The electrical and optical properties of zinc oxide films deposited by DC sputtering

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Zinc oxide (ZnO) in its film form is an n-type semiconductor and has gained much interest in research community because of better optical properties such as uv-visible luminescence. It is a known fact that the intrinsic and extrinsic defects in ZnO control the optical and electrical properties. The ZnO films were deposited on glass substrates by sputtering using vacuum arc produced from pure metal plate of zinc (99.9%) in oxygen (O_2) and nitrogen (N_2) atmosphere. The XRD analysis revealed the role of oxygen ambience in crystallanity of the films. Photoluminescence (PL) measurement suggested that there is no chance of sharp reemission from both films. Transmission and sheet resistance studies infer that ZnO films deposited in oxygen ambience is a better candidate for transparent conducting electrodes. The optical band gaps were determined and found to be equal to 3.47 and 3.35 eV for films deposited in O_2 and N_2 atmosphere, respectively.

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1. Introduction

For many years Zinc oxide (ZnO) is gaining more and more interest because of its better optical and electrical properties. The knowledge of different parameters which controls the native defect formation in ZnO films makes possible to improve its optical and electrical properties [1-10]. It is a fact that the deposition method is a main factor controlling the different properties of ZnO films because the type of defect formed and its concentration depend on the deposition technique and different deposition parameters such as temperature, partial pressure etc.[2-4, 7-11, 18-19]. The most common technique for deposition of ZnO films is dc sputtering. The structural, electrical and optical properties of the film can be easily controlled by adjusting the sputtering parameters [1, 13-15]. Dc sputtering involving vacuum arc process is an ion plating method that exhibits a high deposition rate, excellent adhesion and ease of system scale up. The major disadvantage of the process is the emission of macro droplets from the target metal and their adhesion to the films under preparation.

In this paper the optical and electrical properties of ZnO films deposited by dc sputtering using pure Zn metal plate as target is discussed. To study the effect of extrinsic defect in the structural, electrical and optical properties of the films, the film is deposited in nitrogen atmosphere also.

2. Experimental

The ZnO films were deposited on glass substrates by sputtering using vacuum arc produced from pure metal plate of zinc (99.9%) in oxygen (O_2) and nitrogen (N_2) atmosphere without using a sputtering gas such as Argon (Ar). The optimized current was found to be 15 mA at 0.2 m bar pressure. The electrical sheet resistance of the sample was measured using four-probe and the thickness of the films was identified by surface profiler. The optical properties were recorded using a UV-visible spectrometer and fluorescence spectrometer (Jobin Yvon, Fluorolog-3) for an excitation wavelength of 350 nm (3.53eV) from Xe-lamp.

3. Results and discussion

3.1. XRD analysis

The XRD spectrum of ZnO films in N_2 and O_2 atmosphere were shown in Fig. 1. The Fig. 1 establishes that the films prepared were of poor crystalline characteristics. However the sample deposited in O_2 atmosphere the preferred orientation is along (101) plane. Poor crystallanity may be due to the low oxygen ambient during film formation.

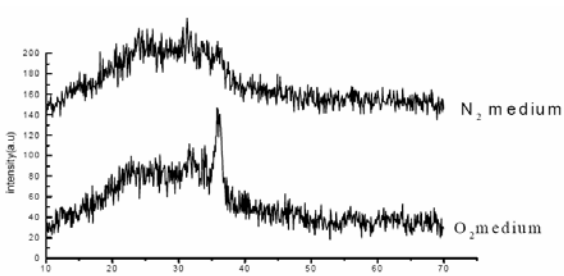

Fig. 1. XRD pattern of ZnO films deposited by sputtering in different at different medium.

3.2. Electrical properties

The electrical sheet resistance of the film deposited in O_2 medium was about 8 KΩ/□ and 812 KΩ/□ for the film deposited in N_2 atmosphere. The sheet resistance of ZnO film prepared in O_2 atmosphere showed least resistance. This may be due to the high concentration of shallow donors created. In the case of sputtering, there is chance of formation of Zn_I along with V_O; because sputtering deals with highly energetic plasma evolution [2, 4, 11]. Also in low oxygen partial pressures, the densities of both point defects, Zn_I and V_O, are high [2, 8, 9]. So the film may contain enough intrinsic donors (Zn_I or V_O) to provide sufficient n type conductivity.

The p-type doping in ZnO films may be possible by substituting group V elements (N, P and As) for oxygen sites [1]. The theoretical suggestions predicted that 'N' is a good candidate for a shallow p type dopant in ZnO [17, 18]. When the ZnO films were deposited in N_2 atmosphere, there is chance of formation of Nitrogen (N) acceptors in the films at low pressures (0.2 m bar). The acceptors created may readily compensate the native shallow donors (Zn_I or V_O) responsible for intrinsic n type conductivity [2]. This is the reason for high sheet resistance of the sample deposited in N_2 medium. Also the poor crystalline nature is another cause of its high resistance.

3.3 Optical properties

3. 4a. Photoluminescence characteristics

The photoluminescence spectra of ZnO films deposited by sputtering in N_2 and O_2 medium is shown in the Fig. 2. The luminescence intensity is more for the sample deposited in O_2 medium. The luminescence spectrum is broad with peak emission at 413 nm. Since it is wide enough, it is impossible to assume the defect or defects behind the emission process. The emission covers the entire visible region and further study is necessary to explore its ability as a white luminescence material. The poor crystalline nature along with high density of N acceptors may be causing much smaller emission intensity from the film deposited in N_2 medium.

