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Dependence of Electron Mobility of ITO Films on Energy of Depositing Particles in Reactive Plasma Deposition

反応性プラズマ蒸着における
蒸着粒子のエネルギーとITO膜の移動度について

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To elucidate the threshold energy of depositing particles required to form the high-quality indium tin oxide (ITO) films, a correlation between the energy of depositing particles and the mobility of ITO films has been investigated. ITO films were deposited with controlling the energy of depositing particles under the condition that the carrier density of deposited ITO films was constant. The mobility of the ITO films deposited at the substrate temperature of 200°C was dependent on the energy of depositing particles, so that the threshold energy was around 12 eV.

1. Introduction

Reactive plasma deposition (RPD) is a commerically available ion plating system for thin film deposition that uses a pressure gradient type plasma gun.[1,2] The major application areas are flat-panel displays and photovoltaic cells. One of the advantages of the RPD method is the formation of high-quality transparent conductive oxide films, such as indium tin oxide (ITO) and zinc oxide (ZnO), on low temperature substrates, which have lower resistivity and higher transmittance than those formed by sputtering methods.[2,3] For instance, ITO films with resistivity less than 1.2×10^{-4} Ωcm can be formed by RPD at substrate temperatures of 200°C or less.[2] It has been suggested that the higher quality of ITO films formed by RPD is due to the higher ionization rates (indium ionized at a rate of 74 % or more) and the lower energy (<40 eV) of depositing particles compared to those in sputtering method.[4] However, a threshold energy of depositing particles required to form the high-quality ITO films is not well understood.

To elucidate the threshold energy of depositing particles in this study, we have investigated a correlation between the energy of depositing particles onto the substrate and the mobility of ITO films.

2. Experimental Methods

Figure 1 shows a schematic diagram of the RPD equipment and the measurement equipment used in this study. The evaporation material was ITO (SnO_2: 5 wt.%). The substrates were non-alkali glass. The substrate temperature was kept at 200°C during ITO deposition. The argon gas flow rate through the plasma gun is 40 sccm. The pressure in the deposition chamber was controlled by the inflows of diluent argon gas and reactive oxygen gas in order to control the energy of depositing particles. The pressure in the deposition chamber was 0.18–0.71 Pa, measured by a ceramic capacitance manometer diaphragm gauge. The oxygen concentration of the total pressure in the deposition chamber was controlled by the inflows of diluent argon gas and reactive oxygen gas in such way that the carrier density of ITO films was ~1.0×10^{21} cm^{-3}. The Hiden Analytical EQP300 was used as a mass-energy analyzer for measuring the energy of depositing particles. The Ecopia HMS-3000 was used for measuring the carrier density and the mobility of ITO films.

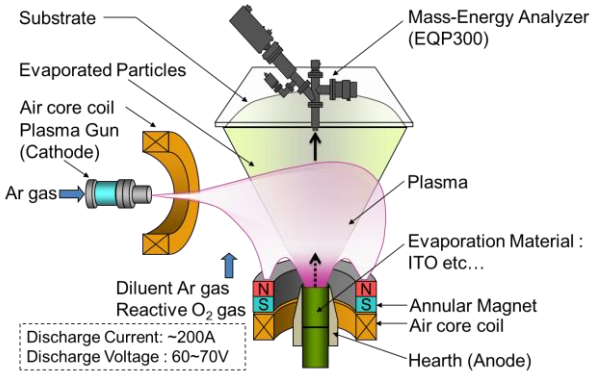

Fig.1. Schematic diagram of reactive plasma deposition equipment and measurement equipment

