ELECTRICAL AND OPTICAL PROPERTIES OF INDIUM DOPED ZINC OXIDE THIN FILMS

Shamsul Nizam Abdul Rahman, Afendi Shafii, Anis Faridah Md Nor, Burhanuddin Kamaluddin

Physics Department, Faculty of Science, University of Malaya
50603 Kuala Lumpur

ABSTRACT

Thin films of zinc oxide were deposited using r.f. magnetron sputtering on glass substrates. The films were transparent with an energy gap of about 3.4 eV. Doping with indium improves the conductivity of the zinc oxide films. Doping level of about 1.8 at.% indium was found to give zinc oxide films with the lowest resistivity of about $10^{-2}$ Ωcm.

Introduction

Zinc oxide thin films have many practical applications owing to its interesting properties. Its piezoelectric properties can be used in various pressure transducers, acoustic wave and acoustic-optical devices [1,2]. An important application of ZnO thin film is the growth of GaN films. The lattice spacing and thermal expansion of ZnO is very close to that of GaN which makes it a good candidate as a buffer layer for growing GaN films. GaN is an important material for fabricating blue light-emitting diode [4]. ZnO has a large band gap and thus it is transparent. In stoichiometric form ZnO is an insulator. Doping with impurities such as Al and In can increase the conductivity of ZnO. The combination of high visible transparency and low electrical resistivity is very useful in applications such as transparent electrodes in solar cells and in display devices [3].
Experimental Method

The zinc oxide thin films were deposited on glass substrates using r.f. magnetron sputtering (Edwards). A 3-inch pure zinc oxide target (99.99%) was used. Indium doping was achieved by placing indium wires on the target prior to deposition. All deposition was carried out at 150W r.f. power and at 1 mtorr pressure. Ar gas was used as the sputtering gas. The substrate was not heated intentionally. Deposition was carried out over about 30 minutes giving film with thickness around 1 μm. Thus the effective deposition rate was about 5 Å s⁻¹.

Results and Discussions

The as deposited undoped zinc oxide thin films are slightly yellowish in colour. Optical transmission measurements show that transmission is about 80% for the lightly doped samples. Heavily doped samples show a considerable attenuation in the infra red region. This can be clearly seen in figure 1. The attenuation of infra red transmission is due to the plasma edge shifting closer towards the visible region. This shift is due to the presence of large numbers of free carriers introduced by the dopants, in this case indium ions. Upon further increase in doping, the transmission spectrum is similar to the very lightly doped case. In samples with a large number of free carriers, another effect is usually observed namely the Burnstein-Moss effect. This is the widening of the measured energy gap. As can be seen in table 1, this effect is also observed in our indium doped samples.

The deposited films are all polycrystalline and show preferred orientation. This can be seen from XRD patterns as shown in figure 2. The most prominent peak is from the (002) plane. This is in agreement with other workers that found similar preferred orientation for their films [5,6].
The resistivity was measured using a two-point probe technique using aluminium contacts on the zinc oxide surface. Current-voltage curves show straight line characteristics and this indicate that the contacts are ohmic. Resistivity measurements shown in table 1 indicates the presence of an optimum doping level for producing films with the highest conductivity. The optimum doping level is about 1.8 at.% and this in agreement with other workers [7,8].

### Conclusions

The conductivity of zinc oxide thin films can be increased by doping with indium. These indium ions introduce donor levels close to the conduction bands and thus are thermalised at room temperature. This results in the presence of large numbers of free carriers and produce the shifting of the measured energy gap. The optimum indium doping for producing highly conducting zinc oxide thin films is about 1.8 at.%.

<table>
<thead>
<tr>
<th>Indium doping (at. %)</th>
<th>Energy gap (eV)</th>
<th>Resistivity (Ωcm) x10^{-2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>3.39</td>
<td>39.5</td>
</tr>
<tr>
<td>1.8</td>
<td>3.63</td>
<td>1.9</td>
</tr>
<tr>
<td>3.3</td>
<td>3.49</td>
<td>2.5</td>
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<td>5.5</td>
<td>3.47</td>
<td>74.0</td>
</tr>
</tbody>
</table>

Table 1. Variation of film resistivity and energy gap with indium doping level.
Acknowledgements

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References

Figure 1. Transmission spectra of indium doped zinc oxide films
(a) 1.0 at.%, (b) 1.8 at.%, (c) 3.3 at.% and (d) 5.6 at.%. 
Figure 2. XRD patterns form indium doped zinc oxide films
(a) 1.0 at.%, (b) 1.8 at.%, (c) 3.3 at.% and (d) 5.6 at.%.