Solar Energy Materials & Solar Cells 95 (2011) 1583–1586

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Review

Wet-etch texturing of ZnO:Ga back layer on superstrate-type microcrystalline silicon solar cells

Kuang-Chieh Lai [a], Fu-Ji Tsai [b], Jen-Hung Wang [b], Chih-Hung Yeh [b], Mau-Phon Houng [a],*

[a] Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, No. 1, Dasyue Rd., East District, Tainan City 701, Taiwan
[b] NexPower Technology Corporation, No. 2, Houke S. Rd., Houli Dist., Taichung City 421, Taiwan

ARTICLE INFO

Article history:
Received 27 July 2010
Received in revised form
26 October 2010
Accepted 14 February 2011
Available online 8 March 2011

Keywords:
Transparent conductive oxide
Surface plasmon
Microcrystalline silicon
Thin film solar cells

ABSTRACT

Surface wet etching is applied to the ZnO:Ga (GZO) back contact in μc-Si thin film solar cells. GZO transparency increases with increasing deposition substrate temperature. Texturing enhances reflective scattering, with etching around 5–6 s producing the best scattering, whereas etching around 5 s produces the best fabricated solar cells. Etching beyond these times produces suboptimal performance related to excessive erosion of the GZO. The best μc-Si solar cell achieves FF=68%, V_{OC}=471 mV and J_{SC}=21.48 mA/cm^2 (η=6.88%). Improvement is attributed to enhanced texture-induced scattering of light reflected back into the solar cell, increasing the efficiency of our lab-made single μc-Si solar cells from 6.54% to 6.88%. Improved external quantum efficiency is seen primarily in the longer wavelengths, i.e. 600–1100 nm. However, variation of the fabrication conditions offers opportunity for significant tuning of the optical absorption spectrum.

Contents

1. Introduction

Silicon thin film solar cells with tandem structures are promising candidates for future low-cost high-efficiency solar cells. In high-efficiency tandem cells, hydrogenated microcrystalline silicon (μc-Si:H) plays a key role as an absorber material in the bottom or middle cells. For μc-Si:H cells, light trapping is crucial to obtain a high current density, since the absorption coefficient of μc-Si:H is small in the near infrared region [1–4]. For silicon-based thin film technologies, one must attach importance to the role of light trapping strategies that allow enhanced light absorption in the thin active layers. Light trapping can be achieved by using textured front contacts of transparent conductive oxide (TCO) and/or back reflectors based on TCO and metal layers [5–10].

The influence of a back scattering reflector on the performance of μc-Si solar cells has been widely investigated. However, investigation of textured back reflector structures on the performances of μc-Si solar cells has focused mainly on substrate-type thin film solar cells [11–15] or theoretical simulation [16–19]. There has been relatively little research focused on the effect of textured back reflector structures on the performance of superstrate-type thin film solar cells [20]. The purpose of this paper is to investigate the effect of a wet etching textured back reflector on the performance of superstrate-type microcrystalline silicon solar cells.

2. Experimental

The μc-Si thin film solar cells used in this study are fabricated in a conventional plasma enhanced chemical vapor deposition (PECVD) system using a 27.12 MHz plasma with SiH_4, H_2, B_2H_6, CH_4 and PH_3 as gas sources. Commercially prepared textured glass/SnO_2:F is used as the substrate for a GZO film that is deposited as a protective layer.

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* Corresponding author. Tel.: +886 6 275 7575x62342; fax: +886 6 234 5482.
E-mail address: mphoung@eembox.ncku.edu.tw (M.-P. Houng).

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doi:10.1016/j.solmat.2011.02.011

Solar cells are then grown on the SnO_2:F/GZO coated glass substrate with a p–i–n structure of the sequence: glass/SnO_2:F/GZO /p-μc-Si:H/ i-μc-Si:H/n-μc-Si:H/etched GZO/Ag (all sputtered GZO are from the same target). The GZO layer is deposited by a commercial DC magnetron sputtering system using a ZnO target containing 3.2 wt% Ga_2O_3. Surface texture on the GZO layer is then created by a wet etching process using a diluted HCl (0.5%) solution. Optical properties, i.e. total transmittance, scattering reflectance and total reflectance, are determined by a double-beam UV–visible spectrophotometer (UV-4100, Hitachi). X-ray diffraction (XRD) patterns are obtained by 40 kV–20 mA CuK_α radiation (UltimaIV, Rigaku). The surface morphology is observed by scanning electron microscopy (SEM). Incident photon-to-current efficiency (IPCE) is evaluated to characterize the external quantum efficiency of specific samples. *I–V* measurements are performed with a dual light solar simulator (WXS-220S L2, Wacom) under AM1.5G 100 mW/cm^2 illumination.

3. Results and discussion

Fig. 1 shows the total transmittance of the 100 nm GZO thin films deposited at an argon pressure of 0.31 Pa and at different substrate temperatures ranging from room temperature to 200 °C. The deposition temperature is held below 200 °C because of the process threshold. From the spectrum, it can be observed that the total transmittance of the film increases with growth temperature. Defects such as oxygen vacancies or zinc interstitials decrease due to increased up-take of oxygen with increasing deposition temperature, which therefore results in reduced carrier concentration and improved optical properties [21].

