Applied Surface Science 257 (2011) 4978–4981

Contents lists available at ScienceDirect

Applied Surface Science

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

Highly crystallized sputtered silicon with textured morphology for thin-film solar cells

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ARTICLE INFO

Article history:
Received 9 July 2010
Received in revised form
28 December 2010
Accepted 4 January 2011
Available online 8 January 2011

Keywords:
Light trapping
Copper-induced crystallization
Magnetron sputtering
Thin-film solar cells

ABSTRACT

A light-trapping structure with textured morphology for thin-film solar cell is demonstrated in this paper. It is fabricated through Al evaporation, and has a root-mean-roughness (Rms) of about 120 nm and lateral width of about 1 μm for single bulge. A Mo layer is introduced to be a barrier layer. Subsequently sputtered amorphous silicon film is 100% crystallized by Cu induced crystallization. Reflectivity of samples with different silicon thickness is studied to reveal the light-trapping efficiency and the reflectivity as low as 10% is obtained with only 840 nm thick silicon film. This is a low-cost structure promising for future thin-film solar cells with high efficiency.

1. Introduction

Solar cells have attracted much attention and been developing rapidly in recent years. Although the present photovoltaic market is dominated by crystalline silicon (more than 90%), thin-film silicon solar cells are believed to be the best candidates by reducing the silicon usage [1]. To gain high cell efficiency for thin-film silicon solar cells, the fabrication of light-trapping structure and the transformation from amorphous silicon (a-Si) to poly silicon (p-Si) are two essential processes. Firstly, a light-trapping structure can enhance the absorption of incoming light by increasing the optical path length, especially for p-Si due to its lower absorption coefficient than a-Si [2]. Textured structure is widely studied to optimize the absorption, such as textured ZnO etched by diluted acid [3,4], textured Al by anodic oxidation [5], textured back electrodes by restructuring [6], and textured mono- and polycrystalline substrates [7]. For those methods, either pre-treatment or post-treatment is needed to produce a textured morphology, which increases the fabrication complexity as well as the cost. Secondly, compared with a-Si, p-Si film has better optical and electrical properties and wider spectrum region that can be absorbed. And the high crystallization of p-Si is crucial to the realization of high cell efficiency [8–10]. Various p-Si growth technologies have been reported in the past few years, such as excimer laser annealing (ELA) [11], solid-phase crystallization (SPC) [12] and metal induced crystallization (MIC) [13]. Since MIC can operate at a temperature lower than 600 °C, low-cost substrate, i.e. soda-lime glass, can be used. In all above technologies, Chemical vapor deposition (CVD) is widely utilized to deposit a-Si films, but it cost a lot. Magnetron sputtering is believed to be an alternative technique with high deposition rates, large deposition areas, no toxic gases and low cost [14,15]. However, few reports about highly crystallized sputtered silicon based on glass can be found.

In this paper, we have developed a light-trapping structure based on evaporating Al, without any pre- or post-treatment. The a-Si film is deposited by Magnetron sputtering and crystallized by Cu induced crystallization. This structure can be obtained with a simple process, which is applicable for future low-cost thin-film solar cells with high efficiency.

2. Experiment

Fig. 1 shows the multilayer light-trapping structure. A layer of 50 nm thick Cr is first deposited by DC magnetron sputtering to enhance the adhesion between Al and glass substrate. Next about a 1 μm thick Al layer is fabricated by e-beam evaporation at a fixed substrate temperature 250 °C. The textured morphology can be obtained by controlling the evaporation rate. A 300 nm thick Mo layer is sputtered as a barrier layer, and a 20 nm thick Cu layer is sputtered on it subsequently. Then a 1.2 μm thick Si layer is deposited on the top as an absorber layer by DC magnetron sputtering from a p-type silicon target (99.999%). At last the whole sample is annealed in a furnace at 530 °C for 10 h within a nitrogen protecting atmosphere.

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doi:10.1016/j.apsusc.2011.01.006

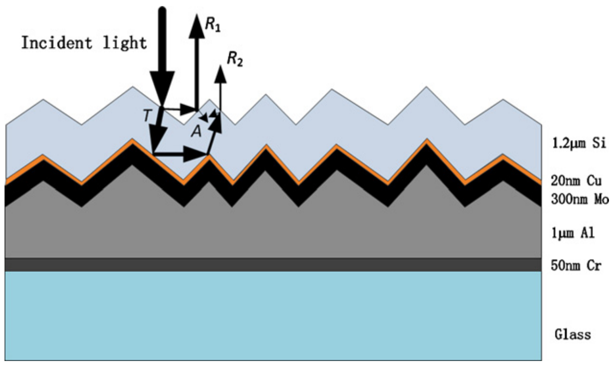

Fig. 1. Schematic sketch of the cross section of the light-trapping structure. The concept of light trapping is illustrated by the arrows representing incoming and scattered sunlight. Thicknesses of the individual layers are typical values in the present work.

