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Deposition of ITO thin films on acryl substrate

Yoichi Hoshi and Jyun-ichi Oka

Faculty of Engineering, Tokyo Institute of Polytechnics, 1583 Iiyama, Atsugi,
Kanagawa 243-02 Japan

Deposition of indium tin oxide (ITO) thin films on an acryl substrate was attempted by using dc planar magnetron sputtering. In order to suppress arc discharge, 10 kHz pulse voltage was added to dc voltage during sputtering. The acryl substrate had very poor heat resistance so that sputtering had to be performed at a very low input power (discharge current = 100 mA), where the substrate had to be maintained at a temperature below 50 ℃. Insertion of a shield plate at a position between the target and substrate was effective in suppressing the increase in substrate temperature during sputtering.

Films deposited with a shield plate had an amorphous crystal structure. On the other hand, films deposited without a shield plate were composed of small crystallites. The resistivity of the film depended on partial oxygen gas pressure during sputtering. By controlling the partial oxygen gas pressure, we obtained a film with a resistivity below 1×10^{-3} Ω cm and optical transmission above 85%, even though the film had an amorphous crystal structure.

1. INTRODUCTION

ITO thin films with excellent conductivity and transparency can be obtained on a glass slide substrate at a temperature above 200 ℃[1-3]. However, it is difficult to obtain good quality film at low temperatures, especially below 80 ℃, although many researchers have tried to obtain ITO thin films at low temperatures [4-7].

Acryl is a well known inexpensive plastic material with good transparency in visible light, although it has poor heat resistance along with poor thermal conductivity. In this study, we tried to deposit ITO thin films on an acryl substrate by using a dc planar magnetron sputtering system.

2. EXPERIMENTAL

A dc planar magnetron sputtering system with an ITO target (In_2O_3-5wt%SnO_2) 10 cm in diameter as shown in Fig.1 was used for film preparation. Typical film preparation conditions are listed in Table 1.

Table 1. Typical film deposition conditions.

Target voltage	345 - 350	V
Discharge current	100 - 300	mA
Sputtering gas pressure	5, 8	mTorr
Partial oxygen gas pressure	0.1 - 4 ($\times10^{-5}$)	Torr
Film thickness	~100	nm
Deposition time	10~14	min
Back ground pressure	$<1\times10^{-6}$	Torr

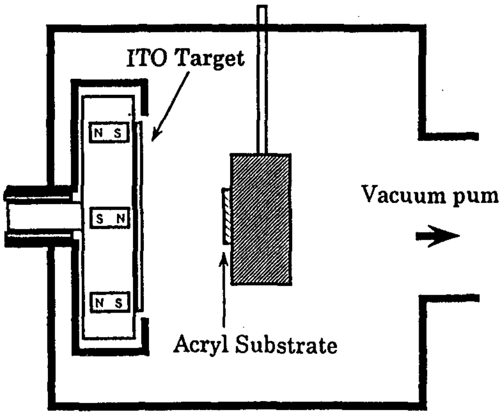


Fig. 1 Planar magnetron sputtering system used for film preparation.

Sputter cleaning of the substrate surface was performed by applying 13.56 MHz rf voltage to the substrate holder for 15 min before film deposition. Films with thicknesses of about 100 nm were deposited on an acryl substrate.

Electrical properties of the film were determined using the four point probe method and Hall effect measurements. The optical transmittance of the film was measured at a wavelength of 600 nm. Film structure was investigated by X-ray diffraction analysis.

3. RESULTS AND DISCUSSIONS

When sputtering was performed by applying a constant dc voltage, stable discharge could not be produced because of an outbreak of arc discharge. In order to suppress the arc discharge, constant dc voltage and 10 kHz pulse voltage were simultaneously applied to the target electrode. In this way, stable sputtering could be performed at a discharge current up to 1 A. Figure 2 shows the changes in plasma potential Vp, plasma density Ne and electron temperature Te with discharge current Id. These plasma characteristics during sputtering were determined by the single probe and double probe methods. It should be noted that the 10 kHz pulse voltage barely changed plasma characteristics from those using conventional dc grow discharge and both plasma potential and electron temperature had much smaller values than during rf sputtering (Vp: 50~20 V, Te>5 × 10^4 deg). This suggests that ion bombardment on the film surface during sputtering was less significant during this sputtering than during rf sputtering.

