

## DEVELOPING NEW FUNCTIONAL TCS

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Transparent Conductors (TCs) are increasingly critical to the performance and reliability of a number of technologies. Traditionally based primarily on oxides of Ga, In, Zn and Sn the class is rapidly expanding into new materials including both other oxides and more recently composites of metallic or carbon nanowires. Many of these materials offer unique functionality as well as processing and reliability advantages over some of the historic materials. These compounds are all classically non-stoichiometric and often metastable consisting of oxide, non-oxide and composite materials which are being collectively looked at for an increasingly broad set of applications including photovoltaics, solid state lighting, power electronics and a broad class of flexible and wearable electronics. In this talk, we will focus on two main areas; the development of predictive models to be able to identify dopants and the processing regimes where they can be activated as well as the use of nanowire oxide composites to develop a new generation of tunable high performance TC.

The complex set of demands for a desired TC include not only classical performance, but also processibility, cost and reliability necessitating a search for new materials. The ability to use materials genomics to identify new dopable TC materials that are experimentally realizable is rapidly increasing. We will discuss recent work on predicting the dopability of  $\text{Ga}_2\text{O}_3$  films, which potentially have broad applicability as buffer layers, TCOs, and in power electronics if the doping level can be well controlled. We will discuss the theoretical predictions for the process windows to activate both Sn and Si as dopants and compare this to experimental results and the literature. We will also present recent results on the theoretical prediction and realization of a new p-type TC based on CuZnS, which has demonstrated conductivities of up to 100 S/cm. The latter while not classically an oxide is certainly non-stoichiometric and properties are enhanced in many cases by the use of complex oxide, sulfide and selenide materials. Together these will illustrate the evolving tools both theory and experiment to develop and realize dopants in wide band gap materials.

In cases where single materials may not be sufficient, nanowire (metal or carbon based) composites with oxides is increasingly attractive. For example, Ag, and potentially Cu, nanowires embedded in a metal oxide matrix can potentially produce TCs that can be processed at low temperature, have conductivity and transparency comparable to the best TCOs, control interface stability and electronic properties and are suitable to flexible electronics. We will present work on ZnO, InZnO and ZnSnO composites with Ag nanowires where the performance can be as good as high quality InSnO with films  $R_s < 10 \text{ Ohms/sq}$ . We will discuss the dependence on the interrelationship between the nanowire properties and the oxide properties. We will also discuss the concept of employing sandwich oxides to separately optimize the top and bottom interfacial properties.

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