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Preprint

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Synthesis of $CdSe_xTe_{1-x}$/CdTe for graded solar cells

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Abstract —Here, we have developed $CdSe_xTe_{1-x}$/CdTe bilayer deposition for graded solar cell technolgoly. Smoothly graded Se profiles with > 16% efficiency with Jsc=28 mA/cm^2 and 20-ns bulk lifetime has been observed. The CdSeTe reveals longer carrier lifetimes than CdTe within the same device.

***Index Terms* —CdSeTe/CdTe gradient absorber, charge carrier lifetime, photovoltaic cells, Closed-space sublimation, MZO.**

I. Introduction

CdTe has a high absorption coefficient and bandgap well suited for thin film photovoltaics. However, relative to GaAs thin film solar cells, low Voc, hole density and carrier lifetime limit performance [1]. By incorporating Se into the CdTe absorber, higher Jsc and longer lifetime have been observed [2]. Here we describe methods to created smoothly graded Se profiles by a simple two-step process. Lifetime and luminescence measurements indicate that performance increases wihin the CdSeTe regions relative to CdTe regions of the same device.

Several methods have been used to prepare $CdSe_xTe_{1-x}$ thin film. Naba R. sputtered a CdSe and CdS/CdSe bi-layer with thickness variation, then form $CdSe_xTe_{1-x}$ alloy through interdiffusion by followed fabrication process [3]. Zhang Bao [4] reported using pulsed laser deposition, followed by CSS CdTe. Brandon I. MacDonald etc [5], used colloidal CdSe and CdTe nanocrystal particles, sintered layer by layer to form $CdSe_xTe_{1-x}$ films with accurate control of Se concentration. Here we report the deposition of CSS $CdSe_xTe_{1-x}$ poly-crystalline thin films on MZO substrates from $CdSe_xTe_{1-x}$ alloy powder sources, followed by CSS CdTe deposition. After the $CdCl_2$ treatment, the resulting graded CdSeTe/CdTe solar cell acheives Jsc> 28 mA/cm^2. Devices with Se incorporation show better performance than CdTe-only control devices.

II. Experiment

CdSeTe/CdTe bilyar structures were deposited at NREL on MZO substrates by using $CdSe_xTe_{1-x}$ alloy powder from 5N plus. Relative to binary compound deposition, fabricating CdSeTe films with a CdSeTe alloy source is challenging. The incorporation of Se from the source to the substrate varies due to different vapor pressures between Se, Cd and Te. Also because of the sticking coefficient and bonding energy difference between Se and Te, evaporating $CdSe_xTe_{1-x}$ usually requires higher temperature differences between the source and substrate, followed by more aggressive $CdCl_2$ treatment [2,5]. Therefore, instead of using deposition process with high substrate temperature, small delta T and high ambient pressure for CdTe, lower substrate temperature at 480°C and higher source temperature at 670 °C were modified for CdSeTe deposition in vacuum (~0.1 torr, the pump limit of mechanical pump in our system), followed by CSS CdTe deposition in the same chamber with a substrate temperature at 625°C and source temperature at 660°C under 20 torr He ambient pressure. After that, samples were annealed in $CdCl_2$ vapor in a separate chamber at 450°C, with and without oxygen partial pressure. Instead of sputtering a Cu/Au back contact, the Cu dopant was introduced by a $CuCl_2$ wet process [6], then annealed at 210°C in the air. Afterwards, a 200-nm thick Au was deposited by physical evaporation to complete the glass/MZO/CdSeTe/CdTe/Au device. For comparison, devices were also made without any CdSeTe for a CdTe-only absorber.

The crystallinity of as-grown CdSeTe and that after $CdCl_2$ treatment series has been calibrated by X-ray diffraction (XRD). Average Se incorporation into the film has been evaluated roughly by X-ray fluorescence (XRF) mapping. Devices performance has been characterized, two-photon time-reserved photoluminescence (TRPL) decay, cathodoluminescence.

III. Results and Discussions

Fig 1. shows the Se distribution and film crystallization before and after $CdCl_2$ treatment on an MZO substrate. In Fig. 1(a), the as-deposited Se distribution is shown. By using $CdSe_{0.2}Te_{0.8}$ alloy, the film ends up Se rich relative to the source. In Fig 1. (b), unlike CdTe, as-deposited films with average Se% =18.% shows mixed phases by XRD [7]. Besides the three main (111), (220) and (311) zincblende phase, a weak (101) peak belonging to the wurtzite phase is observed. However, this wurtzite feature disappears through recrystallization under $CdCl_2$ vapor**.** This indicates contrast to the phase diagram reported by J. Poplawsky [8], in that as-deposited $CdSe_xTe_{1-x}$ could be mixed phases, even when xSe in the alloy is <0.6. Meanwhile, a clear recrystallization occurs after the $CdCl_2$ treatment particularly for temperatures greater than 380°C, which is near the recrystallization point predicted by MeangJun Kim [7].

