rf 스퍼터된 **In_2O_3-ZnO** 박막의 광학적, 전기적 특성에 미치는 스퍼터링 변수의 영향

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Influence of sputtering parameters on the optical and electrical properties of rf–sputtered In_2O_3-ZnO films

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1. Introduction

Transparent conducting oxide (TCO) thin films have been widely applied as transparent electrodes in solar cells, flat panel displays, sensors, and organic light emitting diodes due to their unique properties of low electrical resistivity and high optical transparence in the visible spectrum range. During the last decades, most researches for TCO films have focused on the binary compounds such as In_2O_3, ZnO and SnO_2.

Recently, a ternary compound of In_2O_3-ZnO (IZO) thin film, as a very promising TCO film, has attracted great attention because of its better electrical conductivity [1], high optical transparence [2], cleaner etched surfaces [3], lower internal stress and smoother surface morphology [4].

The film properties are intimately dependent on the process parameters. Therefore, the properties of IZO thin films are optimized by varying process parameters such as rf power, gas pressure, distance of target to substrate, film thickness to meet the requirements of high electrical conductivity and high optical transparence in this study.

2. Experiment details

IZO films were deposited by radio frequency (rf) magnetron sputtering on glass slides using an IZO target consisting of In_2O_3 and ZnO as a weight ratio of 9:1. The optical and electrical properties were studied by varying process parameters such as rf power, gas pressure, and distance of target to substrate. Through the preliminary studies, the rf power applied to target was fixed at 30W. The base pressure in the chamber was kept below 6.0×10^{-6} Torr and the working pressure was fixed at 5×10^{-4} Torr. The deposition was carried out at room temperature (RT). The effect of film thickness on optical and electrical properties was also investigated by varying the film thickness from 50 to 300 nm.

The film thicknesses were measured using surface profilometer and all the films for property measurement were deposited at a constant thickness of about 100 nm. The optical transmittance was measured in the wavelength range from 300 to 900 nm by UV-VIS spectrophotometer. The electrical resistivity was obtained from the sheet resistance measured using a four-point probe method.

3. Results and discussion

Figures 1(a) and (b) showed the changes in optical transmittance, electrical resistivity and deposition rate of IZO films prepared as a function of rf power. From Figure 1(a), the transmittance

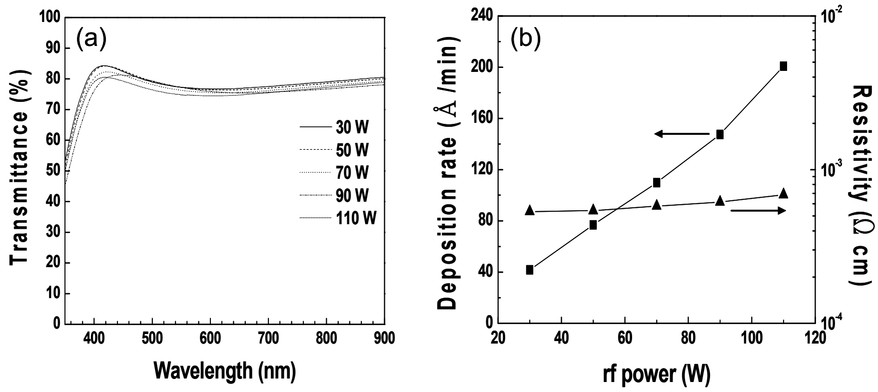

Fig. 1. Optical and electrical properties of IZO film prepared by varying rf power.

showed a tendency of decreasing as the rf power increased and the maximum transmittance of about 85% was obtained from IZO film deposited at 30 W in the visible region. The reason may stem from uneven surface morphology of IZO film due to higher deposition rate at higher rf power. The kinetic energies of In and Zn elements increase by the higher sputtering yield because of increased rf power. Therefore, the deposition rates showed a drastic increase from 40 to 200 Å/min, as shown in Fig. 1(b).

