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Improvement of amorphous silicon solar cell properties by using niobium oxide coated textured gallium-doped zinc oxide front contact

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Amorphous silicon solar cells combining a novel anti-reflection (AR) material niobium oxide (Nb_2O_5) and textured gallium-doped zinc oxide (ZnO:Ga) front contact etched by a new etchant adding buffer solutions have been investigated. The incorporation of Nb_2O_5 between ZnO:Ga and a-Si:H decreases reflectance at the interface almost over the whole useful part of spectrum range, with a side effect of slight decrease in fill factor resulted from increased ohmic loss. An improved initial efficiency of 9.32 % on aperture area of 10×10 cm^2 is obtained from an a-Si:H solar cell fabricated on Nb_2O_5 coated textured ZnO:Ga front contact.

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1. Introduction

Efficient photon management is one of the most important ways to enhance conversion efficiency of thin film solar cells [1]. In the case of glass substrate based amorphous silicon (a-Si:H) solar cells, efficient photon management needs both light trapping induced by light scattering of rough transparent conductive oxide (TCO) and minimized interface reflection loss between TCO (n~1.9) and a-Si:H (n~3.5) due to mismatch of refractive index [2]. Doped ZnO has emerged as one of the promising substitutes of commercial fluorine-doped tin dioxide (SnO_2:F) [3-5], which suffers high purchase price and poor durability against hydrogen plasmas [6, 7]. The random surface-textured morphology of doped ZnO can be achieved by wet-chemical etching, and the etching process is typically dipping the sputter deposited doped ZnO in 0.5 % HCl solution for 15 s [8]. The most commonly used ARL between TCO and a-Si:H is TiO_2-ZnO bilayer, in which a thin ZnO layer is coated to protect TiO_2 from hydrogen-induced reduction reaction [9-11].

In this work, we first employ a new etchant, other than 0.5 % HCl solution, to etch as-grown ZnO:Ga films to achieve efficient light trapping. Secondly we apply Nb_2O_5 (n~2.4) [12], instead of TiO_2 (n~2.5) [13], as a novel ARL to reduce the optical loss due to mismatch of refractive index.

2. Experimental

The ZnO:Ga films were fabricated on float glass at 70 °C by rf-magnetron sputtering from a ZnO:Ga target with 0.5 wt.% of Ga_2O_3. In the wet-chemical etching process, buffer solutions such as acetic acid and potassium acetate were added to the traditional etchant 0.5 % HCl. Thus, the etching time was prolonged up to 120 s while maintaining good optical and electrical properties of the ZnO:Ga films. The Nb_2O_5 layers were sputter deposited on the textured ZnO:Ga films from an Nb_2O_5 target with an Ar/O_2 gas mixture. The surface morphology of textured ZnO:Ga film was examined by atomic force microscope (XE-100, Park Systems), the optical transmittance, reflectance and haze factor of the film were measured by UV-Vis-NIR spectrophotometer (Cary 5000, Varian) and hazemeter (MFS-530, Hongming technology), respectively. In order to evaluate the effects of textured ZnO:Ga front contact textured by a new etchant and coated by a novel ARL on solar cell properties, a-Si:H single junction solar cells were prepared on Nb_2O_5 coated ZnO:Ga front contact with aperture area of 10×10 cm^2. The current-voltage (J-V) characteristics of the solar cells were determined under standard test conditions (AM 1.5, 100 mW/cm^2 at 25 °C) using a sun simulator (93194A-1000, Newport).

3. Results and discussion

For the usually adopted etchant 0.5 % HCl, the etching time is generally in the range of 10-20 s, which is too short to be controllable from the viewpoint of industrialization. Moreover, Kluth et al. showed that the etching rate increased with decreasing substrate temperature due to low compactness of deposited ZnO:Al films [14]. In the case of etching ZnO:Ga films deposited at low temperature, buffer solutions, such as acetic acid and potassium acetate were added so that the pH changed less than what it would be if 0.5 % HCl was not buffered. As a result, etching time can be extended to 90 s while maintaining the proper optical and electrical properties of textured ZnO:Ga film, as described by us in detail in reference [15].

The haze factor, which is calculated by the ratio of diffuse to total transmittance, is an indicator for light scattering ability. Haze factor of ZnO:Ga film can be adjusted over a wide range depending on the sputtering and etching processes. Fig. 1 shows high haze factor of 27.58 % at the wavelength of 550 nm is achieved by ZnO:Ga film etched for 90 s.

