The Effect of MgO precursor on light trapping of Al-doped ZnO Transparent Conducting Oxide for Thin Film Solar Cells

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Abstract — We have proposed MgO/AZO bi-layer transparent conducting oxide (TCO) for thin film solar cells. From XRD analysis, it was observed that the full width at half maximum of AZO decreased when it was grown on MgO precursor. The Hall mobility of MgO/AZO bi-layer was 17.5 cm²/Vs, whereas that of AZO was 20.8 cm²/Vs. These indicated that the crystallinity of AZO decreased by employing MgO precursor. However, the haze (=total diffuse transmittance/total transmittance) characteristics of highly crystalline AZO was significantly improved by MgO precursor. The average haze in the visible region increased from 14.3 to 48.2%, and that in the NIR region increased from 6.3 to 18.9%. The reflectance of microcrystalline silicon solar cell was decreased and external quantum efficiency was significantly improved by applying MgO/AZO bi-layer TCO. The efficiency of microcrystalline silicon solar cell with MgO/AZO bi-layer front TCO was 6.66%, whereas the efficiency of one with AZO single TCO was 5.19%.

Keywords — Transparent conducting oxide, MgO, ZnO:Al, silicon thin film solar cell.

I. INTRODUCTION

Al-doped ZnO (AZO) has been widely used as front transparent conducting oxide (TCO) for thin film solar cells in terms of high transparency and low resistivity [1-2]. Haze (=total diffusion/transmittance) property of surface textured AZO is also an important factor for characterizing light trapping ability. The improvement of those AZO properties is crucial for solar cell efficiency. It was reported that the crystallinity of ZnO was improved by MgO buffer layer on sapphire substrate [3]. However, the sapphire substrate is not suitable for thin film solar cells employing low cost glass substrate. In addition, the optoelectronic properties of MgO/AZO bi-layer deposited on glass substrate for thin film solar cell applications were not reported yet.

Thus, the purpose of our paper is to report the effect of MgO precursor on film crystallinity and haze properties of AZO film. The structural, electrical, and optical properties of MgO/AZO bi-layer TCO have been systemically investigated. In addition, the performance of thin film solar cell employing MgO/AZO bi-layer front TCO, forming the solar cell structure of (glass/MgO/AZO/microcrystalline silicon p-i-n/AZO/Ag/Al), have been investigated.

II. EXPERIMENTAL DETAILS

MgO and AZO films were prepared by magnetron sputtering. The 4-inch ceramic targets consisted of AZO (2wt.% Al₂O₃) and MgO (4N) were used. Prior to deposit thin films, 5 min pre-sputtering was performed to eliminate possible contaminants on the targets and base pressure under 1.0×10⁻⁶ Torr was maintained by cryo-pump (GENESIS ICP-150). At first, reference AZO film of about 1μm was prepared on glass substrates (Corning) at the substrate temperature of 250°C, working pressure of 3mT, and power density of 3.7 W/cm². In the case of the fabrication of proposed MgO/AZO bi-layer films, MgO film of about 20 nm was deposited at 500°C, 1mT, and 10% dilution of oxygen. After the MgO deposition, AZO film of about 1μm was continuously deposited on MgO precursor. Structural properties of deposited films were analyzed by X-ray diffraction (XRD, D8 advance). Electrical properties such as Hall mobility, carrier concentration, and resistivity were measured by Hall measurement. For characterizing light scattering properties in terms of solar cell application, wet chemical etching of the deposited films was carried out. The optical properties of surface textured AZO and MgO/AZO films were measured by spectrophotometer. Microcrystalline silicon solar cells employing conventional AZO and MgO/AZO bi-layer TCO were fabricated and tested the performances.

III. RESULTS AND DISCUSSION

Fig. 1 shows XRD patterns of deposited AZO and MgO/AZO film. The AZO film showed diffraction peak near 34.4°, which indicates hexagonal wurzite structure. It also means that the AZO and MgO/AZO bi-layer films have preferred (002) orientation along the c-axis perpendicular to substrates. However, the (002) peak intensity decreased by employing MgO precursor. Full width at half maximum (FWHM) increased from 0.151° to 0.213°, indicating that the crystallinity of AZO film decreased by the MgO precursor. It is believed that the MgO precursor increased a structural disorder of crystalline growth of AZO film.
Fig. 1. XRD spectra of deposited AZO and MgO/AZO bi-layer films. The films exhibited a preferred orientation along the c-axis.

