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ITO films prepared on c-axis oriented AlN films by facing target sputtering system

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ITO films were prepared on AlN-coated glass by planar magnetron sputtering system with facing targets of In_2O_3 doped of 10 wt% SnO_2, and electrical, optical and structural properties were examined. Results indicate that preferentially (222) oriented ITO films were prepared on (00·1) AlN films in Ar gas. A slight mixture of oxygen gas in Ar gas improved slightly film resistivity and crystallinity, but transmittance near 400 nm decreased. This is supposed to be due to a mixture of (400) oriented grain in preferentially (222) oriented polycrystalline film. Film crystallinity was increased with increasing substrate temperature until 300 °C, but slightly degraded at 350 °C according to the data of cathodoluminescence spectra. This suggests the film degradation at above 300 °C. The data of ITO films prepared on Corning 7059 glass substrates are also indicated.

1. INTRODUCTION

Indium tin oxide films (ITO) have been intensively investigated for their applications to transparent electrodes, and many researchers are expending their efforts to decrease film resistivity. To attain this requirement without degrading optical properties in visible region, some techniques of reducing discharge voltage, adding water molecules and oxygen gas in Ar gas etc. were proposed. [1,2]

In ITO films deposited on glass substrate, growth direction of grain crystal is not definite when the sputtering conditions were changed. To obtain definete a growth direction, epitaxitial film may be appropriate. Shigesato et al. prepared ITO film on (100) yttria-stabilized zirconia single crystal and c-axis oriented ZnO polycrystalline substrate. [3,4] In this paper we also prepared ITO film on AlN film, since the AlN film is good in transparency and stable in etching.

2. EXPERIMENTAL RESULTS

2.1 Sputtering apparatus

Figure 1 illustrates a facing target sputtering system.[5] Two targets for planar magnetron sputtering are faced each other. In_2O_3 ceramic targets of 10 cm diameter containing 10 wt % SnO_2 were used. These targets were prepared by Mitsui Metal Co. A distance between the targets was 12 cm. In this sputtering, film bombardment by energetic oxygen can be avoided, since substrate is placed beside the targets as shown in the figure.

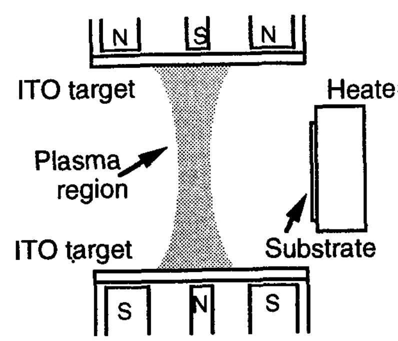

Fig.1. Schematic diagram of facing target sputtering system.

2.2 Gas pressure dependence of film properties of ITO prepared on AlN-coated glass in Ar gas

ITO films were prepared in Ar gas on Corning 7059 glass coated with (00·2) oriented AlN film. X-ray diffraction patterns showed that ITO films at 1 mTorr was singly (222) oriented, but a small (400) signal was observed for the films prepared at the other gas pressures.

Figure 2 shows electrical properties for the ITO films prepared at a temperature of 350 °C. At a pressure of 0.7 or 1 mTorr, resistivity has a minimum and increases with increasing gas pressure. This is due to an decrease of carrier concentration. For comparison, data of films on Corning 7059 glass are indicated by dashed curves. Carrier concentration on AlN film is higher than that on glass, whereas Hall mobility has an inverse trend. Totally film resistivity on AlN films is slightly smaller than that on glass substrate.

Optical transmittance data are shown in Fig.3 for several Ar gas pressures. Only transmittance near absorption edge changed. The transmittance at 350 nm, e.g., increased for the film prepared at 2 mTorr. This will be explained by Burstein-Moss shift effect, because carrier concentration has a maximum at this gas pressure.

2.3 Oxygen partial pressure dependence of ITO films

Electrical properties for the films prepared in Ar and O_2 mixed gas and at a substrate temperature of 350 °C were examined. Results are indicated in Fig.4. Total pressure was maintained at 1 mTorr and ratio of oxygen pressure to total pressure, $f_O=P_{O2}/(P_{O2}+P_{Ar})$, was changed. Resistivity increase at larger f_O in Fig.4 is mainly due to a decrease of carrier concentration. This will be explained by the decrease of oxygen vacancy or Sn donor. In Fig.4, the data of ITO films on glass substrates are also indicated by dashed curves. The resistivity becomes low at f_O=1-2 %.

