Vacuum 117 (2015) 91–97

Contents lists available at ScienceDirect

Vacuum

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

SF_6/Ar plasma textured periodic glass surface morphologies with high transmittance and haze ratio of ITO:Zr films for amorphous silicon thin film solar cells

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ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form
28 March 2015
Accepted 1 April 2015
Available online 12 April 2015

Keywords:
ITO:Zr films
SF_6/Ar plasma
rms roughness
Haze ratio
Modulated surface morphology
Amorphous silicon thin film solar cell

ABSTRACT

We report various SF_6/Ar plasma textured periodic glass surface morphologies with high transmittance, haze ratio, and root mean square (rms) roughness of ITO:Zr films for amorphous silicon thin film solar cells (a-Si TFSCs). SF_6/Ar plasma textured glass surface morphologies contain micro- and nano-textured features that help to scatter the light in visible and near infra-red (NIR) wavelength regions. We designed the textured glass surface morphologies with big square craters to smaller pyramids for various glass etching times from 30 to 75 min. Magnetron sputtered ITO:Zr (~210 nm) films were deposited on textured glass surface morphologies and showed higher transmittance and haze ratio of 88.48% and 77.61%, respectively, in the visible-NIR (400–1100 nm) wavelength region. The sheet resistance and resistivity of ITO:Zr films decreased with the increase of etching time, due to high rms roughness and better step coverage. A passivation AZO (30 nm) layer was added to the ITO:Zr films, due to its better stability against hydrogen plasma exposure. The ITO:Zr/AZO films were employed as a front TCO layer and the current density–voltage (J–V) characteristics of a-Si TFSCs increased by light scattering effect, without any reduction in either the open circuit voltage (V_{OC}) or the fill factor (FF). Relative to flat glass substrate, J_{SC} and the efficiency of a-Si TFSCs were enhanced by 7.51% and 19.39%, respectively, for textured glass surface morphology.

1. Introduction

Amorphous silicon thin film solar cells (a-Si TFSCs) are considered as promising candidates for future high efficiency large-area and low cost photovoltaic devices. The performance of a-Si TFSCs can be improved by minimizing the optical and electrical losses. The optical losses can be reduced by employing a thinner transparent conductive oxide (TCO) layer, as a substitute for the randomly textured fluorine doped tin oxide (FTO) and aluminum doped zinc oxide (AZO) films textured with approximately 1 μm thickness [1–3]. Light trapping allows a reduction of reflection losses with an increase in the optical path length of incident light, as well as reductions in the size and material cost of the photovoltaic devices. Randomly textured wet and dry etched glass surface morphologies with high rms roughness and haze ratio are proposed for high efficiency a-Si TFSCs [4–8]. Recently, the periodic textured surfaces received a great deal of interest, due to their ability for high current density compared to randomly textured surface morphologies. The size and cost of photovoltaics can be reduced by employing periodic boundary conditions in optical calculations and uniformity in textured surface morphologies [5,9]. Textured glass surface morphologies also reduced the electrical and optical losses compared to textured TCO films. Uniformly deposited TCO films with high rms roughness and haze ratio can scatter more

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http://dx.doi.org/10.1016/j.vacuum.2015.04.003

light, reduce the overall size of the device, and improve the performance of a-Si TFSCs.

For solar cell applications, the surface morphology of glass can mainly be modified by wet chemical and dry etching processes. Even though wet chemical etching is simple and inexpensive, it is difficult when trying to control the glass surface morphology. The inductive coupled plasma-reactive ion etching (ICP-RIE) process has received much attention, as the glass surface can be textured with high rms roughness and haze ratio. Hongsingthong et al. [6–8] reported the influence of ICP-RIE textured glass substrates with high rms roughness and haze ratio of ZnO films for high efficiency a-Si TFSCs, due to their nano- and micro-size textured surface morphologies. Isabella et al. [4] reported the concept of modulated surface morphologies with various geometrical features for an enhanced scattering mechanism. These nano- and micro-size textured surface morphologies can scatter the light in the visible and NIR wavelength regions [4,7–10]. Janthong et al. reported the influence of ZnO:B films deposited on W textured low cost soda lime glass surface morphologies, with high haze ratio and low reflectance for TFSCs [11]. The influence of various textured glass surface morphologies on the performance of TFSCs has been reported in a few simulation studies [12–14]. Battagalia et al. reported a comparative study of random and periodic surface morphologies for a-Si TFSCs [15]. Recently, Hussain et al. [37] reported the uniform 3D hydrothermally deposited zinc oxide (ZnO) nanorods with high haze ratio for the a-Si TFSCs. We previously reported the light trapping mechanism in periodic textured glass substrates for high haze ratio of ITO films [5]. Various suitable future periodic textured glass surface morphologies for a-Si TFSCs are shown in Fig. 1. The main aim is to replace the commercial FTO glass by periodic textured glass with enhanced performance. These periodic SF_6/Ar plasma textured glass surface morphologies showed better light scattering with high current density due to micro- and nano-size textured features. This alternative approach can enhance the performance and lower down the cost of a-Si TFSCs fabrication. Even though various reports have been presented related to the textured glass surface morphologies for the a-Si TFSCs, the influence of periodic front textured glass surface morphologies for the high transmittance and haze ratio, and low sheet resistance of ITO:Zr films in a-Si TFSCs has yet to be reported.

