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Glass Texturing Affects Optical Properties of Perovskite Solar Cells: Comparison Study between Mesoscopic and Planar Structure

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Glass texturing is an effective method for changing the surface morphology to improve light trapping. In this paper, the technique is applied to hybrid inorganic-organic solar cells (perovskite solar cell) to enhance light trapping and current density. We optimized wet chemical etched fluorine doped tin oxide (FTO) coated glass substrates using a simple treatment then compared the mesoscopic and planar structures. Thus, we present the implication study of the wet etching process with a random pattern surface that enables punch light scattering and ideally balanced the optical and electrical properties of the perovskite solar cell. As a result, we achieved short-circuit current density for 26.5 mA/cm^2 and PCE for 15.2 %.

1. Introduction

Clean and renewable sources need to be developed to meet the increasing energy demand. Renewable energy technology is important because of insufficient fossil fuels and pollution. Especially, it is highly anticipated that the solar cell industry will become an alternative green energy source. Though the silicon solar cell is commercially available worldwide, it has a number of limitations including cost effectiveness. The next generation solar cell, the perovskite solar cell, is intended to overcome the economic and technical limitations of silicon solar cells. Perovskite materials are well recognized as a very attractive photovoltaic material because of several attractive properties. The rapid evolution of Methyl ammonium lead halide perovskite solar cells, specifically due to their higher power conversion efficiency, raises new potentials for practical applications (Kazim et al., 2014). Perovskite materials were first used as dyes instead of N-719 in liquid dye sensitized solar cells in 2009 (Kojima et al., 2009). The perovskite solar cells brought about technological innovation when the first solid-state mesoscopic heterojunction perovskite solar cell was introduced in 2012 (Kim et al., 2012). The power conversion efficiency of mesoscopic heterojunction and planar heterojunction perovskite solar cells has exceeded 18%, while the most recent, verified perovskite solar cell efficiency is as high as 20.1 % (Nie et al., 2015). However, several problems related to mesoscopic heterojunction devices such as the high processing temperature above 400 °C for the n-type layer as well as the existence of a mesoporous structure in TiO_2 coated substrates can lead to pore-filling problems, which may not only decrease the performance, but also lower the stability and cause I-V curve hysteresis (Lee et al., 2012). In order to overcome the foregoing discussions, researchers have attempted to find a solution to these issues. The first reports on planar structure discussed the evaporation of the perovskite material, achieving a uniform perovskite film with more than 15 % efficiency (Liu et al., 2013). Moreover, a vapor-assisted solution process was demonstrated as an efficient deposition technique for the planar structure, achieving 12.1 % efficiency (Chen et al., 2014).

The loss of light in solar cells is a matter of concern in the scientific research community. In the past decade, there have been a number of suggestions for the use of light scattering through external and internal reflections to increase effective absorption in solar cells. In particular, it was suggested that light trapping

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would have important benefits for solar cells and that high efficiency can be maintained without a mesoporous layer. Light scattering is an essential approach in thin film perovskite solar cells used to reduce optical losses in the absorber layer. The approach involves the scattering of light at rough interfaces, introduced into the solar cell by means of substrates treated with random-pattern surface substrates (Zeman et al., 2006). The multi junction approach is widely used in these solar cells (Yang et al., 1997). TCO substrates with different surface textures have recently been developed and tested in solar cells, such as optimized wet-etched (Sittinger et al., 2006), or surface plasma-treated (Dominé et al., 2008), zinc-oxide, double-textured tin-oxide (Kambe et al., 2008), and a combination of etched glass with zinc-oxide (Hongsingthong et al., 2010). Even though the potential of high performance TCOs has already been investigated oxide (Krč et al., 2010), a physical explanation of why these textures result in high scattering properties is still missing. In this study, the key challenge for the fabrication of substrates with a random pattern is the optimal compromise between electrical, optical, light-trapping and light-scattering properties using elementary methods. In the ideal case, the scattered light is confined within the multi-layered thin films of the solar cell and is almost completely absorbed after multiple passes through the absorption layer. The overall thickness of the solar cells while minimizing, light trapping is very important in order to enhance the optical property. The reflection at the air/glass interface decreases and the refractive index increases in accordance with the amount of light reflected through the mesoporous layer or the number of counter electrodes at the glass/interior interface of the solar cell. Glass texturing was applied to the perovskite solar cell. Surface texturing was successfully used to enhance the light absorption. By comparing the external quantum efficiency of two types of solar cells on texturing glass substrates, it was found that a texture that exhibits random patterns and roughness also exhibits good light scattering in the solar cells. The current density and cell efficiency were affected because of light trapping by the glass texturing in the perovskite solar cells. The enhancement of light harvesting by the light scattering and the light trapping effects in the visible region was confirmed.

