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Research Paper

Efficiency of Photovoltaic Cell with Random Textured Anti Glare (RTAG) Glass

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Abstract The surface treatment of cover glass for conversion efficiency of photovoltaic cell is important to reduce reflectivity and to increase the incident light. In this work, random textured anti glare (RTAG) glass was prepared by wet surface coating method. Optical properties due to the changes of surface morphology of RTAG glass were compared and conversion efficiency of photovoltaic cell was researched. Grain size and changes of surface morphologies formed with surface etching time greatly affected optical transmittance and transmission haze. Current density (Jsc) were high at the condition when surface morphologies reflection haze were low and transmission haze were high. Jsc was 40.0 mA /cm^2 at glancing angle of 90^o. Incidence light source was strongly influenced by surface treatment of cover glass at high incidence angle but was hardly affected light source at the low angle of incidence.

Keywords: Random textured anti glare, Conversion efficiency, Photovoltaic, Incidence light, Current density

I. Introduction

Texturing to conversion efficiency from incidence light on the photovoltaic cell surface is important because it can decrease optical reflectance. Texturing of cell surface can increase optical trapping by decreasing the optical reflectance. And the short circuit Jsc can be improved as optical reflectance decrease at low altitude of the Sun by texturing [1-2]. Texturing of cell surface for decrease of optical reflective loss is being applied to various etching processes depending on the size and shape of pattern [3-4]. Antireflective glass with self-cleaning according to super hydrophobic at the interface between glass surface by deposition and etching of nano structure on the front glass has recently studied [5-7]. Surface texturing processes include dry and wet etching. Dry etching process for texturing is performed by physical ion bombardment and reactive ion etching (RIE) including heterogeneous chemical reaction interface of gas and solid phase from generation of plasma in vacuum condition. Wet etching is the way of direct surface treatment on glass using acid or base etching solution [8-10]. Semiconductor device and display process to preparation the required nano or microstructure is need to more precisely surface control by ion etching or RIE. However there is limit in dry etching process to large area etching due to expensive cost in commercialization. Wet etching process using HF acid solution is applied in anti glare surface treatment of display device because of low-cost surface treatment of large scale. [11-15]. In wet etching method, dipping method which surface is treated by directly contacting etching solution, flowing the surface that has a slope with etching solution, and eliminating product after surface reaction by coating the gel state etching solution. Among these methods, dipping method has difficulty in controlling surface reaction rate due to fast surface etching rate and environmental pollution which is caused by using large amount of etching solution. Therefore, coating surface with gel state etching solution is used. [12].

In this work, wet etching method using gel state etching solution is used to research the change of optical property according to PV cell cover glass's surface morphology after it's being random textured. Effect of PV cell cover glass on conversion efficiency of photovoltaic cell was also researched.

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II. Experimental

1. Wet etching of cover glass

In order to decrease the Incidence light loss by optical reflectance on PV cell cover glass, random texturing was done with wet etching. In this experiment, low iron white glass having thickness of 1.1 mm, 250×250 mm active dimension, 91.7% optical transmittance, refractive index of 1.5229, density of 2.56 g/cm^3 was used. Random texturing AG process by wet etching was coated uniformly in the range of 0.3~1.0 mm thickness by using 80 mesh silk

