

Research Paper

Influences of Glass Texturing on Efficiency of Dye-Sensitized Solar Cells

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Abstract The etching processes of glass in aqueous hydrofluoric acid (HF) solutions were used to improve the current density of solar cell. In this study, the textured glass substrate has been etched by solution and the TiO₂ thin films have been prepared on this textured glass. After the TiO₂ film deposition the surface has been etched by HF under different concentration and the etched TiO₂ thin films had a longer electron lifetime and higher haze ratio as well as light scattering, resulting in 1.7 times increment of dye-sensitized solar-cell(DSSC) efficiency. Increases in the surface root-mean-square roughness of glass substrates from 80 nm to 1774 nm enhanced haze ratio in above 300 nm wavelength. In particular, haze ratio of etched TiO₂ films on textured glass showed gradually increasing tendency at 550 nm wavelength by increasing of HF concentration up to 10 M, suggesting a formation of crater with various sizes on its surface.

Keywords: Glass and TiO₂ texturing, HF wet etching, Haze ratio, Dye-sensitized solar-cell(DSSC)

I. Introduction

In thin film solar cells, diffractive layers or interfaces are used to scatter the impinging light. This may lead to a light trapping effect, which can significantly improve the energy efficiency of such a solar cell device [1]. Light trapping effect was improved by transparent conductive oxides (TCO) film formed on textured substrate [2]. Therefore, high efficiency solar cells need a textured front surface to reduce reflectance since optical losses due to reflectance of incident solar radiation are one of the most important factors limiting their efficiency. Textured glass and oxide thin film has been prepared by a variety of methods such as reactive ion etching [3,4], mechanical texturization [5,6] and wet-chemical etching with acid based solutions [7,8]. In particular, the wet-chemical etching method has several advantages such as very simple process and low-cost [9]. In this work, surface of TiO₂ films deposited on with/without etched glasses has been textured with different HF concentrations. The combined effect of the textured TiO₂ and glass substrates on the electrical and optical properties as well as dye-sensitized solar-cell efficiency has been investigated.

II. Experimental

FTO (fluorine doped tin oxide) coated glass substrate was

sonicated in an ethanol and IPA mixture (1:1 volume ratio) for 10 min, and then rinsing in distilled water for 10 min. The cleaned glasses were dried by nitrogen gas blowing. After FTO coated glass part was covered using masking tape (PI tape), glasses were etched for 5 min. by wet chemical etching process using HF and H₂O mixture (1:1 volume ratio) under different concentrations of 0, 5, 10, and 15 M, respectively. To prepare a TiO₂ paste, p-25 (Degussa, 0.5 g) powder were grounded with water (1 mL) containing some acetylacetone (Aldrich) and hydropropyl cellulose (Aldrich, 0.25 g) to prevent reaggregation of the particles. The paste was spread uniformly on the surface of the FTO coated non-textured/textured glass using the doctor-blade technique. All samples were annealed in air at 450°C for 60 min to remove the alcoholic solvent. For DSSC fabrication, the resulting films were sensitized by immersing in an ethanol solution containing 0.5 mM N719 dye (Solaronix Inc.) for 24 h. Afterward, the sensitized films were sandwiched and bonded with a platinum coated FTO counter electrode. The two electrodes were separated by about 20 μ m thick polypropylene spacer, and the internal space of the cells was filled with a liquid electrolyte (Solaronix Inc., Iodolyte AN-50). The active area of the DSSCs was 0.25 cm².

III. Results and Discussion

Figure 1 shows AFM images and RMS roughness of etched glasses by various concentration of HF etchant. As shown in Fig. 1, the RMS roughness of etched glasses is

