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Electron Drift Mobilities in CIGS

We continued our work on drift-mobility measurements in CIGS ([Ga]/([In]+[Ga]) = 0.3) prepared by the NREL group. As noted in previous reports, our hole drift-mobilities in CIGS are quite a bit lower than estimated using admittance measurements on IEC cells by Dave Cohen's group at Oregon. However, the main work in this quarter was to try to establish sensitivity to *electron* drift.

CIGS solar cells have two distinct regions. The top region, extending about 0.5 micron below the CdS/TCO interface, drops essentially all of the electric potential across the sample, and leads to capacitances which are larger than the geometrical capacitance of a typical, 2 micron thick cell. The back region, extending 1.5 – 2 microns beneath the top region, has very little electric potential drop.

For time-of-flight measurements, one usually tries to obtain sensitivity to the two photocarriers by using strongly absorbed top illumination for one carrier, and strongly absorbed back illumination for the second carrier. The same electric field polarity, corresponding to reverse biasing of the diode, is used for both experiments. This approach presumes that it is possible to create an essentially uniform electric field across the sample; pulsed voltage bias is usually used in time-of-flight experiments to help achieve this.

This approach can't work in CIGS due to the very fast dielectric relaxation time of the back region of the cells. As an alternative, we tried switching from strongly absorbed top illumination (λ = 700 nm) to more weakly absorbed top illumination (940 nm). This change actually required that we change nitrogen lasers (to a more powerful one) and purchase special infrared dyes. We do not have independent measurements of the absorption coefficient for our particular samples; some careful work by Alonso, *et al.* on CIGS with x = 0.2 indicates 50% absorption at depths of 0.1 μm (λ = 700 nm) and about 0.3 μm (λ = 940 nm).

We expect very weakly absorbed light to give photocurrent transients with contributions from three different transport processes: (i) holes photogenerated in the top region and drifting to its bottom; (ii) electrons photogenerated in the top region and drifting to its top; and (iii) electrons photogenerated in the back region, diffusing to the top region and being subsequently swept up to the top.

If the electron processes were slow enough, we would expect to see a "tail" in the photocurrent transient that we could assign to them. With our choices of wavelength, we wouldn't expect to see the diffusion process (iii), but our transients should have been sensitive to electron drift (process (ii)). In practice, we did not measure any substantial difference between the form of the photocurrent transient for λ = 700 nm and for λ = 940 nm. We believe that this indicates that the electron drift-mobility is not less than the hole drift-mobility (so $\mu_e > 0.1$ cm^2/Vs).

There are two pathways that might be considered to get better sensitivity to electron drift or diffusion. One could employ still longer laser wavelengths; λ = 1000 nm is about the longest wavelength available for dye laser using a nitrogen laser pump, so a different pulsed illumination may be needed. Single-wavelength semiconductor lasers may be a possibility here. The second pathway would be to use rear illumination, and measure the charge collection due to diffusion of electrons out of the back region of the cell. This second approach requires CIGS cells deposited onto semi-transparent metal contacts; a previous effort to do this by IEC proved problematic.

Amorphous Silicon Solar Cell Metastibility

Our paper summarizing our device measurements and modeling for a-Si:H solar *nip* solar cells from United Solar, as a function of thickness and temperature, were published in January in *Applied Physics Letters:*
J. Liang, E. A. Schiff, S. Guha, B. Yan, and J. Yang, *Appl. Phys. Lett.* **88** 063512 (2006).
DOI:10.1063/1.2170405 [.pdf].

While we are satisfied with the conclusion of this paper that the efficiency of as-deposited a-Si:H solar cells is dominated by hole mobility effects (i.e. not defects), the paper establishes what we view as a toolbox for exploring metastability using the modeling approach outlined in this paper. We have also largely completed experiments and modeling of the metastability kinetics for the same samples used in the January paper, and are writing these up for publication. The kinetics certainly disagree with the classic "Stutzmann-Jackson-Tsai" analysis, and are reasonably consistent with our expectations for the hydrogen-collision model. The most interesting aspect is actually the saturation of the Staebler-Wronski effect at long times, and we are continuing to explore this area.

Polymer p-layers

In this quarter we have purchased some new hole-transporting polymers to see if they have better properties as spin-cast *p*-layers than polyaniline and PEDOT. We are writing up our work on polyaniline *p*-layers on n-type c-Si and on a-Si:H *n/i* structures; our main conclusions have been summarized in previous reports.

As we study these results, we have realized that there is an oddity that we have not emphasized in previous reports. This is the fact that, despite the reasonably satisfactory open-circuit voltages we achieved in several structures, the short-circuit current density is often lower than we can readily account for. The low values aren't attributable to series resistance effects. In addition to our own work with spin-cast polyaniline and PEDOT:PSS, it appears that early work with polyacetylene *p*-layers on c-Si (M. J. Sailor, et al., *Science* **249**, 1146 (1990)) showed the same effect, although it went uncommented at the time. We don't have an explanation for this effect, nor is it obviously present in our work with the highest conductivity polyaniline we obtained from Ormecon, Inc..