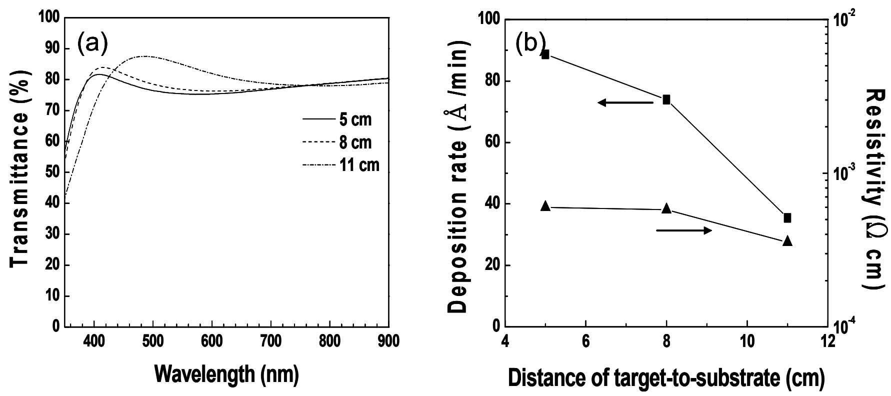

Fig. 2. Optical and electrical properties of IZO film prepared by varying distance of target to substrate.

With higher deposition rate, there is no enough time for In and Zn atoms to form smooth and dense film, so the surface morphology and density of IZO films deposited at higher sputtering power become rougher and lower, which can be attributed to optical transmittance decreasing and electrical resistivity increasing (shown in Fig. 1(b)). Furthermore, it was proposed that the kinetic energy of negatively charged O^- ions increases as sputtering power, so higher sputtering power can enhance the lattice damage of the films by the high-energy ions. It might deteriorate the crystallinity of the films, and reduce the concentration of electrically active donor sites, leading to the increase in resistivity [5].

Shigesato et al. reported the same tendency of resistivity of ITO thin film [6].

Figures 2(a) and (b) showed tendencies of optical transmittance, electrical resistivity and deposition rate of IZO films deposited by varying the distance of target to substrate. Figure 2(a) showed that the optical transmittance increased as the distance increased and Fig. 2(b) presented that the deposition rate and electrical resistivity decreased with increasing distance. When the distance increases, In and Zn atoms undergo more collisions during their travels from the plasma to the substrates, thereby continuously losing their initial energy and direction [7], resulting in the decrease in deposition rate. With lower deposition rate, the IZO atoms or molecules have enough time to form dense IZO thin film, and hence the surface morphology and density of IZO thin film become smoother and higher as the distance of target to substrate increase. This can be the reason for the increase in optical transmittance and the decrease in electrical resistivity.

Figures 3(a) and (b) showed the variation in optical transmittance, electrical resistivity and deposition rate of IZO films prepared by varying gas pressure. From Figure 3(a), the optical transmittance showed a decreasing tendency first and then increased. As the gas pressure increased,

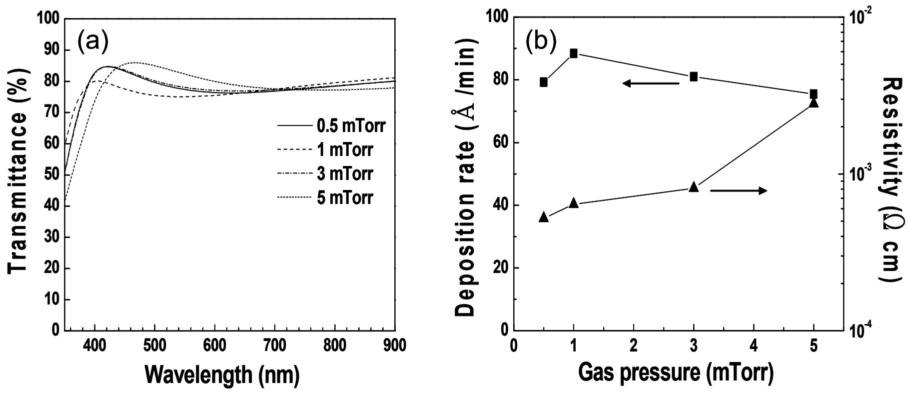

Fig. 3. Optical and electrical properties of IZO deposited by varying gas pressure.

the electrical resistivity increased. However, the deposition rate increased from 0.5 mTorr to 1 mTorr and then decreased from 1 mTorr. That is because the plasma density is so low at 0.5 mTorr that the deposition rate becomes low and with further increasing gas pressure, the deposition rate decreases, showing the maximum at 1 mTorr. When gas pressure increases exceeding 1 mTorr, more collisions take place between atoms including In, Zn and O owing to the reduced mean free path, so the deposition rate decreases through 1 mTorr. C.V.R. Vasant Kumar et al. also reported the same result [8]. The fact that the higher deposition rate with the rougher surface morphology can explain the tendency of optical transmittance. Furthermore, during the travels of In, Zn and O atoms down to substrate from plasma at higher gas pressure, more impurity atoms could be involved in the deposition processing because of more collisions, these impurity atoms could be the scattering centers of electron, which can be attributed to the increase in electrical resistivity.

