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Inline RF sputtered TAZO films for applications in hydrogenated amorphous silicon thin film solar cells

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ABSTRACT

In this paper, we aim to evaluate feasibility of replacing tin oxide (SnO_2) films by in-line sputtered (titanium, aluminum)-doped zinc oxide (TAZO) as a front electrode of hydrogenated amorphous silicon (a-Si:H) thin film solar cells. The HCl wet-etching process and the device performances are investigated and optimized. The results show that the textured TAZO can have a lower sheet resistance of 7 Ω/square and a higher haze of 22% compared to commercial Asahi-U SnO_2 films. The a-Si:H solar cells with a TAZO front contact is found to have a low fill factor due to a poor TAZO/p-a-Si:H interface. However, the interface problem can be significantly improved by inserting a microcrystalline p-layer silicon thin-film. In addition, the reproducibility of the wet-etching process is investigated. The fluctuation in the haze of the etched TAZO films can be obviously reduced when a multi-step wet-etching process is used. Moreover, the light soaking test is performed on the TAZO films. Only slight degradation in film properties indicates high stability with respect to time. These results encourage potential adoption of cost-effective in-line sputtered TAZO films as an alternative for the front contact of a-Si:H thin film solar cells.

1. Introduction

Materials such as fluorine-doped tin oxide (SnO_2:F) and zinc oxide (ZnO) films are well-known transparent conductive films used in silicon-based thin film solar cells. Currently, SnO_2:F is a commercial standard TCO substrate, but its manufacturing processes demand high deposition temperature and use expensive toxic gas. ZnO films are promising alternative because of low material cost, environmental friendliness, good stability in H_2 plasma, non-toxicity and good optoelectronic properties [1–3]. Most of the careful doping studies have been performed by kinds of techniques in order to improve the performance of ZnO films [4–7]. Trivalent cation-doped ZnO, especially Al-doped ZnO (AZO), shows excellent transparency over the entire visible spectrum and has better transport properties due to higher electron mobility. Few researches on quardrivalent cation-doped ZnO films, such as Ti-doped ZnO (TZO) [8–12], have been reported that they can provide two free electrons to contribute the conductivity as it substitutes Zn in ZnO films.

For further improvement of doped ZnO films' properties, the co-doping effect of some impurity and Al^{3+} has been reported before [13,14]. M. Jiang et al. [15] studied the effects of annealing treatment on electrical, optical and magnetic properties of the (Ti, Al)-doped ZnO (TAZO) films prepared on glass substrates by radio frequency (RF) magnetron sputtering. They reported that the TAZO films could have good preferential c-axis orientation and lower resistivity as compared to AZO. However, the studies of the TAZO films related to chemical wet-etching process and solar cell applications are rarely reported.

In this study, we prepare TAZO films with in-line RF magnetron sputtering, and focus on a comparative investigation of the performances between solar cells with either TAZO or SnO_2:F front contact. Furthermore, the reproducibility of the wet-etching process performed to improve light scattering capability of the TAZO films is investigated. The stability against light soaking of the TAZO films and solar cells is also presented.

2. Experimental

TAZO films with thickness of 800 nm were prepared on low cost Taiwan Glass substrates using an in-line reactive RF magnetron sputtering system. The target was a high-purity ZnO ceramic target with 1.5% Al_2O_3 and 1.5% TiO_2 (wt%). Before loading them in the sputtering chamber, the substrates were ultrasonically cleaned with ethanol and de-ionized water then dried with pressurized

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Table 1
Deposition conditions of the in-line sputtered TAZO films.

Parameter	Value
Base pressure (Pa)	6×10^{-5}
Process pressure (Pa)	0.1–1.5
Gas flow (sccm)	45
RF power (W)	1000
Deposition time (min)	10
Substrate temperature (°C)	300

nitrogen. Table 1 lists the experimental deposition parameters. We examined the dependence of the working pressure varying from 10^{-1} to 1.5 Pa on the electrical properties of in-line sputtered TAZO films. A post-annealing process was carried out at 350 °C in vacuum for 1 h. To increase the surface roughness of the TAZO films, a single-step wet-etching process with a traditional 0.5% HCl solution was performed. For film characterization, the light scattering capability of a rough film was evaluated by using the haze ratio defined by

$$\text{haze} \quad (\%) = \frac{T_d}{T_d + T_s} \times 100 \tag{1}$$

where T_d is the diffuse transmittance, and T_s the specular transmittance. The spectral range for optical characterization was limited to the range of 380–880 nm, which adequately covered the spectral response of a-Si:H solar cells. The electrical properties were quantified by Hall-effect measurement, and optical transparency was measured by UV-visible spectroscopy. The root-mean-square roughness (rms) of the microscopic morphological surface is measured by atomic force microscope (AFM) as an indicator of the scattering properties of the textured TAZO film.

