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Microstructural and diffusion properties of CIGS thin film solar cells fabricated using transparent conducting oxide back contacts

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Abstract

The cell performance of the $Cu(In_{1-x}Ga_x)Se_2$(CIGS) devices fabricated using transparent conducting oxide (TCO) back contacts deteriorated at high absorber deposition temperatures used for conventional CIGS devices with Mo back contacts. Therefore, understanding of the interfacial properties at the CIGS/TCO boundary is one of the most important issues for achieving high efficiency semi-transparent and bifacial devices. It was found that the deterioration in cell performance was due to reduction in the fill factor (FF) originating from the increased resistivity of the TCOs. TEM, EDX, SIMS, and XPS analyses revealed that the increased resistivity was mainly attributable to the removal of fluorine from SnO_2:F and the undesirable formation of a Ga_2O_3 thin layer at the CIGS/ITO and CIGS/ZnO:Al interfaces. The formation of Ga_2O_3 was eliminated by inserting thin Mo layer between the ITO and CIGS layers.

Keywords: $Cu(In,Ga)Se_2$; $CuGaSe_2$; Tandem; Bifacial; Thin film solar cells; Transparent conducting oxides; Ga_2O_3; ITO; SnO_2

1. Introduction

$Cu(In_{1-x}Ga_x)Se_2$(CIGS) thin film solar cells usually use metallic Mo back electrodes thus making it impossible for light to pass through the metal electrode layer. However, a semitransparent solar cell is required for use as the top cell of tandem devices and, in addition, such a cell has potential applications as bifacial devices and solar windows. For these reasons, we have investigated an alternative cell structure for CIGS-based thin film solar cells using transparent conducting oxide (TCO) back contacts by which light can pass through the entire solar cell structure [1–4].

In previous reports, we demonstrated that the cell performance of CIGS devices was almost the same as that of conventional CIGS solar cells with metallic Mo back contacts when CIGS deposition temperatures were kept below 500 °C for the SnO_2:F and 520 °C for the ITO back contacts [2–4]. However, the cell performance deteriorated for higher deposition temperatures which are commonly used for conventional CIGS devices. This is attributed to the increased resistivity of the TCOs which leads to a decrease in fill factor (FF) of the solar cells. In order to

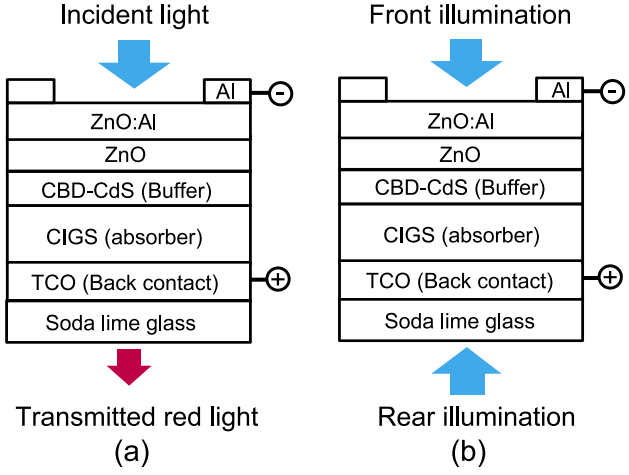

Fig. 1. Device structures of (a) semi-transparent and (b) bifacial CIGS-based thin film solar cells fabricated using TCO back contacts. Basically the structures are the same except that they are used in two different illumination configurations.

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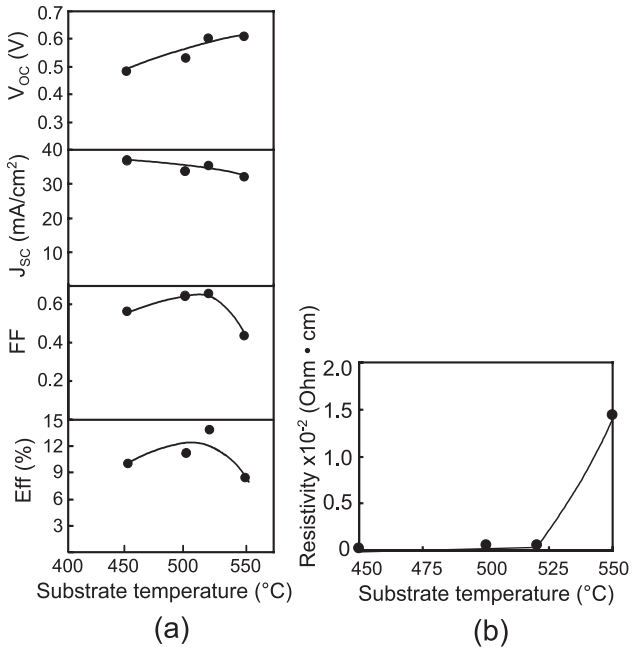