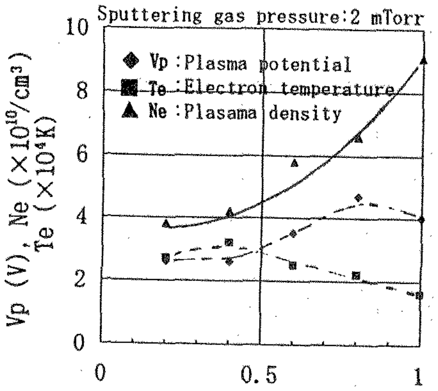
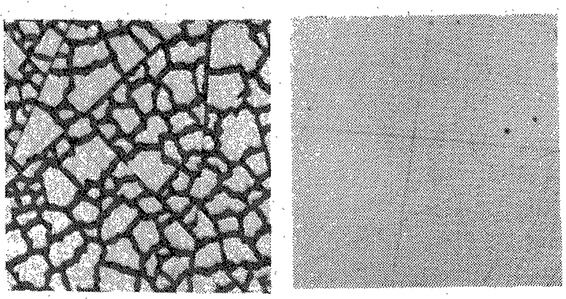


Fig. 2 Changes in plasma potential Vp, plasma density Ne and electron temperature Te with discharge current Id.

All of the films deposited at a discharge current above 200 mA peeled off the substrate as shown in Fig.3 (a). This poor adhesion of the film seemed to be due to the poor heat resistance of the acryl substrate. The acryl substrate was heated during film deposition and its temperature increased as shown in Fig.4. Deposition of film at a discharge current above 300 mA led to a deformation of the substrate. Only film deposited at a discharge



(a) ITO film with poor adhesion.

(b)ITO film deposited at 100 mA.

Fig. 3 Surface photographs of the film deposited on acryl substrate.

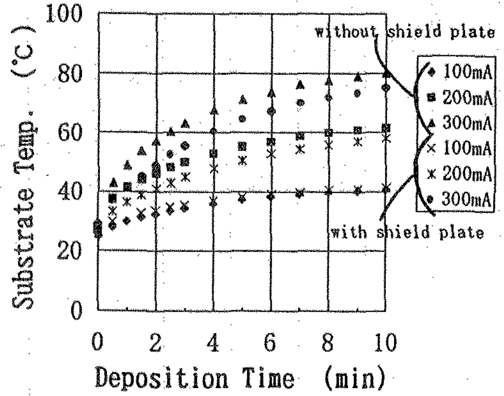


Fig. 4 Changes in substrate temperature with deposition time at various discharge currents.

current below 100 mA had excellent adhesion (shown in Fig.3 (b)), where the substrate was maintained at a temperature below 50 ℃. Insertion of a shield plate at a position between the target and substrate was also attempted as shown in Fig.5 to suppress heating of the substrate and bombardment of high energy oxygen atoms to the substrate. In Fig. 4, changes in substrate temperature due to the insertion of the shield plate are also shown. These results indicate that the insertion of the shield plate was effective in suppressing substrate heating during sputtering.

Sputter cleaning of the substrate surface before deposition was also effective in improving the adhesion of the film. Figure 6 shows the changes in film adhesion based on sputter cleaning conditions. Sputter cleaning when Ar gas pressure was 2 mTorr and self bias voltage was 170 V improved the adhesion of the film, although the reason is still unclear.

Figure 7 shows typical X-ray diffraction diagrams of film deposited with a shield plate and without a shield plate. The film deposited with a shield plate had no clear reflection peaks. On the other hand, the film deposited without a shield plate had a clear reflection peak. Since the difference in the substrate temperature during sputtering between deposition with a shield plate and without a shield plate was small as shown in Fig.4, this result indicates that control of high energy particle bombardment to the film surface by the insertion of a shield plate suppresses crystallization in the film.

Figure 8 shows the changes in electrical properties of the film with partial oxygen gas pressure. Partial oxygen gas pressure had to be adjusted to an adequate value to obtain a film with a resistivity below 1×10^{-3} Ω cm during sputtering. In this study, we could not obtain a film with a low resistivity below 1×10^{-3} Ω cm, since both carrier mobility and carrier density had a small value. It seemed that a strict control of the partial oxygen gas pressure to the order of 10^{-6} Torr was needed

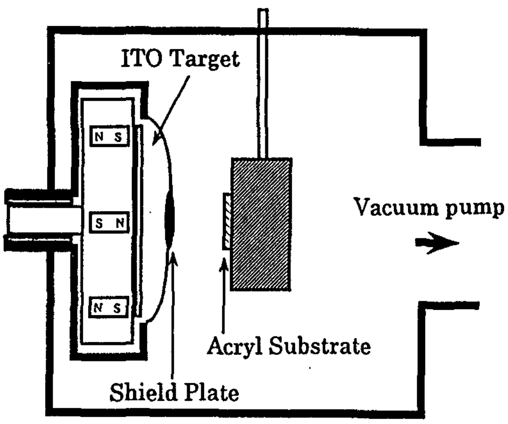


Fig. 5 Insertion of a shield plate in the sputtering system.