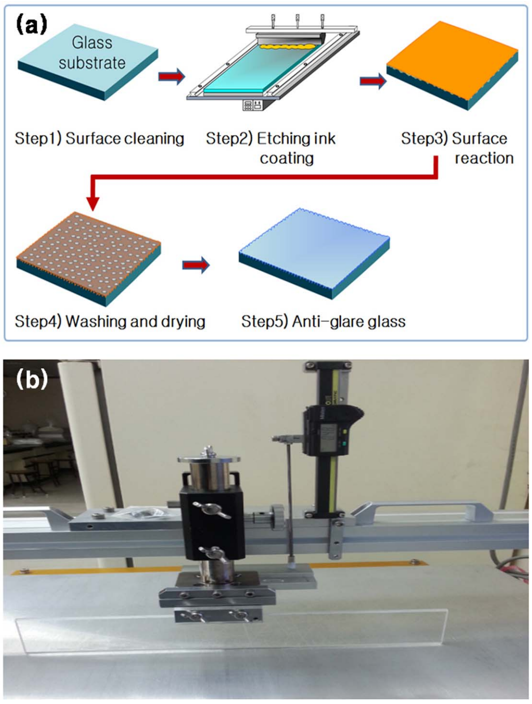

Figure 1. Schematics diagram for random-texturing of the cover glass and silk screen coating system image.

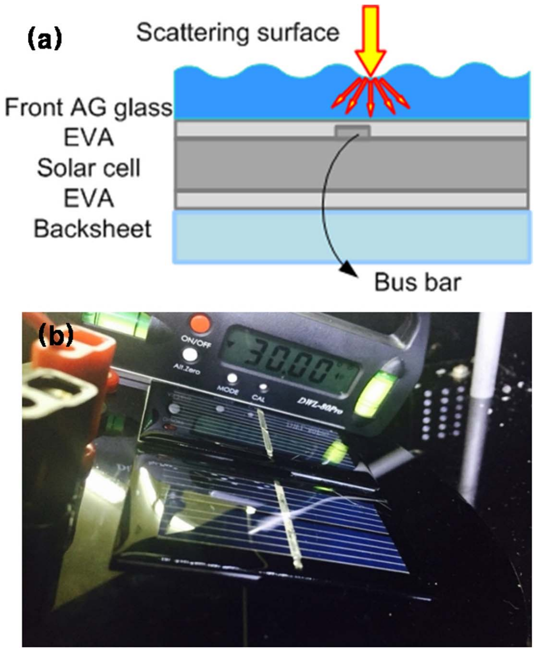

Figure 2. (a) Light trapping on random-texturing cover glass and (b) photovoltaic cells system image.

screen printing method with acid etching solution which was made with ammonium fluoride (NH_4F_2) having gel state viscosity after washed with DI water. Coating thickness of the gel state etching solution and surface reaction time is big parameters to determine which variables are contributing to the surface roughness and optical properties for incidence light. Reaction with glass and the gel state etching solution have for 30 sec~120 sec. RTAG glass of PV cell cover glass is completed washing with distilled water and thoroughly dry the glass surface. Surface reaction with glass substrate using gel state etching solution produce an intermediate product of silicon tetrafluoride (SiF_4) and hexafluorosilicic (H_2SiF_6) acid. Surface product of glass substrate is hydro-gel state (H_2SiO_3) on which solidification are generated and etching reaction is performed[12]. Silk screen coating system to coating the gel state etching solution up to a few hundred micrometers and etching steps for random texturing of PV cell cover glass is shown in Fig. 1.

2. Analysis

Physical and optical properties of random textured PV cell cover glass by wet etching were examined. To measure surface roughness, portable RA measurement system of Mitutoyo (Model SJ 210/SJ) was used. After surface treatment, the chemical component of etched glass substrate surface was examined by x-ray photoelectron spectroscopy (XPS, PHI 58000) with MgK radiation source. Surface topography was measured by atomic force microscopy (AFM) of Park Science Instrument. Optical microscopy and field emission scanning electron microscopy of Hitachi (FE-SEM, S-4100) were used to measure surface morphology and grain size of etched surface. Optical transmittance and optical reflectance before and after surface etching was examined by UV-visible spectrophotometer (Model 8453, Agilent) of Hewlett-Packard. Transmission haze and reflection were used haze Rhopoint Gloss meter (model iQ 3 Angle) and Hazemeter (Murakami, Model HM-150). Transmission haze was measured at 20 mm glancing light diameter of halogen lamp with the procedure of ASTMD 1003. To compare with conversion efficiency of RTAG glass for PV cell, the current-voltage (I-V) with incidence light source and angle were measured.

