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Deposited indium-tin-oxide (ITO) transparent conductive films by reactive low-voltage ion plating (RLVIP) technique

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Abstract

Indian-tin-oxide ITO transparent conductive films were deposited by the Reactive low-voltage ion plating (RLVIP) technique. CO_2 and O_2 gases were used as reactive gases coming into the vacuum. The effect of the CO_2 gas flow rate on the optical and electrical properties of the ITO films was studied in detail. The results showed that the CO_2 gas had similar oxidizing action to O_2 except for the magnitude of the flow rate. But, the conductivity of ITO films were not sensitive to the CO_2 gas flow rate over a wide region in contrast to the results to O_2. The optical transmission in the visible spectral region as well as the infrared reflectivity of ITO films varied as the CO_2 flow rate changed. Thus, a better quality ITO film was obtained by the RLVIP technique with reactive gas of 30 sccm CO_2, having of more than 90% transmittance, above 80% reflectance in long-wave IR and 28.7 Ω/□ sheet resistance.

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Keywords: ITO film; RLVIP; Optical transmittance; Infrared reflectance; Sheet resistance

1. Introduction

Indium-tin-oxide (ITO) film has unique optical and electrical characteristics, high transmittance in visible region and strong reflectance in the infrared (IR) region, as well as excellent conductivity. For these characteristics, ITO film plays an important role in the field of optoelectronic devices, such as transparent electrode for liquid crystal displays (LCD) [1] and architectural applications [2], etc. A variety of thin-film deposition techniques have been employed to make ITO film, including chemical vapor deposition [3], reactive evaporation [4], DC magnetron sputtering [5] and pulsed laser deposition [6], etc.

In contrast to the most common methods of sputtering, the reactive low-voltage ion plating (RLVIP) technique was used to deposit ITO transparent conductive film in this work. Furthermore, the metal oxide films easily lose oxygen during the deposition process, so that reactive gas usually O_2 is introduced into the vacuum chamber to decrease the absorption and form stoichiometric film. In our work, CO_2 gas was introduced into the chamber nearby the crucible of the electron-beam (e-beam) gun acting as a reactive gas substitute for O_2.

2. Experiment

The ZZSX-800 coater with an e-beam gun and a low-voltage ion source were used to deposit ITO film. Fig. 1 presents a schematic of the RLVIP arrangement used in our vacuum coater. The evaporation source material was an ITO pellet with a composition of 90 wt% In_2O_3 and

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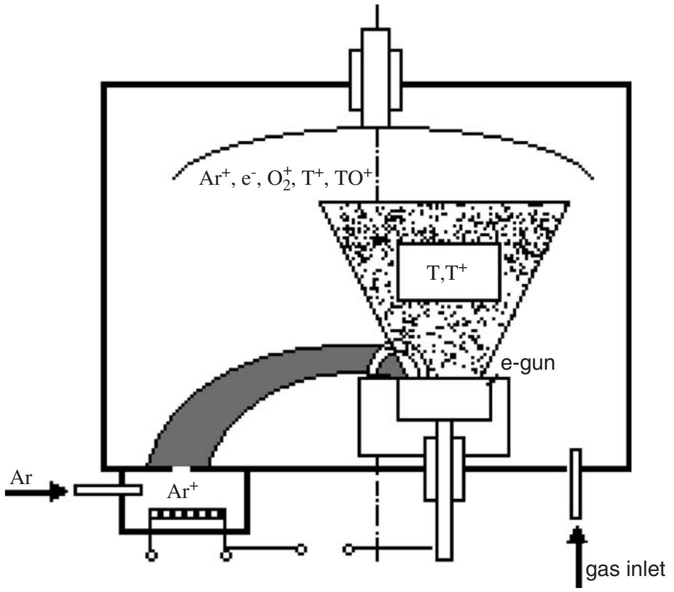

Fig. 1. Schematic of RLVIP system.

10 wt% SnO_2. The substrates had carefully polished K9 glass.

Two separate mass-flow controllers were used to monitor the gas flow rate of Ar and CO_2 or O_2. Base pressure of the chamber was 1.8×10^{-3} Pa. Ar was introduced into the low-voltage ion source, adjusting the focusing current, arc voltage and filament current of the low voltage ion source, made Ar ionize and caused arc discharging with the e-beam gun. The CO_2 or O_2 was used as the reactive gas coming into the chamber near the crucible of the e-beam gun with the same inlet. The deposition was carried out at dynamic pressure below $7–8 \times 10^{-2}$ Pa and the substrate was unheated. In the deposition process, a certain number of independent process parameters were kept constant, i.e., Ar flow rate $Q(\mathrm{Ar}) = 15$ sccm, deposition rate $V = 0.45$ nm/s, film thickness $d = 250$ nm, except for reactive gas flow rate.

