Figure of Merit for Deposition Conditions in ITO Films

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Indium tin oxide (ITO) films were deposited on unheated PET substrates by DC reactive magnetron sputtering of In-Sn (90-10 wt%) metallic alloy target. Electrical and optical properties of as-deposited films were systematically studied by control of the deposition parameters such as working pressure, DC power, and oxygen partial pressure. The figures of merit are important factors that summarize briefly the relationship between electrical and optical properties of transparent conducting films. The formulae of T/R_{sh} and T^{10}/ R_{sh} are expressed as a function of transmittance and sheet resistance. The best values of those figures of merit were approximately 38.6 and 8.95 ($\times 10^{-3}\ \Omega^{-1}$), respectively.

Keywords : ITO, Magnetron sputtering, PET substrate, Metallic alloy target, Figure of merit.

1. INTRODUCTION

ITO films have received attractive attention as an ɛcellent candidate among the various transparent ɔnducting oxides. ITO is commonly treated as a ɜgenerate n-type semiconductor material. The electrical ɔnduction of ITO depends upon oxygen vacancies and valent indium or tin atoms that are incorporated during lm growth[1]. The low electrical resistivity of the film ith the range of $\sim 10^{-4}$ Ωcm is resulted from this ɔnduction mechanism. The carrier concentration is rger than 10^{20} cm^{-3} and the mobility is as large as 10 to) cm^2/Vs. On the other hand, these excellent conductive [O films have been mainly used as a transparent ectrode for optoelectric devices and flat panel displays ıch as solar cells, liquid crystal display (LCD), ectrochromic display (ECD), electroluminescent dis-ay (ELD) and so on[2]. It has been recently required ıat ITO films are deposited on polymeric substrates ıstead of the conventional glass substrate for the ansparent conducting applications. That is, these ɜvices using glass substrate are somewhat heavy and ın break easily, while those of polymeric substrate have gnificantly light and flexible properties. The substrate mperature and/or post-heat treatment of ITO films deposited on polymeric substrates are very restric because polymers can not withstand high temperat Therefore, the deposition methods of ITO films prepa at low temperature are important technology[2,3, Nevertheless, the electrical and optical properties in I films on polymeric substrates should be almost sim with those on glass. ITO films for the transpaı conducting devices are required at least higher opt transmittance than 80 % and low electrical resistivity much as $\sim 10^{-4}$ Ωcm.

It is necessary to optimize simultaneously electrical and optical properties for the transpaı conducting applications. Therefore, figure of mɛ which can explain in an easy manner as a relat between sheet resistance and optical transmittance, been proposed sometimes to estimate the performanc transparent conducting films. Moreover, some reseaı ers have defined and discussed the figure of merit several approaches[4-6]. In order to evaluate electrical and optical properties of ITO films with br applications, we have systematically studied electrical and optical properties with control deposition conditions such as operating gas pressure, power and oxygen partial pressure (PO_2). The dep dency of these deposition parameters on the sl resistance and optical transmittance of as-deposited fi is investigated by figure of merit.

2. EXPERIMENTAL

TO films were deposited on polyethylene tere- ıalate (PET) substrate by DC reactive magnetron ttering of metallic alloy target. The substrate perature was not applied during the film deposition as l as post annealing treatment for as-deposited ITO ıs was not performed. Prior to ITO deposition, all strates were ultrasonically cleaned for 5 min. using hanol as a solvent. The deposition parameters such as DC power, working pressure, and oxygen partial ssure (PO_2) were controlled. PO_2 in the operating gas ture of total pressure was expressed as]/([Ar]+[O_2]) percentage and its ranges from 8 to 12 % e used. A disk In 90 wt%-Sn 10 wt% target, supplied Cerac, with 2 inch diameter and 1/4 inch thick was d. A serious problem in the reactive sputtering of allic alloy is the oxidation of metal target surface, well wn as a poisoning phenomenon. Therefore, the target face should be cleaned necessarily before every ttering run. Moreover, the target was pre-sputtered in on atmosphere for about 10 min in order to remove the dizing surface and impurity layer, which may have ned during exposure to air.

Transparent conducting films have two important tors; that is, electrical resistivity and optical ısmittance. These two qualities have sometimes ility characteristics each other, which is inversely or arly related with several deposition ways and film ure. With broad application fields, only lower ctrical resistivity neglecting high optical transmittance y be required, or vice versa. No matter which side oses, these two factors are significantly used in many es, and therefore the figure of merit, which involves ultaneously the electrical and optical properties, has atly meaningful.

