Factors limiting growth rates and determining structure and electrical properties of Ga-doped ZnO films deposited by reactive plasma deposition with direct-current arc plasma

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We have fabricated and provided reactive plasma deposition (RPD) which is an ion plating with low-pressure-direct-current arc discharge. The RPD enables us to achieve highly transparent conductive oxide (TCO) films deposited on amorphous substrates at low temperature; TCO films are based on Sn-[1)], Ce-, or W-doped indium tin oxide and Ga-doped zinc oxide (GZO) films[2)].

We have investigated the influences of incident-particle fluxes during film growth on the growth and properties of Ga-doped zinc oxide (GZO) films on glass substrates at temperature of 200 °C deposited by RPD. The Ga_2O_3 contents in the pellets was 4.0 wt.%. Deposition conditions were as follows: the oxygen (O_2)-gas flow rates (OFRs) and discharge current (I_D) were varied from 0 to 20 sccm and from 100 to 140 A, respectively. We measured the incident-particle flux of the neutral atoms and their ions for each species quantitatively at the substrate level using a mass-energy analyzer (Hiden, EQP300), a Langumuir probe and a diaphragm gauge during the deposition.[3)] We elucidated a relationship between the growth rates, the electrical properties, the alignment between columnar grains and incident flux (IF) properties of Zn species such as neutral Zn atoms and Zn^+ ions and O species such as neutral O atoms, O^+ and O_2^+ ions. Note that the IF of the Zn species depend little on OFR and I_D. IF control of the O species is essential discussed below.

Fig. 1 shows the growth rates as functions of the sum of IFs of those O species of GZO films with various OFRs and I_D. This clearly shows that an increase in the sum of IFs of neutral O atoms, O^+ and O_2^+ ions during the film growth increased the growth rates of GZO films. Fig. 2 shows the optical mobility (μ_{opt}), intrinsic or in-grain carrier mobility, as functions of the IF ratios of neutral O atoms to the sum of O species of GZO films with various OFRs and I_D. This clearly shows that μ_{opt} increased linearly with the IF ratio, suggesting that μ_{opt} would be determined by O-related defects, regardless of OFRs and I_D. Fig. 3 shows the contribution of grain boundary (GB) scattering to carrier transport defined by μ_{opt}/μ_{GB}, where μ_{GB} denotes carrier mobility at GBs[2)], as functions of the IF ratio described above of GZO films with various OFRs and I_D. With an increase in the IF ratio, the μ_{opt}/μ_{GB} values remained almost constant for lower OFRs ranging from 0 to 10 sccm, while the μ_{opt}/μ_{GB} values tend to increase rapidly for higher OFRs of more than 15 sccm. Considering IF-dependent behavior of μ_{opt} as shown in Fig. 2, Fig. 3 clearly yielded that the further increase in OFRs above 15 sccm drastically reduced μ_{GB}: This may be due to the promoted O-atom trapped at GBs. We also present the effects of O-ion species on the microstructures of GZO films.

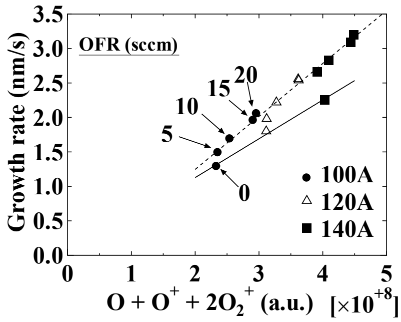

Fig. 1. Growth rates as functions of O-related species fluxes of GZO films.

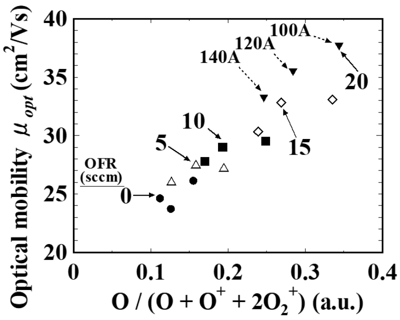

Fig. 2. Optical mobility as functions of O-related species fluxes of GZO films.

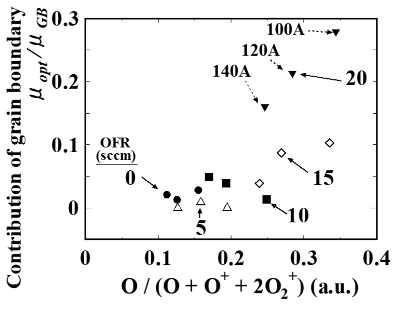

Fig. 3. Contribution of grain boundary scattering as functions of O-related species fluxes of GZO films.

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