**Cation Engineering and Quantum Effects in Zinc Tin Oxide Films**

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Amorphous zinc tin oxide (a-ZTO) has emerged as a promising candidate among transparent conducting oxides (TCOs) due to its excellent optical transparency, controllable charge carrier concentration, and the use of earth-abundant elements. To optimize its performance for applications in transparent electronics, it is essential to understand the correlation between its local bonding environment and its macroscopic electronic properties. In this work, we investigate the structural and electronic characteristics of a-ZTO thin films fabricated via magnetron sputtering and spray pyrolysis, with a particular focus on how variations in the Zn:Sn cation ratio influence material behaviour.

Using a combination of X-ray absorption techniques—X-ray absorption near-edge structure (XANES) and extended X-ray absorption finestructure (EXAFS)—we demonstrate that although the films are amorphous in long-range order, their short-range structure is dominated by ZnO- and SnO₂-like units. These local motifs are found to significantly influence conduction band hybridization, thereby affecting charge carrier mobility, concentration, and band gap values.

Complementary in situ X-ray photoelectron spectroscopy (XPS) and scanning tunneling spectroscopy (STS) measurements reveal a measurable blue shift of ~0.33 eV in the electronic band gap, attributed to quantum confinement. STS results are compared with optical band gaps obtained from Tauc analysis of UV-Vis spectra. Together, these findings deepen our understanding of the structure–property relationships in a-ZTO and offer insights for the rational design of next-generation transparent electronic materials.