Fig. 2 show the light trapping on random-texturing cover glass and photovoltaic (PV) cells system image. Active PV cell dimension for comparison of cell performance is 35 mm×65 mm. The short circuit Jsc is calculated by measuring the I-V in the range of 60~90° tilt of glancing light at 25.

III. Results and Discussions

Wet etching was performed by silk screen printing for the purpose to increase the optical trap and to decrease reflection with incidence light source at PV cell cover glass surface. RTAG glass also aim at facilitating the removal of dust which prevents the incident light on cover glass. Optical properties of PV cell cover glass for RTAG glass were examined because optical properties at cover glass on incidence light of PV cell rely heavily on surface properties of cover glass.

Fig. 3 show the Cross-sectional coating image of gel state etching solution on glass substrate and XPS wide scan

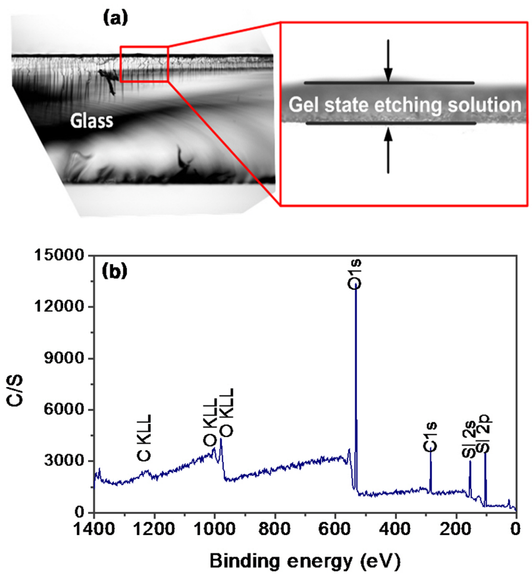

Figure 3. Cross-sectional coating image of gel state etching solution on glass substrate and (b) wide scan of XPS analysis of RTAG glass surface.

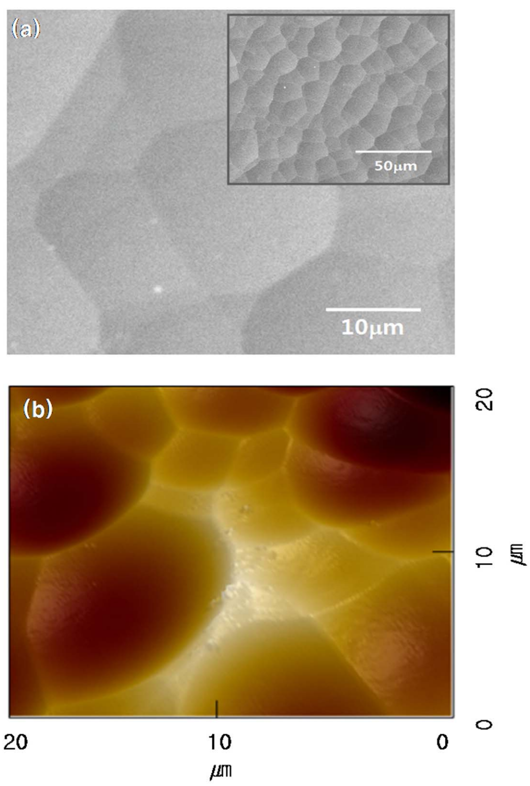

Figure 4. (a) FESEM surface image and (b) AFM topography of RTAG glass.

analysis of surface treated with the anti-glare glass. The Cross-sectional coating image of optical microscopy of Fig. 3(a) is showing a uniform coating layer of gel state etching solution on glass substrate. Coating thickness of gel state etching solution changed texturing pattern and roughness of cover glass. It can greatly affect the optical properties of incidence light to PV cell. Fig. 3(b) show the wide scanning result of XPS at surface to investigate the etching glass's chemistry. Silicon and Oxygen peaks can be confirmed on surface of the etching glass and carbon peak was weakly detected due to contaminant. Metal ion and inorganic materials in gel state etching solution was not found because it was completely cleaned and etched.

