

Accessible, Cleanroom-Free Surface Acoustic Wave Resonators

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Surface Acoustic Wave (SAW) devices are a foundation for telecommunications and sensor technologies [1]. However, commercial deployment is bottlenecked by expensive cleanroom manufacturing, requiring vacuum-based physical vapor deposition and multi-step photolithography to pattern Interdigitated Transducers (IDTs) directly onto the piezoelectric film [2]. While solution based Chemical Bath Deposition (CBD) offers a low-cost, benchtop alternative, undoped zinc oxide (ZnO) films exhibit high n-type conductivity due to unintentional incorporation of shallow-donor impurities, primarily hydrogen [3]. This causes the applied RF signal to dissipate as a parasitic electrical short. To overcome these limitations, we introduce a dual-strategy approach. First, copper (5 at.% Cu) is introduced into the CBD precursor solution to act as a deep acceptor, trapping the free electrons and restoring the films piezoelectric properties. Second, films are grown onto glass pre-coated with a conductive Indium Tin Oxide (ITO) underlayer to terminate electric field lines and prevent energy dispersion into the substrate. Traditional lithographic IDTs are replaced with off-the-shelf Flexible Printed Circuit Boards and are mechanically coupled to the films. Electrical and acoustic characterization validates the success of this platform. Undoped CBD films show a flat and featureless S_{11} response, whereas the 5 at.% Cu-doped films exhibit a well-defined Rayleigh resonance mode at 15.4 MHz (Figure. 1(a)). The ZnO/ITO/Glass architecture demonstrated a significantly deeper reflection magnitude and an improved electromechanical coupling coefficient (k^2) compared to films grown on bare glass. (Figure 1(b)). 3D Laser Doppler Vibrometry (LDV) confirms the out-of-plane Rayleigh wave generation, showing a 27% increase in peak mechanical displacement (56 pm vs. 44 pm) for the ITO-supported configuration. By combining wet-chemical defect engineering, structural field confinement, and mechanical off-the-shelf components, this work establishes a fully functional, highly accessible method for rapid, low-cost SAW device manufacturing.

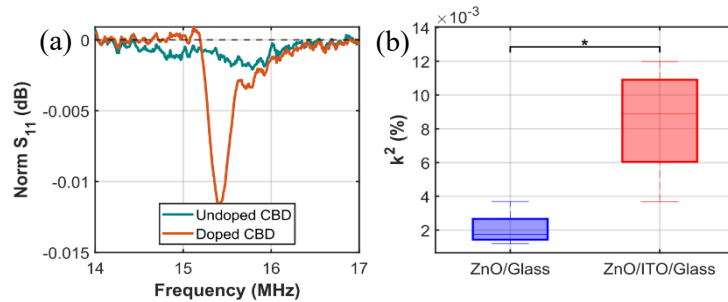


Figure 1: (a) normalized S_{11} of undoped and 5 at.% Cu-doped CBD ZnO films. (b) k^2 of ZnO/Glass and ZnO/ITO/Glass at Rayleigh resonance ($n = 5$) for each configuration. (*) indicates a significant difference.

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[2] C. Sun *et al*, IEEE Transactions on Electron Devices, **68**, 393 (2021)

[3] A. Janotti and C.G. Van de Walle, Rep. Prog. Phys, **72**, 126501 (2009)

Supplementary Information

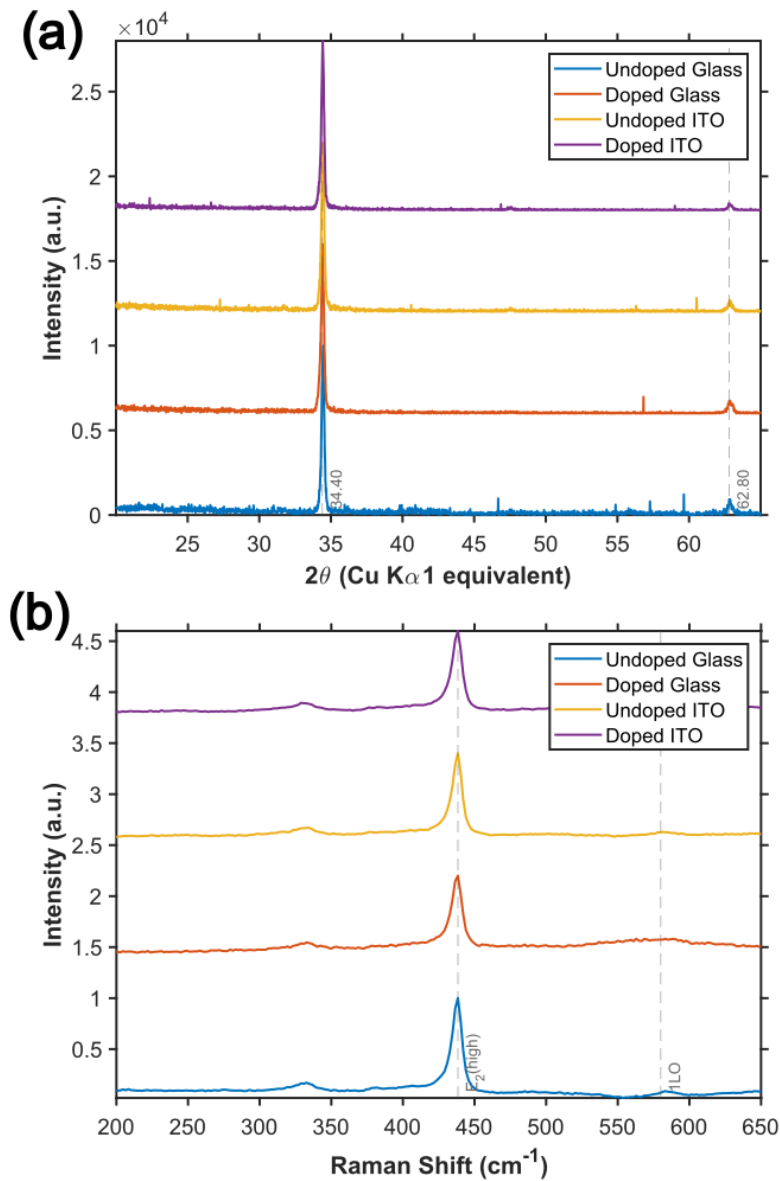


Figure 2: Structural Characterization of Synthesized ZnO Films. (a) Grazing Incident X-ray Diffraction (GI-XRD) patterns comparing undoped and 5 at.% Cu-doped CBD ZnO films grown on bare borosilicate glass and ITO-coated substrates. A dominant (002) reflection at $2\theta = 34.4^\circ$ confirms a strong preferential c-axis orientation that remains intact regardless of copper incorporation or the underlying substrate architecture. (b) Raman spectra detailing local lattice dynamics. A stable and sharp $E_2(\text{high})$ optical phonon mode at 438 cm^{-1} confirms that the copper ions are smoothly accommodated into the wurtzite lattice without inducing macro strains or impurity phases.