Reactive DC magnetron sputter deposition of Zn:Al oxide transparent conductors

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Introduction

Thin films of Zinc oxide with different additives are widely investigated as a potential substitute to ITO. In the present work, we examine the process of deposition of Zn:Al oxide films by DC reactive magnetron sputtering of metallic ZnAl target. As for most oxides deposited by reactive sputtering, simply setting the reactive gas flow to the same value every time does not guarantee the reproducibility of the ZnAl oxide film properties. The aim of the present work was to develop a process control method with the emphasis on the simplicity of the control algorithm and the reproducibility of the film properties from run to run, and to optimize the film properties in terms of minimum electrical resistance and maximum optical transmittance.

Experimental details and results

The films have been deposited by DC magnetron sputtering of metallic ZnAl (2 weight % Al) target in an Ar+O2 and an Ar+O2+H2 atmosphere, with the deposition conditions covering the whole range from metallic to fully oxidized target surface. The sputtering was conducted in the constant power mode.

Plasma optical emission spectroscopy has been used for the process control, the optical emission spectrum for sputtering in an atmosphere of Ar+O2 is shown in Fig.1.

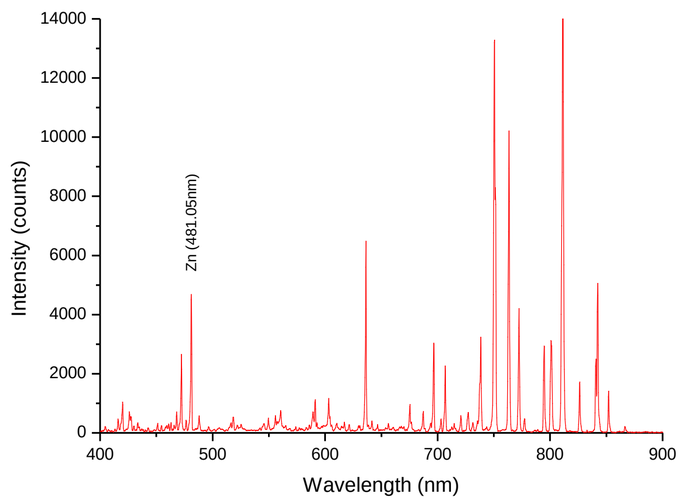

Fig.1. Optical emission spectrum upon sputtering of a metallic ZnAl (2 weight % Al) target in an Ar+O2 atmosphere.

The behavior of the Zinc emission line at 481.05 nm was investigated to address the question whether the process control can be based on a single spectral line intensity measurement.

It was found that the Zinc line intensity passes through a maximum as the oxygen content increases in the sputtering atmosphere (Fig.2).

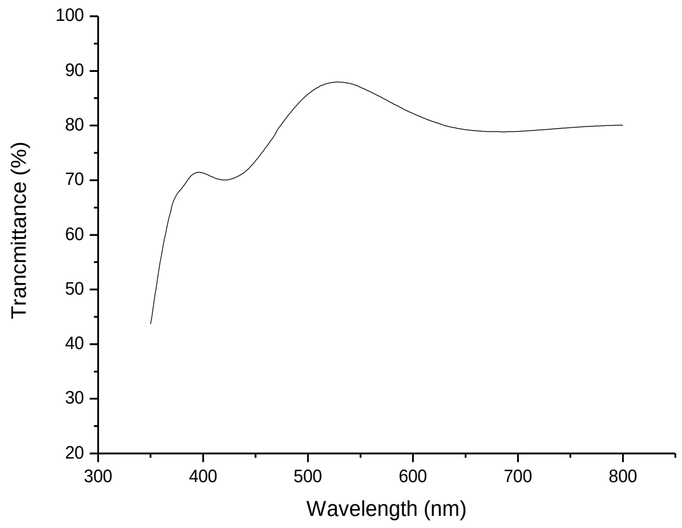

Fig.2. Zinc optical emission line intensity variation with the amount of oxygen in the sputtering atmosphere.

The optimum properties were obtained for the films deposited in the process window directly after the Zinc line intensity has started to decrease, i.e., at oxygen flows of 1.4-2 sccm.

The ratio of the Zinc emission line intensity at a certain oxygen flow and its maximum value at the peak position in Fig.1 has been found to be a reliable parameter for the process control. Even if the curves in Fig. 1 may move with respect to the oxygen flow values as a result of varying base pressure level between different vacuum cycles, developing erosion track profile upon target lifetime etc, choosing the oxygen flow so as to set the ratio IZn/IZnmax between the values of 0.6 and 0.9 was found to provide the minimum film resistivity in a reproducible way (Fig.3).