We report the SF_6/Ar plasma textured periodic glass surface morphologies for high transmittance and haze ratio of ITO:Zr films for a-Si TFSCs. Various surface morphologies of textured glass and ITO:Zr films as a function of glass etching time are discussed. The optical transmittance and haze ratio of ITO:Zr films as a function of glass etching time is explained. The rms roughness, sheet resistance, and electrical characteristics of ITO:Zr films deposited on the textured glass surface morphologies are also discussed. Finally, the influence of textured glass surface morphologies on the performance of a-Si TFSCs is discussed.

2. Experimental details

We present the SF_6/Ar plasma texturing of Corning (Eagle, 2000) glass substrates for various surface morphologies using an ICP-RIE system. The glass substrates were cleaned using acetone, methanol, and distilled water for 15 min each in an ultrasonic bath, followed by blowing with N_2 gas. The annealing was performed at 100 °C for 10 min to vaporize the remaining moisture on the glass surface. The thermal evaporation system was used to deposit Al (~800 nm) on the glass surface. A uniform positive photo-resist (PR) (AZ-7220) layer was deposited on the Al surface of glass by spin-coating, followed by soft baking for 10 min at 120 °C. The square-size patterns with the dimension of $(8 \times 4)\ \mu m^2$ were transferred onto the PR by ultra-violet (UV) photo-lithography. The hard baking was performed for 15 min at 140 °C, followed by Al etching and PR removal. An optical microscope (OM) system was used to verify the pattern formation.

An ICP-RIE (ATS CVD series Etcher-200) system with a load-lock chamber was used for the SF_6/Ar plasma texturing of glass substrates. RF, biased power, and SF_6/Ar flow rates were kept constant at 650 W, 200 W, and 50/50 sccm, respectively, while etching time was varied from 30 to 75 min at regular intervals. The glass substrates $(2.5 \times 2.5)\ cm^2$ were attached to a 4 inch Si wafer placed on a wafer chuck. The rear side temperature of the wafer chuck was maintained at 18 °C by circulating the cooling water through a chiller. ITO:Zr films with uniform thickness of ~200 nm were deposited by a RF magnetron sputtering system, using an ITO:Zr target composed of 90 wt% of In_2O_3, 9.8 wt% of SnO_2, and 0.2 wt% of ZrO_2, with 99.999% purity. The passivation AZO (~30 nm) layer was

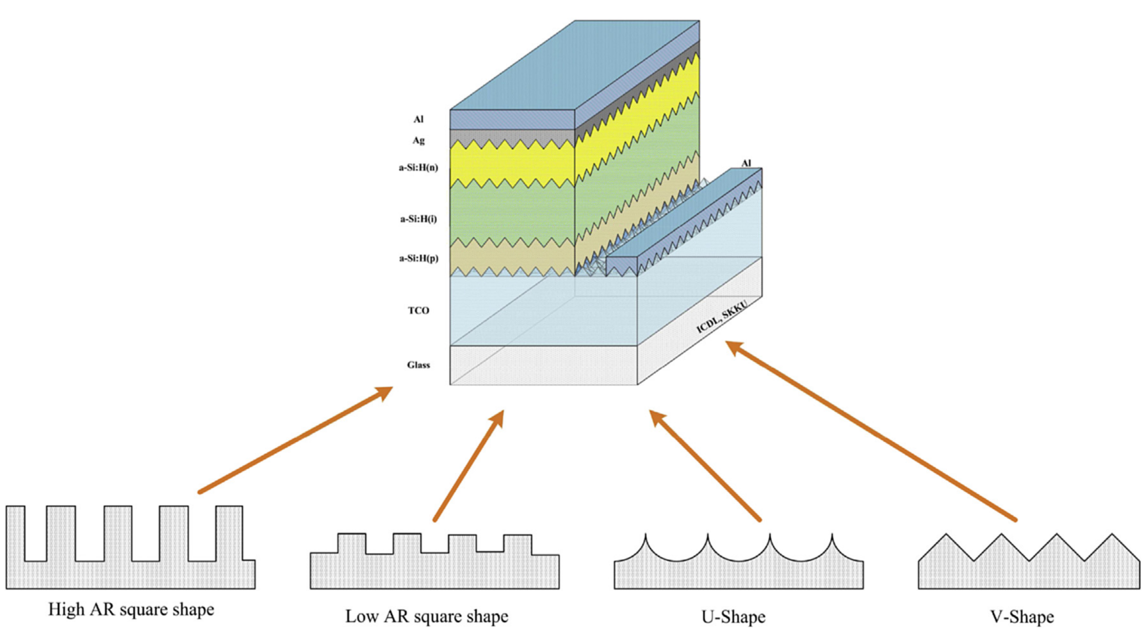

Fig. 1. Schematic diagram of various textured glass surface morphologies in a-Si thin film solar cells.