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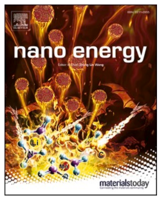

Semitransparent and bifacial ultrathin $Cu(In,Ga)Se_2$ solar cells via a single-stage process and light-management strategy

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ABSTRACT

Semitransparent and bifacial photovoltaic (PV) technology has received considerable attention recently owing to its potential for energy-harvesting window applications. Ultrathin $Cu(In,Ga)Se_2$ (CIGS) solar cells with transparent conducting front and rear electrodes, which enable partial visible light transmission, are considered promising candidates for this purpose. However, to realize improved performance, a variety of challenges, including fabrication processes, material selection, and device structure design, remain to be addressed. Here, the material properties and performance characteristics of semitransparent ultrathin CIGS solar cells prepared on two types of transparent conducting oxide (TCO) rear contacts, namely, textured SnO_2:F and flat In_2O_3:Sn films, using a single-stage co-evaporation method, are reported. Comparative performance evaluations of devices with the different TCO rear contacts reveal that the single-stage process is a very effective method for fabricating high-performance semitransparent CIGS solar devices, and that light management plays an important role in devices with ultrathin CIGS absorbers. A textured polydimethylsiloxane (PDMS) layer with light-scattering and antireflection properties enhances the light absorption properties of the devices. The device (absorber thickness: 322 nm) prepared on the flat In_2O_3:Sn rear contact with the textured PDMS layer exhibits superior performance as compared to other state-of-the-art solar devices, with a conversion efficiency of 10.5% and an average visible transmittance of 12.3%.

1. Introduction

Photovoltaic (PV) devices and systems are playing an increasingly important role in renewable energy supply, as they provide practical and sustainable solutions to growing energy demands and climate change issues [1]. Various solar cell technologies have been developed for PV applications. In particular, chalcopyrite $Cu(In,Ga)Se_2$ (CIGS) thin-film solar cells have proven to be promising candidates with high power conversion efficiencies (PCEs) greater than ~23% on the lab scale and ~14% on the module scale [2,3]. In the past few decades, typical device designs using 1.5–2 μm thick absorber layers and metallic Mo rear contacts have been applied to achieve CIGS solar cells with high PCEs. Recently, new challenges have been considered, including thinning the CIGS absorber (thickness, t = ~1 μm) and adopting advanced device structures with bifaciality and/or visible-light transparency [4–6]. The use of a thinner CIGS absorber layer can reduce the deposition time and material cost—especially for the rare-earth element indium—leading to a reduction in the fabrication cost. Bifacial devices, where the absorber layer is sandwiched between transparent conducting oxide (TCO) front and back electrodes, can absorb direct and diffuse sunlight from both the front and rear surfaces, which provides an additional energy-yield gain [7,8]. Moreover, semitransparent and bifacial solar cells with ultrathin CIGS absorber layers ($t \leq 300$ nm), where a part of the incident light is converted into electric energy while the remaining light is transmitted, can be employed for building-integrated PV (BIPV) applications such as façades, windows, and skylights. Such innovative device designs enable new applications and provide opportunities in other potential markets beyond conventional utility-scale plants or rooftop installations.

Previous studies have reported the material properties and performance of semitransparent and bifacial CIGS solar cells using TCO rear contacts [9,10]. Primarily, F-doped SnO_2 (SnO_2:F), Sn-doped In_2O_3 (In_2O_3:Sn), and Al-doped ZnO (ZnO:Al) films have been considered as potential alternatives to opaque Mo films. However, serious performance losses are commonly incurred in semitransparent and bifacial

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