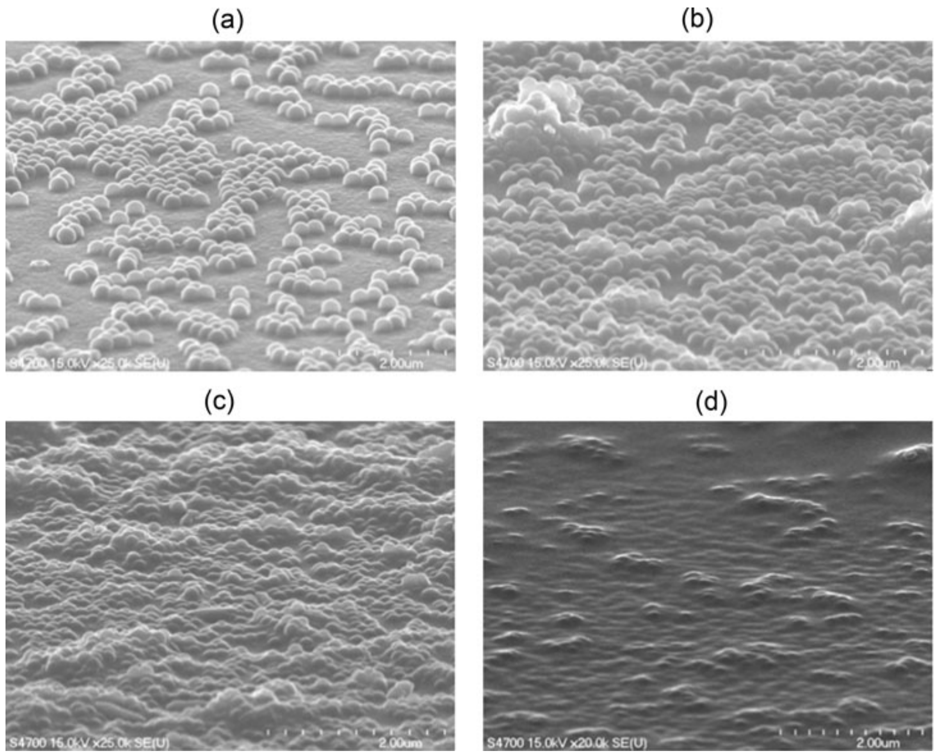

Figure 1. SEM images of tempered glass coated with various TEOS/PS ratios of anti-contaminative solution after thermal treatment at 550°C for 2 min, (a) TEOS/PS = 0/50, (b) 1.2/50, (c) 2.4/50 and (d) 5.0/50.

nanobeads, as an uneven coating was observed for cover glasses which were coated without TEOS, as shown in Fig. 1(a). As shown in Figs. 1(b)–(d), a highly dispersed coating layer of populous polystyrene nanobeads was observed when TEOS was included in the mixing solution. The polystyrene nanobeads were also fixed in the silica layer which was deposited over the tempered cover glass. When a 1:10 ratio of TEOS:PS was used in the mixed solution, the polystyrene nanobeads were buried in the silica layer, as shown in Fig. 1(d). The hydrophobic property of polystyrene was not expected, due to the complete covering of silica layer when the mixture solution was prepared with a high content of TEOS. Therefore, it was concluded that TEOS was formed in the silica thin layer over the tempered cover glass, improving the dispersion and stability of polystyrene nanobeads over the surface of the cover glass.

Meanwhile, the changing morphology of the coating layer treated at the different temperatures was observed, as shown in Fig. 2. The polystyrene nanobeads were observed after thermal treatment at 600°C, as shown in Figs. 2(a)–(b). However, the morphology of the beads was not observed over the surface of tempered cover glasses treated at 650°C, and the pores were formed in the silica layer by the decomposition of polystyrene nanobeads, as shown in Fig. 2(c). It was confirmed that polystyrene nanobeads were not completely decomposed after 2 min of thermal treatment at 600°C. The flat silica layer was formed