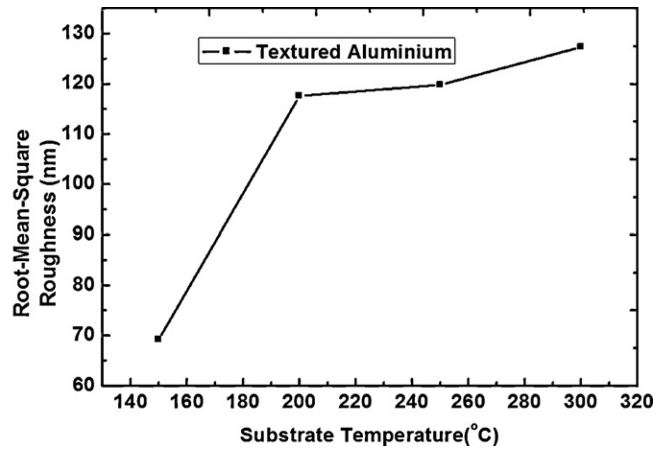

Fig. 3. Relationship between the surface root-mean-roughness (Rms) and the substrate temperature.

3. Results and discussion

The surface morphology is characterized by Scanning electron microscope (SEM) and the roughness is examined by Atomic force microscopy (AFM) as shown in Fig. 2. Fig. 2 shows the surface morphology of Al which is quite uniformly textured and the lateral width of each single bulge is about 1 μm. According to Fig. 2(c), the maximum altitude is more than 200 nm. Fig. 2(b) demonstrates the surface morphology of silicon deposited on the textured structure. It shows that, compared with Fig. 2(a), the Si layer has maintained the textured morphology well. The micrometer scale bulge indicates better light trapping in long wave spectrum near the band gap of p-Si, which could compensate the low absorption coefficient [5,16].

To further analyze the relationship between the topography and the substrate temperature (ST), root-mean-roughness (Rms) of samples with textured Al, obtained at different ST from 150 °C to 300 °C and the increment of 50 °C, is characterized and the result is shown in Fig. 3. The Rms changes rapidly when the ST increases from 150 °C to 200 °C. According to Fig. 3, the Rms is about 120 nm when the ST is 250 °C.

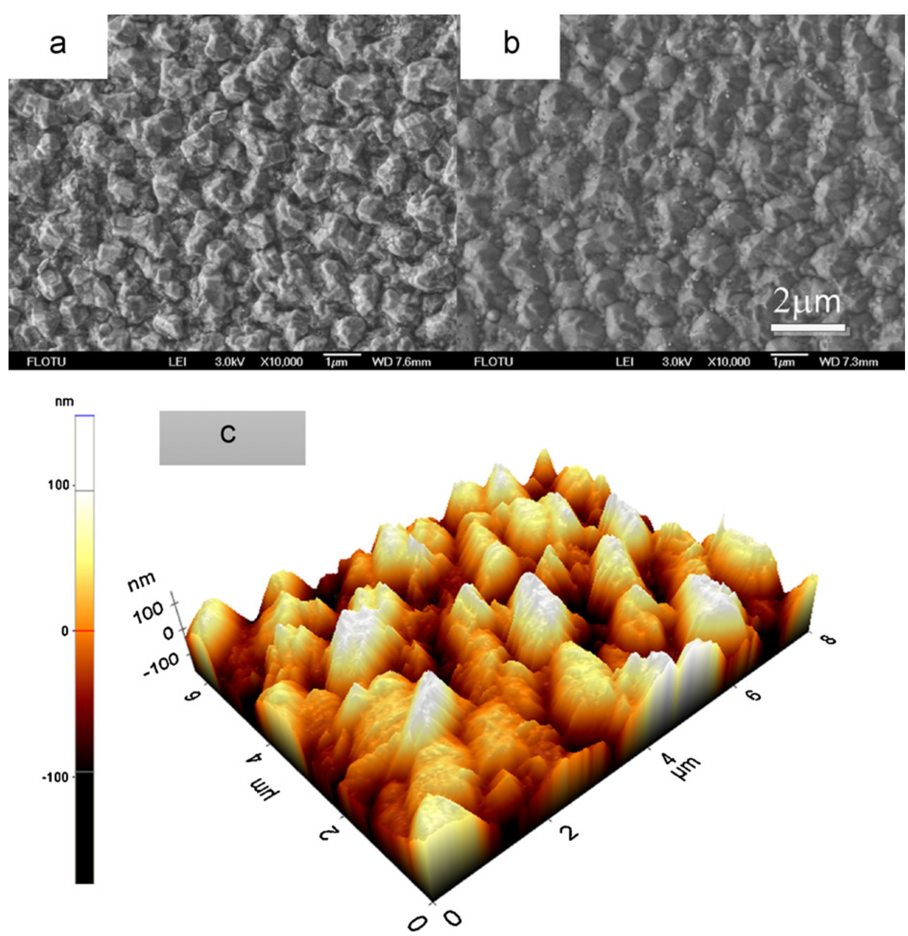

Fig. 2. (a) SEM image of textured Al evaporated at 250 °C by e-beam, (b) SEM image of Si surface morphology, (c) AFM image of the textured Al.