Electrical characteristics of AZO and MgO/AZO bi-layer films was analyzed by Hall measurement with Van der Pauw geometry. The resistivity of MgO/AZO bi-layer film was $4.86 \times 10^{-4} \, \Omega \cdot \text{cm}$ which is slightly higher than that ($4.86 \times 10^{-4} \, \Omega \cdot \text{cm}$) of AZO film. It was mainly attributed to decrease in the Hall mobility from 20.8 to 17.5 cm$^2$/Vs. The degradation in the Hall mobility is related to the deterioration of film crystallinity as examined by above XRD results. The level of carrier concentration showed little difference between AZO and MgO/AZO bi-layer film.

Fig. 2 (a) shows optical transmittance of surface textured AZO and MgO/AZO bi-layer films. The average visible transmittance of surface textured AZO and MgO/AZO bi-layer films was 93.0 and 93.6%, respectively. The average NIR visible transmittance was 86.8 (AZO) and 85.7 % (MgO/AZO bi-layer). The fluctuation in AZO transmittance curve is attributed to interference effect which resulted from multiple reflections among interfaces. It also related to insufficient surface texturing compared to MgO/AZO bi-layer film. Fig. 2 b) exhibits haze (=total diffusive transmittance/total transmittance) characteristics of surface textured AZO and MgO/AZO bi-layer films. The AZO film showed relatively low haze property, which is related to film compactness. The reference AZO film was deposited at low working pressure of 3mT so that the film would be densely formed. Through the low pressure deposition, highly crystalline and low resistive AZO films could be obtained. When the surface texturing was performed, AZO film showed highly resistant to chemical etching, and low etch rate of about 8 Å/s was observed.

However, MgO/AZO bi-layer showed a significant improvement in haze property compared to AZO reference. The average haze in the visible region increased from 14.3 to 48.2%, and that in the NIR region increased from 6.3 to 18.9%. It was related to film structure and compactness. As the AZO was deposited on MgO precursor, the crystallinity was degraded. In terms of the surface texturing, the etch rate of about 43 Å/s was observed, implying that the compactness of MgO/AZO bi-layer was low and it showed less resistance to wet chemical etching compared to AZO single layer. These chemical etching properties can be confirmed by analyzing the etching profiles.

Fig. 2. (a) Optical transmittance and (b) haze characteristics of surface textured AZO and MgO/AZO bi-layer films.

Fig. 3. shows surface morphologies of surface textured AZO and MgO/AZO bi-layer analyzed by FE-SEM. The AZO film (Fig. 3 (a))) showed relatively flat surface, which resulted in low haze property as confirmed in Fig. 2 (b). However, the MgO/AZO bi-layer film had much
rough surface compared to AZO film. It corresponds to high haze property of MgO/AZO bi-layer film and it is expected that the bi-layer film will exhibit an enhanced light trapping characteristics for solar cell applications.

![Surface morphologies of (a) AZO and (b) MgO/AZO bi-layer film, which were measured by FE-SEM.](image)

Fig. 3. Surface morphologies of (a) AZO and (b) MgO/AZO bi-layer film, which were measured by FE-SEM.

Fig. 4 (a) shows reflectance curves of microcrystalline silicon solar cells with AZO and MgO/AZO bi-layer TCOs. The microcrystalline silicon solar cell with MgO/AZO bi-layer front TCO showed lower reflectance than one with AZO TCO in the overall wavelength regions. It can be attributed to the high haze property of MgO/AZO bi-layer, decreasing the reflection at interface of AZO/p-type microcrystalline silicon. Furthermore, high haze of MgO/AZO bi-layer led to an efficient light trapping, which increased external quantum efficiency (EQE) of microcrystalline silicon solar cell in the whole wavelength regions as shown in fig. 4 (b). The short circuit current increased from 21.2 to 26.3 mA/cm² by employing MgO precursor. The efficiency of microcrystalline silicon solar cell with MgO/AZO bi-layer front TCO was 6.66%, whereas the efficiency of one with AZO single TCO was 5.19%.

MgO/AZO bi-layer structure has been proposed for high haze and low resistive TCOs. By introducing MgO precursor, the crystallinity of AZO film was degraded in terms of crystal structure. In electrical characteristics, the

IV. CONCLUSIONS
Hall mobility of MgO/AZO bi-layer was less than that of AZO due to the deterioration of film crystallinity. The resistivity of MgO/AZO bi-layer film was $4.86 \times 10^{-4} \ \Omega \text{cm}$, whereas that of AZO film was $4.04 \times 10^{-4} \ \Omega \text{cm}$. However, MgO/AZO bi-layer showed high haze characteristics compared to AZO TCO. From the SEM images, it turned out that MgO/AZO bi-layer had larger craters than AZO. It seems that decreasing the compactness of AZO film by MgO precursor is main factor to increase in the haze property. Thanks to high haze property, the reflectance of microcrystalline silicon solar cell with MgO/AZO bi-layer decreased and EQE of the cell with MgO/AZO bi-layer was improved compared to one with AZO single TCO.

**REFERENCES**

