

Interactions between Chemical Bath Deposited CdS and Neighbor Layers in CdS/CdTe Solar Cell Devices

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Cadmium Sulfide (CdS) is used as the primary n-type layer in photovoltaic devices utilizing CdTe as the p-type absorber layer. In polycrystalline solar cells, the CdS has been grown by a variety of techniques. These techniques can be grouped into those representative of vacuum processing (sputtering and evaporation) and those involving solution processing (chemical bath deposition (CBD) and electrodeposition). Of these, solution-based processes are generally viewed as being less “manufacturable” than their vacuum-based counterparts. This comes with some consternation since CBD is recognized as the CdS deposition process by which the highest CdS/CdTe solar cells are routinely fabricated.

We have found it extremely important to understand how CdS films grown by CBD interact with neighbor layers during CdS/CdTe solar cell fabrication. In this paper, we highlight how such research has contributed to improvements in device performance, in particular, as concerns tin-oxide/CdS/CdTe/backcontact structures. In this structure, the tin-oxide commonly consists of two layers. The layer adjacent the CdS film is undoped, presumably to provide protection against shunting. Several types of buffer layer tin-oxide films have been studied, including films deposited on unheated substrates by sputtering, and those deposited at higher temperatures by chemical vapor deposition (CVD). CBD CdS films are grown by an optimized process involving the titration of Cd-acetate containing solutions with a thiourea-base. CdS films grown by close-spaced sublimation (CSS) are used to better delineate the impact of CBD impurities on interfacial reactions. These latter films, grown at higher substrate temperatures, show significantly better crystallinity and less oxygen content. CdTe films were deposited on the glass/tin-oxide/CdS structures using CSS though some results using evaporated and sputtered CdTe films will be shown for comparison.

Regarding buffer layers, room-temperature, sputtered tin-oxide films were found susceptible to reduction in H<sub>2</sub> anneals at higher annealing temperatures. Tin-oxide layers deposited by CVD at higher temperatures were far more resistant to this effect. Elemental Sn was easily detected in sputtered films after H<sub>2</sub> anneals. When coated with CBD CdS, elemental Sn can react with S-containing impurities to form SnS. The formation of this phase is clearly seen in the grazing-incidence x-ray diffraction data of Figure 1.

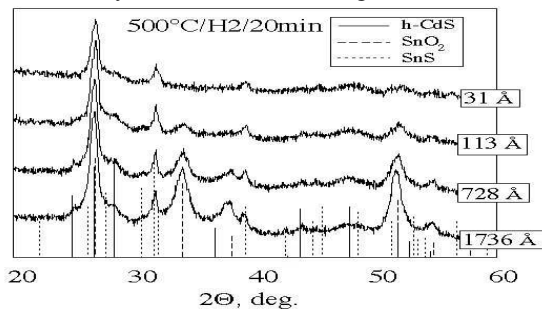


Fig. 1 – SnS presence detected by GIXRD in H<sub>2</sub> annealed glass/tin-oxide/CBD CdS samples

High oxygen-content in CBD CdS (averaging 10- 12 at%) can also favor the formation of SnO. Both phases have the effect of darkening the film. Secondary phase formation is mirrored by significant changes in CBD CdS film composition with processing. Figure 2 shows CBD CdS film composition measured by x-ray photoelectron spectroscopy (XPS) as a function of ambient treatment conditions. The observed changes in film stoichiometry are a direct result of interactions between secondary phases in the CBD CdS film and the reducing-oxidizing nature of subsequent processing prior to the CSS growth of CdTe. Modifications to our CdS/CdTe deposition processes to mitigate these effects, including the use of more stable tin oxide layers and lower temperature (or the absence of) H<sub>2</sub> anneals, have yielded devices with higher open-circuit voltages and fill factors.

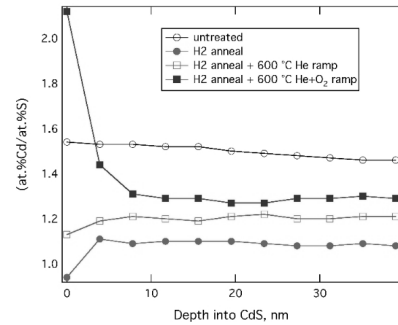


Fig. 2 CBD CdS Stoichiometry Shifts Under Different Ambient Conditions

When CdTe layers are subsequently grown on CBD CdS films at the high substrate temperatures characteristic of CSS deposition, significant interdiffusion between the CdS and CdTe can occur. The extent of this interdiffusion appears to be controlled by the amount of oxygen found in the CdS layer. Fig. 3 shows transmission electron micrographs of similarly processed CdS/CdTe interfaces for (a) a CSS CdS (low oxygen containing) layer, and (c) a CBD CdS (high oxygen containing) layer. In the low-oxygen case, the CSS CdS layer is almost entirely consumed by interdiffusion while in the high-oxygen CBD CdS case, this interdiffusion is almost absent. Energy-dispersive spectroscopy (EDS) using electron probe analysis also shows that CBD CdS is more resistant to the indiffusion of Te from the CdTe layer.

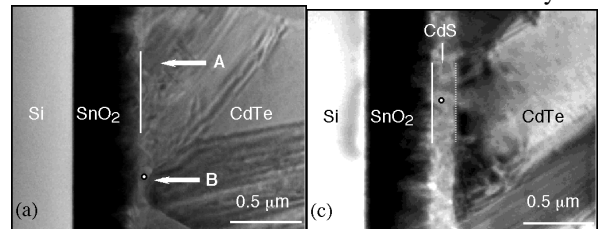


Fig. 3 Interdiffusion differences observed between (a) CSS CdS and (c) CBD CdS films in CdS/CdTe interfaces.

Oxygen present during the subsequent CdTe deposition in effect determines how the CdS layer is consumed into the CdTe layer. When the CdTe is deposited without oxygen, sulfur diffuses more quickly along grain boundaries than within grains. When CdTe is deposited with oxygen, grain boundary diffusion is suppressed as is CdS film consumption.

Diffusional processes at the CdS/CdTe interface are thus seen to be highly dependent upon the chemical nature of the CdS layer as well as conditions during the subsequent CdTe deposition.