Fig. 4 show the SEM image and AFM topography of surface treated with the anti-glare glass. Fig. 4(a) is surface morphology of RTAG glass obtained from SEM. Surface morphology of RTAG glass show an array of irregular shape by grains less than 20 μm with a clear boundary line. AFM topography is also similar to FESEM surface image as shown in Fig 4(b).

Fig. 5 show optical microscope images and surface roughness analysis of the RTAG glass obtained by wet etching time. Surface image and roughness distribution obtained from scanned 4mm of sample etched with 30 second (RTAG #1) exhibition match with each other as shown in Fig. 5(a). Surface image show an irregular array with a different size of grains. Roughness may seem to be uniform, but it can confirm deep boundary line formed between the grains from surface roughness distribution. In case sample etched for 60 second (RTAG #2) of Fig. 5(b), etching surface image is comparatively composing uniform grains. Surface roughness show the high gap between peaks and valley by etching deeply into the glass substrate. In case of etching sample for the longest etching time of 120 sec (RTAG #3), surface image show containing big grains due to excessive etching of the micro size grains formed on the glass surface for long reaction time. Consequently, surface roughness decreased and grain boundary increased. Physical

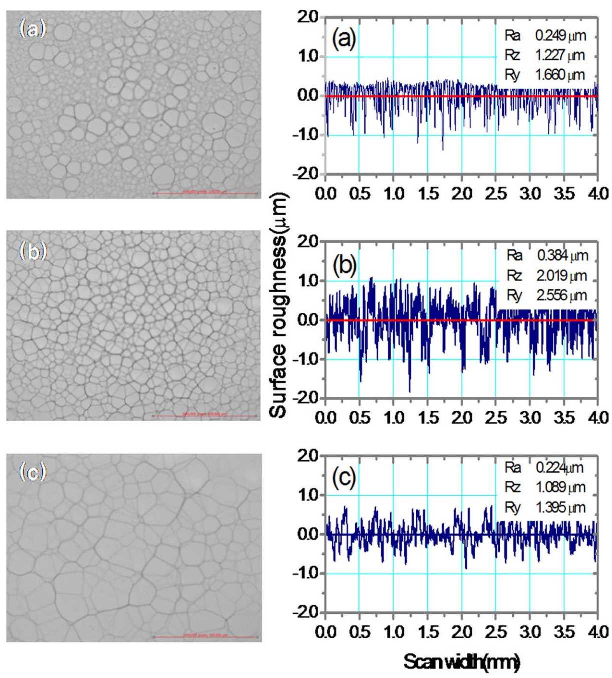

Figure 5. Optical microscope images and surface roughness analysis of the RTAG glass obtained by (a) etching time at 30 sec (sample RTAG #1), (b) 60 sec (sample RTAG #2), and (c) 120 sec (sample RTAG #3).

