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High Rate Deposition of ITO Thin Films on Plastic Substrate by Sputtering

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Abstract In this study, high rate deposition of ITO thin films at a low substrate temperature was attempted by using a facing target sputtering (FTS) system. As a result, deposition rate as high as 120nm/min was easily realized on acryl substrate. This deposition rate is more than ten times higher than that we can obtain by using conventional magnetron sputtering system. This is mainly caused by the fact that bombardment by high energy electrons and oxygen atoms to substrate surface can be completely suppressed in the FTS. Resistivity of the film depended little on the deposition rate and the films with resistivity as low as 4.0×10^{-4} Ω cm were obtained, although surface smoothness of the film was degraded by the increase in the deposition rate.

Key words: ITO thin film, high rate deposition, plastic substrate, low temperature deposition

1. INTRODUCTION

Tin (Sn)-doped indium oxide (ITO) thin films are widely used in electronic devices, such as solar cells and liquid crystal displays (LCDs), because of their high transparency in the visible light region and their low resistivity. Deposition of transparent conductive thin films on plastic substrates has been in strong demand recently, especially for use with organic LEDs. Low temperature deposition is necessary because of the poor thermal stability of plastic substrates. From this point of view, bombardment of the substrate surface with high energy particles, such as secondary electrons and negative oxygen ions emitted from the target, should be suppressed during sputtering [1-4]. This suppression during film deposition is needed for ITO films to obtain low resistivity at low temperatures, such as below 100 ℃ [5,6]. Low voltage sputtering is one of the most useful deposition techniques for suppressing high energy particle bombardment and for getting film with low resisitivity [7,8]. The deposition rate, however, decreases sharply as the sputtering voltage decreases, as shown in Fig.1. In addition, no small number of secondary electrons bombard the substrate surface during magnetron sputtering, as shown in Fig.2 (a). This damages the plastic substrate and increases the temperature.

Hoshi et al. reported that an ITO film with resistivity below 5.0×10^{-4} Ωcm can be obtained at temperatures below 50℃ using facing target sputtering (FTS), where the bombardment of the film surface by high energy particles is completely suppressed [9], as shown in Fig.2 (b). This indicates that a high sputtering voltage above 500 V can be used for the sputter-deposition of ITO films in FTS. This is suitable for achieving high rate deposition.

In this study, high rate deposition of ITO thin films on acrylic substrate was attempted using an FTS system. It became clear that a deposition rate above 120 nm/min was easily achievable for deposition on an acryl substrate. High rate deposition of ITO thin films using FTS will be explained in detail and the structural and electro-optical properties of the films obtained by this method will be discussed.

2.EXPERIMENTAL

Figure 3 shows the FTS system used for the film preparation. A 10-cm-diameter 95 wt.% In_2O_3- 5 wt.% SnO_2

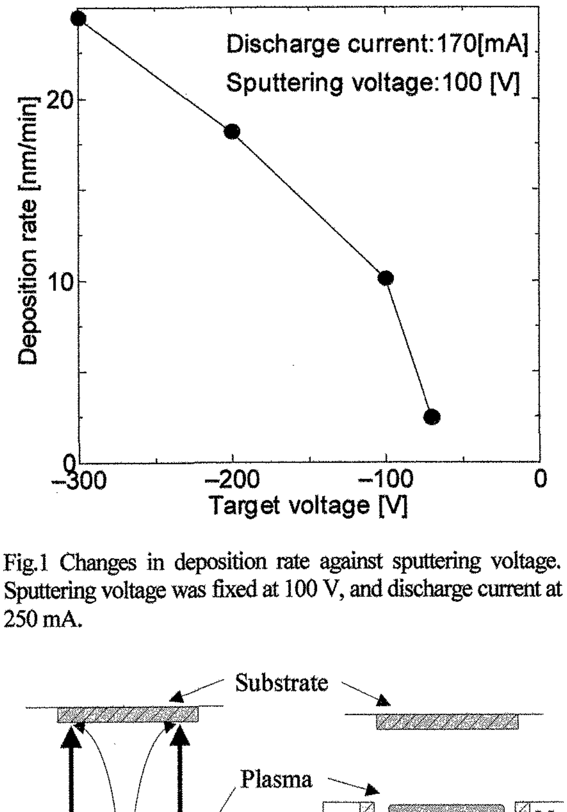


Fig.1 Changes in deposition rate against sputtering voltage. Sputtering voltage was fixed at 100 V, and discharge current at 250 mA.