2. Experimental

2.1 Glass texturing

In this study, a FTO coated glass substrate with a size of 20 × 20 mm^2 was used. The glass substrate was etched using HF solution of 14 M concentration. We prepared texture-glasses and non-texture for cover glass.

2.2 Fabrication of perovskite solar cells

The FTO electrodes were fabricated by etching the FTO coated glass with a mixture of zinc metal powder and 2 M hydrochloric acid solution. The substrate was rinsed with water and then cleaned in an ultrasonic bath with acetone and, deionized water each for 10 min and then washed with ethanol and dried with N_2 gas. The etched FTO electrodes were rinsed with water. These electrodes were cleaned in an ultrasonic bath containing acetone and distilled water for 10 min, respectively, and then treated with oxygen plasma cleaner for 5 min. To make a TiO_x compact layer, the FTO electrode was coated with 0.15 M titanium diisopropoxide bis(acetylacetonate) in 1-butanol solution via the spin-coating method by heating on a hot-plate at 155 °C for 10 min. A mesoporous TiO_2 layer was coated on the prepared TiO_x compact layer by the spin-coating method using TiO_2 paste (18NR-T), and then annealed at 500 °C for 60 min in a box furnace. The perovskite layers were fabricated by two-step processes. First, the mesoporous TiO_2 photoanode layers were coated using PbI_2 solution by spin-coating, and drying at 120 °C. Then, perovskite layers were deposited by spin-coating (10 mg/mL) using a CH_3NH_3I solution on the PbI_2 coated layers, which dried at 135 °C. The hole-transporting materials (HTM) solution was prepared by dissolving spiro-MeOTAD (72.3 mg), 4-tert-bytylpyridine(28.8 μL) and a Li-TSFI stock solution(17.5 μL) in 1 mL chlorobenzene loaded on the perovskite layer, which was coated by the spin-coating method. Finally, Au electrode was deposited on the top of the HTM over layer by the thermal evaporation system.

2.3 Characterizations

The simulated solar light was achieved using a xenon lamp and an AM 1.5 filter. The J-V curves were obtained by measuring the photocurrent using a source meter. External quantum efficiency (EQE) was measured using an EQE system (PV measurement Inc.) under DC mode, where a 75 W xenon lamp was used a light source for generating a monochromatic beam. Transmittance and diffusion transmittance spectra were recorded using a Spectral Response Measurement System in the 300 ~ 1,100 nm wavelength range and Haze was calculated both the transmittance and diffusion transmittance by using the following equation. Reflectance and absorption were measured using a UV-3600 spectrophotometer.

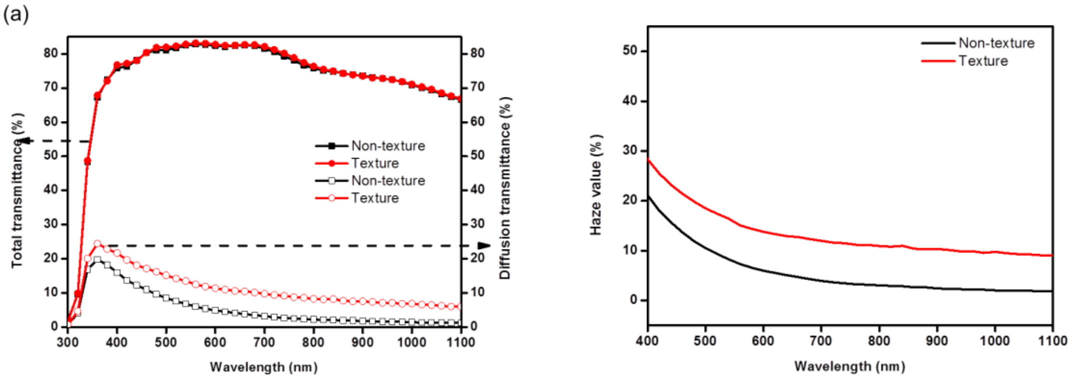

Figure 1: (a) Total transmittance and Diffusion transmittance. (b) Spectral haze value (texture glass and bare glass)