The variation in optical transmittance and electrical resistivity of IZO films deposited at the best sputtering condition chosen from the experiments mentioned above were shown in Figures 4(a) and (b) respectively. It can be seen from Fig. 4(a) that the optical transmittance of IZO films increased as the film thickness increased and the 300 nm thick IZO film exhibited an average transmittance of about

85% in the visible region. It was also observable that the absorption band edge shifted toward a longer wavelength with increasing film thickness. This shift in the absorption band edge can be attributed to

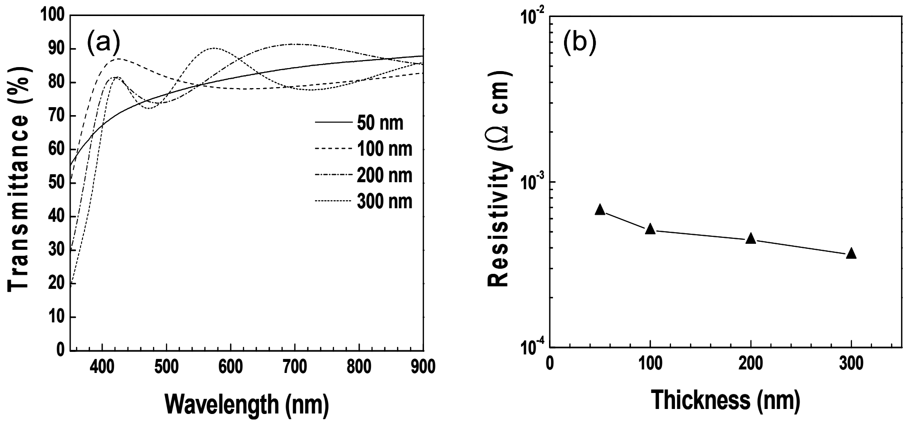

Fig.4. Optical and electrical properties of IZO film prepared by varying film thickness.

increasing the films conductivity, which causes blocking of low energy transitions, known as the Burstein-Moss effect [9]. From Figure 4(b), the thicker IZO films exhibited lower resistivity of about 3.63×10^{-4} Ω cm. It might suggest that the free carriers occupy states at the bottom of the conduction band, resulting in a block of low energy transitions [10].

4. Conclusion

The effect of deposition parameters such as rf power, distance of target to substrate, gas pressure, and film thickness on optical and electrical properties were studied in this work. IZO films showed higher optical transmittance and lower electrical resistivity at lower rf power, lower gas pressure, longer distance of target to substrate and thicker film thickness. In summary, the highest transmittance of about 85% and the lowest resistivity of about 3.63×10^{-4} Ω cm were achieved when IZO films were grown on glass substrate at room temperature, using the optimized sputter conditions.

References

1. T. Minami, T. Kakumu and S. Takata, J. Vac. Sci. Technol. A **14**, 1704 (1996).
2. N. Naghavi, A. Rougier, C. Marcel, C. Guery, J.B. Leriche and J.M. Tarascon, Thin Solid Films **360**, 233 (2000).
3. G.S. Chae, Jpn. J. Appl. Phys. **40**, 1282 (2001).
4. T. Sasabayashi, N. Ito, M. Kon, P.K. Song, K. Ustumi, A. Kajio and Y. Shigesato, Thin Solid Films **445**, 219 (2003).
5. Y.S. Jung, J.Y. Seo, D.W. Lee and D.Y. Jeon, Thin Solid Films **445**, 63 (2003).
6. Y. Shigesato and David C. Paine, Thin Solid Films **238**, 44 (1994).
7. W.D. Westwood, J. Vac. Sci. Technol. **15**, 1 (1978).
8. C.V.R. Vasant Kumar and Abhai Mansingh, J. Appl. Phys. **65** (3), 1270 (1989).
9. A.P. Roth, J. B. Webb and D. F. Williams, Phys. Rev. B **25**, 7836 (1982).
10. E. Burstein, Phys. Rev. **93**, 632 (1954).