The deposition rate and film thickness were monitored by Inficon IC/5 thin film deposition controller. The optical transmittance spectra of the films were recorded by Perklin–Elmer lambda 900 UV/VIS/NIR spectrometer and the IR reflectance was tested by Perklin–Elmer spectrum GX. Sheet resistance was measured using a model BD-86 Semiconductor Resistivity Meter. Neglecting substrate absorption, the physical thickness of these ITO samples calculated was 280 nm by essential Macelod software from the spectral measurement results.

3. Results and discussion

No diffractive peak appeared in the XRD measurements. This proved that structure of these ITO samples were all amorphous. The experiments were carried out without any heating to the substrate so that insufficient energy was present to cause the material particles to nucleate and crystallize.

Fig. 2 presents the optical transmission curves as a function of reactive gas flow rate. The maximum transmittance in the visible light was in the curve of 30 sccm CO_2. The transmittance of ITO film was not a linear change with increasing CO_2. With increasing CO_2, the transmittance increased much, and then decreased. It was consistent with the values reported by Yadin et al. [7]. Compared to the influence of O_2, the transmittance of 30 sccm CO_2 was slightly above that of 20 sccm O_2, and 20, 40 sccm CO_2 were all below 10 sccm O_2.

It could be considered that the transmittance in visible light region of ITO films was closely related to the oxidization of indium and tin. When the CO_2 content was at a low level, it offers little oxygen. Therefore, a lot of opaque, low valence state compounds of In and Sn were formed, which induces the transmittance to decrease with much absorption. When CO_2 is increased, sufficient oxidized of In and Sn made the opaque, compound transparent. But, with the CO_2 is flow rate continuing,

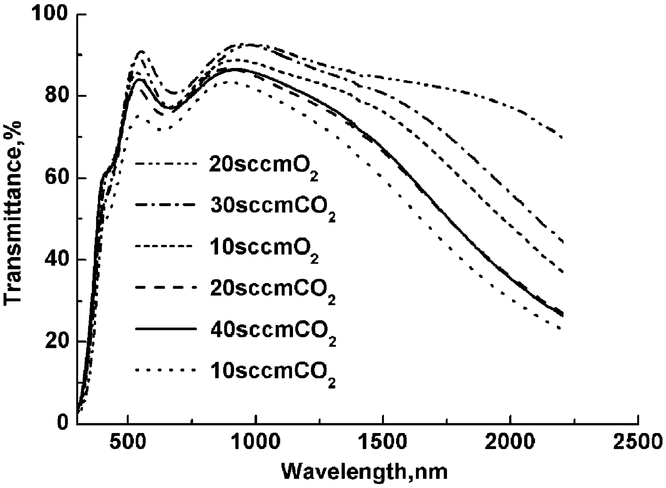

Fig. 2. Optical transmission curves as a function of reactive gas flow rate.

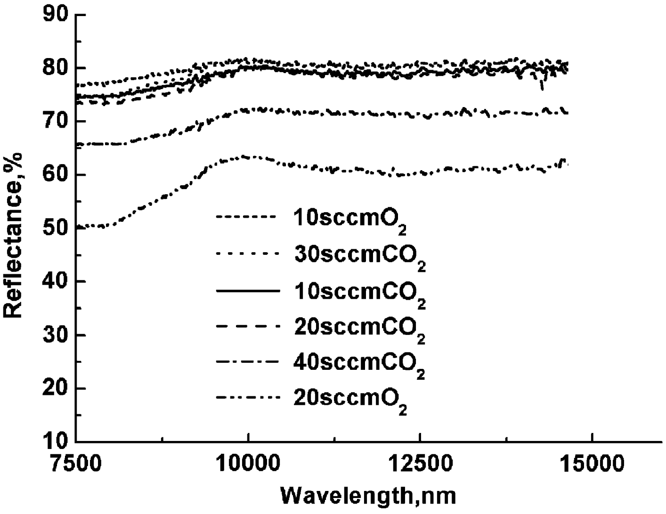

Fig. 3. Optical reflectance curves in long wave region as a function of reactive gas flow rate.

