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Dual magnetron oblique sputtering of biaxially oriented ZnO thin films on amorphous substrates

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Abstract – Biaxially oriented ZnO thin films have been deposited on amorphous substrates, such as low alkali glass, SiO_2, and polymer substrates using dual magnetron oblique sputtering (DMOS). DMOS uses two dc magnetron sputter sources positioned opposite each other and at angles of 20° to 40° relative to the substrate normal. Orientation was measured by x-ray Φ scans and pole figures. Maximum orientation in as-deposited films was observed when incident angles were ~30°, with {101} Φ scans having a FWHM of ~23°. In-plane orientation was improved with post-deposition annealing; decreasing Φ FWHM by ~60%. Elevated substrate temperature during growth had a detrimental affect on orientation.

This talk will describe results on deposition and characterization of biaxially oriented ZnO thin films on amorphous substrates, such as glass, thermally oxidized Si, and polymer substrates. Biaxially-oriented ZnO thin films on low-cost substrates are of interest for ZnO-based devices and as “substrates” for subsequent growth of devices based on AlN, GaN, InN, and their alloys. Expensive single crystal substrates, which are typically used to achieve the requisite crystalline perfection of the epitaxial device layers, could be replaced by biaxially-textured ZnO substrates if sufficiently good orientation can be achieved.

The dual magnetron oblique sputtering (DMOS) geometry utilized two dc magnetron sputter sources [1], with metallic Zn targets, positioned opposite each other and at angles of 20 to 40° relative to the substrate normal. Sputtering was carried out in an oxygen-rich Ar-O_2 atmosphere. The as-deposited films were under considerable compressive stress, as measured by x-ray peak position, in agreement with prior results on sputtered ZnO. Atomic-force microscopy measurements on as-deposited 1.5 μm thick films showed relatively high rms roughnesses of 8.3 nm.

The ZnO films exhibited (002) out-of-plane orientation, as suggested by θ-2θ x-ray scans and verified by x-ray pole figures (Figure 1) that were completed for selected samples. Sputtering from a single target (instead of the usual dual-target geometry) caused a shift in the out-of-plane orientation, causing the (002) plane normal to be up to 10° off normal. X-ray scans as a function of azimuthal angle ϕ were carried out to detect reflections from (101) planes. The strongest biaxial orientation was observed when the sputter sources were placed at 30° from the substrate normal, with ϕ-scan peaks exhibiting a full width half maximum (FWHM) value of 23°. Elevated substrate temperature during deposition, up to 600℃, decreased the orientation in the films, yielding a ~17% increase in Φ FWHM. As seen in Figure 2, post deposition annealing at up to 1000℃ substantially improved the degree of biaxial orientation, decreasing the ϕ-scan FWHM by ~60%. The effects of a range of deposition and post-deposition annealing conditions on the film orientation will also be reported. The orientation mechanism also will be discussed as well as comparison between substrate types, including low alkalai glass, oxidized Si, and polymer substrates.

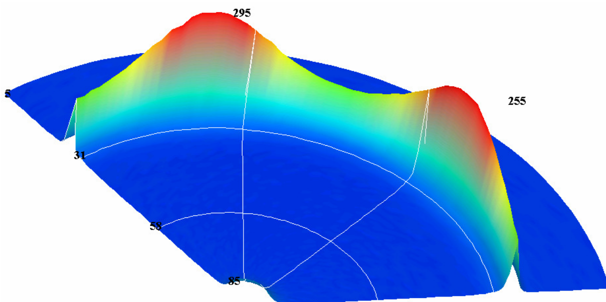

Figure 1: X-ray {101} partial pole figure (120° slice) of an as-deposited ZnO film grown via DMOS on glass with incident ion angle ~30°.

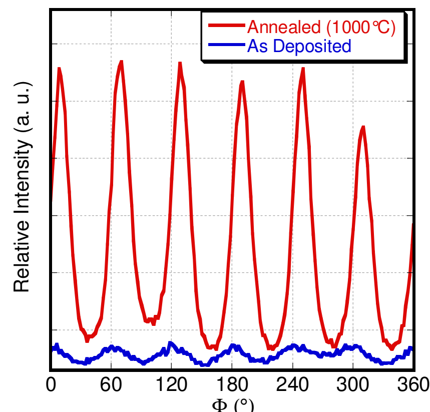

Figure 2: XRD phi scans of the {101} reflections showing in-plane orientation from an as-deposited (bottom) and annealed (top) ZnO film grown via DMOS on SiO_2.

[1] D.Y. Kaufman, P.M. DeLuca, T. Tsai, and S.A. Barnett. J. Vac. Sci. Technol. A 17 (1999) 2826-2829.