First, Fraser and Cook[7] developed figure of merit ed on the sheet resistance (R_{th}) and transmittance (T) transparent conducting films; i. e. defining as a mula of T/R_{th}. The higher value in figure of merit omes, the better film quality signifies owing to the uirement of high transmittance and low sheet istance. However, transmittance and sheet resistance the formula are actually expressed as a function of n thickness. The transmittance becomes generally ver with an increase of film thickness due to orption in the films. It has been known that the ctrical properties of ITO films sensitively depend on thickness[8]. On the other hand, it was reported that resistance for the as-deposited films prepared at room perature was no significant difference with a iation of film thickness below 300 nm[2,9]. All films his work were the as-deposited state without any heat atment, and film thickness was about 120± 5 nm. other figure of merit developed by Haache[10] was more emphasis on the transparent properties in the film although it had similar formation to Fraser and Cook formula. The figure of merit is defined as a T^x/R_{th}, wher x is larger integer than 1 and the value chosen in thi work is 10.

3. RESULTS AND DISCUSSION

Figure 1 shows the figures of merit for ITO films o PET substrate with a variation of DC power. The figur of merit, T/R_{th} and T^{10}/R_{th}, increase with an increase c DC power, particularly T/R_{th} grows up from 2.1 to 38. ($\times 10^{-3}\ \Omega^{-1}$). The reason is mainly caused by the reductio of sheet resistance which is probably related to a increase of oxygen vacancies[2], as the DC power increased. It is considered that the mechanism c electrical conduction in ITO films depends critically o oxygen vacancies. The optical transmittance increas slightly from 80 to 85 % at 550 nm wavelength with variation of DC power. But the PET substrate of 100 μı thick using in this work was bended occasionally higher power than or same to 40 W because of th raising temperature effect on substrate generated b ejected atom from target.

Figure 2 expresses the figures of merit of the films a function of working pressure under the followin deposition conditions: DC power of 30 W and PO_2 c 12 %. T/R_{th} and T^{10}/R_{th} decrease with an increase c working pressure. As the working pressure increases, th sheet resistance shows the increasing trend abruptly ar the transmittance increase slowly. As the results, it seen that the figure of merit depends upon the sheet resistan rather than the slowly increasing effect of transmittan

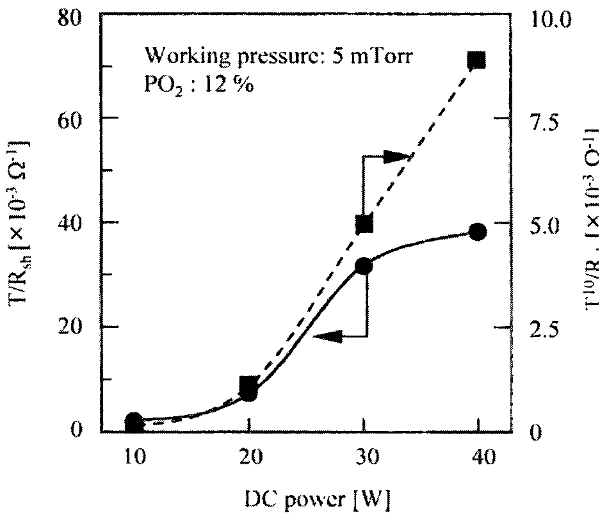
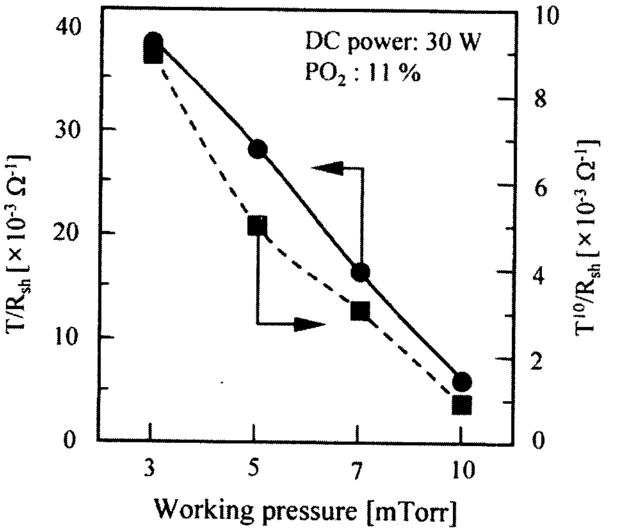


Fig. 1. Figures of merit for ITO films on PET with increase of DC power.

