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Fabrication of CIGS solar cells with a Na-doped Mo layer on a Na-free substrate

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Abstract

The photovoltaic properties of CIGS cells on an alumina substrate were improved through the use of Na-doped Mo as the bottom layer of a Mo back contact. Na was supplied to the CIGS bulk region from an alumina/Na-doped Mo/Mo structure, similar to the Na diffusion from soda-lime glass. The diffusion of Na from the Na-doped Mo was controlled effectively compared to that from Soda-lime glass (SLG). The present results indicate that Na-doped Mo acts as a Na source material and that the Na amount can be controlled by adjustment of thickness of Na-doped Mo layer, without the use of an alkali barrier layer. The highest conversion efficiency of 13.34% (J_{sc} = 34.62 mA/cm^2, V_{oc} = 0.58 V and FF = 66%) for an active area of 0.45 cm^2 on an alumina substrate was obtained for 100 nm Na-doped Mo/1000 nm Mo.

Keywords: CIGS; Solar cells; Na-doped Mo; Alumina substrate

1. Introduction

Cu(In,Ga)Se$_2$ (CIGS) and related chalcopyrite compounds are of great interest in photovoltaic devices, as a high optical absorption coefficient and a direct band gap in the absorber layer coupled with the possibility of band gap engineering lead to the production of cost-effective thin-film solar cells. Efficiencies as high as 19.5% have been achieved by the NREL group using only a soda-lime glass substrate in combination with a high growth temperature [1]. The effect of a soda-lime glass substrate in CIGS cells has been interpreted as being due to Na diffusion into the absorber layer during high temperature processing. However, in these cases, it is difficult to control Na diffusion from the substrate. Therefore, several groups have applied Na source materials such as NaF or Na$_2$Se with an alkali barrier in an effort to control Na diffusion from the substrate [2]. To date, many research groups have studied the role of Na diffusion from soda-lime glass or from a Na source [3–5]. In this study, a Na-doped Mo/Mo bi-layer is proposed and developed as a back contact in CIGS solar cells fabricated on a Na-free alumina substrate. This Mo bi-layer supplies Na without the need for additional processes, and controls Na diffusion by an adjustment of the Na-doped Mo thickness. A Na-doped Mo layer was deposited by DC sputtering using a Na-doped Mo target. The effect of the Na-doped Mo layer on the cell characteristics is reported.

2. Experimental

A Na-doped Mo/Mo bi-layer was deposited onto an alumina substrate by DC magnetron sputtering. The thickness of the Na-doped Mo, which was the bottom layer of the Mo back contact, varied from 100 nm to 600 nm, keeping the total thickness at approximately 1100 nm. As is normally done for CIGS thin film solar cells, the bottom layer of the Mo back contact was deposited at a high working pressure of 10 mTorr, and the top layer was deposited at a low pressure of 3 mTorr. This was done in order to enhance the adhesion and electrical properties. Following this, a CIGS absorber layer was prepared through a three-stage process by means of the evaporation of In, Ga, Cu and Se. In the first stage, In, Ga and Se element sources were evaporated on substrates at 350 °C to form a (In, Ga)$_2$Se$_3$ layer with a thickness of 1 µm. In the second stage, Cu

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and Se were added and reacted directly with the $(In,Ga)_2Se_3$ layer at approximately 550 °C to form a Cu-rich CIGS film. In the third stage, In, Ga and Se elements were evaporated on the CIGS layer in order to convert an (In,Ga)-rich CIGS composition. A CdS buffer layer with a thickness of 60 nm and i-ZnO/n-ZnO TCO with a thickness 50 nm/500 nm were deposited by chemical bath deposition (CBD) and RF magnetron sputtering, respectively. An Al grids were applied as a top contact using thermal evaporation. SEM (Scanning Electron Microscopy) and SIMS (Secondary Ion Mass Spectrometry) were performed to investigate the morphology and thickness of each layer and to verify the Na diffusion from the back contact, respectively. The photovoltaic parameters of devices were evaluated under 1.5 AM illumination.