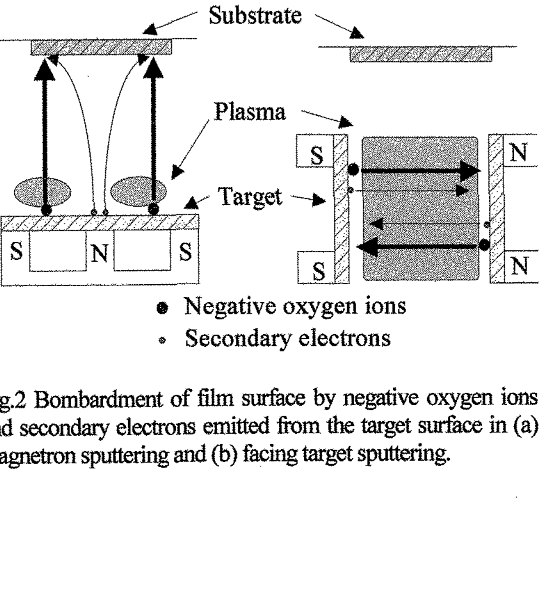


Fig.2 Bombardment of film surface by negative oxygen ions and secondary electrons emitted from the target surface in (a) magnetron sputtering and (b) facing target sputtering.

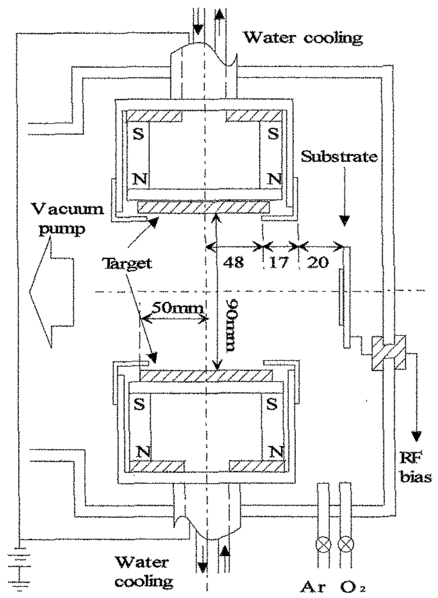


Fig.3 Schematic drawing of the facing target sputtering (FTS) system

Table I. Film preparation conditions.

Target	5wt%SnO_2-In_2O_3
Discharge current	400~1000[mA]
Sputtering voltage	≒500[V]
Ar gas pressure	2 × 10^{-4}[Torr]
Sputter gas pressure	2[mTorr]
Film thickness	≒150[nm]
Substrate	Glass
Substrate temperature	Room temperature

sintered ceramic disk target, made by Mitsui Metal Co., and the substrate were arranged as illustrated. ITO films with about 150 nm thickness were deposited on the glass slide and acryl substrate, whilst the deposition time was controlled. Typical film preparation conditions are listed in Table I. The substrate temperature increased during film deposition from room temperature to about 70℃. The film thickness was measured using a surface profiler (Decktak .3030). The structure of the films was investigated using X-ray diffractometry and high resolution transmission electron microscope (TEM). The film surface morphology was analyzed with an atomic force microscope (AFM). Electrical properties (resistivity, carrier concentration, Hall mobility) were evaluated from the measurements based on Van der Pauw's method and the hall effect, and optical transmittance was measured with an optical spectrophotometer.

