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Semi-transparent photovoltaics using ultra-thin $Cu(In,Ga)Se_2$ absorber layers prepared by single-stage co-evaporation

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ABSTRACT

Semi-transparent thin-film solar cells with ultra-thin $Cu(In,Ga)Se_2$ (CIGS) absorber layers were fabricated on fluorine-doped tin oxide coated glass substrates using a single-stage co-evaporation process. The effects of the deposition conditions, such as the absorber thickness, deposition temperature, and post-deposition treatment using NaF on the material properties of the CIGS films were evaluated. In addition, the power conversion efficiency (PCE) and average visible transmission (AVT) in the wavelength range of 420–720 nm for semi-transparent CIGS solar cells using these absorber layers were systematically investigated. The AVT of the solar cells was directly dependent on the thickness of the CIGS absorber films. When the film thickness of the absorber layers increased from 300 nm to 950 nm, the AVT decreased gradually from 9.04% to 0.30%, while their PCE values did not show a clear dependence on the absorber thickness. Narrow columnar grains were observed in the microstructure of the ultra-thin CIGS absorber layers, irrespective of the film thickness and deposition temperature. Doping the ultra-thin CIGS absorber layers with Na after film deposition enhanced solar cell performance (the open circuit voltage (V_{OC}) and fill factor (FF) were improved). The enhanced cell performance was attributed to the lack of a resistive GaO_x film at the CIGS/FTO interface and thermal damage to the FTO back contact. The PCE values of semi-transparent solar cells with ultra-thin CIGS absorber layers prepared under the optimal deposition conditions varied from 6.46% to 9.78% when the CIGS absorber thickness was varied from 200 nm to 300 nm, respectively, while the corresponding AVT values changed from 18.59% to 9.04%.

1. Introduction

Using photovoltaic (PV) devices to generate electricity from sunlight is now a well-established alternative to producing energy via fossil fuels, which produce green house gases and are associated with other environmental damage. Building-integrated PV (BIPV) devices are promising for use in urban energy systems as they do not require additional installation space, but simply replace existing building exteriors. In addition, BIPV devices generate electricity close to the areas of high energy consumption, which could reduce electrical transmission losses and installation costs (Saifullah et al., 2016a). In addition to conventional roof installations, new BIPV systems for façades, skylights, and windows using semi-transparent solar cells (modules) have been recently evaluated for increasing power production. Semi-transparent solar cells can be designed to convert a portion of the incident sunlight into electricity while transmitting the remaining solar irradiance into the building. They reduce bright sunlight indoors, thereby reducing the summer cooling load and enhancing visible and physical comfort, similar to typical architectural glass products (Hegedus, 2006). Manufacturers suggest that a 10% transmission, resulting in useful daylight illuminance within the range of 100–2000 lx, is optimal for a comfortable soft daylight effect (Yang et al., 2013). Many studies have been carried out to evaluate the energy generation of semi-transparent PV products with around 10% transmission into the buildings (Chae et al., 2014; Didoné and Wagner, 2013; Li et al., 2009).

The power conversion efficiency (PCE) and average visible transmission (AVT) of the semi-transparent solar cells need to be optimized depending on the requirements of the application as there is a trade-off

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