Effects of Postannealing on the Structural and Electrical Properties of W-Doped In_2O_3 Conductive Films Deposited on Glass Substrates

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We have reported the thicknesses (*t*)-dependent electrical properties of polycrystalline indium-oxide (In_2O_3)-based thin films deposited on alkali-free glass. The polycrystalline films were obtaied with solid-phase crystallization (SPC) of amorphous films in our previous works[1,2]. The analysis of the data determined by Hall effect measurements reveals a classical size effect: the electrical resistivity is governed by the ratio of t/λ: λ denotes the mean free path of carrier electrons. In this work, to clarify the effects of the postannealing on the properties of ultra-thin W-doped In_2O_3 (IWO) films with *t* of less than 10 nm, we elucidate the relationship between structural and electrical properties, carrier concentration (n_e) and Hall mobility (μ_H).

Experiment: IWO (WO_3: W content of 1 wt. % (=0.6 at.%)) films with *t* ranging from 5 to 50 nm deposited on alkali-free glass substrates (Corning EAGLE XG) by reactive plasma deposition with dc-arc discharge (RPD). The growth was carried out without intentionally heating of the substrates. The postannealing process was performed at 200°C for 30 min in air. The electrical properties were determined by Hall effect measurements (Nanometrics HL5500PC). The structural properties were determined from the data obtained by XRD measurements (Rigaku SmartLab): The characteristics of the microstructures of films before and after the postannaling were analyzed on the profiles determined by out-of-, grazing incident out-of- and in-plane X-ray diffraction (XRD) measurements.

Results and discussion: The analysis of the XRD measurement results revealed that as-deposited IWO films with *t* of 20, 30, and 50 nm were polycrystalline with weakly (111) orientation. In such films, we find that the difference in n_e among the samples with different *t* was small: n_e varies within from 1.5× to 1.8×10^{20} cm^{-3}, as regardless of the postannealing. Concerning μ_H except for 50-nm-thick IWO films, we find the dependence of μ_H on *t* and the postannealing that is similar to those of n_e descried above.

On the other hand, as-deposited IWO films with *t* of 5, 7, and 10 nm were amorphous phase. For the above ultra-thin films, we found *t*-dependent effects of the postannealing on the microstructure. From Fig. 1, where in-plane (an incident angle, ω=0.2 degree) XRD patterns are shown, at *t* of 7 and 10 nm, we find SPC: the postannealing caused a change from amorphous to polycrystalline IWO films. For 5-nm-thick amorphous IWO films, the XRD profiles yielded no solid-phase crystallization after the postannnealing. In the case of IWO films with *t* of less than 10 nm, we confirmed the effects of the postannealing on the electrical properties as follows. n_e showed a decrease from 1.6× to 0.5×10^{20} cm^{-3} for 5- and 7-nm-thick IWO films; n_e dratiscally decreased from 2.1× to 0.8×10^{20} cm^{-3} for 10-nm-thick IWO films. The decrease of n_e would possibly be due to postannealing conditions in air unlike under vacuum conditions[2]. We tentativlely conclude that the cause was the formation of an *n*-type killer, i.e., the annihilation of oxygen vacancies as a donor defect. The postannealing process produces 7- and 10-nm-thick IWO films that showed high μ_H of 53 and 58 cm^2/Vs, respectively. In such polycrystalline films, taking into the account of the XRD profiles described above, ionized impurity scattering mechanim would be a dominant factor that determines μ_H. For 5-nm-thick IWO films, however, surface and interface scattering mechanism may largely contribute to carrier transport, resulting in reduced μ_H of 43 cm^2/Vs.

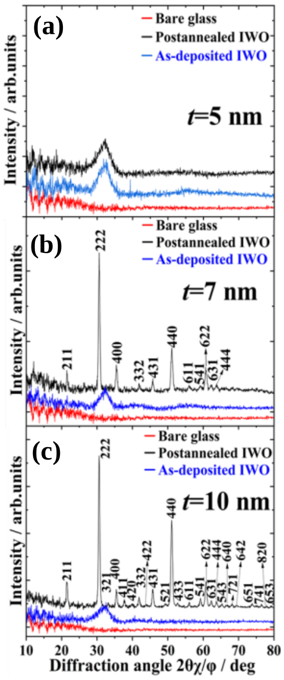

Fig.1 In-plane XRD patterns of bare-glass substrates, as-deposited and postannealed IWO films with thicknesses of (a)5, (b)7, and (c)10 nm.

References:

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