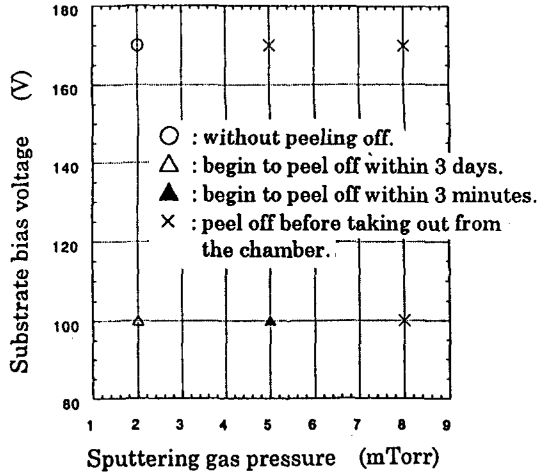


Fig. 6 Changes in adhesion of the film with sputter cleaning conditions.

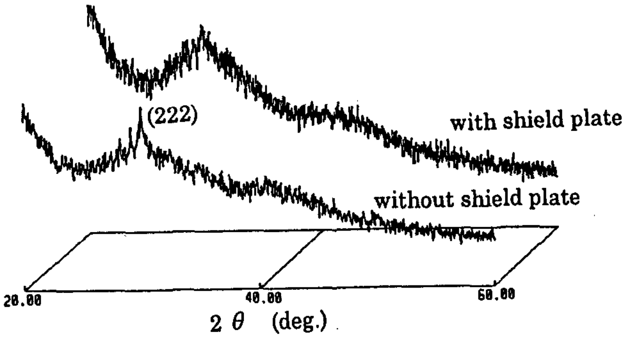


Fig. 7 Typical X-ray diffraction diagrams of film deposited with shield plate and without shield plate.

to obtain a film with low resistivity. Further investigation should be implemented to optimize the deposition conditions.

Figure 9 shows a change in transmittance of the film with partial oxygen gas pressure at a wave length of 600 nm. Film with optical transmission above 85% was obtained at a proper partial oxygen gas pressure.

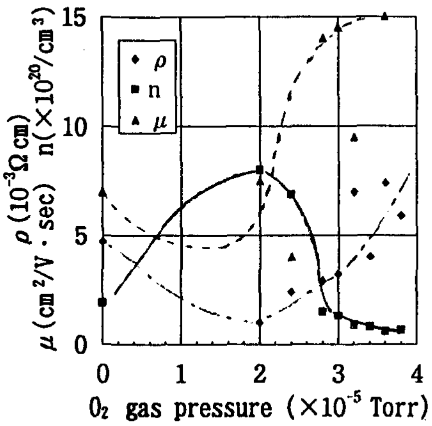


Fig. 8 Electrical properties of film with partial oxygen gas pressure.

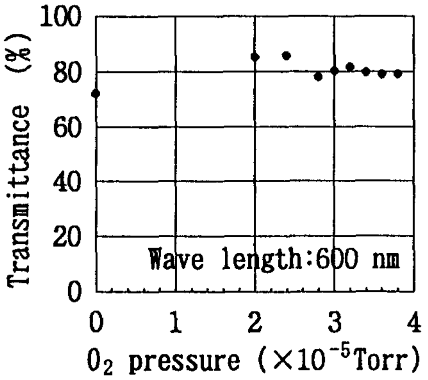


Fig. 9 Transmittance of the film at a wave length of 600 nm.

4. CONCLUSIONS

The deposition of ITO thin films on an acryl substrate was attempted using dc planar magnetron sputtering. 10 kHz pulse voltage and dc voltage were applied simultaneously during sputtering to suppress an outbreak of arc discharge. The acryl substrate had very poor heat resistance so that sputtering had to be performed at a very low input power (low discharge current = 100 mA), where the substrate had to be maintained at a temperature below 50 ℃. The Insertion of a shield plate at a position between the target and substrate was effective in suppressing the increase in substrate temperature during sputtering.

By controlling the partial oxygen gas pressure, resistivity below 1×10^{-3} Ω cm and optical transmission better than 85% were able to be obtained for these films, although the film had an amorphous crystal structure.

Further investigations should be made to obtain a film with lower resistivity on the acryl substrate at a higher deposition rate.

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