Fig. 2. The dependence of (a) cell performance and (b) the resistivity of the ITO surface covered with Ga_2O_3 measured after removing CIGS layers on substrate temperature during CIGS deposition.

reveal the cause for the increased resistivity, we have investigated the microstructure and diffusion properties at the CIGS/TCO interface by using transmission electron microscopy (TEM), energy-dispersive X-ray spectroscopy (EDX), secondary ion mass spectroscopy (SIMS) and X-ray photoelectron spectroscopy (XPS). In this paper, the dependence of cell performance on substrate temperature during CIGS deposition is briefly described. The microstructure and diffusion properties at the CIGS/TCO interface are discussed on the basis of the TEM, EDX, SIMS, and XPS results.

2. Cell structure and fabrication

Fig. 1 shows the cell structure of a CIGS-based thin film solar cell fabricated using a transparent conducting oxide (TCO) back contact as an alternative to metallic Mo thin film contacts. This type of solar cell can be considered to be a basic unit of both bifacial [2,5] and tandem [6–8] devices. CIGS solar cells with a ZnO:Al/ZnO/CdS/CIGS/TCO back contact/SLG structure were investigated using commercially available F-doped tin oxide (SnO_2:F) and indium tin oxide (ITO) as back contacts. In addition, a ZnO:Al thin film prepared by rf-magnetron sputtering using a 2 wt% Al_2O_3-doped ZnO ceramic target was used as a back contact. The sheet resistance and optical transmission of the TCOs were 7–10 Ω/□ and more than 85% at 550 nm, respectively. CIGS films were deposited by the three-stage process onto TCO-coated glass substrates. The elemental composition of the films was measured by inductively coupled plasma spectroscopy (ICP) which is well known as a sensitive technique.

The film compositions were typically Ga/(In+Ga)=0.36, Cu/(In+Ga)=0.90 and Se/metal=1.04 for CIGS thin films and Cu/Ga=0.93 and Se/(Cu+Ga)=1.02 for CGS thin films. A CdS buffer layer prepared by chemical bath deposition (CBD) method was then deposited onto the CIGS absorber layer using a $CdSO_4$(0.16 M)–ammonia (7.5 M)–thiourea (0.6 M) aqueous solution at 80 °C. Non-doped ZnO and transparent conducting ZnO:Al thin films were then subsequently deposited at room temperature by rf sputtering. Current–voltage (*J–V*) characteristics were measured using a solar simulator calibrated using a Si standard cell under AM 1.5, 100 mW/cm^2 illumination at 24 °C.

3. ITO back contacts

Fig. 2(a) shows the dependence of cell performance on the substrate temperature used during CIGS deposition for devices fabricated using ITO back contacts. For devices fabricated using ITO back contacts, the cell efficiency increased as the substrate temperature increased to 520 °C. This can be interpreted as being a result of improved crystalline quality of the CIGS absorber layer. The best cell performance was achieved at a CIGS deposition temperature of 520 °C, a temperature higher than that used for SnO_2. The best cell showed an efficiency of 15.2% (without an

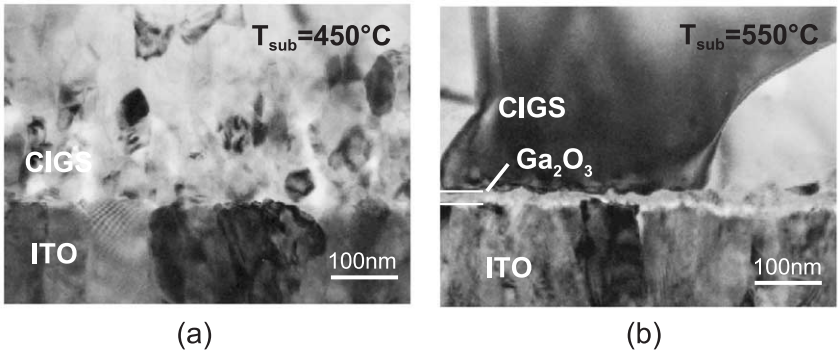

Fig. 3. High-resolution TEM images of the CIGS/ITO interfaces deposited at substrate temperatures of 450 and 550 °C.