Surface modification of 10-nm thick ZnO films as interface layers to tailor the properties of Al-doped ZnO films and control of surface and interface roughness to achieve high carrier transport ultra-thin W-doped In_2O_3 films

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1. Introduction

We have investigated factors limiting carrier transport of highly transparent conductive oxide (TCO) films such as ZnO- and In_2O_3-based films with thicknesses (t) ranging from 5 nm to 2 μm. To achieve high Hall mobility (μ_H) TCO films deposited on amorphous glass substrates, we have developed different types of nanoscale technology. In this talk, we elucidate the effect of the two types of technologies on μ_H of TCO films deposited on the substrates.[1,2]

2. 10-nm-thick critical layer

The rf-magnetron-sputtered Al-doped ZnO (rf-MS-AZO) polycrystalline films have a texture with a well-defined (0001) orientation, whereas polycrystalline AZO films deposited by dc-MS (dc-MS-AZO) have a texture with a mixed orientation of the (0001) plane with other planes, as shown on the bottom right in Fig. 1, resulting in reduced μ_H due to a high contribution of grain boundary scattering to carrier transport.

The analysis of the data obtained by atomic force microscopy (AFM:Park Systems NX10) measurements shows distinct differences in the surface roughness and structure between rf- and dc-MS-AZO films having t of more than 20 nm. We, thereby, develop a multistep deposition of dc-MS-AZO/10-nm-thick rf-MS-AZO/substrates [1]. Figure 1 shows cross-sectional schematic diagrams, AFM images and out-of-plane wide-range reciprocal space maps (RSMs) of the samples (RIGAKU, SmartLab), where R_a and R_q are average roughness and mean-square roughness, respectively. From Fig. 1, we concluded that the use of the 10-nm-thick critical layer produces improved surface roughness thick AZO films that have a texture with a well-defined (0001) orientation.

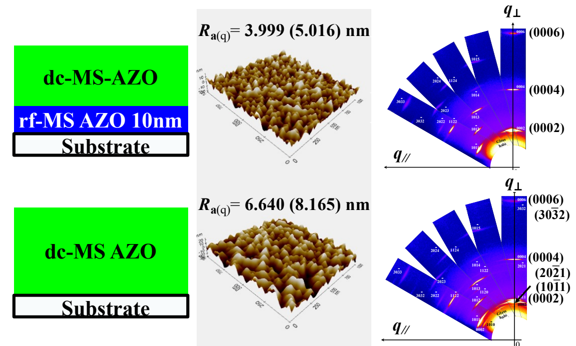

Fig. 1 cross-sectional schematic diagrams of samples, AFM images and out-of-plane wide-ranged reciprocal space maps of AZO films.

The results of Hall effect measurement at room temperature yield that the presence of the critical layers enhances the carrier concentration (n_e) by 6.76 % as well as μ_H by 15 % compared with AZO films deposited on critical-layer-free glass substrates. This results in a decrease in electrical resistivity (ρ), that is inversely proportional to the products of n_e and μ_H, by 18.3 % (ρ =2.32×10^{-4} Ωcm). Analysis of the experimental data clearly reveals that the increase of μ_H is due to the fact that the GB scattering mechanism contributes very little to the carrier transport.

3. Specular or diffuse scattering

We achieve 5-nm-thick conductive polycrystalline W-doped In_2O_3 (p-IWO) films showing μ_H of 57.7 $cm^2/(Vs)$ with solid-phase crystallization of amorphous IWO (a-IWO) films deposited on glass substrates (Coring EAGLE XG). We used reactive plasma deposition with dc arc discharge (RPD: Sumitomo Heavy Industries, Ltd.). The a-IWO films were deposited on the substrates without intentionally heating of them.