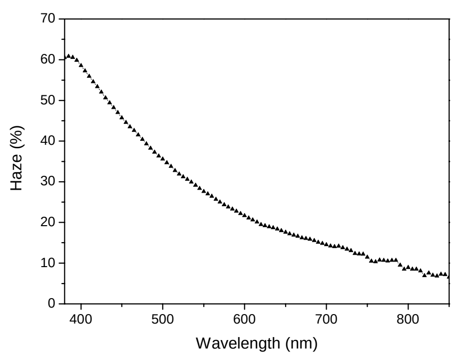

Fig. 1. Haze spectrum of the textured ZnO:Ga film.

As for the ARL, many research groups suggested that the usually used AR material TiO_2 need to be covered with a very thin ZnO layer to protect hydrogen plasma [2, 9-11]. However, reflectance enhances as the thickness of ZnO layer increases [16]. In the case of a-Si:H single junction solar cells, hydrogen plasma produced in the deposition process of p-type a-SiC:H is relatively weak and the interaction time is limited within 30 s. The weak hydrogen-induced reduction reaction makes Nb_2O_5 less transparent but more conductive. Based on these consideration mentioned above, the insertion of ZnO between Nb_2O_5 and a-Si:H is absent in this work. The results in Fig. 2 show that with application of Nb_2O_5, the reflectance at the ZnO:Ga/a-Si:H interface decreases significantly over the whole useful part of spectrum range. The reflectance measured from glass side of glass/ZnO:Ga/Nb_2O_5/a-Si:H is minimized to 5.3 % in the wavelength range of 550-600 nm, which is smaller than the reported reflectance values by other research groups [16, 17]. The remaining reflection loss is totally attributed to the reflection at glass interfaces, which demonstrates the excellent AR effect of Nb_2O_5 at ZnO:Ga/a-Si:H interface.

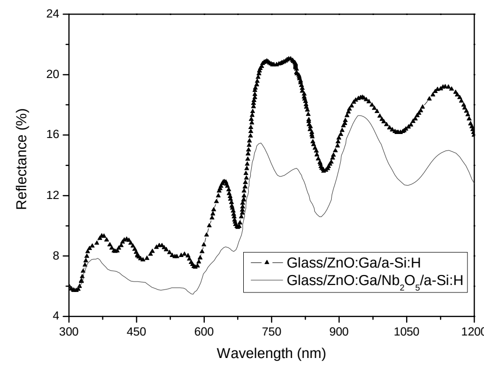

Fig. 2. Reflectance spectra of ZnO:Ga/a-Si:H coated glass with and without a ARL Nb_2O_5.

Solar cells studied in this paper consist of float glass/front contact/(p)a-SiC:H/(i)a-Si:H(260 nm)/(n)a-Si:

H/ZnO:Ga/Al. In this device structure the front contact is textured ZnO:Ga coated with or without Nb_2O_5. Fig. 3 shows J-V curves of a-Si:H solar cells fabricated on the different front contacts. The initial cell efficiency of 9.13 % on aperture area of 10×10 cm^2 without ARL indicate effective light trapping ability and balanced optical and electrical properties of the optimized textured ZnO:Ga films. Adding the ARL Nb_2O_5, an improvement in short circuit current density by 0.6 mA/cm^2 can be attributed to the reduced reflectance at ZnO:Ga/a-Si:H interface. An increase of 13 % in series resistance leads to a decrease in fill factor from 74.58 % to 72.02 %. Finally, an initial efficiency of 9.32 % on aperture area of 10×10 cm^2 is achieved from an a-Si:H solar cell prepared on Nb_2O_5 coated textured ZnO:Ga front contact.

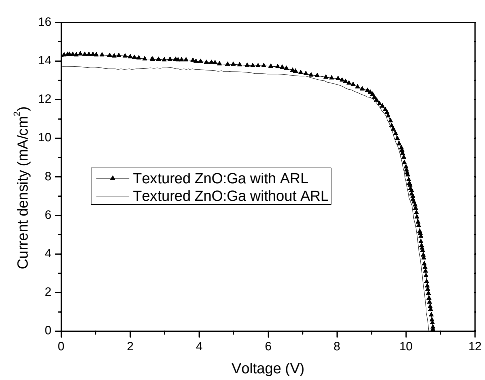

Fig. 3. J-V curves of a-Si:H solar cells fabricated on textured ZnO:Ga with and without ARL.

4. Conclusions

In summary, a new acidic etchant containing buffer solutions has been successfully applied to etch sputter deposited ZnO:Ga to form good light trapping ability. After using a novel AR material Nb_2O_5, the reflectance at ZnO:Ga/a-Si:H interface is minimized to 5.3 % with respect to the wavelength range of 550-600 nm, which improves short circuit current density by 0.6 mA/cm^2 but decreases fill factor from 74.58 % to 72.02 % due to the increased ohmic loss. Finally, an improved initial cell efficiency of 9.32 % has demonstrated effective light trapping ability and AR ability of Nb_2O_5 coated textured ZnO:Ga front contact.

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