BAPVC Annual Project Report

Project Title: Non-Equilibrium Processing of CdTe Absorbers

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Summary:
The fundamental roles of ZnTe in promoting high efficiency and improved durability in CdTe solar cells were elucidated using high resolution TEM imaging and atom probe tomography (APT). It is shown that rapid thermal activation creates a ~50 nm interface region characterized by strong CdTe-ZnTe interdiffusion and Cu segregation to defects and grain boundaries in the CdTe, forming $Cu_{1.4}Te$ clusters encased in Zn. It is proposed that these changes passivate interface states, improving series resistance and limiting Cu migration which is a key to long term stability.

Key Accomplishments:
A critical question is how the composition and structure of the ZnTe:Cu back contact was altered during the RTP process used for optimal activation. Figure 1 display TEM images before and after processing, as well as the composition profile after activation. The as-deposited ZnTe:Cu is uniform, nanocrystalline, with little evidence of intermixing with adjacent layers. After RTP a bilayer structure is formed with substantial grain growth adjacent to the gold metallization layer and the formation of an amorphous layer in contact with CdTe, suggesting ZnTe-CdTe interdiffusion. This is confirmed by elemental profiling, and it is suggested that interdiffusion passivates defects and reduces the impact of the back contact, resulting in improved voltage.

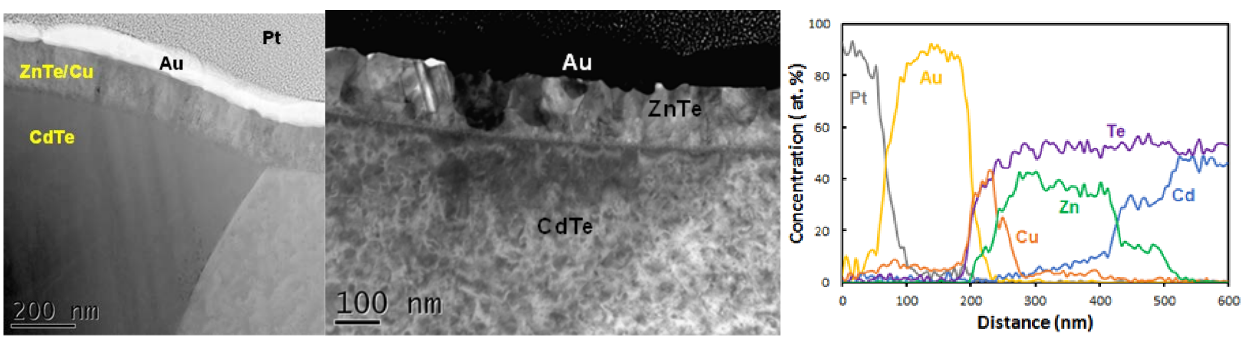

Figure 1. HR-TEM images of back contact region before RTP, after RTP, and plot showing EDAX profiles of elemental composition through the back contact region after RTP.

Nanoscale imaging revealed that much of the Cu segregates to the metallization layer as shown in Fig. 1c, and defects and grain boundaries in the CdTe are passivated by forming Cu_xTe clusters that as shown in **Figure 2**. Moreover the released Zn during the formation of these clusters accumulates at the surface, forming core-shell structure as revealed by APT. This provides the molecular level explanation for the macroscopic measurements that show that the amount and extent of Cu diffusion in these device is orders of magnitude less than expected. Copper, a fast diffuser, has been implicated as a contributor to device degradation. It is believed that the sequestration of copper into these zinc-encased structure limits electromigration and may account in part for the improved stability reported for CdTe modules using ZnTe back contact buffer layers.