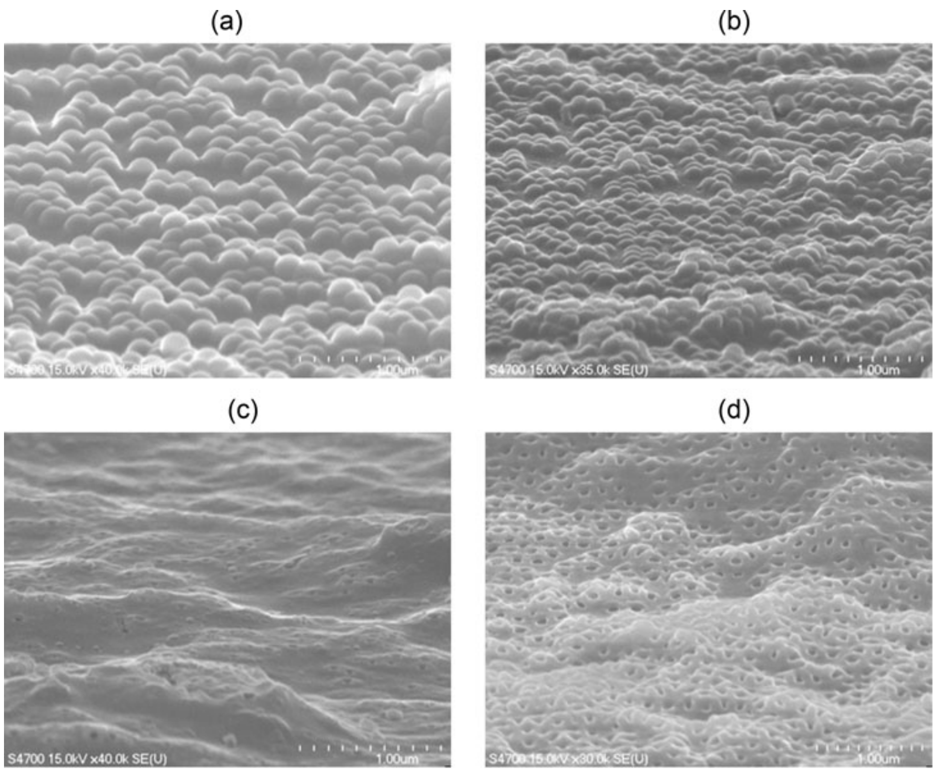

Figure 2. SEM images of tempered glass coated with TEOS/PS = 1.2/50 ratio of anti-contaminative solution after thermal treatment at various temperatures for 2 min, (a) 500°C, (b) 550°C, (c) 600°C and (d) 650°C.

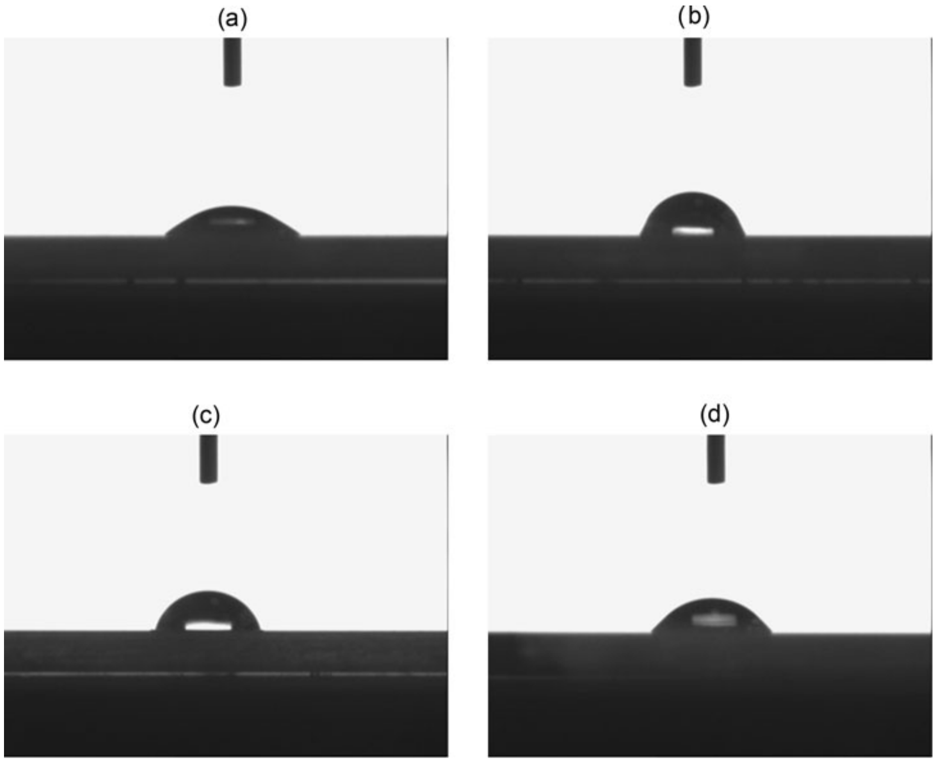

Figure 3. Water droplet images of tempered glass coated with various TEOS/PS ratios of anti-contaminative solution after thermal treatment at 550°C for 2 min, (a) TEOS/PS = 0/50, (b) 1.2/50, (c) 2.4/50 and (d) 5.0/50.

above 550°C. Thus, it was concluded that the optimum anti-contaminative property can be achieved with a thermal treatment between 550 and 600°C.