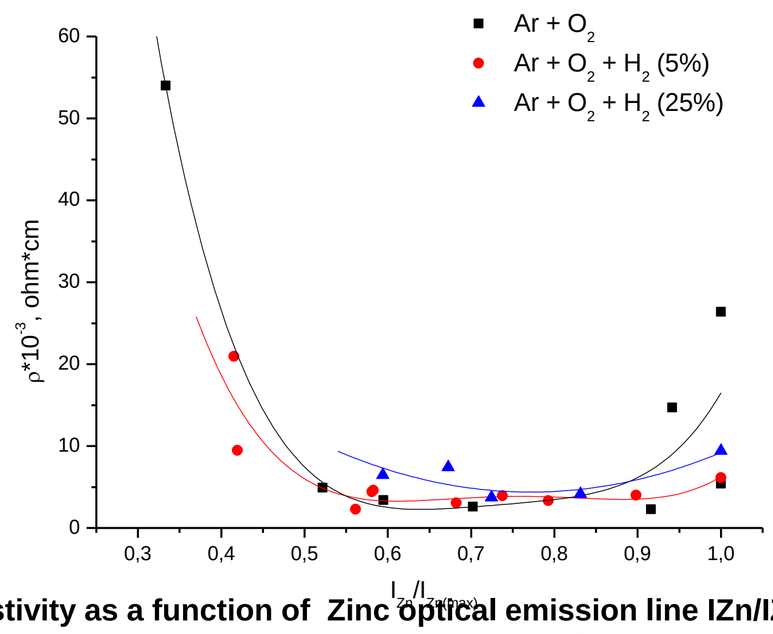

Fig.3. Film resistivity as a function of Zinc optical emission line IZn/IZnmax ratio. The IZn/IZnmax ratio range corresponds to the oxygen flow range after the maximum in Zinc line intensity is passed in Fig. 2.

Post-treatment in hydrogen plasma has been reported to reduce the electrical resistivity of Zinc oxide films [1]. We did not, however, observe any improvement in film properties by adding 5% or 25% of hydrogen to the sputtering atmosphere.

The films were optically transparent in the whole IZn/IZnmax ratio range shown in Fig.3. Transmittance curve for a 280 nm thick film with the resistance of 85 ohm/square, deposited at IZn/IZnmax of 0.9, is shown in Fig.4.

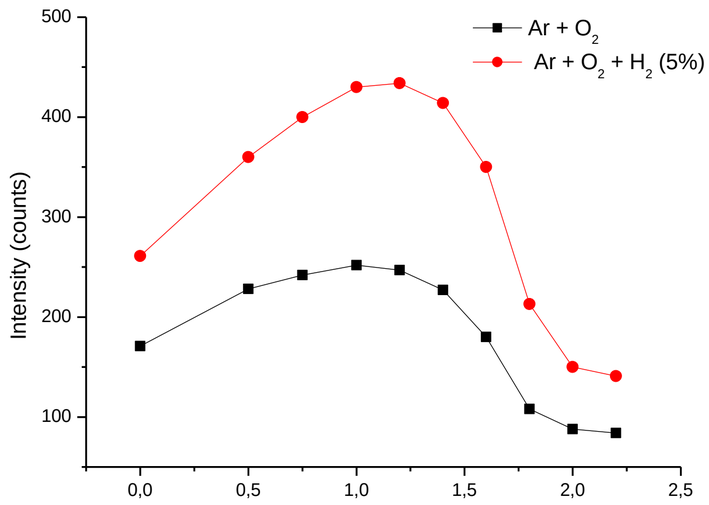

Fig.4. Optical transmittance spectrum for a ZnO:Al film deposited at IZn/IZnmax ratio of 0.9

From a single process stability point of view, monitoring of the Zinc emission line intensity would allow to implement the feedback with the oxygen flow adjustment during the deposition, if such an adjustment would be necessary. However, with the deposition time of 10 minutes for a 300 nm thick film, the Zinc line intensity was practically constant during the deposition of the films made within the present set of experiments.

Conclusion

A simple algorithm, using the oxygen flow control based on a single Zinc optical emission line intensity, has been shown to provide a sufficient level of the process control to guarantee the reproducibility of the film properties upon reactive DC magnetron sputter deposition of Zn:Al oxide films.

Reference: *1*. **Hao Chen, Hu-Jie Jin, Choon-Bae Park,** Influence of Hydrogen on Al-doped ZnO Thin Films in the process of Deposition and Annealing. *Transactions on electrical and electronic materials.*

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