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Full paper

Mechanisms of extrinsic alkali incorporation in CIGS solar cells on flexible polyimide elucidated by nanoscale and quantitative analyses

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ABSTRACT

In this work, $Cu(In,Ga)Se_2$ (CIGS) solar cells on polyimide (PI) substrates were fabricated using a low-temperature three-stage co-evaporation process. To enhance device performance, the CIGS films were extrinsically doped with alkali (Na and K) using an *in-situ* post deposition treatment (PDT). To account for mechanisms of extrinsic alkali incorporation in CIGS solar cells on flexible polyimide, the alkali dopant concentrations in the film bulk (intragrain and grain boundary) and the surface chemistries/band structures were quantitatively investigated with various advanced characterization methods. In addition, the effects of the PDT sequences on the resulting device performance were studied with a particular emphasis on the characteristics of CIGS surfaces. By controlling the alkali incorporation into the CIGS absorber films, flexible lightweight CIGS thin-film solar cells with an efficiency of approximately 19% were obtained.

1. Introduction

In recent years, the development of high-efficiency CIGS-based solar cells on flexible lightweight substrates has gained significant attention owing to their potential for versatile applications (e.g., building-integrated photovoltaics (PV) and wearable PV) and massive deployments in the PV market by the spiking need for environment friendly energy sources [1–3]. This wide dissemination of flexible CIGS solar cells appears to be attributed to rapid improvements in efficiency [1,4], comparable to conventional CIGS solar cells on rigid soda-lime glass (SLG). Undoubtedly, one notable step for this significant advance is the extrinsic incorporation of alkali elements [5–10]. Extrinsic doping with alkali elements is particularly crucial for achieving high-efficiency $Cu(In,Ga)Se_2$ (CIGS) thin film solar cells on alkali-free substrates (e.g., polymer and metal-based webs) [1].

Until 2012, device performance enhancements of CIGS solar cells on flexible sheet mostly relied on Na incorporation [5,11–13], even though alkali elements [14] other than Na have been known to lead similar effects as Na. Recently, additional extrinsic K doping, as well as conventional Na incorporation, has been intensively attempted, consequently leading to further device performance enhancements, mostly by increasing the open circuit voltage and charge collection [1,15–17]. Given that both the extrinsic Na and K incorporation (more specifically, NaF and KF post deposition treatment (PDT)) has firstly enabled the demonstration of CIGS films on flexible polyimide (PI) exceeding 20% efficiency [1], doping of low-temperature-grown CIGS films with extra potassium (K) seems to be of great importance. Although some papers reported the detrimental effects of K incorporation on the device performance [18–20], K incorporation into CIGS (or K PDT), along with conventional Na incorporation, has been mostly recognized as being beneficial for device efficiency [1,21–24].

The roles and effects of K incorporation (or K PDT) have been

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