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Modified Surface Texturing of Aluminium-Doped Zinc Oxide (AZO) Transparent Conductive Oxides for Thin-Film Silicon Solar Cells

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Abstract

For thin-film solar cells, the properties of the front transparent conductive oxide (TCO) electrode is an important factor in determining the overall performance of the solar cells. An efficient light trapping scheme is required to increase the optical light path and thus enhance the photon absorption within the solar cells. Improved photon absorption is necessary to increase the short-circuit current density (J_{sc}) and thus the efficiency of cells. In this paper we report the results of the texturing of aluminium-doped zinc oxide (ZnO:Al or AZO) thin films for enhanced light scattering. AZO films were deposited onto soda-lime glass sheets by in-line DC magnetron sputtering. An effective AZO texturing method was developed using diluted hydrogen chloride (HCl) and hydrogen fluoride (HF) acids through either a two-step etching or a mixed etching process, which significantly improves the uniformity of the textured surface. Texturing based on HCl and HF combines the advantages of the large craters created by HCl etching and smaller jagged but uniform features resulting from HF etching. In this work, we demonstrate that by adopting the two-step or the mixed texturing method, it is possible to achieve high haze values of above 40% with very low surface roughness values. The combination of low surface roughness and high haze is beneficial to prevent shunting issues, and is thus very attractive for the fabrication of thin-film silicon solar cells.

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Keywords: Transparent conductive oxides; thin-film solar cells; light trapping; texturing; AZO; HCl; HF

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1. Introduction

Transparent conductive oxides (TCOs) are extensively utilised in thin-film photovoltaic devices as front contact electrodes. As an alternative to wafer-based solar cells, thin-film silicon (Si) solar cell technology greatly reduces the Si material consumption [1]. However, due to the very thin active absorber layer (e.g. ~ 250 nm for amorphous and 1.5 to 2 μm for microcrystalline silicon [2]), thin-film solar cells require a more effective light management scheme to scatter as much of the incoming light as possible into the Si absorber layer to trap photons and enhance the photon absorption within the Si layer [3]. Better light trapping assists in improving the short-circuit current density (J_{sc}) and thus increasing the efficiency of the thin-film Si solar cells.

Common TCO materials are tin-doped indium oxide (ITO), fluorine-doped tin oxide (FTO) and impurity-doped (e.g. Al, Ga, B) zinc oxide [4]. Nowadays aluminium-doped zinc oxide (ZnO:Al or AZO) films are becoming increasingly favourable as the front contact and window layer for superstrate thin-film solar cells, owing to advantages such as low cost, non-toxicity, stability against a hydrogen plasma environment and easy post-deposition texturing by wet-chemical etching for light management [5-7].

In general, depending on the deposition techniques, the surface texture of ZnO polycrystalline films is obtained either through wet chemical etching (resulting in crater-like features) in weak or diluted acid for magnetron sputtered films or during the deposition process itself (giving pyramid-like features) by the low pressure chemical vapour deposition (LPCVD) method [8, 9]. The post-deposition etching of magnetron sputtered AZO films using different acids such as hydrogen chloride (HCl), nitric acid (HNO_3), oxalic acid ($H_2C_2O_4$) and hydrogen fluoride (HF) are reported widely [10-16]. Texturisation of magnetron sputtered AZO by HF could result in rather sharp features [13], which are more likely to cause shunting issues in the final solar cell device. Whereas the texturisation of AZO using HCl may suffer from uniformity issues since HCl acid is reported to be less homogeneously attacking the etching sites of polycrystalline AZO films [10]. Therefore in this work, we prepared AZO films with a high visible transmission value (> 85%) and a low resistivity of approximately 8×10^{-4} Ωcm (sheet resistance < 10 Ω/□) by DC magnetron sputtering. Subsequently two-step texturing and mixed texturing procedures based on diluted HCl and HF aqueous solutions were systemically investigated for texturing the AZO films.

2. Experimental details

2.1. Preparation of AZO samples

AZO thin films were deposited onto planar A3 size (30×40 cm^2) soda-lime glass sheets by pulsed DC magnetron sputtering (FHR, Germany). A cylindrical aluminium-doped (2 wt%) zinc oxide ceramic target was used for the deposition of the AZO films. During deposition, the heater temperature was maintained at 350 °C while the chamber pressure was maintained at 3×10^{-3} mbar by keeping constant Ar and Ar+O_2 (1%) flow rate, and 2 kW power was applied to sputter the cathode. Prior to deposition the glass substrate was pre-heated for 10 minutes in order to achieve better film crystallinity.

The glass sheet was vertically attached on a moving carrier and allowed to oscillate in front of the AZO sputter cathode for 18 times at a speed of 15 mm/s. This multiple pass deposition potentially results in a lower pinhole density which could benefit the subsequent etching process [17]. After deposition, the AZO-coated glass sheets were cut into 12 square pieces (each 10×10 cm^2) for the wet-chemical texturing