3. Results and discussion

3.1 Transmittance and diffusion transmittance spectra

The effect of glass texturing on light scattering and trapping properties was observed by the naked eye. Texturable films change their clear transparent appearance to a milky form after a short dip in diluted HF acid. If the glass is textured, the process has a big impact on the optical properties, reducing the transmittance properties, solar cell's performance will deteriorate. Therefore we measured the transmittance to confirm Figure 1, shows the specular transmittance and diffusion transmittance spectra of the textured glass films. The glass surface changed to a milky form after the etching process. When both films were highly transparent, the average specular transmittance curves in the entire wavelength range was above 80 %. We confirmed that transmittance was not affected by the etching process. The diffuse transmittance of the different surfaces is presented in (Figure 1(a)). Both the textured and non-textured films exhibited an almost diffusion transmittance over a broad range of whole wavelength. The diffuse transmittance curve for both film exhibited an exponential rapid decay. The glass textured substrate had the highest total diffuse transmittance in the entire wavelength range. One can observe that the diffusion transmittance of the glass textured surface correlates with the optical behaviour. We observed haze phenomenon by the naked eye on the glass surface with wet etching and the average specular transmittance curves were maintained while the diffuse transmittance rose gradually, which shows the increasing roughness of the substrate. Especially, the intensity of the diffuse transmittance curve increased at 370 nm. The haze value (Total diffuse transmittance / Total transmittance) was calculated. The haze value provided an index for the characteristics of light scattering and trapping effects in the textured film. In the overall visible light wavelength range, the value of the haze was above 10. The haze level at the wavelength of 400 nm increased by about 50 % even after the etching process. In order to further study light scattering and trapping in the texture-etched glass, the haze in the layers was determined (Figure 1(b)). shows the haze values and analysis of the diffusion transmittance showed a continuous shift in the crater opening angle. The origin of the optical effects produced by the wet etching process can be understood from the random order morphologies of the etched glass surface. Transparency ≥ 80 % over the entire visible region is a good optical property in solar cells. We also expect that the light scattering and trapping properties can be controlled by varying the etchant, etchant concentration and etching time.

3.2 Reflectance spectra

Figure 2, shows the results of reflectance measurements on the textured and non-textured glass (Figure 2(a)), curves are shown for the front side of the glass (when the light enter the glass, light scattering occurs at the air/glass interface). The other curves are for the back side of the glass (when the light enter the glass, part of the light is reflected back by the mesoporous layer or the back contact and then, part of the reflected light can be reflected once again at the FTO/glass interface). The results of the bare glass provide a good indication of the effectiveness of glass texturing in glass substrates with random order patterns, which will further change the overall reflection property. The reflectance of the solar cell with glass texturing is significantly reduced in the visible range at the front side of the glass when compared with the bare cell. This reduction is attributed to an increased light scattering property at the front side of the glass. The random pattern on the glass surface leads to light scattering and the perovskite layer absorbs more light. The sample with textured surfaces has

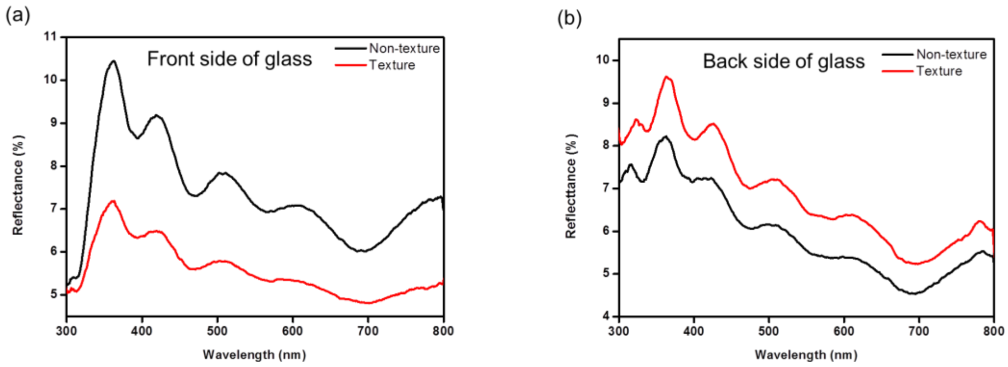

Figure 2: Reflectance of the etched glass surfaces. (a) Front side of glass (Air/glass). (b) Back side of glass (glass/FTO)

relatively enhanced reflection ability due to light trapping at the inner solar cell. A more direct illustration of the light trapping effect is observed in the visible region for the reflectance curves in (Figure 2(b)). Little difference is observed in the reflectivity of the back side of the glass substrate after treatment. The reflectance value increased as more light was trapped at the inner solar cell. Especially, the intensity of the reflectance curves also increased at 370 nm, these results were affected by diffusion transmittance. A major advantage of glass texturing is that it leading to reduced optical losses.

3.3 Absorbance spectra

To examine the light scattering and trapping effects of the random pattern, glass substrates were prepared using two types of substrates. The amount of absorbed light was significantly enhanced after wet etching. The spectra in (Figure 3(a)) quantifies the similar, uniformly reflectivity value of as little as 1 ~ 3 % in the high absorption at visible region of glass texturing samples. This resulted in a nearly complete suppression of surface reflectivity in the entire high optical absorption region of the perovskite layer, with an enhancement of light scattering and trapping in the inner solar cell. These results can be partly explained by the optical images and haze data see Figure 1, with the assumption that higher diffusion transmittance results in better light scattering. Absorbance curves maintain as similar as from 300 nm to 550 nm and then rapidly decay. Absorbance value was increased at visible region. We can know that absorbance region was wider than before. The utilization of the light was increased due to of the foregoing effect. In particular, it increased significantly the optical properties, the result is good influence on characteristics of current density. These effects exert a positive influence on optical property of solar cell. Thus, in other to allow a good incoupling of incident light as well as light scattering and trapping in perovskite solar cells.

