Thin Film Solar Cells from Colloidal Nanocrystal Coatings

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The global installed solar cell capacity has doubled every 2.5 years between 1975 and 2013. Maintaining this growth rate towards terawatt levels requires continued reduction in manufacturing costs with abundant and nontoxic materials. While silicon-based solar cells dominate the current solar cell market, silicon is an indirect band gap material and its light absorption is low. Consequently several hundreds of micron thick silicon is required to absorb a significant fraction of the sunlight: this increases the cost of silicon-based solar cells. In contrast, thin film solar cells made based on direct band gap materials such as CdTe and $CuIn_{1-x}GaSe_2$ (CIGS) require only a few micrometers of these materials because they absorb light very strongly. Thin film solar cells based on CdTe and CIGS compete with silicon solar cells for market share. However, reaching terawatt levels with CdTe and CIGS based solar cells may be difficult because the abundance of indium and tellurium in earth's crust is very low. Copper zinc tin sulfide (Cu_2ZnSnS_4 or CZTS) and copper zinc tin selenide ($Cu_2ZnSnSe_4$ or CZTSe) are earth abundant, low cost, and non-toxic alternatives to CdTe and CIGS and are being considered as the absorber layer in thin film solar cells. These p-type semiconductors have high absorption coefficients and solar cells based on CZTS and CZTSe have already achieved power conversion efficiencies as high as 12.04%. Rapid rise in power conversion efficiencies over a relatively short time period (~5 years) is remarkable. Several methods for making thin CZTS and CZTSe films have emerged and most are based on vacuum deposition. However, a potentially low cost approach for making thin CZTS (and CZTSe) films relies on coating suitable substrates with a thin layer of CZTS nanocrystals from colloidal dispersions and then annealing this layer to form a polycrystalline film. This potentially low-cost and high throughput approach is compatible with roll-to-roll manufacturing. Towards this end, my group and collaborators are engaged in fundamental research required to bring this approach to fruition. In this talk, I will describe our approach in the laboratory scale. We synthesize colloidal dispersions of CZTS nanocrystals (inks) using rapid thermal decomposition of copper, zinc, and tin diethyldithiocarbamates in presence of hot (150-300 ˚C) oleylamine and then use these inks to form nanocrystal coatings on various substrates which are then annealed in sulfur and/or selenium to form large grain microcrystalline films suitable for solar cells. I will describe the effects of various process parameters and summarize the challenges in making continuous, dense, polycrystalline CZTS and CZTSe films for solar cells.