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Light-trapping enhancement based on Ga_2O_3 nano-islands coated glass substrate

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Abstract

Nano-size textured topography is important to gain high absorption ratio of the incoming light for thin film solar cells. In this paper, a Ga_2O_3 nano-islands coated glass substrate is introduced by annealing Ga nano-islands in air. The aspect ratio of the islands can be easily controlled by tuning the average thickness of Ga film. Based on the proposed substrate, with average horizontal size of 500 nm and root-mean-square roughness of 80 nm of the nano-islands, the average reflectivity under AM 1.5 illumination spectrum can be limited at 6.6% when Si absorber layer is only 480 nm thick.

Keywords: Light trapping; Nano-textured topography; Magnetron sputtering; Thin-film solar cells

1. Introduction

Thin-film Si solar cells (TFSC) have attracted much attention recently in advantage of Si usage (Maycock, 2005). To become a major energy source, two key problems have to be solved for TFSC: increasing the conversion efficiency and decreasing the production cost. However, to realize cost cutback, thinner Si film is needed, but this would affect the effective light absorption and further affect the conversion efficiency. Introducing a light-trapping structure is an effective way to overcome this contradiction (Zhao et al., 2010; FeiWang et al., 2010). The key step to realize light trapping in TFSC is to introduce a textured topography, which can enhance the absorption of incoming light by increasing the optical path length in the absorber layer. Many methods have been reported, like Asahi-U type glass (SnO_2:F), textured Al by anodic oxidation, and ZnO etched by diluted acid (Sai et al., 2008; Kluth et al., 2003; Krasnov, 2010), etc. Unfortunately, the aspect ratio of the textured interface, obtained in those methods, is always very small, with lateral size over 1 μm and root-mean-square (RMS) roughness less than 50 nm. Based on these textured substrates, only when the absorber is thick enough, like over 1 μm, light-trapping effect can be realized, because the final surface of the absorber is much smoother than, hence not parallel to the initial substrate topography and the incident light can be scattered into large angles beyond the internal total reflection (ITR) angle (Keevers and Young, 2007). However, when the absorber layer reduced to some extent, like several hundred nanometers, the two surfaces tend to be parallel to each other, these textured substrates can no longer scatter the incident light beyond the ITR angle effectively.

For further development of silicon TFSC, thinner absorber of several hundred nanometers is especially necessary due to the short carrier diffusion length (Wong et al., 2010). Thus, a new method that can introduce a nano-size textured topography with relatively high RMS by a simple

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process is quite urgent. In this paper, we realize this goal based on Ga_2O_3 nano-islands, obtained by a two-step method, evaporation and oxidation.

2. Simulation

In Fig. 1, the light-trapping efficiency of a triangle-type period structure, with a 500 nm thick Si layer, is analyzed by 2-D finite element method (FEM). The free space wavelength is set as 550 nm. The cross section schematic of the structure is shown in Fig. 1a. The triangle shape is assumed to be introduced by Ga_2O_3 here. By changing the period and height, shown in Fig. 1b, the power absorption distribution in the absorber layer changes as shown in Fig. 1c–f, corresponding to (period, height) of (1 μm, 50 nm), (1 μm, 100 nm), (500 nm, 50 nm), (500 nm, 100 nm), respectively. The absorption ratio is defined as the ratio of the power absorbed in the silicon layer and the power incident at the glass side. Fig. 1g indicates that the absorption ratio can be effectively increased by increasing the aspect ratio. When the (period, height) is (1 μm, 50 nm), the absorption ratio is only 57.2%, but when decreasing the period to 500 nm and increasing the height to 100 nm, the absorption ratio can rise up to 93.2%. However, it should be noted that the absorption distribution is slightly different in real device, because the textured interface always does not show perfect periodic characteristics.