X-ray diffraction patterns of ITO films prepared in Ar and O_2 mixed gas are shown in Fig.5 for several values of f_O. A ratio of (400) signal intensity to (222) signal became large with adding oxygen gas, which are shown in Fig.5. This indicates that the presence of oxygen gas prevents preferential growth of (222) plane on the AlN-coated glass substrate.

Optical transmittance are shown in Fig.6 as a parameter of mixed oxygen gas. For small mixing of oxygen gas in Ar gas during the

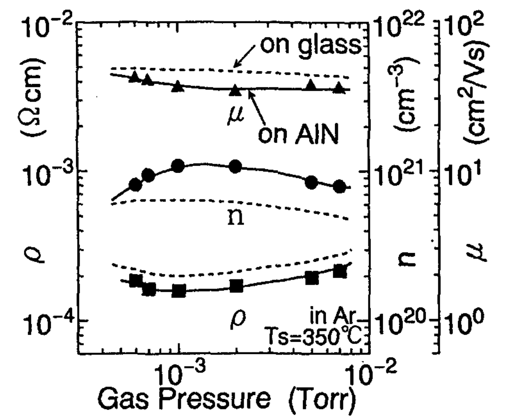

Fig.2. Electrical properties of ITO films prepared on AlN in Ar gas. Dashed curves are for ITO films on glass substrate.

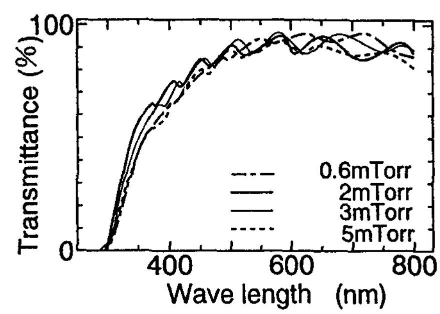

Fig.3. Optical transmittance as a parameter of Ar gas pressure.

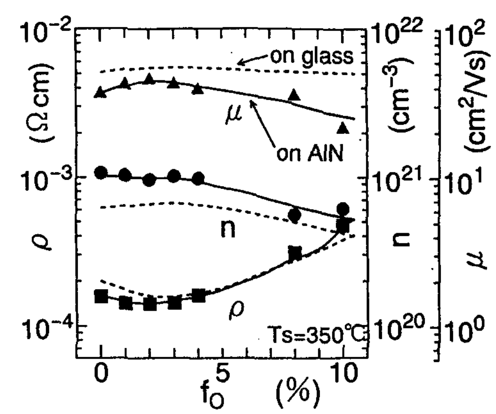

Fig.4. O_2 partial pressure dependence of electrical properties of ITO films. Dashed curves are for on glass substrate.

deposition, the absorption edge wavelength did not shift largely, but fairly large adding of oxygen partial pressure of 8 % increased the edge wavelength. This is understood by the change of carrier concentration in Fig.4. However, optical transmittance near a wavelength of 400 nm decreased even a slight oxygen adding of 1 and 2 %. This may be related with grain growth of (400) with mixing oxygen in Ar gas.

In order to estimate the film crystallinity, cathodoluminescence spectra were observed. Figure 7 shows the data for the films of f_O between 0 and 6 %. All films have similar shape of spectra. a maximum point in the spectrum corresponds to 3.65 eV, which is thought to be an energy where the electron distribution has an maximum in conduction band. At f_O=1-2 % the spectrum intensity is strong, which indicates that the film crystallinity is improved by adding small oxygen gas during deposition. This corresponds to the increase of Hall mobility in Fig.4.

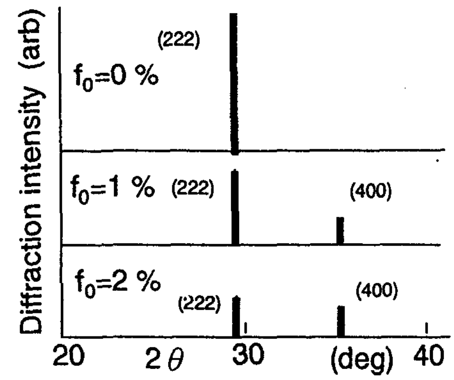

Fig.5. Diffraction patterns as a parameter of oxygen partial pressure.

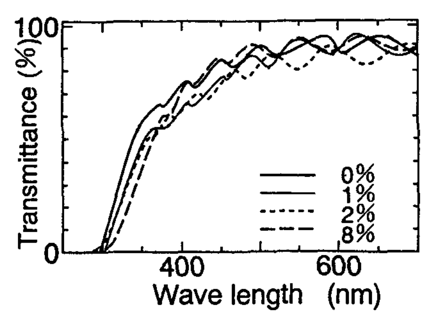

Fig.6. Optical transmittance as a parameter of O_2 partial pressure.

