

Optimising Sol-Gel SnO₂ Electron-Transport Layers for Organic Solar Cells: Processing versus Cu-Doping Effects

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Abstract

This study addresses that challenge by establishing a processing–surface–optical correlation framework for sol–gel SnO₂ and Cu-doped SnO₂ thin films intended for electron transport applications. The central objective is to determine the dominant processing lever for obtaining smooth, highly transparent SnO₂ surfaces, while clarifying the trade-off introduced by Cu incorporation. Thin films were deposited by spin coating on glass, ITO, FTO, and Si substrates, with systematic variation of spin speed, layer number, precursor viscosity, annealing temperature, substrate type, and cleaning/etching protocol. Surface and optical properties were resolved through atomic force microscopy, profilometry, UV–Vis spectroscopy, and spectroscopic ellipsometry.

The most significant finding is that substrate preparation, when coupled with high spin speed, outweighs compositional modification in controlling the ETL surface. Undoped SnO₂ deposited at 8000 rpm produced uniform ultrathin layers of approximately 20–25 nm with RMS roughness below 40 nm and high visible transparency, while ellipsometry confirmed a low-loss optical response with $n \approx 1.61$ – 1.68 and $k < 0.018$. By contrast, 3 mol% Cu doping systematically increased thickness and roughness and reduced transmittance by about 9–20%, with the strongest penalty observed on FTO. Moderate annealing improved uniformity, whereas higher temperatures promoted anisotropic topographies and microcracking.

These results define a practical surface-optimised processing window for SnO₂-based electron-transport layers and show that contamination control and film-growth kinetics are more decisive than Cu doping for preserving optical quality. For the surface science community, the work highlights how interfacial preparation governs the morphology–disorder transmission relationship in functional oxide coatings for photovoltaics.

Keywords

SnO₂ thin films, surface morphology, electron-transport layers; spin coating; organic solar cells.