

Characterization of Photovoltaics: From Cells Properties to Atoms

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Photovoltaics are an attractive option to supplement our nations energy supply as they provide continuous power under illumination throughout the lifetime of the device. Making these devices as efficient as possible will inevitably increase their presence in the market as the installation cost to power return ratio will increase. The reality is that the majority of PV technologies have been extensively studied over the last several decades and for many the slope of the efficiency vs. time curve has drastically decreased. Research is now focused on making small improvements in device efficiency. Efficiency measurements provide feedback on the quality of the entire device structure but ultimately device properties are determined at the atomic scale through the interaction of charge carriers and defects. In order to determine how defects are related to the discrepancy between theoretical and actual device efficiency it is necessary to employ a suite of characterization techniques that vary in scale from centimeters to angstroms.

At the cell level there are a variety of techniques capable of identifying performance limiting regions of a solar cell. There are non-contact techniques such as photoluminescence imaging and microwave photoconductive decay lifetime mapping that indicate the spatial distribution of non-radiative recombination centers and reduced minority carrier lifetimes respectively [1]. Other techniques require full devices and or contacts to be present in order to extract the desired information. Thermographic imaging and electroluminescence in forward and reverse biased conditions have become valuable tools for identifying the locations of shunts in various types of solar cell materials [2]. In this work we utilize such techniques to identify specific regions that are responsible for reducing the efficiency of solar cells. An example is shown in Figure 1 where the areas of interest for further study are indicated by the white circles.

After regions with properties known to be problematic for PV devices are located, the next step is to remove these areas so that they can be prepared for further analysis. SEM-based characterization techniques such as cathodoluminescence (CL), electron beam induced current (EBIC), and electron backscatter diffraction (EBSD) [3, 4] provide information about the microstructure and related optoelectronic behavior that affects solar cell properties. As with the macro-scale imaging techniques these SEM-based analysis methods are effective on wafer-based as well as thin-film based solar cells. An example of EBIC analysis of a thin-film solar cell cross-section is shown in Figure 2.

All of the above mentioned techniques provide valuable information on the spatial distribution and optoelectronic activity of defects in various solar cell absorber materials. However, the recombination of charge carriers is ultimately governed by the atomic scale structure and chemistry of defects in solar cell materials. Fortunately there have been many recent developments in high resolution characterization technologies that enable atomic scale chemical analysis. These include synchrotron-based x-ray fluorescence, STEM-based EDS and EELS analysis, and laser-pulsed atom probe tomography. An example of atom probe tomography analysis on a CIGS absorber is shown in Figure 3.

These characterization methods are critical to understanding how defects govern the efficiency of solar cells, but due to the small volume analyzed it is necessary to use a combination of techniques and in-situ preparation to make accurate correlations. In this work the authors present the application of a multi-scale characterization approach to analyzing solar cell absorber materials.

References

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Figure 1. Microwave photoconductive decay lifetime map (left) and photoluminescence image (right) showing areas with reduced minority carrier lifetimes and enhanced non-radiative recombination identified by the white circles.

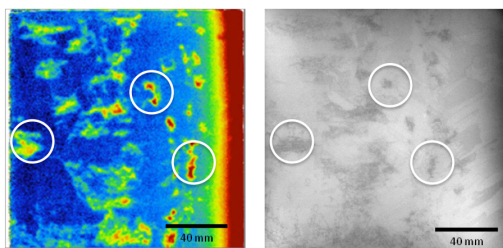


Figure 2. SEM (top) and corresponding EBIC (bottom) images of a cross section of a CIGS absorber based solar cell.

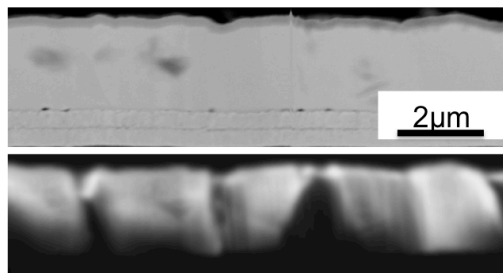


Figure 3. APT three dimensional reconstruction of a CIGS sample showing compositional inhomogeneities along grain boundaries.

