

## Renewable Energy and Energy Storage Room Naupaka Salon 4 - Session RE2-MoM

### Surfaces and Interfaces in Photovoltaics

Moderator: Elisa Miller, National Renewable Energy Laboratory

11:00am RE2-MoM-10 Low Dos Tails Dominate Band Alignments in State-of-the-Art Cd(Se,Te) Solar Cells, *Craig Perkins*, National Renewable Energy Laboratory

As the efficiency of single junction CdTe-based solar cells approaches the thermodynamic limit, further device improvements depend heavily on identifying the limiting aspects of cell architectures. Device modeling is the main tool for apportionment of efficiency losses and for guiding research into which aspects of cell designs need improvement. State-of-the-art device models though require numerous input parameters related to both bulk and interfacial properties, many of which are not known. Detailed characterization of an interface in any completed thin film solar cell presents a challenge but is particularly difficult in CdTe-based solar cells where the heterojunction is formed first, evolves during subsequent processing, and ultimately gets buried between mm-thick glass and microns of other materials. In this contribution, we show how an unusual sample preparation method coupled with electron spectroscopic methods was used to tease out details of the front interface of new record efficiency CdTe solar cells. A combination of X-ray photoelectron spectroscopy (XPS), ultraviolet photoelectron spectroscopy (UPS), low energy inverse photoemission spectroscopy (LEIPS), and Auger electron spectroscopy (AES) was used to probe the electronic and structural properties of the front oxide-Cd(Se,Te) interface in fully completed solar cells. Prior to our destructive analysis of the front interface, operating cells were fully characterized by transport measurements, which when modeled, allowed independent assessment of band positions measured by surface analytical techniques. Band alignments based mainly on X-ray excited valence band spectra do not agree with alignments estimated from device modeling, whereas measurements using UPS-derived band edges do agree. A major conclusion from this is that low density of states (DOS) tails can be missed by X-ray excited valence band measurements, even when XPS data are used in conjunction with theoretical total DOS. The low DOS tails detected directly by UPS are found to be present in several different materials and structures found in modern CdTe solar cell designs, including SnO<sub>2</sub>, a material used widely in other solar cell designs as well as in gas sensors and other electronic devices. It is believed that the low DOS band edges critical to this work are present in many other electronic materials. For that reason, our work has important implications for the use of electron spectroscopy in understanding and improvement of a wide variety of semiconducting devices.

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