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Influence of Al-doped ZnO transparent electrodes on thin-film interference in $Cu_2ZnSn(S,Se)_4$ thin-film solar cells prepared via a sputtering method

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ABSTRACT

Transparent electrodes are often regarded as a trade-off between transmittance and sheet resistance, although the effect of thin-film interference on the performance of an optoelectronic device is significant. In this paper, we report the effect of optical thin-film interference of an Al-doped ZnO (AZO) transparent electrode on the performance of $Cu_2ZnSn(S,Se)_4$ (CZTSSe) solar cells. First, we distinguished the transmittance in the overall wavelength region (450–800 nm) of the AZO transparent electrode from the transmittance in the maximum absorption region for CZTSSe solar cells (550–700 nm). From the results, a thicker AZO transparent electrode showed higher transmittance (87.1%) than that of a thinner AZO transparent electrode (82.9%) in the maximum absorption region. These electrodes were applied in CZTSSe solar cells, which showed a difference of up to 26% in power conversion efficiency. In addition, the colors generated by the optical interference between the AZO transparent electrodes. We anticipate that our results will be useful for improving the performance and/or color tuning of thin-film solar cells for application in building-integrated photovoltaics.

1. Introduction

$Cu_2ZnSn(S,Se)_4$ (CZTSSe) thin-film solar cells, discovered after Cu $(In,Ga)Se_2$ (CIGS) thin-film solar cells, have been actively studied in recent years due to their low-cost and eco-friendly characteristics [1–13]. In addition to efforts to improve the performance of thin-film solar cells, various applications, including wearable devices [14], indoor photovoltaics under LED lights [15], and color-tuned solar cells for building-integrated photovoltaics (BIPV), have also been reported [16, 17]. Although the thin-film interference effect in transparent electrodes has been considered for performance improvement and wavelength-dependent applications, relevant studies in this area are still insufficient [16–28]. Among them, Cho et al. [16] demonstrated the color tuning in CIGS thin-film solar cells well under various conditions whereas Zhang et al. [18] showed improved performance of organic solar cells by controlling and optimizing the optical interference, respectively. Similarly, Chen et al. [19] fabricated high-performance triple-junction polymer solar cells by optimizing the optical interference and via bandgap matching. Mann et al. [24] optimized the reflectivity of Al-doped ZnO (AZO) and anti-reflection (AR) layers in CIGS and Cu_2ZnSnS_4 (CZTS) thin-film solar cells, although they were unable to show an effect on the actual device performance.

We analyzed the thin-film interference of AZO transparent electrodes via transmittance, reflectance, and sheet resistance measurements. In addition, the effects of the interference on the device parameters and power conversion efficiency (PCE) were analyzed by applying various AZO transparent electrodes in thin-film CZTSSe solar cells. We confirmed that a difference in PCE of up to 26% occurred due to the thin-film interference and obtained the optimal AZO condition for the maximum absorption region of the CZTSSe solar cells. We also checked the color of AZO transparent electrodes and CZTSSe solar cells via thin-film interference, thereby showing the possibility of the color tuning of CZTSSe solar cells.

2. Experimental section

2.1. Fabrication of the CZTSSe absorber films with varying compositions

A Mo layer with a thickness of 1 μm was deposited on a 2 mm-thick soda-lime glass (SLG) via DC magnetron sputtering, followed by Zn, Cu, and Sn precursor layers via sequential DC and RF magnetron sputtering (the Zn and Cu layers using DC sputtering and the Sn layer using RF sputtering) at 50 W (1.1 W/cm^2) of power. An Ar atmospheric pressure was maintained at 0.4 Pa during the precursor sputtering. The Zn

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