3. Results

Fig. 1 shows SEM images of alumina/Na-doped Mo/Mo/CIGS with Na-doped Mo/Mo layers of various thicknesses. The total thicknesses of the Na-doped Mo/Mo bi-layers were fixed to a value of 1100 nm, corresponding to the Mo thickness of the baseline process for CIGS cells on soda-lime glass used in this study. No boundary between the Na-doped Mo and Mo layers was observed. Despite the use of an alumina substrate with a slight curvature, the CIGS films grew very well, and no peeling phenomena of the CIGS films were observed for all Na-doped Mo layer thicknesses. However, the grain size of the CIGS absorber decreased as the thickness of the Na-doped Mo increased. The reduction of the CIGS grain size by Na incorporation was previously reported by Tiwari et al. [2]. According to their contribution, Na incorporation during the growth of CIGS was found to reduce the grain size; the effects being independent of the Na incorporation method. The change in the morphology of the films here indicates that Na is supplied from the Na-doped Mo and its amount is controlled by the thickness of the layer.

To confirm the existence of Na in the CIGS films and to verify the dependence of Na diffusion on the Na-doped Mo layer thickness, an SIMS analysis was performed for different Na-doped Mo layer thicknesses (100 nm and 600 nm), as shown in Fig. 2. For comparison, the Na profile of a CIGS cell with a soda-lime glass/Mo substrate is also shown. Na was observed in the CIGS layer deposited onto alumina/Na-doped Mo/Mo as similar to that on soda-lime glass/Mo. The content of Na

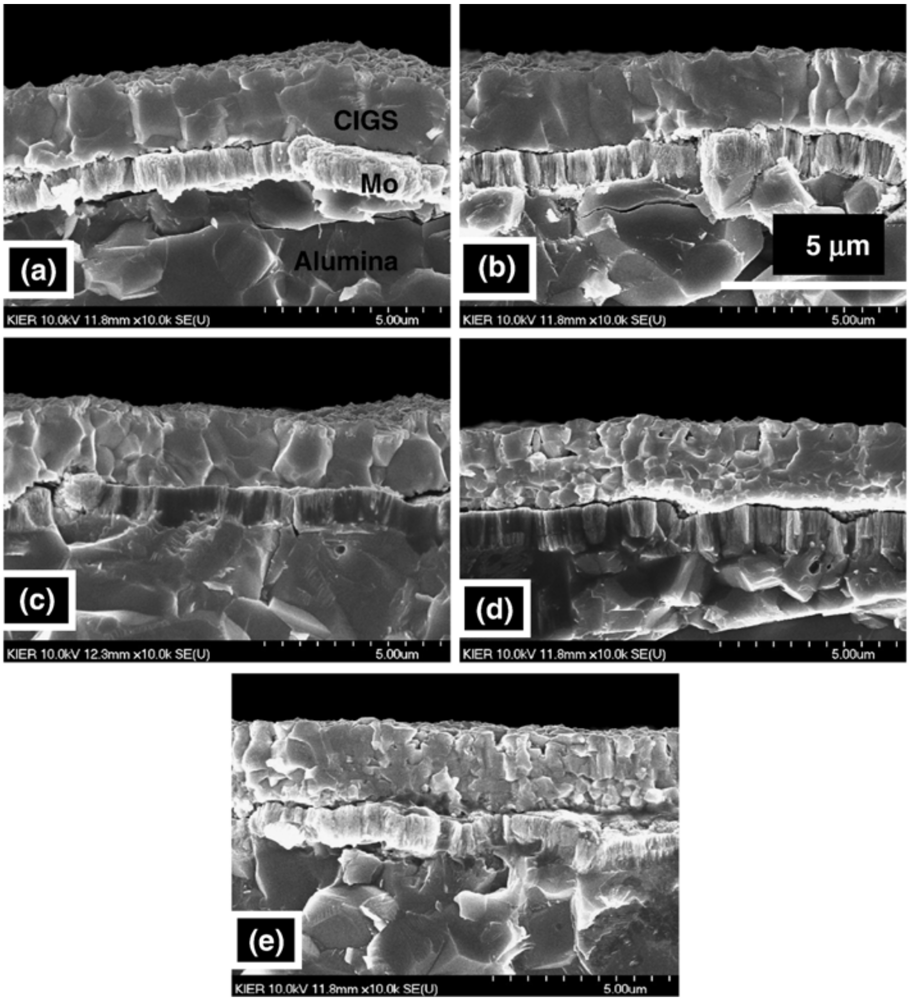

Fig. 1. SEM images of alumina/Na-doped Mo/Mo/CIGS with various Na-doped Mo/Mo thicknesses. (a) 0/1100 nm (b) 100/1000 nm (c) 200/900 nm (d) 400/700 nm (e) 600/500 nm.