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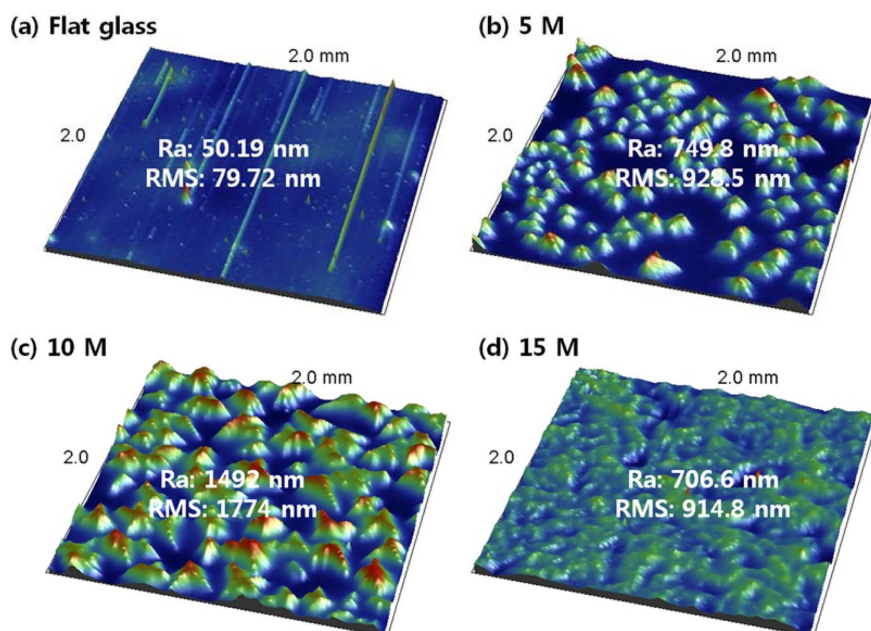


Figure 1. AFM images and RMS roughness of the FTO glasses textured under different HF etchant concentration of (a) 0 M, (b) 5 M, (c) 10 M, and (d) 15 M, respectively.

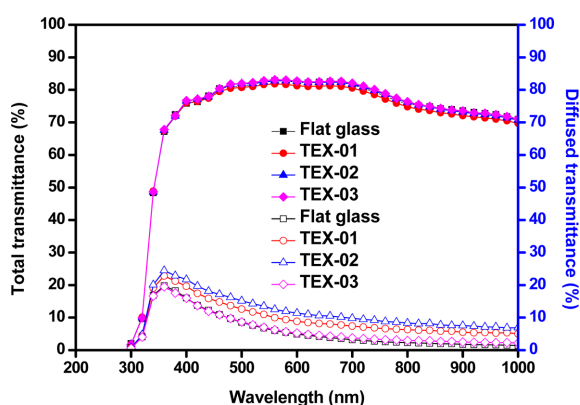


Figure 2. Total (closed symbol) and diffused (opened symbol) transmittance of the FTO glasses textured under different HF etchant concentration of 0 M (flat glass), 5 M (TEX-01), 10 M (TEX-02), and 15 M (TEX-03), respectively.

increased from 80 nm to 1774 nm with increasing HF concentration up to 10 M and then decreased to 915 nm when the glass was etched with 15 M of HF solution. TiO_2 films were deposited on both flat and textured glasses. This result shows that TiO_2 film was grown along by curve of textured glass substrate. Therefore, roughness of TiO_2 film on textured glass substrate was higher than TiO_2 film on the flat glass substrate and high concentration of HF solution is made crater with various size on the textured surface.

Sun light had occurred reflection, transmittance and diffusion at injection into the solar cell devices [10]. Figure 2 shows optical properties (total & diffused transmittance) of glass substrate before (closed symbols) and after (opened symbols) texturing treatment. In the cases of non-etched glasses with smooth TiO_2 surface, good transmittance over 80% is observed for all samples. However, injection light

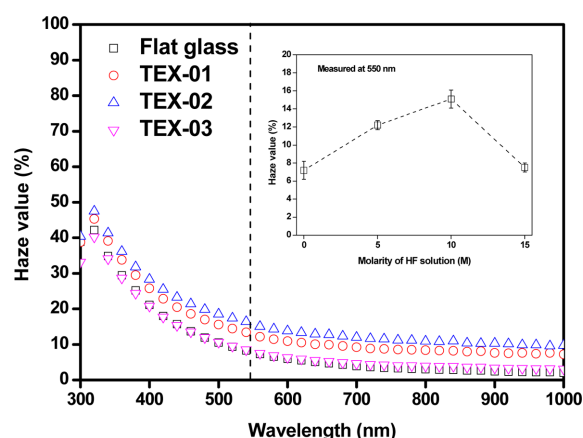


Figure 3. Haze ratio of etched TiO_2 films at UV-Vis. range of 300~1000 nm wavelengths. Insert shows haze ratio of etched TiO_2 films measured at 550 nm wavelength.