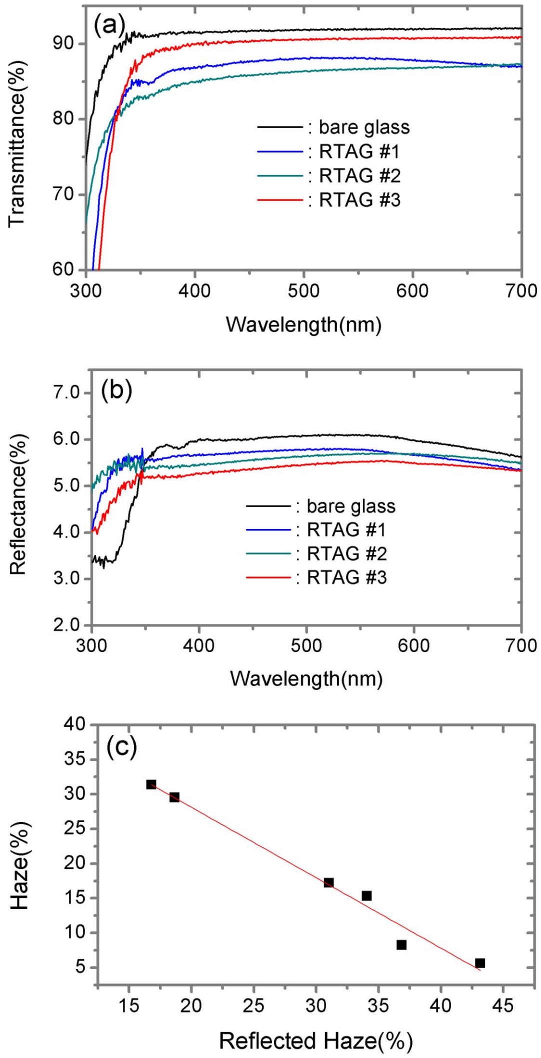

Figure 6. (a) Optical transmittance, (b) reflectance, and (c) transmission haze and reflection haze of random texturing anti glare glass at different etching time.

parameters of surface roughness, grain size, and deep boundary line forming between the grains can greatly affect transmittance and reflectance of the incident light on cover glass of photovoltaic cell.

Fig. 6 show optical transmittance, reflectance, and haze from integrating sphere of RTAG glass at different etching time. Fig. 6(a) shows optical transmittance in visible range of 300 to 700 nm of bare glass and RTAG glass with etching time. Optical transmittance of samples obtained from etching of bare glass having 91% transmittance increased over 350 nm wavelength. Optical transmittance of etching sample for the longest etching time of 120 sec (RTAG #3) is higher than any other samples. As shown in Fig. 5, in case of sample having deep boundary line formed between the grains and high surface roughness, optical transmittance decreased. Optical reflectance in Fig. 6(b) decreased with etching time. Therefore, optical transmittance and reflectance change depending on the surface morphology and surface roughness. The correlation of transmission haze with reflection haze for samples having different surface morphology is shown in Fig. 6(c). Transmission haze increases as reflection haze decrease, transmission haze is directly proportional to reflection haze.

Table 1 compared the optical properties of random texturing anti glare glass samples. From the comparison of optical transmittance and reflectance at 550 nm and roughness with surface morphology, reflection haze decreased at sample having high surface roughness, while transmission haze increased. Optical transmittance and gloss are linearly related.

Fig. 7 show Isc-V curves of RTAG glass devices at glancing angle of 60° and 90° in white light source condition. Fig. 7(a) compared the short circuit Jsc of sample with different roughness and optical properties at glancing angle of 90°. Bare glass has the highest of optical transmittance, reflectance also is the highest. Isc and Voc have lowest values (Voc=0.9 V, Isc=890 mA (Jsc=39.1 mA/cm^2)). Whereas in case of sample RTAG #3 having low reflection haze and high optical transmission haze, Isc and Voc have highest values (Voc=0.9 V, Isc=910 mA (Jsc=40.0 mA /cm^2)). The short circuit Jsc at glancing angle of 60° is shown in 7(a). Bare glass and sample RTAG #2 having low optical transmission haze and optical reflectance have the lowest short circuit Jsc (Isc=860 mA (Jsc=37.8 mA/cm^2)). That is, low optical reflectance and high transmission haze improved by surface etching mainly attributed to the increase in the short circuit Jsc by increasing incidence light.