3. RESULTS AND DISCUSSION

Figure 4 shows the typical changes in the deposition rate versus the sputtering current in the system used in the study. The deposition rate increases linearly with an increase in the sputtering current. A deposition rate above 100 nm/min was obtained at a sputtering current of more than 1 A. The deposition rate obtained with FTS is not as high as that using conventional magnetron sputtering. However, films could not deposit on acryl substrate using conventional magnetron

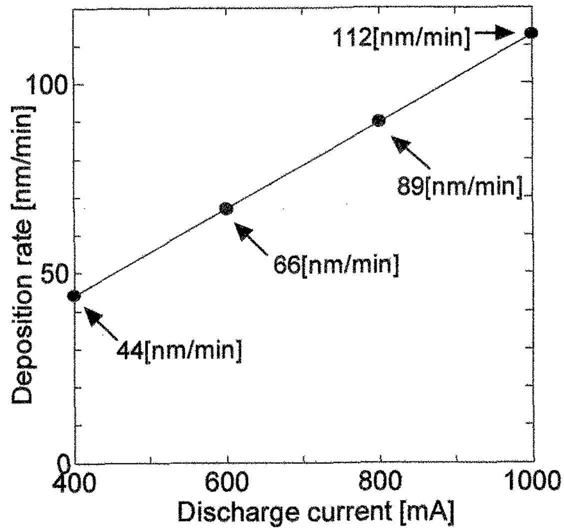
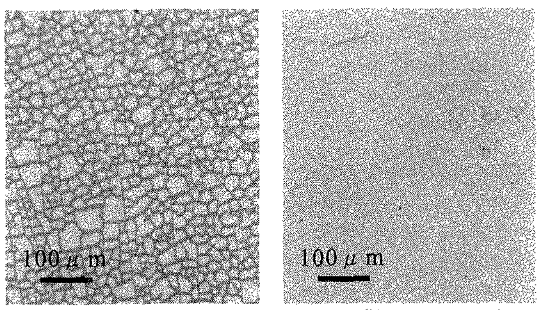


Fig.4 Changes in deposition rate against sputtering current.



(a)ITO film deposited at a deposition rate above 20nm/min by magnetron sputtering.

(b)ITO film deposited at a deposition rate above 110nm/min by FTS.

Fig.5 Surface photograph of films deposited on acryl substrate.

sputtering at a deposition rate above 20 nm/min as the films peel off from the substrate after a few days, as shown in Fig.5 (a). Such phenomena were not observed for a deposition rate above 110 nm/min using FTS, as shown in Fig.5(b). This is mainly attributable to the fact that the bombardment of substrate surface by high energy particles, such as secondary electrons and negative oxygen ions, is completely suppressed in FTS, as shown in Fig.2. In FTS, the input power for sputtering was limited by the target cooling system to a maximum of about 500 W. A much higher deposition rate is achievable if the cooling system can be improved. Clear differences in the film structure and electrical properties between the films deposited on glass slide substrate and acryl substrate were not observed in this study.

Control of the oxygen concentration in the sputtering gas is known to be very important for obtaining ITO film with low resistivity. Figure 6 shows the typical changes in the film resistivity against the oxygen gas concentration in the sputtering gas. The deposition rate was fixed at about 44 nm/min. Optimum oxygen gas concentration exists with film with the lowest resistivty. Films were deposited at these optimum conditions, although the optimum oxygen gas concentration does also depend on the sputtering conditions. Figure 7 show X ray diffraction diagrams and Fig. 8 shows

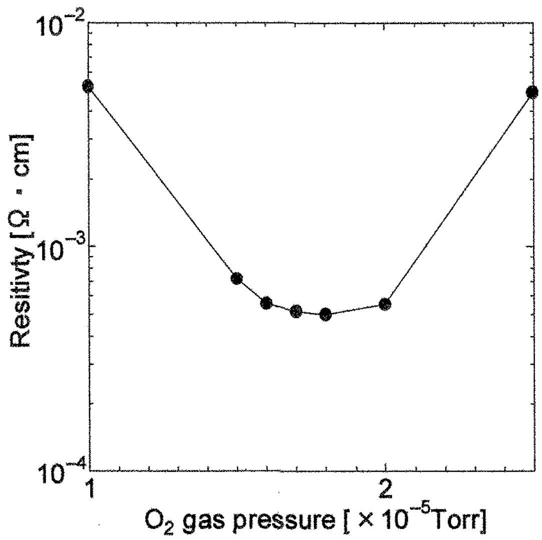


Fig.6 Changes in film resistivity against partial oxygen gas pressure. Deposition rate was fixed at 44 nm/min.