gets out fast for low reflection and diffusion in the solar cell devices. While for the etched glasses with rough TiO_2 surface, it had not only high diffusion but also staying for long time into the solar cell devices. And injection light makes the best use of all wavelengths [11]. Therefore, we calculated haze ratio ($H = T_{\text{diff}}/T_{\text{total}}$) of all etched glasses to know light scattering effect of etched TiO_2 films and it showed in Figure 3. Haze ratio of as-grown TiO_2 thin films on textured glass substrates had lower than 15% at 500~1100 nm wavelengths. But, relatively high haze ratio of 20~50% at 300~500 nm wavelength are measured for all etched TiO_2 films at various concentration of HF etchant such as 5, 10 and 15 M, respectively. In particular, haze ratio of etched TiO_2 films showed gradually increasing tendency at 550 nm wavelength by increasing of HF concentration up to 10 M. This means that etched TiO_2 films had more high haze ratio than those of non-etched

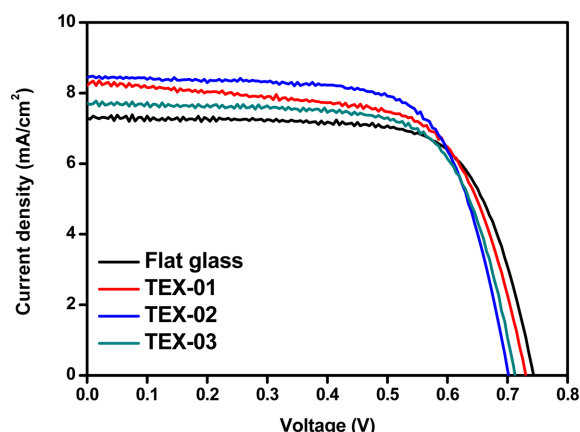


Figure 4. Photocurrent–voltage characteristics (J-V curve) obtained from dye-sensitized solar-cell (DSSC) devices fabricated with both non-textured (flat glass) and textured (etched under various HF concentrations of 5, 10 and 15 M) glasses.

Table 1. The measured values of photocurrent density-voltage characteristics (Top) and the $-Z_{00}$ - Z_0 characteristics (Bottom) for the dye-sensitized solar-cell devices fabricated with both non-textured (flat glass) and textured (TEX-01, 02, 03) glasses.

Cell efficiency				
	Voc (V)	Jsc (mA/cm ₂)	FF (%)	CE (%)
Flat glass	0.74	7.29	69.6	3.77
TEX-01	0.73	8.05	66.7	3.91
TEX-02	0.70	8.42	68.2	4.02
TEX-03	0.71	7.67	68.9	3.76
Electron lifetime				
	Flat glass	TEX-01	TEX-02	TEX-03
ω_{\max}	25.2	17.9	15.9	20.0
τ_{eff} (sec)	6.32E-03	9.03E-03	1.0E-02	7.96E-03

glasses by formation of crater with various sizes on its surface. Also, we can regulate the surface roughness and property of light scattering by adjusting the concentration of HF etchant. Based on data shown in Figs. 2 and 3, relatively higher diffused transmittance and haze value are obtained from the textured (etched under 10 M HF concentration; TEX-02) sample, expecting good solar-cell efficiency.

Figure 4 shows the photocurrent density–voltage characteristics (J-V curve) obtained from dye-sensitized solar-cell (DSSC) devices fabricated with both non-textured (flat glass) and textured (etched under various HF concentrations of 5, 10 and 15 M) glasses. The most high cell efficiency was obtained from the textured (etched under 10 M HF concentration; TEX-02) solar-cell device. As shown in the table 1 and Fig. 4, the open-circuit photovoltage (Voc), short-circuit photocurrent density (Jsc), fill factor (FF), and the energy conversion efficiency (CE) of the standard (flat glass) DSSC were 0.74 V, 7.29 mA/cm², 69.6%, and 3.77% respectively, while the Voc, Jsc, FF, and CE of the textured TiO₂ thin film (TEX-