Fig. 8 compare the fill factor with incidence angle at the white and red light source using RTAG #3. FF showed the highest value of 0.81 at 90° glancing angle of the white light source. In case of red light source with long wavelength, FF was 0.79, it was about 2.5 percent lower than the white light source. FF decrease with glancing angle at different wavelength of light source. FF at high glancing angle increased dependence on wavelength of light source. That is, FF of photovoltaic cell was greatly

Table 1. Comparison of optical properties of RTAG glass samples.

Sample	Transmittance (%) at 550 nm	Reflectance (%) at 550 nm	Reflection haze (%)	Transmission haze (%)	Roughness (μm)	Gloss (%)
bare glass	91.91	6.10	0.00	0.0	0.012s	99.60
RTAG#1	88.10	5.79	31.03	17.2	0.262	54.86
RTAG#2	86.67	5.69	16.8	31.37	0.363	20.76
RTAG#3	90.67	5.53	43.16	5.60	0.233	60.90

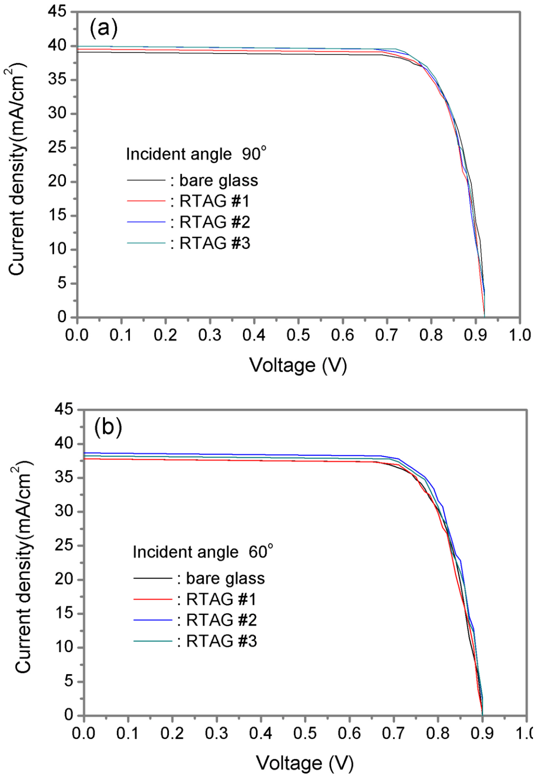

Figure 7. Comparison of the Jsc of photovoltaic cells with bare glass and the random texturing anti glare glass at incident angle (a) 90° and (b) 60°.

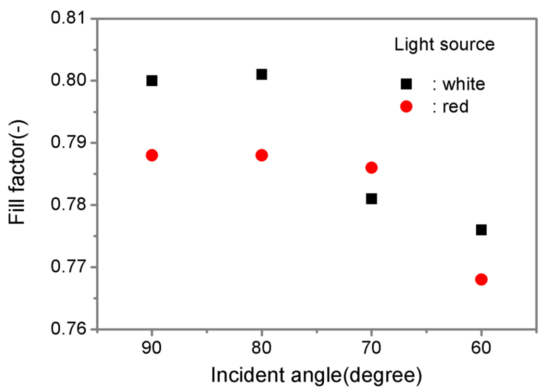

Figure 8. Comparison of the fill factor with incident angle of photovoltaic cells at white and red light sources.

influenced by surface roughness and optical properties according to surface etching. However FF at low glancing angle slightly depended on surface property due to high optical reflectance and low optical transmission haze.

IV. Conclusions

After RTAG of cell cover glass by wet surface etching, effect of surface morphology by RTAG of cover glass on optical properties and conversion efficiency of photovoltaic cell were researched. Grain size under 10 μm of RTAG surface and change of surface morphology with etching time have an effect on optical transmission and transmission haze. Jsc improved by using cover glass having low reflection haze and high transmission haze. FF of cell having RTAG glass at high glancing angle depended on incidence light source. More research is required to have high incidence light on photorefractive design having AR coating layer on RTAG glass for conversion efficiency of photovoltaic cell.

Acknowledgements

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