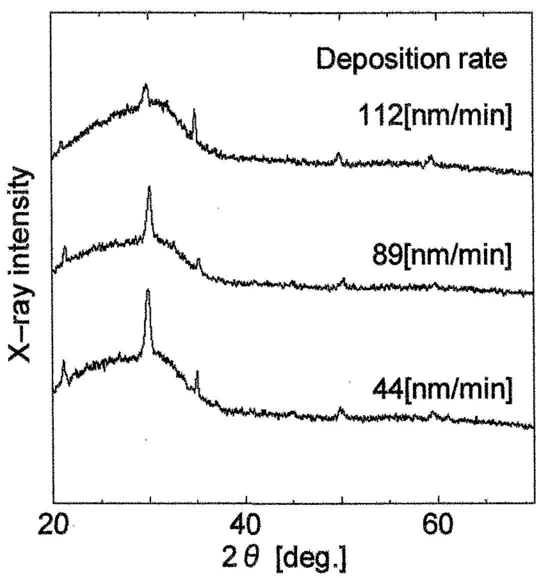
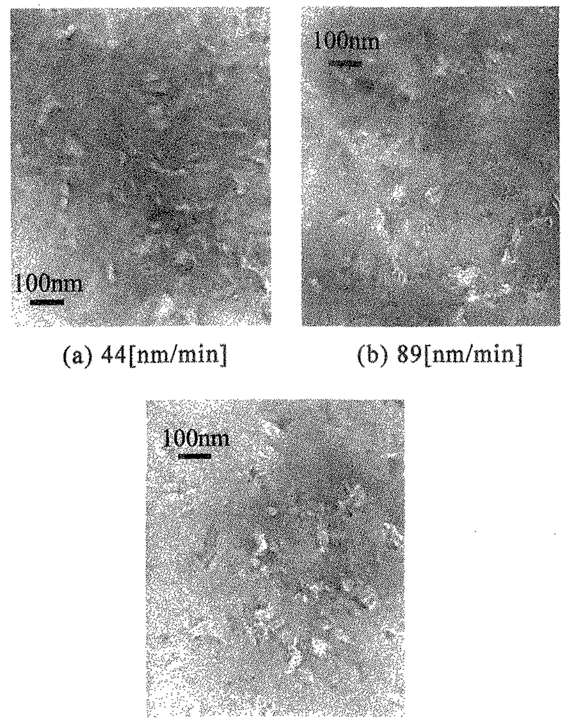


Fig.7 X-ray diffraction diagrams of the film deposited at various deposition rates.

TEM images of the films, deposited at various deposition rates. It is clear from these figures that all of the films have a mixed structure, composed of an amorphous phase and randomly oriented crystallites of about 50 nm in size. Clear differences were not observed in the structure of these films.

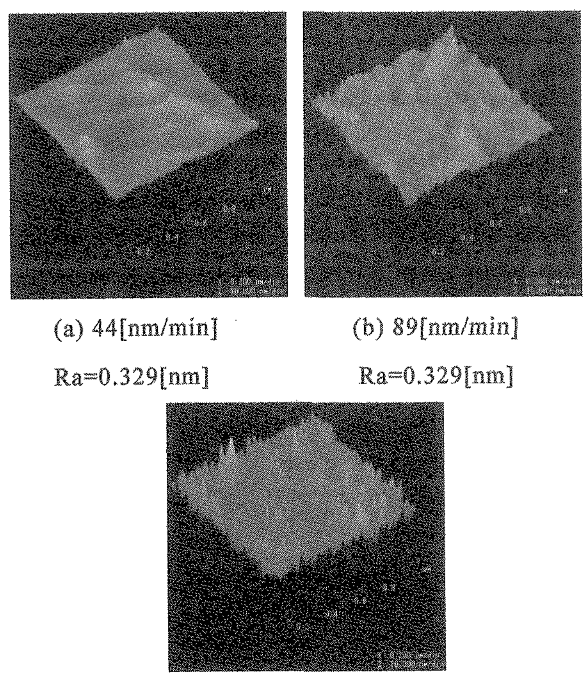
Figure 9 shows the surface morphologies. The mean surface roughness Ra increased in the films deposited at 112 nm/min, although the reason is not clear. During deposition at the rate of 112 nm/min, the substrate temperature increased and reached about 80 ℃ by the end of deposition. This increase in substrate temperature may have had an effect on the structure of the film. Figure 10 shows the changes in the electrical properties of the films against the deposition rate. It is clear that the electrical properties are not dependant on the deposition rate. Films with resistivity of about 4.0×10^{4} Ωcm were realized at a deposition rate above 100 nm/nm.