3.4 Cell property

The EQE was measured to demonstrate both the scattering effect at the air/glass interface and light trapping at the glass surface/inner solar cell. EQE is drastically increased in the wavelength range between 400 nm and 800 nm when compared with the reference cell. This upswing is attributed to increased absorbance at the

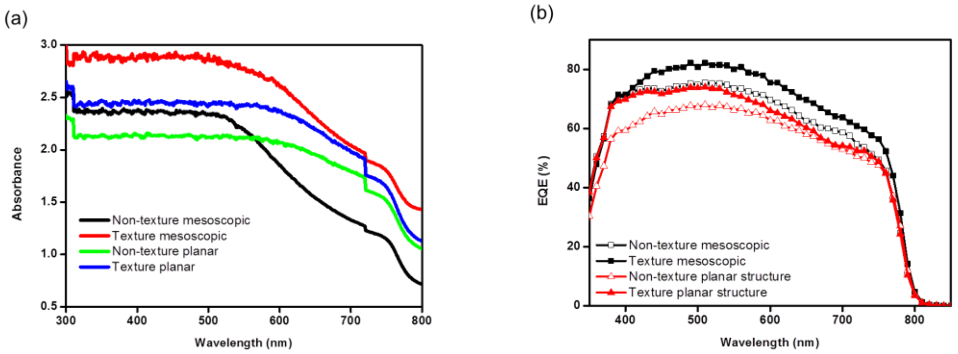

Figure 3: (a) Absorbance (b) EQE (including mesoscopic and planar structure)

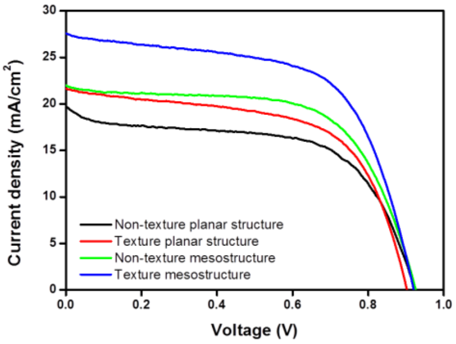

Figure 4: J-V curves of Perovskite solar cells

perovskite layer. Due to the scattering effect for the perovskite solar cells on the textured glass substrate, interferences in the reflectance are apparent at the front side. These interferences induce light scattering at the front side, at the structure of the textured glass/FTO/solar cell. As shown in (Figure 3(b)), when comparing the EQE curves measured in substrate configuration, a strongly increased EQE is apparent in the visible region. Quantum efficiency above 80 % at wavelengths of 400 ~ 600 nm was obtained when glass texturing was applied to the perovskite solar cell. The EQE of the perovskite solar cell after glass texturing was higher than without glass texturing.

The solar cell characteristics with respect to the mesoporous layer and etching process for the cells fabricated using these specimens are shown in Figure 4. Unfortunately the cell performance deteriorates drastically in the planar structured cell without a mesoporous layer and non-glass texturing process. Jsc contributes significantly to the overall cell performance in textured glass substrates. In this case, the cell current density reached 26.5 mA/cm^2 due to an improved QE in the visible wavelength ranges. The gain in efficiency is considerable because of the superior electrical properties of the glass textured samples, leading to a high optical property. Finally, 11.7 % ~ 15.2 % efficiency was achieved with the textured glass substrates. All these results demonstrate the effectiveness of optical confinement at the inner solar cells using textured surfaces with a certain haze ratio, which results in higher absorption of the incident light. Furthermore, notable differences can be found among the textured surface with respect to the Voc. Texturing samples with higher roughness show lower Voc.

Table 1: J-V curves of Perovskite solar cells

	Jsc (mA/cm^2)	Voc (V)	FF (%)	PCE (%)
Non-texture planar	17.7	0.93	63.1	10.5
Texture planar	20.4	0.90	63.6	11.7
Non-texture mesoscopic	21.3	0.93	63.7	12.6
Texture mesoscopic	26.5	0.92	62.4	15.2

4. Conclusions

We optimized the effect of glass texturing on mesoscopic and planar structures as well as the light scattering and trapping ability of perovskite solar cells. The random pattern of the glass affects light trapping by the perovskite solar cell as determined by the absorption and EQE. The scattering and light trapping effects were enhanced for the Perovskite solar across all ranges because of the increased optical property. As a result, the photovoltaic property of the perovskite solar cell using textured glass improved the photocurrent density by up to 24.4 % and the conversion efficiency was 21.1 %.

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