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Study on thermal durability of AZO/Ag(Al)/AZO transparent conductive film

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Abstract

The effect of Al doping in Ag layer (Ag(Al)) on the thermal durability of dielectric/metal/dielectric (DMD) transparent conductive film was investigated. The AZO/Ag(Al)/AZO-DMD (Al content of Ag layer: 0.0~10.5 at%) film were prepared on SiO_2 substrates by ion beam sputtering at room temperature. After the deposition, all the films were annealed for 1 hr in the vacuum at temperatures of 100 to 600 °C with an interval of 100 °C. The effects of annealing on the structure, surface morphology, optical and electrical properties of the DMD films were investigated. Thermal durability of the DMD with Ag(Al) was markedly improved about 200 °C compare to the DMD with pure Ag layer. After 500 °C annealing, the average transmittance (λ=380~780nm) T_{AVE} and sheet resistance Rs of DMD with 10.5 at% Al doped Ag were improved to 83.3 % and 14.1 Ω/sq., respectively.

1. Introduction

Transparent conductive oxide (TCO) films such as indium tin oxide (ITO), gallium doped zinc oxide (GZO) and zinc doped indium oxide (IZO) have been studied for various applications such as touch panels, solar cells, thin film transistors (TFTs), organic light emitting diodes (OLEDs) and LEDs due to their high transmittance and good electrical conductivity. In some cases, like in the fabrication process of dye-sensitized solar cells (DSSCs) and visible light-emitting diodes (LEDs), high-thermal durability are required. However, it was reported that electrical conductivity of amorphous based TCO tend to degrade after high-temperature thermal annealing (>250 °C) [1]. On the other hand, the dielectric/metal/dielectric (DMD) structure is expected as a candidate of high performance transparent conductive film having high transmittance and conductivity [2]. For the Al-doped ZnO (AZO) based DMD, it has been reported that annealing up to 300~400 °C improves DMD characteristics but further increase in temperature decreases transparency and electrical conductivity due to aggregation, diffusion and/or oxidation of Ag [3].

In this study, effect of Al doping in Ag layer [4, 5] on the thermal durability of AZO/Ag(Al)/AZO-DMD transparent conductive films were studied.

2. Experimental and results

Fig. 1 shows the schematic diagram of DMD film used in this study. The AZO/Ag(Al)/AZO-DMD films were prepared on SiO_2 substrates by ion beam sputtering at room temperature with thickness of 45/20/50 nm. Al contents of the Ag(Al) layer were set to be 0.0, 4.7, 7.5, 10.5 at%. After the deposition, all the films were annealed for 1 hr in the vacuum at temperatures of 100 to 600 °C with an interval of 100 °C.

Fig. 1 Schematic diagram of AZO/Ag(Al)/AZO-DMD.

Fig. 2 shows the average transmittance T_{AVE} in visible region (380~780 nm) with the variation of annealing temperatures for the samples with Al content of 0.0 and 10.7 at%. For the case of DMD with pure Ag, the T_{AVE} slightly increased from 65.2% of as deposition to 66.8 % of after 300 °C annealing. But at 400~600 °C, the T_{AVE} decreased due to Ag aggregation. On the other hand, for the case of DMD with Ag(Al) (Al content:10.5 at%), the T_{AVE} mono-

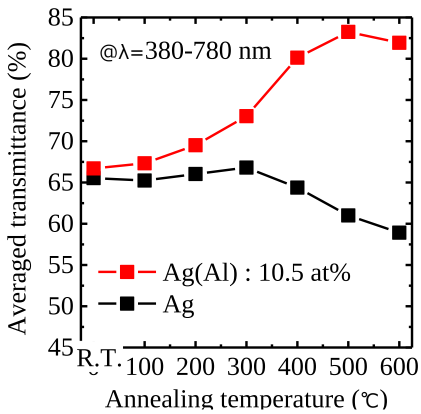

Fig. 2 Annealing temperature dependency of the average transmittance T_{AVE} in visible region (380-780 nm).

tonically increased up to 500 ºC and T_{AVE} reached to 83.3 % and then it decreases slightly at 600 ºC.

SEM images of these DMD films as a function of annealing temperatures are shown in Fig. 3. For the case of DMD with Ag, many dark area where the Ag was not detected in EDS measurement were observed at 500~600 ºC. The dark area without Ag was considered to be formed due to Ag aggregation. For the case of DMD with 10.5 at% Al doped Ag, uniform surface morphology was maintained up to 500 ºC, and only small dark spots were appeared even at 600 ºC.

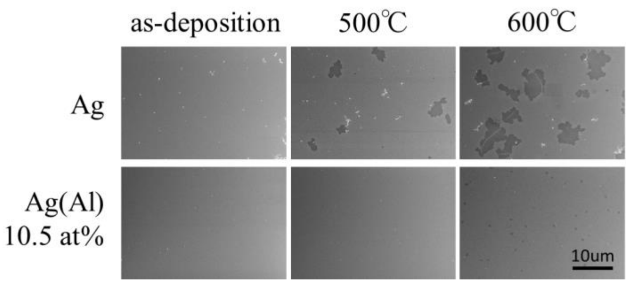

Fig. 3 SEM images of DMD films with pure Ag and with 10.5% Al-doped Ag layer at different annealing temperatures.

For comparison of the performance of transparent conductive coatings, Haccke's figure of merit (FOM, T_{AVE}^{10}/Rs)[6] is plotted in Fig. 4. For the case of DMD with pure Ag, FOM slightly increase to 300 ºC and showed the highest value of 0.49 × 10^{-2} Ω^{-1}. At 400~600 ºC, it decreased mainly due to decrease of transmittance. For the case of DMD with 10 at% Al doped Ag, FOM significantly improved to 500 ºC, and showed the highest value of 1.1 × 10^{-2} Ω^{-1}. The maximum FOM value of DMD with Al doped Ag are 2.2 times higher than that of DMD with pure Ag. The thermal durability of AZO/Ag/AZO-DMD was about 200 ºC improved by Al doping in Ag layer.

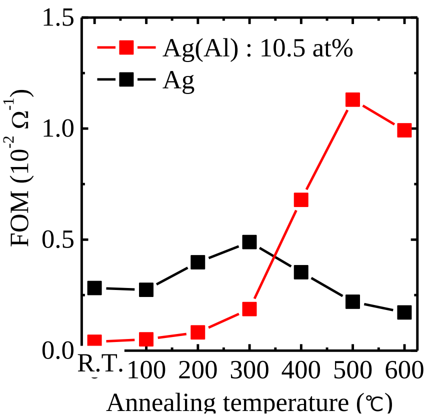

Fig. 4 Figure of merit of DMD films with pure Ag and with 10.5% Al-doped Ag layer as a function of annealing temperatures.

3. Conclusions

We investigated the effects of Al doping in Ag layer of AZO/Ag/AZO-DMD films on the thermal durability. It was revealed that Al doping was remarkably suppressed aggregation of Ag layer in DMD film under high temperature annealing. The maximum FOM of DMD with 10.5 % Al doped Ag layer was 2.2 times higher than the DMD with pure Ag.

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