3. Results and Discussion

Figure 2 shows the energy distributions of In ion measured in the SIMS mode of the EQP300. The energy distributions are commonly composed of two regions. The one peak around 7.5 eV is ascribed to the ions accelerated by the plasma sheath potential. The other peak is ascribed to the ions accelerated by the potential difference between the anode and substrate. As the pressure increases in the chamber, the second peak shifts to a lower energy and decreases in intensity, while the first peak increases in intensity. These shows the amount of high-energy ions decreases due to the increased number of collisions between the ions and background neutrals or ions. To clarify the second peaks, each energy difference based on of the high-pressure was calculated. Fig. 3 shows the energy difference distributions of In ion. These peaks correspond to those peaks shown in Fig. 2. The positive values indicate the energy that exits in large numbers compared to the high-pressure. The negative values indicate that the first peak increases as the pressure increases, i.e., the first peak energy is commonly present in the each condition. Thus, this result suggests that the second peak energy is contributed to the mobility of ITO films.

Figure 4 shows the correlation between the energy of In ion and the mobility of the ITO films deposited at the substrate temperature of 200°C. The energy represents is the In energy at the maximum value of the second peak in the distribution shown in Fig. 3. It is shown that the mobility of ITO film increases with the energy until around 12 eV, then becomes nearly constant. The difference in energy is thought to be the cause of this difference in the mobility of ITO films because the carrier density of ITO films was fixed to ~1.0×10^{21} cm^{-3} in order to equalize the effect of the ionized impurity scattering due to oxygen vacancies. [5,6]

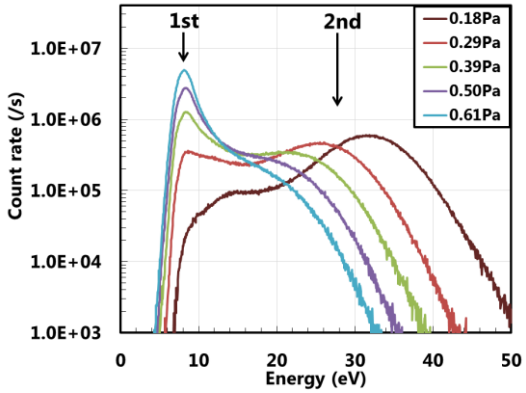

Fig.2. Pressure dependence of the energy distributions of In ion measured in the SIMS mode of the EQP300

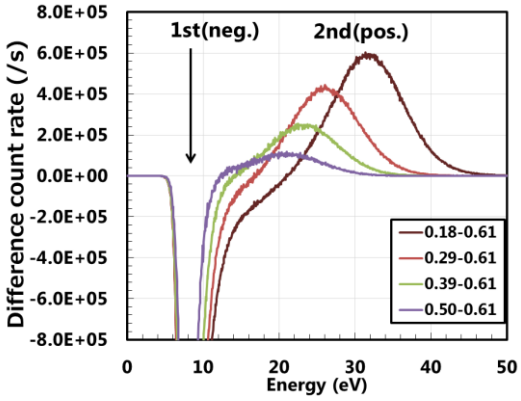

Fig.3. Pressure dependence of the energy difference distributions of In ion based on the energy at high-pressure

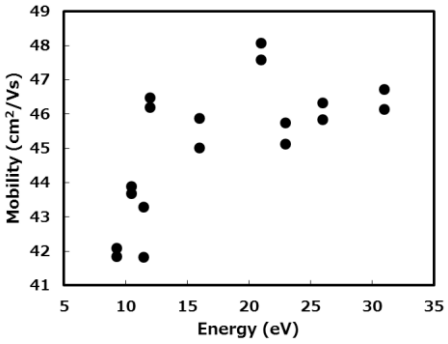

Fig.4. Correlation between the energy of In ion onto substrate and the electron mobility of the ITO films

4. Conclusions

A correlation between the energy of depositing particles and the electron mobility of ITO films has been investigated. ITO films were deposited with controlling the energy of depositing particles under the condition that the carrier density of deposited ITO films was ~1.0×10^{21} cm^{-3}. The electron mobility of the ITO films deposited at the substrate temperature of 200°C was dependent on the energy of depositing particles, so that the threshold energy was around 12 eV.

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