3. Experiments

The substrate used here is soda lime glass. A 100 nm thick Ga film is first deposited by heating-evaporation at room temperature (RT, 4×10^{-5} torr). Since the melting point of Ga is only 30 °C, the film is easily formed as separate nano-islands. Obviously, the Ga coating is too soft to serve as a light-trapping structure, so we oxide the coating to be Ga_2O_3 in air at 530 °C for 6 h in a furnace. Ga_2O_3 is a wide band gap material, and it is suitable to be a light window from visible to infrared region (Orita et al., 2000; Rebien and Henrion, 2002). A 500 nm thick AZO (ZnO:Al) layer deposited on the Ga_2O_3 coating as a TCO (transparent conductive oxide) layer by DC magnetron sputtering from a ZnO:Al_2O_3 (2 wt.% Al_2O_3) ceramic target. Si is used as an absorber layer, deposited by DC magnetron sputtering (base pressure of 6×10^{-6} torr, 2 nm/s) from a p-type Si target (99.999%) and recrystallized by metal induced crystallization (MIC). The metal used for MIC is Cu. The ratio of Cu to Si is kept at 1:60 (Zhao et al., 2010; Radnoczi et al., 1991; Russell et al., 1991). A 100 nm thick Ag layer is deposited to be a back reflector. The Cu and Ag layers are also deposited by DC magnetron sputtering at base pressure of 6×10^{-6} torr. The recrystallization process is processed at 530 °C for 6 h in a furnace, filled with nitrogen to prevent from oxidation.

The surface morphology was characterized by Scanning electron microscope (S-5500, Hitachi Company) and the surface roughness was examined by Atomic force microscopy (SPM-9600, Shimadzu Company). The optical properties were detected by a spectrometer with an integrating sphere (AvaSpec-2048x14. Avantes company). A He–Ne laser and a detector were used to examine the angle resolved scattering properties of the Ga_2O_3 coating.

4. Results and discussion

The horizontal size of the Ga nano-islands is easy to be controlled by tuning the Ga film thickness. Fig. 2a–d show the SEM images of Ga nano-islands with average thickness from 40 nm to 160 nm, and the increment is 40 nm. The corresponding horizontal size of the islands is about 250 nm, 350 nm, 500 nm and 1 μm, respectively. According to Fig. 2, with the thickness increasing, the Ga film tends to be continuous. We choose 100 nm thick Ga, and the horizontal size is about 400 nm according to Fig. 2. Due to the

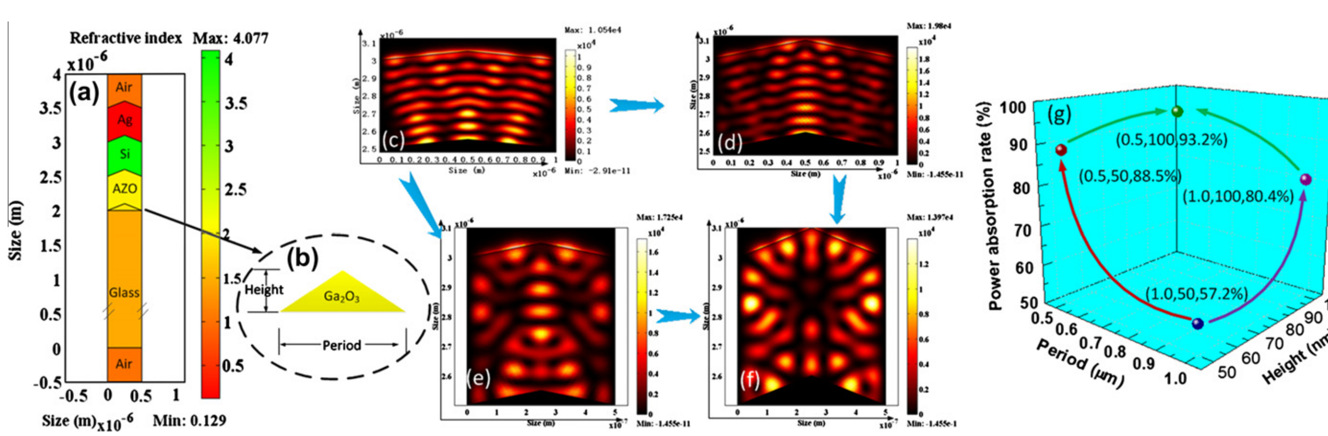

Fig. 1. Free space wavelength: 550 nm (a) shows the cross section schematic of the light-trapping structure, color indicates the refractive index, blue = max, red = min. (c–f) show the power absorption distribution in the Si absorber layer, corresponding to the (period and height), illustrated in (b), of (1 μm, 50 nm), (1 μm, 100 nm), (500 nm, 50 nm), (500 nm, 100 nm), respectively. (g) clarifies the relationship between the triangle-type Ga_2O_3 figures and the power absorption ratio, corresponding to (c)–(f), respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)