Transparent Conducting Oxide Films

R.P.H. Chang
Northwestern University, Evanston, IL 60208, USA

A variety of strategies exist for the optimization of Transparent Conducting Oxides (TCOs). Initially, our work focused on the optimization of dopant concentration in doped single-cation oxides such as Sn-doped CdO and Ga-doped ZnO. In these single oxide systems it is frequently hard to achieve both high conductivity and high transparency. Conductivities in excess of 42,000 S/cm are observed in our Sn-doped CdO films grown by pulsed laser deposition (PLD), however, the relatively small band gap of 2.8 eV for this system results in a low average transparency for the visible range. Alternately, Ga-doped ZnO grown by atomic layer epitaxy (ALE) has excellent transparency in the visible range but conductivities on the order of 1000 S/cm. Progressing up the level of system complexity, multi-cation oxides such as $CdIn_2O_4$ and Cd_2SnO_4 are considered, as well as the dopant concentration within multi-cation oxides. Conductivities, after annealing, for multi-cation oxides grown by PLD can be >9000 S/cm while raising the band-gap to 3.2 eV and improving the average transparency in the visible range. Finally, owing to the difference in optical properties between TCOs, and hence the possibility of multi-layers having properties superior to the simple sum of the individual layers, we have looked at multi-layer films. A bi-layers film of Cd-doped Cd_2SnO_4 and Sn-doped CdO grown by PLD was measured to have a conductivity of 18,800 S/cm while maintaining an average extinction coefficient of 3520 cm^{-1} in the visible range.