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Understanding deposition temperature dependent photovoltaic characteristics of Cu(In,Ga)Se_2 solar cells: A study with thermally stable alkali aluminosilicate glass substrates

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ABSTRACT

During 3-stage thermal co-evaporation of Cu(In,Ga)Se_2 (CIGSe), alkali aluminosilicate (AAS) glass has proven to be stable at process temperatures T_{max} of up to 650 °C. This is considerably higher than the maximum endurable T_{max} for soda-lime glass (SLG), which is in the range of 530–550 °C. As the Na-content of the AAS glass used here is comparable to that of SLG, growing CIGSe at elevated T_{max} is expected to promote Na diffusion from the glass substrate through the Mo back contact (BC) into the absorber layer. An increased Na concentration in the CIGSe absorber would be expected to result in an improved device performance as it is mostly associated with an increased open-circuit voltage (V_{oc}) and fill factor (*FF*). This paper discusses the influence of varying T_{max} from 530 to 650 °C during the 2nd and the 3rd stage of the 3-stage process on the morphological, electrical, and photovoltaic performance of CIGSe solar cells. Upon raising T_{max} from 530 to 650 °C, the short-circuit current density (J_{sc}) decreased due to bandgap (E_g) widening. Glow discharge optical emission spectrometry analysis reveals that the Na concentration in the absorber is gradually decreased when elevating T_{max}. As will be seen, we attribute this in part to a densification of the Mo BC during the high temperature process. A maximum conversion efficiency (η) was realized at $T_{max} = 600$ °C. An increased V_{oc} at $T_{max} = 600$ °C is due to the wider E_g and to an increased carrier concentration despite the fact that the Na concentration in the CIGSe thin film was low compared to lower T_{max}. Admittance spectroscopy analysis is performed to access information on defect energy level and density in the finished devices. In the light of present findings, ways to further improve η at elevated T_{max} are suggested.

1. Introduction

Thermally co-evaporated Cu(In,Ga)Se_2 (CIGSe)-based solar cells have achieved conversion efficiencies (η) of up to 23.4% [1]. Currently, various types of thermal co-evaporation processes such as 1-stage, 2-stage, and 3-stage process are being used to prepare the CIGSe absorber. But high-quality CIGSe absorbers, which can be transformed to high-efficiency solar cells, are commonly prepared by the 3-stage process [2,3]. Such a CIGSe absorber displays a Ga in-depth front- and back-grading with a high Ga content near the front and the back of the absorber, respectively. Moreover, using a 3-stage process, the composition of the absorber can be controlled due to "end point detection" [4], i.e. monitoring the substrate temperature T_s drop at the end of the 2nd stage when stoichiometry is reached and a $Cu_{2-x}Se$ phase starts to segregate [5,6]. Due to the presence of $Cu_{2-x}Se$ phases at the thin film surface, the emissivity of the sample is altered with the effect that either

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