BAPVC Annual Project Report

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

CdTe, InP, 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 absorber properties and growth conditions. In CdTe and InP, growth conditions were directly linked to observation of particular defects and associated impacts on device performance. In CIGS a new, metastable, optical transition was observed whose impact on performance is not yet understood.

Key Accomplishments:

Building on previous work by this group [1], transient photocapacitance (TPC) and transient photocurrent (TPI) were used to study the sub-bandgap absorption in CdTe thin-film solar cells jointly fabricated by the Colin Wolden's group at the Colorado School of Mines, and by Teresa Barnes at the National Renewable Energy Laboratory. These measurements identified defect levels at E_V + 1.2 eV and E_V + 0.9 eV (Fig. 1). Using rapid thermal processing (RTP) to precisely control copper content in the devices studied (verified using ToF-SIMS) [2], the defect at E_V + 0.9 eV was associated with the presence of copper in the absorber layer [3]. The energetic depth of the copper-associated defect suggests that it could be responsible copper's detrimental effect on the minority carrier lifetime in CdTe devices.

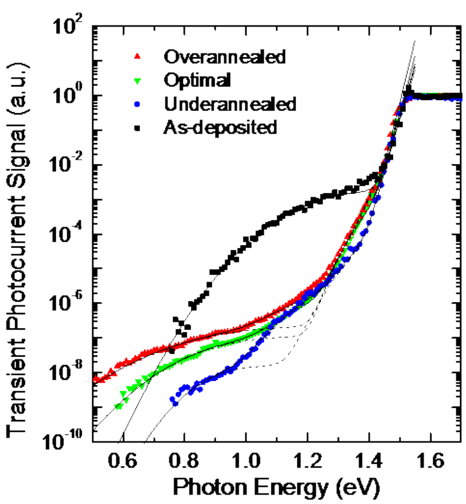

FIG. 1. TPI spectra for CdTe absorbers with Cu content varied using rapid thermal processing. Note that the 1.2 eV feature is greatly reduced by annealing while the 0.9eV feature is enhanced by RTP anneals that incorporate more copper in the absorber.

In collaboration with the Javey group at UC Berkeley we examined a set of vapor-liquid-solid grown InP samples in which a H_2 plasma treatment is associated with an increase in V_{oc} from about 500 to 600 mV. Comparison of TPI spectra from these films shows a corresponding reduction in a defect signal centered at about 1.07 eV, suggesting this defect may play a role in limiting V_{oc} (Fig 2). This is in reasonably close agreement with photoluminescence spectra obtained by the Javey group which show a similar magnitude reduction in a defect centered at ~1.12 eV.

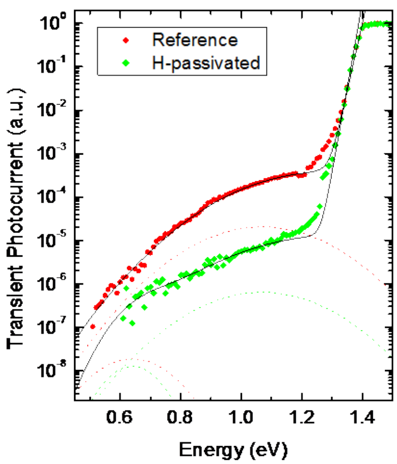

FIG. 2. TPI spectra for VLS-InP absorbers with and without H_2 plasma treatment. While the reference cell's subgap response is dominated by a single defect at ~1.07 eV, two defects are required to obtain good fits to the cell treated with H_2. By fixing the energy and FWHM of the 1.07 eV defect to be the same as in the reference cell, but allowing the magnitude to decrease, the H-passivated spectrum is well fit with the addition of a second defect at 0.64eV. The 1.07eV defect transition is reduced by a factor of 30.

Future Work:

In the case of CdTe, it would be desirable to compare the results so far obtained for polycrystalline devices to truly Cu free single crystalline samples. It remains to be seen whether challenges obtaining good contact to CdTe crystals can be overcome in a way that allows TPC and TPI spectra to be taken. In the case of InP the sample set is being expanded to follow up on these results and TPC spectra will indicate whether a minority or majority carrier transition is associated with the 1.07 eV defect. We are also following up what appears to be a strong temperature dependence of minority carrier collection from the space charge region in these devices. In CIGS we have observed, for the first time, a metastable optical transition in TPC and TPI. Further work is need to understand the relationship between this state, previously observed metastability in CIGS thin films and the impact of associated defects on device performance.

References

[1] 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*, **129**, 57-63 (2014).

[2] J. Li, D. R. Diercks, T. R. Ohno, C. W.Warren, M. C. Lonergan, J. D. Beach, and C. A. Wolden, Sol. Energ. Mat. Sol. C. **133**, 208 (2015).

[3] C.W. Warren, J. Li, C.A. Wolden, D.M. Meysing, T.M. Barnes, D.W. Miller, J.T. Heath, M.C. Lonergan, "The Effect of Cu on the sun-bandgap density of states of CdTe Solar Cells," *2015 Applied Physics Letters*, ***106***, *203903 (2015)*.

[4] 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.