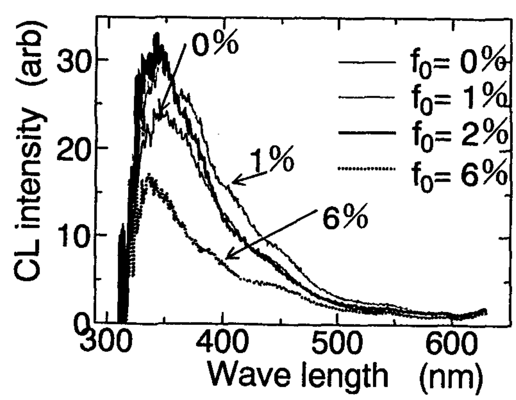

Fig.7. Cathodoluminescence spectra of ITO films on AlN -coated glass substrate.

2.4 Substrate temperature dependence of electrical properties

Figure 8 shows electrical properties as a function of substrate temperature. When substrate temperature was increased from 65°C, film resistivity decreases exponentially and becomes constant at 200 °C. This is due to the increase of both carrier concentration and Hall mobility. This trend was nearly the same as those of films on glass substrate.

Optical transmittance was also measured. The transmittance at 400 nm was not so sensitive to substrate temperature, which is different with the results in Fig.6 for oxygen mixture in Ar gas. Absorption edge shifted to higher energy side with increasing substrate temperature, and nearly constant above 200 °C. This is understood as Burstein-Moss shift, corresponding to the increase of carrier concentration in Fig. 8.

Figure 9 indicates cathodoluminescence for ITO films. Signal intensity is most strong for the film at 284 °C. Until 284 °C, luminescence intensity increases with increasing substrate temperature. This confirms that the film crystallinity is improved by a substrate temperature rise. However, the luminescence intensity of the film prepared at 350 °C decreases compared with that at 284 °C. This shows that the film prepared at 350 °C degrades in crystallinity. Some defects may be incorporated at higher substrate temperature.

3. Conclusion

ITO films prepared on AlN-coated glass substrate have a tendency to orient [222] direction. This is thought to be a result of epitaxial growth. Carrier concentration in ITO film on AlN coated glass is higher than that on glass substrate, but carrier mobility on AlN-coated glass is just smaller. With adding slightly oxygen gas in Ar gas, a slight decrease of film resistivity was observed, but the transparency was influenced near 400 nm. This is due to a mixture of (400) grains in (222) grains. Even at a substrate temperature of 200 °C low resistivity was attained without degrading opical transparency. This may be due to the weak plasma exposure of the substrate in facing target system. (222) preferential orientation is decreased with decreasing substrate temperature or mixing oxygen in Ar gas.

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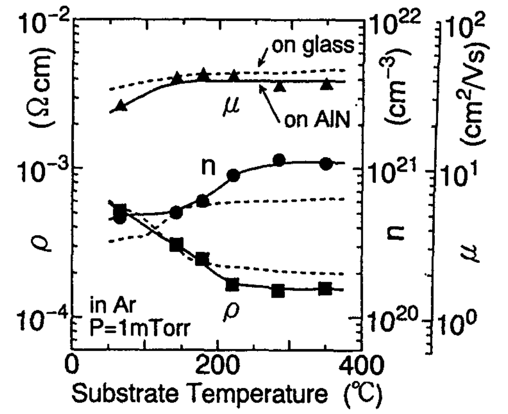

Fig. 8. Substrate temperature dependence of electrical properties of ITO films. Dashed curves are for on glass substrate.

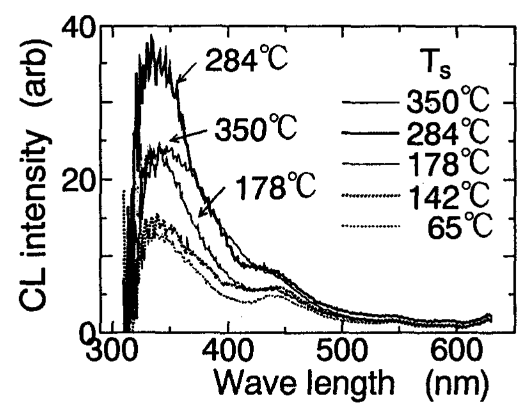

Fig.9. Substrate temperature dependence of cathodoluminescence spectra of ITO films deposited on AlN -coated glass substrate.