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Free-Carrier Scattering in Transparent Conducting ZnO Films: Grain Boundary Effect and Scattering in the Grain Bulk

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Abstract – Basic electronic properties relevant to the free-carrier mobility μ_e were studied in polycrystalline highly transparent conducting Gallium-doped Zinc Oxide (GZO) films with different thicknesses ranging from 30nm to 350nm, prepared by ion-plating deposition with DC-arc discharge. Comparison of Hall mobility μ_H and optical mobility μ_o given by optical characterization (high-frequency transport) provides information about the role of grain boundaries in modifying μ_e. For GZO with thicknesses of less than a critical thickness 100nm, a dominating limiting factor on μ_e is grain boundaries that present a significant obstacle to carrier electrons as they across from one grain to another.

Transparent conductive ZnO films recently have been promoted as alternatives of conventional indium tin oxides (ITO) or tin oxides (SnO_2) with advantages of low total cost including materials cost and process cost, highly visible transparency and non-toxicity. Very recently, we reported that feasibility study of Ga-doped ZnO (GZO) common electrodes has been conducted through the fabrication of 3-inch TFT-LCD panels [1]. The panel showed the stable performance equal to that equipped with ITO-based electrodes. To improve the properties of GZO films, it is important to put the topic on a solid scientific basis by obtaining detailed information about the electronic properties of the films.

Basic electronic properties relevant to the free-carrier mobility μ_e were studied in polycrystalline GZO films with different thicknesses ranging from 30nm (resistivity: 3.5×10^{-4}ohm cm) to 350nm (resistivity: 1.8×10^{-4}ohm cm) on alkali-free glass substrates prepared by ion-plating deposition with DC-arc discharge. We have demonstrated that the electrical properties strongly depend on film thickness [2,3] and grain size increases ranging from 20nm to 40nm with increasing film thicknesses (Figs 1 and 2) on the basis of analysis of data obtained by in-plane XRD measurement. In this study, we have studied the limiting factor on μ_e of GZO films in light of the contribution to carrier scattering of both intra-grains and grain boundaries in the GZO films. Hall mobility, μ_H, was determined by Hall effect measurement system using the Van der Pauw method and the optical mobility, μ_{opt}, was calculated based on collision frequency (relaxation time) measurement using rotating compensator ellipsometer and effective mass values.

In GZO films with a thickness of less than ~100nm, μ_{opt} is larger than μ_H at any given thickness and they increased with film thickness. In the films, the limiting factor on μ_e appears to depend on both the quality of the GZO film within the grains themselves and grain boundary scattering. The grain boundary scattering significantly impacted μ_e and its contribution to the resistivity is more than 30%. With further increasing thickness, whereas μ_{opt} changes little (30-32 cm^2/Vs), μ_H gradually were improved, and approached μ_{opt}. This indicates that grain boundaries do not present a significant obstacle to carrier electrons as they across from one grain to another.

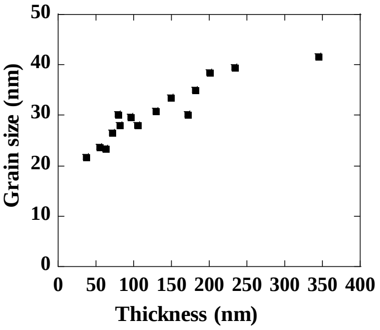

Figure 1: Grain size of GZO films deposited at 200°C as a function of film thickness.

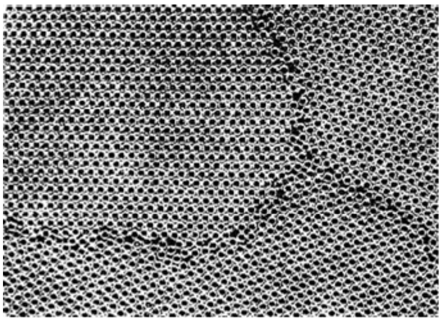

Figure 2: High resolution plan-view TEM image (Hitach H9000UHR) of GZO films deposited at 200°C. The film thickness is 200nm.

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