Table 1
Sheet resistance of different samples

Gas flow rate (sccm)		Sheet resistance Ω/□						Changing region
		A	B	C	D	E	Uniformity	
CO_2	10	33.5	33.6	33.5	33.7	33.6	0.2	9.3
	20	31.2	31.4	31.0	31.2	31.1	0.4	
	30	28.8	28.9	28.7	28.7	28.8	0.2	
	40	37.9	37.9	37.8	38.0	38.0	0.2	
O_2	10	21.4	22.8	22.1	21.7	23.6	2.2	30.8
	20	52.2	48.9	49.6	50.3	50.8	3.3	

transmittance dropped. This may be caused by the presence of C. In addition, it can be seen that the neat-IR curve of 20 sccm O_2 was higher than that of the others. This implies that the carrier concentration of 20 sccm O_2 deposited ITO film was lower than others.

Fig. 3 indicates that the long-wave infrared reflectance curve changed with different reactive gas flow rates. It has been observed that the reflectance had no obvious relationship to the gas flow rate changing. Expect for the curves of 40 sccm CO_2 and 20 sccm O_2, IR reflectance spectra of 8000–14000 nm wavelength were relatively flat and all above 75% and the reflectance of CO_2 gas flow rate from 10–30 sccm had no evident difference. It had been reported that sheet resistance of ITO film was inversely proportional to the reflectance in the long wave region when the sheet resistance was small [8]. Sheet resistances of ITO films with different gas flow rates are listed in Table 1, of which A, B, C, D and E represented 5 diverse points on one sample, respectively. A trend can be noticed that the better was the conductivity of the ITO films, the higher is the long wave reflectance. The results are consistent with Ref. [8].

From Table 1, it can be seen that with an increase in CO_2 flow rate, sheet resistance decreased to a minimum value and then increased. At the minimum sheet resistance, the transmittance in the visible regional up to 90% and the long wave reflectance up to 80% were obtained. In a range from 10 to 40 sccm of CO_2 flow rate, sheet resistance alteration $\Delta R_{\square}$ of ITO film was 9.3 Ω/□. When using O_2 as reactive gas, sheet resistance alteration $\Delta R_{\square}$ was 30.8 Ω/□ just as gas flow changing from 10 to 20 sccm. Furthermore, sheet resistance uniformity of one ITO sample was only 0.2–0.4 Ω/□ measured at 5 different points when using CO_2 whilst it was 2.2–3.3 Ω/□ when O_2 was introduced.

From the above data, it can be concluded that the sheet resistance of ITO film was not sensitive to CO_2 gas flow rate between a wide region from 10 to 40 sccm compared to O_2 from 10 to 20 sccm O_2. It would improve the uniformity of sheet resistance over a large radius substrate width or between multi-substrates, since the influence of a uniform gas distribution on the resistance decreased in the deposition zone. There is therefore, a considerable advantage of using CO_2 rather than O_2.

4. Conclusions

ITO thin films have been deposited on a low-temperature substrate using CO_2 acting as the reactive gas by RLVIP technique. With this technique, good ITO films with 90% transmittance, 80% long-wave reflectance and 28.7 Ω/□ sheet resistance were prepared. It should be a promising method for the depositional ITO films. In addition, it can be concluded from the experiment that CO_2 can act as reactive gas to substitute O_2 to decrease the influence of nonuniform gas distribution in vacuum on sheet resistance and enlarge the permissible error of gas flow coming into the chamber. It can also make deposition control facile by reducing the influence of gas distribution on sheet resistance.

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References

- [1] S.A. Carter, M. Angelopoulos, S. Karg, P.J. Brock, J.C. Scott, Appl. Phys. Lett. 70 (1997) 2067.
- [2] A.S.A.C. Diniz, C.J. Jiely, Renew. Energ. 29 (2004) 2037.
- [3] T. Maruyama, K. Fukui, J. Appl. Phys. 70 (1991) 3848.
- [4] H.-U. Habermeier, Thin Solid Films 80 (1981) 157.
- [5] T. Karasawa, Y. Miyata, Thin Solid Films 223 (1993) 135.
- [6] A. Suzuki, T. Matsushita, T. Aoki, A. Mori, M. Okuda, Thin Solid Films 411 (1993) 23.
- [7] E. Yadin, V. Kozlov, E. Machevskis, Recent Developments in the Deposition of ITO and AR Coatings, in: 2003 Society of Vacuum Coaters, 46nd Annual Technical Conference Proceedings, Albuquerque, USA, 2003, pp. 185–189.
- [8] P.K. Biswas, A. De, N.C. Pramanik, P.K. Chakraborty, K. Ortner, V. Hock, S. Korder, Mater. Lett. 57 (2003) 2326.