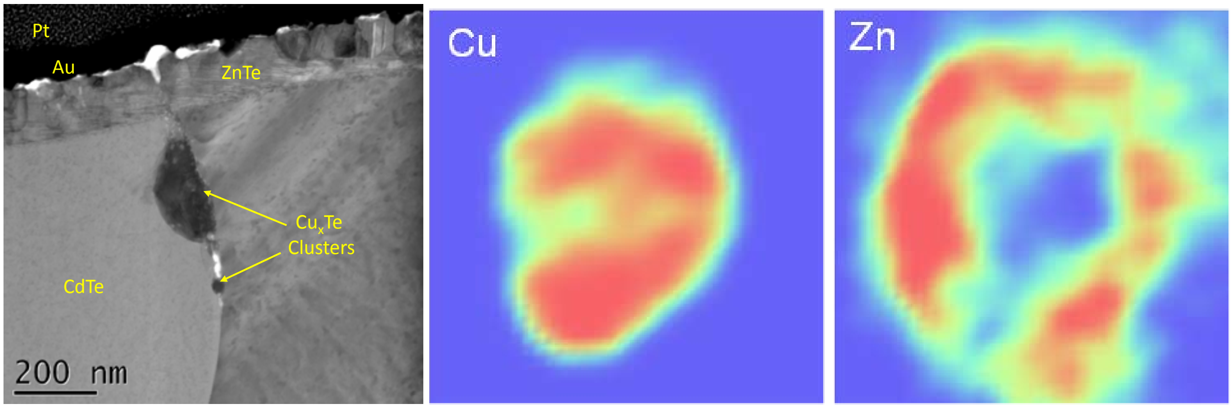

Figure 2. HR-TEM image of back contact region after RTP showing the presence of Cu_xTe aggregates, and 2D contour plots obtained by APT from one of the clusters confirm their core-shell nature.

The stability of unencapsulated devices produced in house have been subjected to accelerated liftetime testing (ALT) as a function of temperature and illumination. **Figure 3** plots the results of ALT testing at 85 ºC for dark and illuminated samples. The stability is quite good up to a 100 hours under these severe stress conditions, particularly under illumination. The J_{sc} and V_{oc} values remain largely unchanged, with losses reflecting decreases in fill factor, with development of rollover, particularly in devices stressed in the dark.

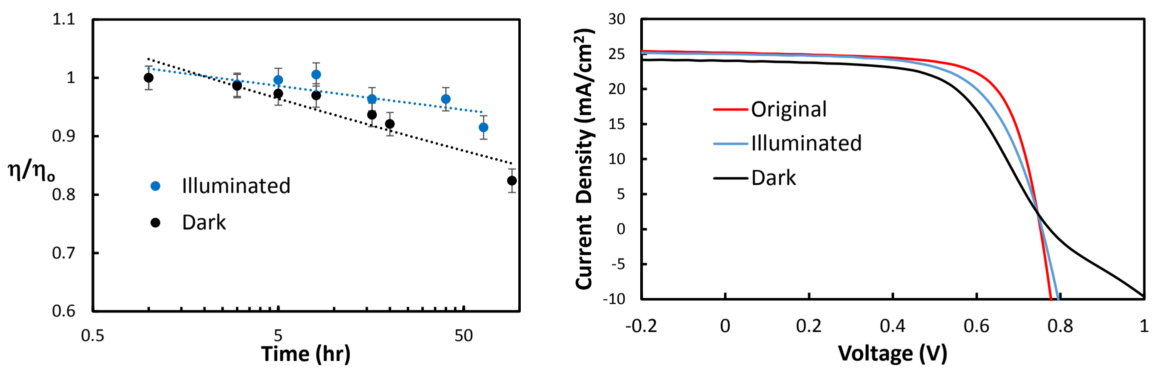

Figure 3. Results of ALT testing at T = 85 ºC showing change in efficiency and representative J-V curves before and after ALT as a function of illumination.

Future Work: There are several areas of ongoing and future work that are being pursued in parallel including the following activities:

- Doping CdTe with group V elements: Recently P-doped source material has been produced and it is demonstrated that significant P is incorporated in final devices.
- Elimination of $CdCl_2$: Preliminary work has yielded ~9% efficient devices without $CdCl_2$, and it is expected that this value may be improved significantly with future study.
- Engineered Heterojunction: The unique evolution of sputtered CdS:O during high temperature device processing has been discerned in collaboration with BAPVC partners at UO and others. This has spurred new work directed at directly engineering the heterojunction without need for post-processing.
- Stability: In collaboration with BAPVC partners at Georgia Tech the stability of novel encapsulants for CdTe solar cells is being examined.