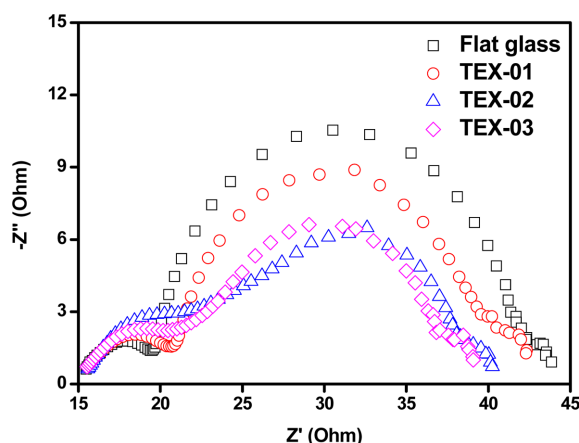


Figure 5. Nyquist diagram of the impedance data obtained from dye-sensitized solar-cell (DSSC) devices fabricated with both non-textured (flat glass) and textured (etched under various HF concentrations of 5, 10 and 15 M) glasses.

02) based DSSC were 0.70 V, 8.42 mA/cm², 68.2%, and 4.02%, respectively. These results are summarized in Table 1. Since the FF is mainly related to the series resistance of DSSCs, we measured the $-Z_{00}$ - Z_0 characteristics of both the standard (flat glass) DSSC and textured TiO₂ thin films (TEX-01, 02, 03) based DSSC by electrochemical impedance spectroscopy measurements. Han et al. showed that the series resistance of DSSCs consisted of three resistance elements, namely, the sheet resistance of FTO, the resistance of ionic diffusion in electrolyte and the resistance at the interface of counter electrode and electrolyte [12]. The FF increases with decrease in the internal resistance elements and conversion efficiency. Consequently, reduction of series resistance can result in high FF. The short-circuit photocurrent density (Jsc) can be described by integrating the product of incident photon flux density, $F(\lambda)$ [13]. The charge collection efficiency is largely determined by the competition between charge transport and recombination that can be measured by electron lifetime and electron diffusion coefficients [14].

Figure 5 shows Nyquist diagram of the impedance data of dye-sensitized solar cells with/without textured FTO glass. Electrochemical impedance spectroscopy (EIS) can be observed four components such as Z_1 (high frequency region), Z_2 (middle frequency region), Z_3 (low frequency region) and sheet resistance of TCO (R_h). The ohmic serial resistance (R_h) in the high frequency region corresponds to the electrolyte and the FTO resistance, while the resistances Z_1 , Z_2 and Z_3 relate to charge transfer processes occurring at the Pt counter electrode in the high frequency region, resistance for TiO₂/electrolyte interface and Nernstian diffusion within the electrolyte in the low frequency region, respectively [15]. In figure 5, we conformed decreasing of R_1 , R_2 impedance by EIS data. This means that textured samples had more electrons as compared with non-textured sample by the increasing of injection light. Also, recombination of electron was

decreased by the active oxidation-reduction reaction and then electron transfer is more active relatively. From Fig. 5, we can calculate the values of series resistance (R_{max}) and electron lifetime (T_{eff}). The obtained values for standard(flat glass) DSSC are 25.2 and 6.32×10^{-3} while the values of textured TiO_2 thin film(TEXT-02) based DSSC are 15.9 and 1.0×10^{-2} , respectively. These results show that the series resistance of textured TiO_2 thin film(TEXT-02) is 1.6 times smaller than that of standard(flat glass) DSSC, resulting in decreasing of FF, while the electron life time of textured TiO_2 thin film(TEXT-02) is higher than that of standard(flat glass) DSSC. That's why we obtained 1.7 times higher conversion efficiency from the textured TiO_2 thin film(TEXT-02) based DSSC compared with that of standard(flat glass) DSSC.

IV. Conclusions

To investigate the influence of glass texturing on the dye-sensitized solar-cell efficiency, wet chemical etching using HF etchant with various concentrations such as 0, 5, 10 and 15 M, respectively, was carried out. Consequently, textured (with 10 M HF solution) glass DSSC exhibits a J_{sc} of 8.42 mA/cm^2 , a V_{oc} of 0.70 V and a fill factor (FF) of 68.2% with an overall conversion efficiency of 4.02%. This result showed 1.7 times increment of conversion efficiency of solar cell using the textured glass due to increase of electron lifetime and current density as well as light scattering. The haze ratio was also increased by increasing HF concentration up to 10 M. These results suggested that glass texturing was very effective in controlling the light-scattering properties into the photovoltaic cell.

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