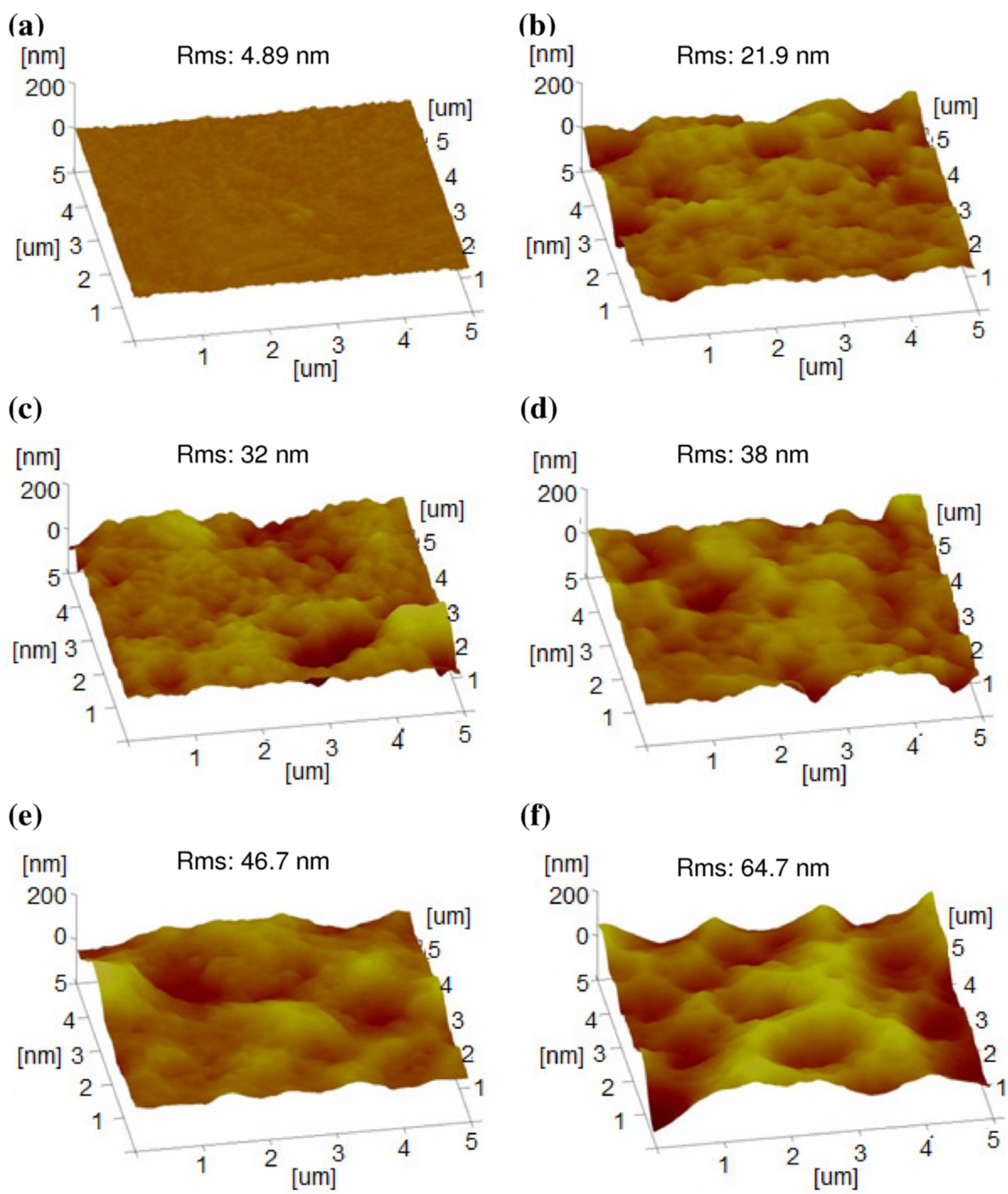

Fig. 1. AFM images of the TAZO films prepared at etching times of (a) 0 s, (b) 10 s, (c) 20 s, (d) 30 s, (e) 40 s and (f) 50 s.