Table 1. Figures of merit in ITO films prepared on the various substrates at low temperature by several papers.

Substrate	Deposition methods	Thickness (nm)	Substrate Temp.(°C)	Sheet resist. (Ω/sq.)	Transmittane (% at 550 nm)	Figures of merit (mΩ^{-1}) T/R_{th}	T^{10}/R_{th}	Referer
Glass	FTS	100-300	RT	<40	>85	21.3	4.92	9
Glass	DCS	115	RT	55	84	15.2	3.18	1
AC	RFMS	390	50	19.06	74	38.6	2.58	5
PC	RFMS	-	<50	27.3	90	32.9	12.7	4
PET	Evaporate	230	>80	52	83	20.0	2.98	12
Glass	RFMS	500	RT	3.1	~56	180	1.00	13
PET	DCMS	125	RT	22	85	38.6	8.95	Ours

AC=acrylic, PC=polycarbonate, PET=polyethylene terephthalate, FTS=face target sputter, and RT=room temp.



ig. 2. Figures of merit for ITO films on PET as a ınction of working pressure.

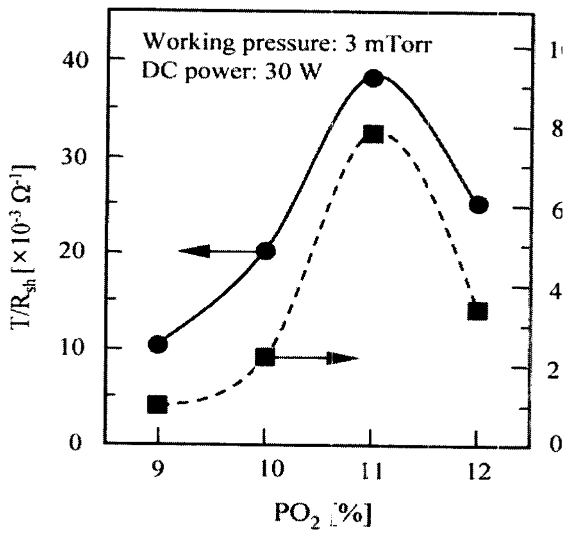


Fig. 3. Figures of merit for ITO films on PET a function of PO_2.

is noticed by Kumar and Mansingh[11] that the carrier ɔncentration of ITO films deposited at low working ressure is larger than that at high working pressure. herefore, the figure of merit goes down at higher 'orking pressure because the electrical conduction of ıe films is decreased at higher working pressure.

Figure 3 shows the figures of merit with a variation of O_2 at the working pressure of 3 mTorr for 30 W. The gures of merit increase gradually with the increasing O_2, while they decline sharply above the PO_2 of 11 %. hat is, the maximum point is obtained at 11 %. As the O_2 increases, the sheet resistance shows inversely milar curve with figure 3. The sheet resistance ecreases until the PO_2 of 11 % and then increases. It is ɔnsidered that these trends of sheet resistance and gure of merit with a variation of PO_2 is due to the ɔtimum requirement of oxygen content for excellent

ITO films. The optical transmittance increases slowly to 84 % at PO_2 of 11 % and then reduces into 81 %.

From the above results, the best values of th figures of merit are approximately 38.6 and 8.95 (× Ω^{-1}), respectively. Table I shows the figures of meri ITO films prepared on the various substrates at temperature by some papers.

From the above Table 1, T/R_{th} and T^{10}/R_{th} of ITO f in the ref. 13 are 180 and 1.00 ($\times 10^{-3}$ Ω^{-1}), respectiv Particularly, its T/R_{th} shows the best value in the Ta and, however, T^{10}/R_{th} expresses the worst value. ' reason is that the transmittance at 550 nm is very p even though the sheet resistance is extremely low. ' thickness of their ITO film is around 500 nm, while ı of our ITO film is approximately 125 nm. Therefore, results show relatively excellent values.

4. CONCLUSION

ΓO films were deposited on polyethylene tere-ıalate substrate by DC reactive magnetron sputtering metallic alloy target. The figures of merit are ıortant factors that summarize briefly the relationship ʌeen electrical and optical properties of transparent ducting films. The formulae of T/R_{th} and T^{10}/R_{th} are ressed as a function of transmittance and sheet stance. The best values of those figures of merit were roximately 38.6 and 8.95 ($\times10^{-3}\ \Omega^{-1}$), respectively.

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