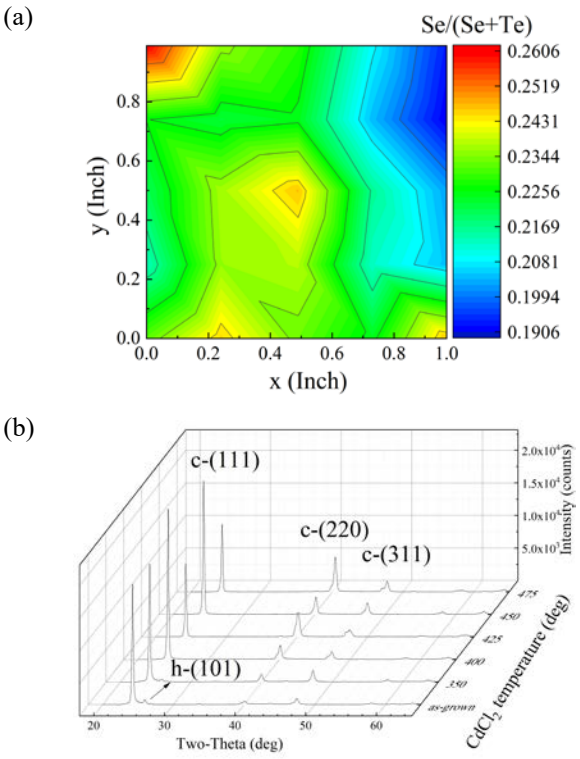

Fig.1 Se distribution of as-deposited CdSeTe through XRF mapping (a), and (b) crytallinity after $CdCl_2$ treatment by XRD

Figure 2 illustrates the Scanning Electron Microscope(SEM) image of a beveled CdSeTe/CdTe bilayer device. As is typical of close-spaced sublimation devices, the grains at the front of the interface are small due in part to nucleating on a nanocrystalline interface, in this case MgZnO on TCO and glass. The grains become larger progressing from the back of the device to the front. The morphology and grain structure is reasonable, and does not indicate voiding or other interfacial issues due to depositing CdSeTe on CdTe and then diffusing them together in the $CdCl_2$ treatment.

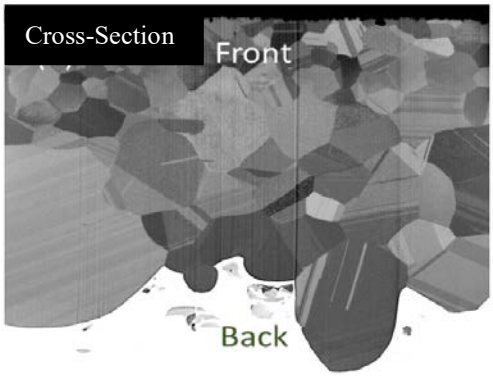

Figure 2. SEM image on a beveled device illustrating the progression of small grains near the front interface to large grains at the back of the device after $CdCl_2$

Instinctively, one would think that the larger grains would provide longer lifetime. To probe this, two-photon excitation capable of reaching beyond the surface was used to measure time-resolved photoluminescence in Figure 3(a). First with the focus on the glass side of the sample so that the light was absorbed and generated electron hole pairs primarily in the CdSeTe region, and second towards the back of the region. The resulting aggregate time-resolved photoluminescence curves binned using time-correlated single-photon counting are shown in Figure 3(b). Contrary to intuition, the results indicate that the lifetime is longer in the smaller grain CdSeTe region than the larger grain CdTe region. Measurements on CdTe-only absorbers revealed again that CdTe had a shorter lifetime relative to CdSeTe. Consequently, CdSeTe appears to passivate the grain boundaries and enhance the bulk lifetime. Corroborative single-photon lifetime measurements indicate lifetimes as long as 25 ns in these samples. The combination of the lower bandgap and higher lifetime help photocurrent exceed 28 mA/cm2 and achieve efficiency values exceeding 16%.

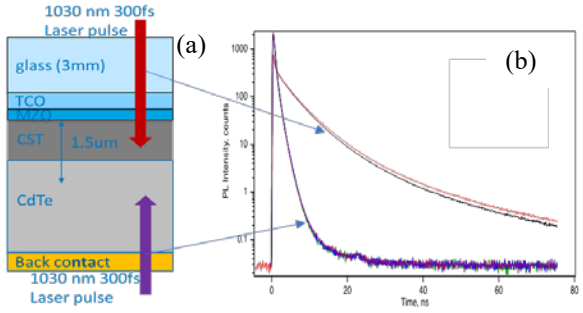

Figure 3. 2PE TRPL lifetime measurement schematic (a), TRPL decay curves (b) for injection through the front (red, black) and back (purple).

IV. Conclusion

Straightforward $CdSe_xTe_{1-x}$/CdTe bilayer deposition for graded solar cell technology is described using closed-space sublimation. Smoothly graded Se profiles with > 16% efficiency with Jsc=28 mA/cm^2 and 20-ns bulk lifetime has been observed. The CdSeTe reveals longer carrier lifetimes than CdTe within the same device.

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