DC magnetron sputter deposition of Zinc oxide based n- and p-type transparent conductor thin films

M.Zubkins, K.Vilnis, A.Ecis, R.Kalendarev, A.Azens, J.Purans
Institute of Solid State Physics, University of Latvia, Riga, Latvia
Email: purans@cfi.lu.lv

Introduction

Zinc oxide (ZnO) is a wide band gap semiconductor with potential applications in multifunctional transparent electronic devices. Developments in p-type transparent oxide semiconductors (TOSs) are of great importance for new applications as blue or ultraviolet light emitting diodes (LEDs) [1] and solid lasers [2]. Depending on the dopant, the films may exhibit either n- or p- type conductivity. The aim of the present work was to investigate the process of DC magnetron deposition of n-type conducting thin films of ZnO:Al (AZO) and p-type conducting thin films of ZnO:Ir.

Experimental details and results

AZO films were deposited by reactive sputtering from metallic (Zn=98%, Al=2%) target in an Ar+O_2 and Ar+O_2+H_2 atmosphere. IZO films were deposited by reactive sputtering from metallic mosaic targets made of Zn and Ir pieces, with Zn=92-96%, Ir=4-8% surface area. In both cases, the substrate was glass kept at ≈310°C temperature, the sputtering was conducted at 3 mTorr working pressure and 100W sputtering power.

The process was controlled by plasma optical emission spectroscopy. To achieve the highest conductivity in AZO films, and to reproduce the process conditions from run to run, the behavior of zinc emission line at 481.05 nm was investigated as a function of oxygen flow. For ZnO:Ir films, the process control was based on zinc emission line at 481.05 nm and iridium emission line at 390.25 nm. (Fig.1).

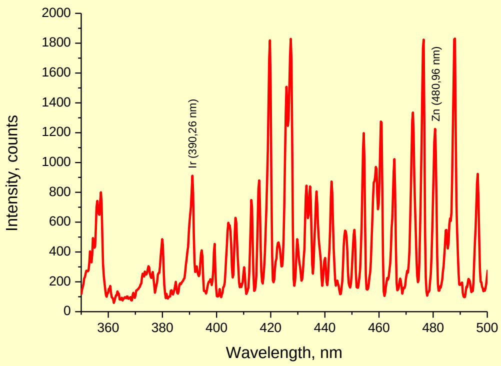

Figure 1. Optical emission spectrum upon sputtering of a metallic mosaic targets made of Zn and Ir pieces, with Zn=94%, Ir=6% surface area.

The thickness of the films was determined by using profilometer "Veeco Dektak 150". Thickness of AZO films was from 200 to 400 nm, but deposition rate for Ir:ZnO films decreased and thickness was around 75 nm for all samples. The resistance of the films was measured using a 2 point method with aluminium contacts and the resistivity was calculated. Fig. 2 shows resistivity depending on the oxygen gas flow. The lowest resistivity $2.3 \cdot 10^{-3}$ Ωcm of AZO film was achieved at 1.2 sccm oxygen gas flow. Resistivity of ZnO:Ir films sharply increased and lowest value of resistivity was $25 \cdot 10^{-3}$ Ωcm at 2.5 sccm oxygen gas flow.

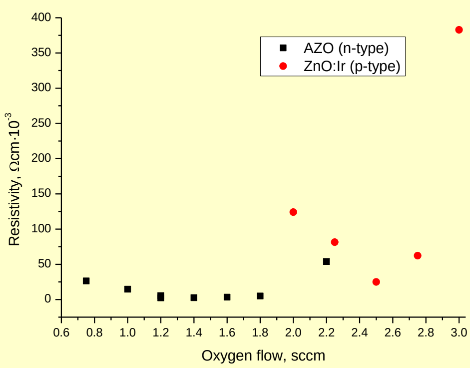

Figure 2. Resistivity of AZO and ZnO:Ir depenting on the oxygen gas flow.

The carrier concentration and the Hall mobility were obtained from Hall-effect measurement by Van der Pauw technique. Both carrier concentration and Hall mobility of ZnO:Ir were lower values compared to AZO films. Poor Hall mobility of ZnO:Ir films (below 1 $cm^2/V \cdot s$) points to amorphous structure.

The optical transmittance of the films was determined using UV/vis spectrophotometer "Specord 210". The average transmittance of AZO films was 85 % in the range of visible light (390-750 nm). Electrical and optical properties of AZO films were independent of hydrogen presence in the sputtering gas. Transmittance of Ir:ZnO was from 38 to 44 % depending on oxygen gas flow and Ir surface area on target. The highest transmittance of ZnO:Ir was achieved at 3.0 sccm oxygen flow and 6 % Ir surface area on target.

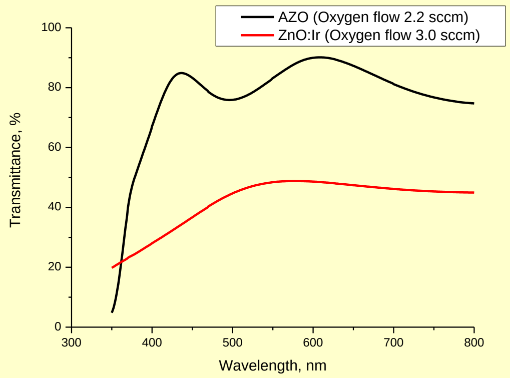

Figure 3. Transmittance of AZO and ZnO:Ir depending on the wavelength.

The structural analysis was carried out by x-ray diffraction (XRD) measurement. XRD showed that AZO have polycrystalline structure, but ZnO:Ir amorphous structure.

Zn emission line (481.05 nm) intensity passes through a maximum at about 1.2 sccm oxygen flow according to the process. The highest conductivities were achieved at I(Zn)/I(Zn,max) intensity ratio 0.6 to 0.9. Ir emission line (390.25 nm) was not a significant dependence on oxygen flow.

Discussion and conclusion

Obtaining doped p-type TCOs was found to be more difficult than n-type [2]. P doping of ZnO is difficult, requiring delicate film growth techniques at high deposition temperatures [1].

Our experiments showed that AZO films presents better optical and electrical properties than Ir:ZnO films. Improvements of Ir:ZnO films could be achieved at higher substrate temperatures.

Acknowledgements

The work has been performed within the ERAF Projects 2010/0272/2DP/2.1.1.1.0/10/APIA/VIAA/088.

References

[1] M. Dekkers, G. Rijnders, Dave H. A. Blank, Applied Physics Letters 90, 021903 (2007) 1-3.
[2] Luis Castaneda, Materials and Applications 2 (2011) 1233-1242.