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Development of ALD In_2O_3 layers and its performance as a TCO in chalcopyrite solar cells

Recently, the efficiency of $Cu(In,Ga)Se_2$ (CIGSe) solar cells could be improved stepwise (currently, November 2015, η ≈ 22 %). This is mainly attributed to the introduction of a post-deposition potassium treatment. Adding this step to the production process led to gains in open circuit voltage *Voc* and/or short circuit current density *Jsc* of the corresponding devices. Compared to the "perfect solar cell" with a band gap energy of 1.15 eV (according to Shockley Queisser), those state-of-the-art solar cells lose about 150 mV in *Voc*, 8 %-points in fill factor and roughly 6 mA/cm² in *Jsc*. While the first two losses can be ascribed mainly to the junction quality and the absorber properties, the drop in *Jsc* is almost completely caused by parasitical absorption in the window layer structure and reflection losses. Thus, the study of potential alternatives is justified.

Most commonly a combination of CdS (buffer) and ZnO:Al (TCO) forms the window layer structure in chalcopyrite solar cells. In the case of ZnO:Al, owing to its rather low mobility μ and high charge carrier density *n*, the main optical losses originate from free charge carrier absorption. Therefore, it is desirable to exchange ZnO:Al by a layer that shows the same (or even larger) conductivity with a reduced number of charge carriers, which still has to work electronically in the solar cell device.

In this talk the development of atomic layer deposited (ALD) In_2O_3 as an alternative TCO is presented. The dependency of electrical and optical properties on the ALD process parameters will be illustrated and related to microstructural changes. An extended empirical study resulted in superior properties of the optimized In_2O_3 layers compared to ZnO:Al (lower resistivity while lowering *n* by the factor of 7). Finally, the application in CIGSe solar cells with different buffer layers (CdS and $Zn_{1-x}Sn_xO$) will be demonstrated and remaining challenges will be discussed.

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