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Enhanced Piezoelectric ZnO Films Grown by Open-Air Spatial ALD

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Abstract

Zinc oxide (ZnO) is a promising material for piezoelectric sensors and actuators due to its abundance, low cost, ease of processing, and environmental friendliness. The piezoelectric behavior in ZnO is closely linked to its crystal orientation, specifically along the c-axis in its wurtzite structure, where the strongest strain-induced polarization occurs. In polycrystalline ZnO films, aligning the individual grains (structural texturization) along this direction is important for enhancing their piezoelectric performance. Typically, texturization involves using monocrystal substrates (such as ZnO or Al_2O_3), which are costly options, or additional buffer layers, which complicate the deposition process.

This thesis research explores the potential for enhancing the piezoelectric performance of ZnO thin films grown without an epitaxial relationship at relatively low temperatures (below 250 °C) and under open-air conditions. In these studies, the growth conditions were optimized to deposit self-textured ZnO films using a custom-built atmospheric-pressure spatial atomic layer deposition (AP-SALD) system. Through systematic methodologies, the effects of various deposition parameters on film texture and piezoelectric properties were examined. As a result, high-quality ZnO films with considerably improved piezoelectric amplitude and domain polarity were successfully produced. Furthermore, the results showed that structural alignment alone does not fully explain these improved piezoelectric properties. Therefore, additional material characterization techniques and further experimental approaches (such as doping the ZnO films or employing templating agents to guide film growth) were explored to better understand the intricate relationships and enhance film performance further.

This study is the first reported use of the AP-SALD method for the deposition of piezoelectric films. It demonstrates that AP-SALD is an effective and practical technique for precisely controlling both the structural and functional properties of ZnO thin films. As an open-air, facile, and cost-effective method, our study shows strong potential for implementation in continuous production processes such as roll-to-roll (R2R). These advances could significantly broaden the use of ZnO piezoelectric films in large-scale electronics, wearable technologies, flexible smart materials, and various integrated surfaces.