Water Contact Angle

The water contact angles of the tempered glasses coated with various solutions of TEOS/PS were determined, as shown in Fig. 3 and Table 1. The water contact angle was approximately 47° when TEOS was not added to the mixture solution, as shown in Fig. 3(a). It was observed that the water contact angles over the tempered cover glasses increased with increasing additions of TEOS to the mixture solution. However, the water contact angle decreased with increasing content of TEOS, as shown in Fig. 3(b)–(d) (Ed note: these two

Table 1. Contact angle of water droplet over the tempered glass coated with various TEOS/PS ratio of anti-contaminative solution thermally treated at 550°C for 2 min

	Water contact angles over tempered glass			
Ratio of TEOS/PS	0:50	1.2:50	2.4:50	5.0:50
Contact angle (°)	47	87	75	54

Table 2. Contact angle of water droplet over the tempered glass coated with TEOS/PS = 1.2/50 ratio of anti-contaminative solution treated at various thermal treating temperature

	Water contact angles over tempered glass			
Temperature of thermal treats (°C)	500	550	600	650
Contact angle (°)	67	94	64	28

statements contradict one another), while increasing the TEOS content results in a higher dispersion and stability of the polystyrene nanobead coating layer, if the silica layer is too thick, the polystyrene nanobeads can remain buried within it, as shown in Fig. 1(d). Therefore, it was concluded that the ratio of TEOS/PS should be optimized in order to obtain the anti-contamination properties of the hydrophobic polymer nanobeads, and a ratio of 1.2/50 TEOS/PS was determined to be optimal.

The water contact angles of the tempered cover glasses which were coated with a 1.2/50 solution of TEOS/PS were determined after thermal treatment at various temperatures, as shown in Fig. 4 and Table 2. The water contact angle increased with increasing temperature up to 550°C. It was concluded that the change of water contact angle with increasing

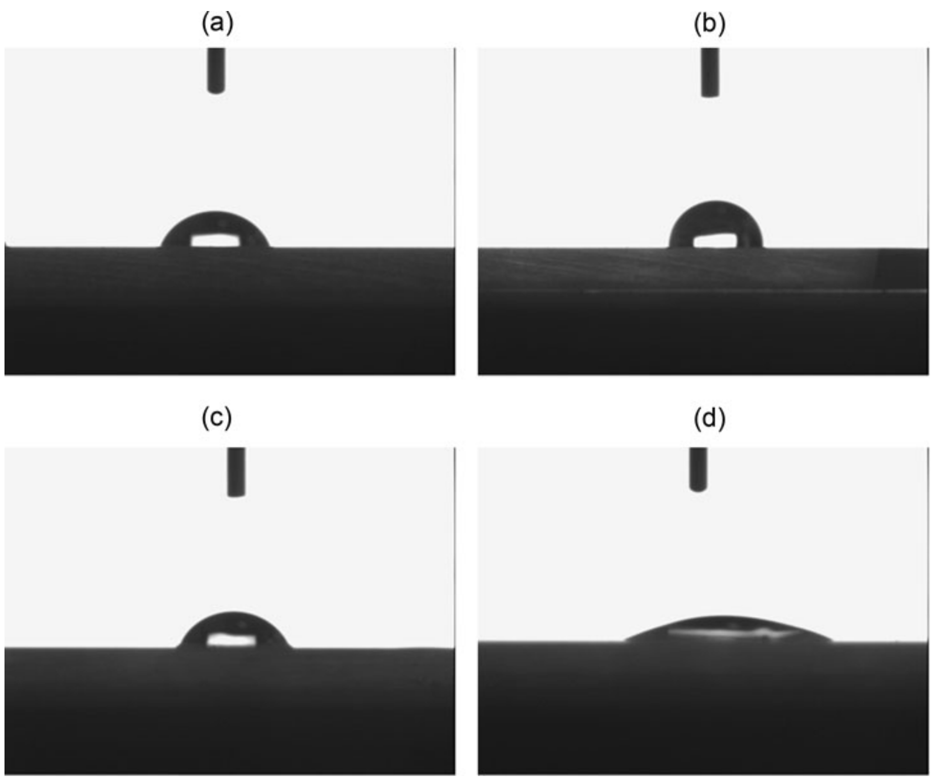

Figure 4. Water droplet images of tempered glass coated with TEOS/PS = 1.2/50 ratio of anti-contaminative solution after thermal treatment at various temperatures for 2 min, (a) 500°C, (b) 550°C, (c) 600°C and (d) 650°C.

temperature is due to the tempering of the silica layer. However, the water contact angle decreased to 40° when thermal treatments above 600°C were applied, and the surface of the tempered cover glass was determined to have hydrophilic properties, as shown in Fig. 4(d). It was concluded that the hydrophilic property of cover glass tempered above 600°C was due to the formation of pores in the silica layer.