(a) 44[nm/min] (b) 89[nm/min]

(c) 112[nm/min]

Fig.8 TEM images of the films deposited at deposition rates of 44 nm/min(a), 66 nm/min(b), 89 nm/min(c), and 112 nm/min(d).



(a) 44[nm/min] Ra=0.329[nm]

(b) 89[nm/min] Ra=0.329[nm]

(c)112[nm/min] Ra=0.768[nm]

Fig.9 Surface AFM images of the films deposited at various deposition rates.

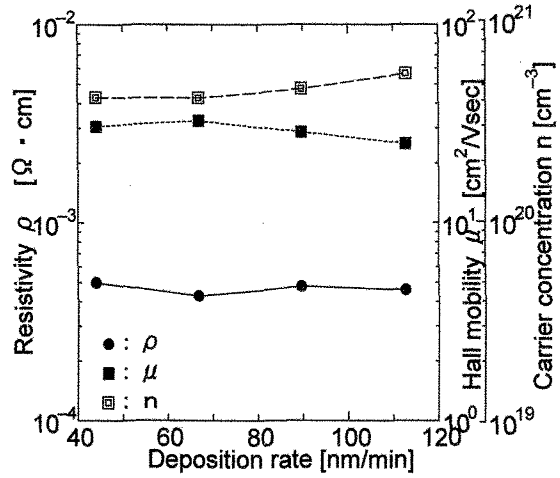


Fig.10 Changes in electrical properties of films against deposition rate.

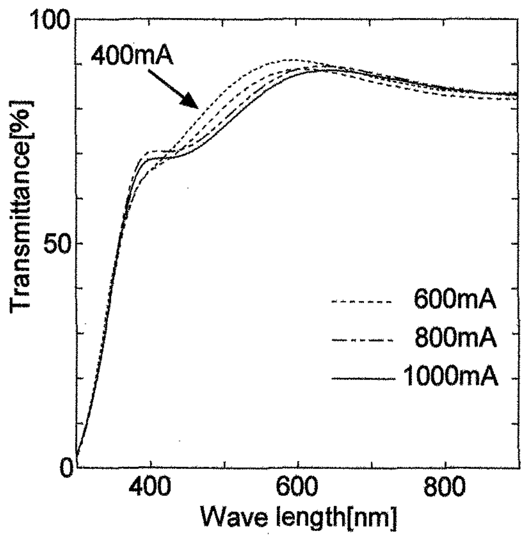


Fig.11 Optical transmittance of the films deposited at various rates.

The optical transmittances of these films, deposited at various deposition rates, are shown in Fig.11. Transmittance of the film is not greatly dependant on the deposition rate. All of the films obtained in this study have transmittance higher than 85% in the visible region.

4. CONCLUSIONS

High rate deposition of ITO thin films on acryl substrate was attempted with an FTS system. A deposition rate above 110 nm/min was achieved on the acryl substrate. This is mainly attributable to the fact that the bombardment of the substrate surface by high energy particles is completely suppressed in FTS. In addition, both electrical and optical properties changed little with changes in the deposition rate. Films with a resistivity below 4.0×10^{-4} Ωcm were obtained at a deposition rate of more than 100 nm/min. Control of the oxygen gas concentration in sputtering gas is necessary, though, to obtain film with low resisitivity.

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