**BAPVC Annual Project Report**

**Project Title:** Identifying Problem Areas in CIGS and CdTe Based Photovoltaic Devices
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**Summary:**

CdTe and CIGS devices were characterized using a variety of junction capacitance techniques which elucidate the spatial, electronic, and chemical properties of defects present in the absorber material. Because these measurements were performed on complete devices, they enable a direct examination of the relationship between device performance, fundamental properties of the absorber, and absorber growth conditions. As such, these results are well-positioned to inform the effort to fabricate higher performance cells.

**Key Accomplishments:**

Deep level transient spectroscopy (DLTS) was performed on CIGS thin-film solar cells fabricated at the Institute of Energy Conversion (IEC). The spatial origin of the well known N1 defect level, which is commonly observed in CIGS device via admittance spectroscopy (AS), has been a subject of much debate in the CIGS community for many years. As seen in Fig. 1, we were able to identify the N1 defect level using DLTS, which provided the spatial sensitivity needed to determine that the N1 level originated from a bulk defect in the device studied. This work was presented at the 2013 IEEE 39$^{th}$ Photovoltaic Specialist Conference [1].

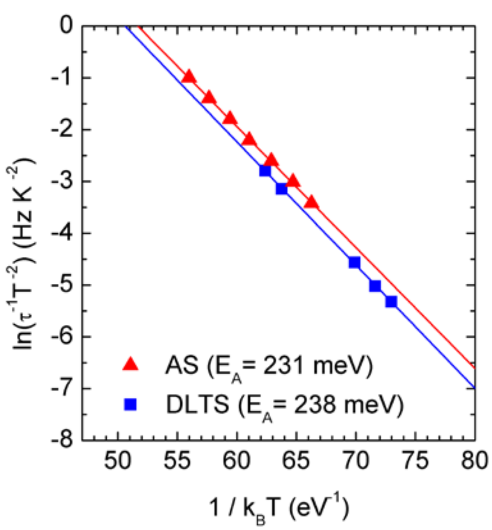


FIG. 1. An Arrhenius plot of the N1-admittance feature derived from AS (red triangles) and from DLTS (blue squares). Both measurements exhibit the same energy, which indicates that the defect observed in DLTS and in AS are one and the same. The spatial sensitivity of DLTS was then used to show that the defect originated from the bulk in the device studied.

Transient photocapacitance (TPC) and transient photocurrent (TPI) were used to study the sub-bandgap absorption in CdTe thin-film solar cells fabricated at the IEC. These measurements indentified a broad defect level at $E_V$ + 1.2 eV (seen in Fig. 2), which could act as a recombination center in these devices [2]. The investigation of defect levels in CdTe was continued through collaboration with BAPVC member Colin Wolden of the Colorado School of Mines. CdTe samples from Wolden's group provided strong evidence for an energetically deep defect level associated with Cu in the absorber layer (publication forthcoming).

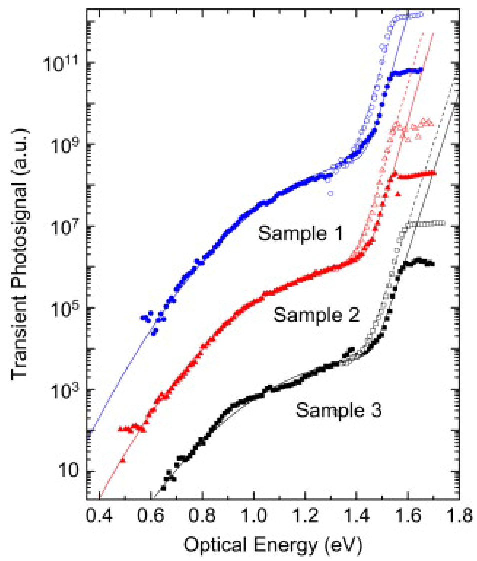


FIG. 2. TPC (closed symbols) and TPI (open symbols) of the CdTe devices studied showing significant sub-bandgap absorption, which indicates the presence of a defect level at approximately 1.2 eV above the valence band. The transient photosignal of the three samples are shifted relative to one and other for clarity.

## Future Work:

Electronic characterization of CIGS and CdTe devices will continue along the following lines. Characterization of samples from the Wolden group will clarify the role that Cu diffusion plays in CdTe cells. Capacitance characterization of CdTe samples from the Scarpulla group at the University of Utah will clearly demonstrate how laser annealing affects sub-gap densities of states in CdTe. If a suitable sample set can be obtained we will also investigate the role of Cu: (In+Ga) ratio in CIGS and Cu: (Zn+Sn) in CZTS. We are hopeful that such a sample set will become available through the BAPVC's other members. Finally, it may be possible to use TPC to distinguish bulk and interface defects or even obtain low resolution profiles of relative defect density in a thin-film as has been done with DLTS. This possibility will be explored and if successful may be of particular interest for CIGS devices where intentional grading of the band-gap and Cu content is present in the highest performance devices.

## References


[1] C.W. Warren, D.W. Miller, F. Yasin, J.T. Heath, "Characterization of bulk defect response in Cu(In, Ga)Se2 thin-film solar cell using DLTS," *2013 IEEE 39th Photovoltaic Specialists Conference (PVSC)*, pp. 0170-0173, 16-21 June 2013.

[2] J.W. Boucher, D.W. Miller, C.W. Warren, J.D. Cohen, B.E. McCandless, J.T. Heath, M.C. Lonergan, S.W. Boettcher, "Optical response of deep defects as revealed by transient photocapacitance and photocurrent spectroscopy in CdTe/CdS solar cells," *Solar Energy Materials and Solar Cells*, In Press, Available online 12 March 2014.