Transmittance of Cover Glass

The change of transmittance of tempered cover glasses which were coated with various ratios of TEOS/PS were investigated by UV-Vis spectrophotometry. As shown in Fig. 5, the tempered cover glass coated with a low TEOS/PS ratio solution exhibited a similar transmittance to that of the non-coated cover glass. The transmittance of the tempered cover glass decreased with increasing TEOS/PS ratio. It was concluded that the thickness of the silica layer increased with increasing TEOS/PS ratio, while the transmittance was reduced due to the increased angle of refraction.

Meanwhile, the transmittance values of cover glasses tempered at various temperatures were measured in order to determine the effects of temperature. The solution which was prepared with a 1.2/50 TEOS/PS ratio was used as an anti-contamination cover glass. The transmittance of the tempered cover glass increased with increasing tempering temperature up to 650°C. It was concluded that the increase of transmittance after thermal treatments above 600°C was due to the reducing reflection angle with the pores in the silica layer, created by the complete decomposition of polystyrene nanobeads at higher temperatures.

Anti-contamination coatings are applied to maintain the efficiency of solar cells, through the reduction of dust and wetting particle matter on the cover glass. However, the anti-contamination coating layer can reduced the efficiency of solar cells by reducing the transmittance. Therefore, the transmittance of the cover glass should be maintained when applying anti-contaminative coating layers. In this study, the mixture solution prepared with a 1.2/50 TEOS/PS ratio was determined to be optimal. It was also concluded from the results obtained in this study that the optimum tempering temperature for the coated cover glass is 550°C, as it resulted in a similar transmittance to that of the non-coated cover glass.

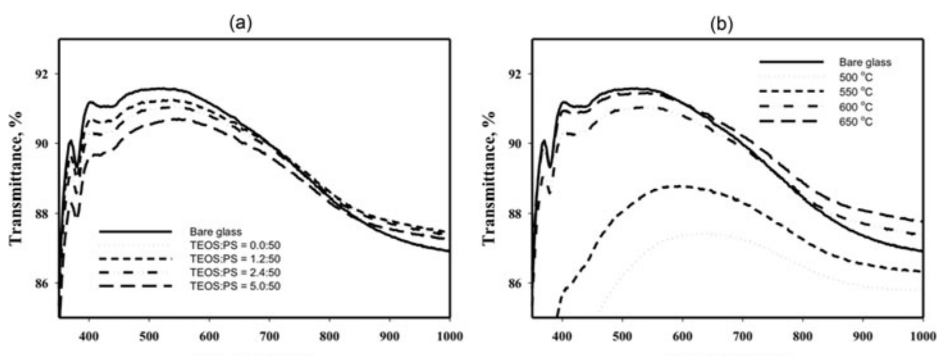

Figure 5. Transmittances of tempered glass coated with various TEOS/PS ratios at various thermal treating temperatures for 2 min, (a) changing TEOS/PS ratio, (b) changing temperature.

Conclusion

Hydrophobic polymer nanobeads were synthesized and their anti-contaminative properties as a coating material for the cover glass of solar cells was investigated. Polystyrene nanobeads were synthesized using a suspension synthesis method, and were used as a hydrophobic polymer. TEOS was added to the coating agent to increase the dispersion and stability of the polymer nanobeads coated over the cover glass. Changes in the anti-contaminative property according to various mixing ratios of TEOS/PS and various thermal treating temperatures were confirmed by determinations of the water contact angle of the tempered cover glasses coated with the various solutions. The water contact angle over the tempered cover glass was enhanced by the addition of TEOS to the coating solution, but decreased with increasing TEOS/PS ratio, as the polystyrene nanobeads became buried in the silica layer once the optimal TEOS content was surpassed. The tempered cover glass treated at 550°C exhibited the highest water contact angle and optimal transmittance values. It was confirmed from the experimental results that the anti-contamination of the cover glass for solar cells can be enhanced by applying a coating layer formed with a solution of hydrophobic polymer nanobeads and TEOS. Therefore, it was concluded that deposition on cover glasses for solar cells can be reduced through coating with polystyrene colloidal solutions, maintaining the efficiency of solar cells over time.

Funding

This work was supported by the 2012 Yeungnam University Research Grant and the Human Resources Development Program of Korea Institute of Energy Technology Evaluation and Planning (KETEP), grant (No 20104010100580), funded by the Korean Ministry of Knowledge Economy.

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