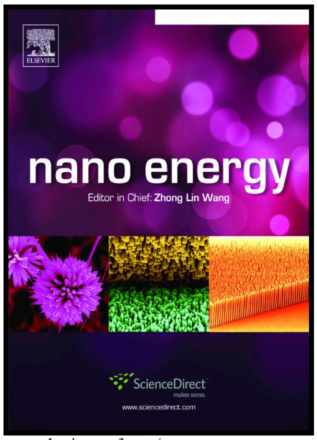

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Grain Engineering: How Nanoscale Inhomogeneities Can Control Charge Collection in Solar Cells

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Abstract

Statistical and correlative analysis are increasingly important in the design and study of new materials, from semiconductors to metals. Non-destructive measurement techniques, with high spatial resolution, capable of correlating composition and/or structure with device properties, are few and far between. For the case of polycrystalline and inhomogeneous materials, the added challenge is that nanoscale resolution is in general not compatible with the large sampling areas necessary to have a statistical representation of the specimen under study. For the study of grain cores and grain boundaries in polycrystalline solar absorbers this is of particular importance since their dissimilar behavior and variability throughout the samples makes it difficult to draw conclusions and ultimately optimize the material. In this study, we present a nanoscale in-operando approach based on the multimodal utilization of synchrotron nano x-ray fluorescence and x-ray beam induced current collected for grain core and grain boundary areas and correlated pixel-by-pixel in fully operational $Cu(In_{(1-x)}Ga_x)Se_2$ solar cells. We observe that low gallium cells have grain boundaries that over perform compared to the grain cores and high gallium cells have boundaries that under perform. These results demonstrate how nanoscale correlative X-ray microscopy can guide research pathways towards grain engineering low cost, high efficiency solar cells.

Keywords: CIGS, Grain Boundaries, Solar Cells, Synchrotron, XRF, XBIC

1. Introduction

What makes polycrystalline (PC) absorbers interesting for large scale deployment solar modules? Growth processes for PC solar cells, are generally faster, cheaper, and less energy intensive , leading to a reduced energy payback time for the final module.[1] The interest in PC solar cells is observed very clearly in the photovoltaic market, where 76% Of the $\sim$ 57 GWp of modules manufactured globally in 2015, came from polycrystalline silicon and thin film solar cells.[2] Lower cost is also driving research of PC growth methods for III-V materials, which are typically grown as single crystals.[3]

While the cost is lower, PC materials have unique challenges when it comes to optimization and tuning of the desired properties. Due to the large variability in chemical, structural and electrical properties of both grain cores and grain boundaries, the path to optimization is not always clear. Measurement techniques having the resolution and sensitivity needed to quantify this variability have an inherent trade off between spatial resolution and area under study. Moreover, the specimens under study are very small fractions of a device and operando measurements of the devices are not possible. We propose to use synchrotron based x-ray microscopy and a suite of techniques based on the collection of electrical response from the x-ray excited area that can help circumvent this limitation. X-ray based tech-

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