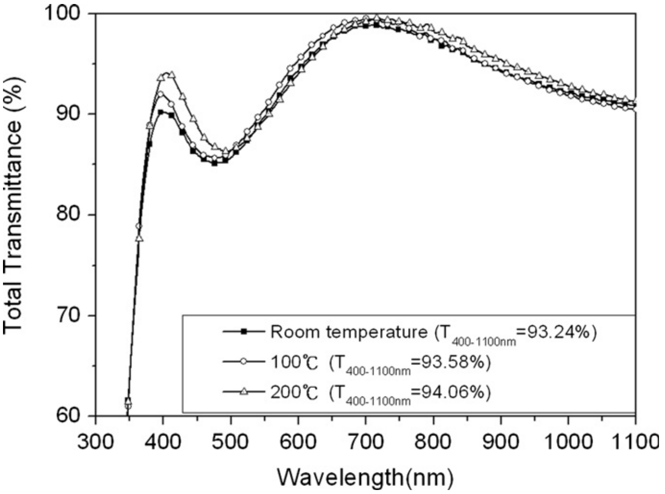

Fig. 1. Total transmittance as a function of wavelength of the GZO films deposited at various substrate temperatures.

Fig. 2(a) shows the scattering reflectance of a typical glass/ etched GZO/Ag sample as a function of etching time at a 200 °C substrate temperature. Reflectance is measured through the glass. It is seen that the scattering reflectance of the back reflector is strongly enhanced by the addition of the textured GZO film. Maximum scattering effect, in general, is achieved by etching of around 5–6 s. Notably, the light scattering effect of the reflectors decreases dramatically when the etching time is extended beyond 6 s, e.g. the reflectance curve at 7 s of etching closely matches the curve with no etching. The total reflectance of the glass/textured GZO/Ag sample is plotted in Fig. 2(b), with the etched ZnO/Ag interface displaying obvious surface plasmon (SP) behavior [22]. A valley in the total reflectance around 440 nm is observed due to SP. This SP resonance moves toward the longer wavelengths when the dielectric material, which is in contact with the rough Ag layer, has a higher index of refraction [23]. However, the etched ZnO/Ag interface shows huge absorption loss in the short wavelengths, indicating that the texture-induced plasmonics have relatively lower light loss in longer wavelengths, thereby allowing improved light trapping effects for the longer wavelengths.

Fig. 3(a–e) present SEM images of the back contact surface: (a) before deposition of the GZO film, (b) after deposition of the 200 nm GZO film, (c) after 3 s etching of the 200 nm GZO film, (d) after 4 s etching of the 200 nm GZO film and (e) after 5 s etching of the 200 nm GZO film. All GZO films are deposited at a 200 °C substrate temperature. Clearly, surface treatment of the GZO films generates surface texturing characterized as periodic cratering, which becomes deeper and rougher as etching time increases. The image in Fig. 3(e) shows the etching process after 5 s, wherein one can see the beginning of over-etching, i.e. the concave deep areas are starting to reveal the underlying n-μc-Si:H layer of the solar cell. At 7 s (not pictured), the deposited GZO has been etched away to the point that the behavior of the resulting solar cell is approaching that of Cell A in Table 1, i.e. the cell with no GZO layer. Additionally, we find the etching rate of GZO on n-μc-Si:H (~25–30 nm/s) is faster than the etching rate of GZO on glass.

Fig. 4 shows the external quantum efficiency (EQE) as a function of wavelength for the smooth and rough μc-Si thin film

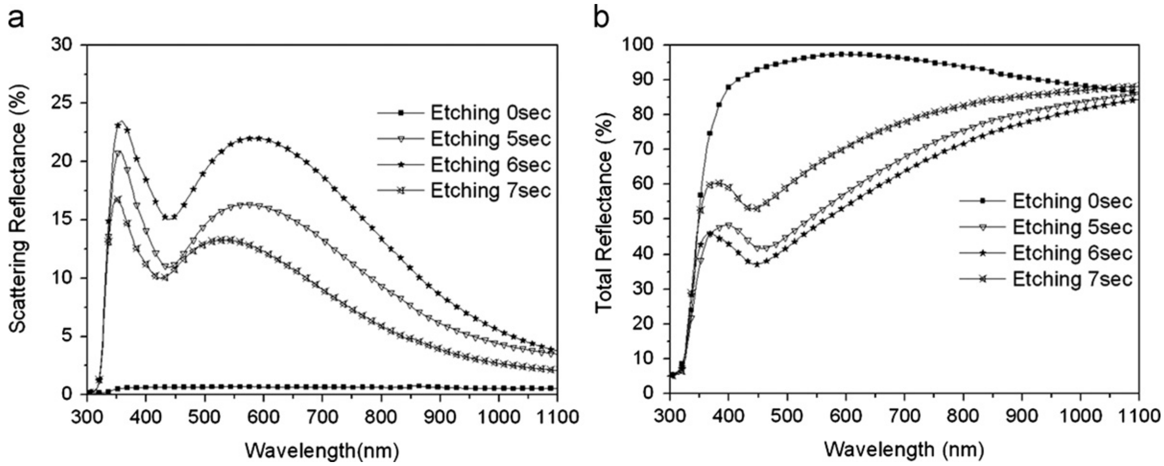

Fig. 2. (a) Scattering reflectance as a function of wavelength for GZO films deposited at 200 °C substrate temperature and (b) total reflectance as a function of wavelength for GZO films deposited at 200 °C substrate temperature.