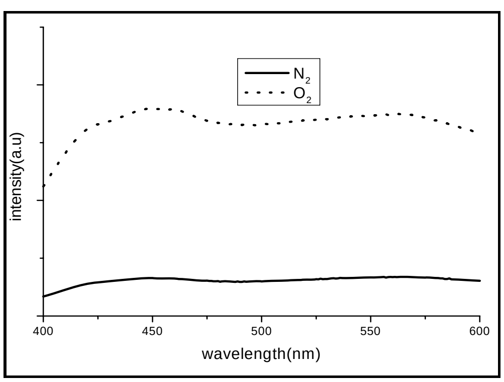

Fig. 2. The visible photoluminescence spectra of ZnO films deposited at different substrate temperatures.

3. 4b. Transmission and absorption characteristics

The optical transmission and absorption properties of films deposited in N_2 and O_2 medium is shown in figures (Fig. 3 to 6). The optical transmission of film deposited in O_2 medium has greater transmission at longer wavelength region, giving maximum at 682 nm (96.1%). The film deposited at low N_2 partial pressure, has maximum transmission at 510 nm (84 %) and the transmission decreases at longer wavelength region (Fig. 3). The decrease in transmission of the film may be due to the poor crystal quality and increased concentration of N acceptors and other defects formed at low oxygen partial pressures.

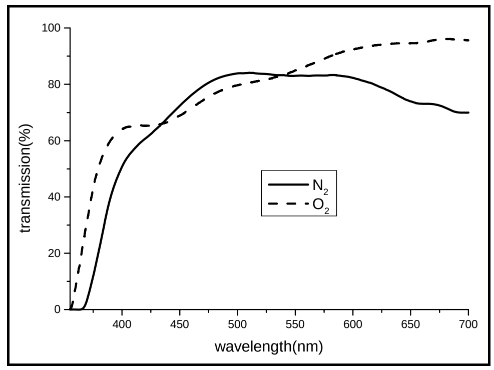

Fig. 3. Transmission spectra of ZnO films deposited at different medium.

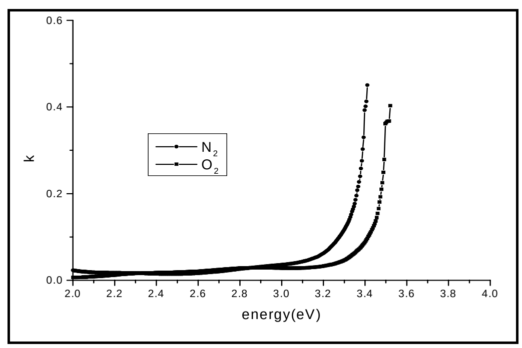

Fig. 4. Variation of extinction coefficient with photon energy of ZnO films.

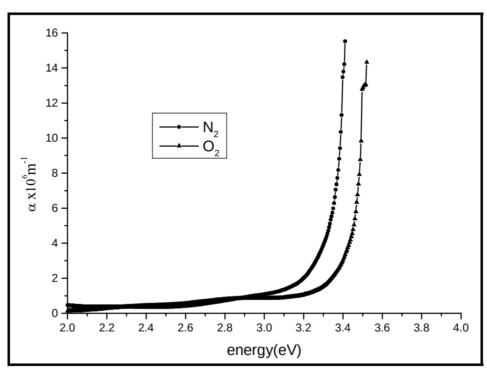

Fig. 5. Variation of absorption coefficient with photon energy of ZnO films.

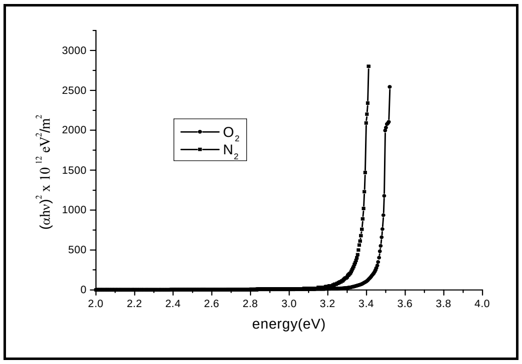

Fig. 6. The $(\alpha h\nu)^2$ vs hν plots of ZnO films.

Since there were no considerable oscillations in the transmission spectra of the films, envelop method is not used to find the thickness of the films. Thickness is determined using surface profiler. For the film deposited in O_2 ambient it was 525 nm and for that in N_2 ambient it was 421 nm. The band gap energy is determined from the $(\alpha h\nu)^2$ vs hν plot. The Optical band gap of film deposited in O_2 medium was found to be 3.47 eV while that for the film deposited at N_2 medium was 3.35 eV (Fig. 6). The increased optical band gap of the former may due to the better crystal quality which provides exciton process [1]. The variation in absorption coefficient and extinction coefficient is shown in Figs. 4 and 5 respectively.

4. Conclusions

Zinc oxide films were deposited on glass substrate by dc sputtering using vacuum arc, both in oxygen and nitrogen atmosphere at a sputtering current of 15 mA and pressure 0.2 m bar. The film deposited in oxygen ambient has least sheet resistance. When the films were deposited in nitrogen atmosphere, there is chance of N acceptor formation in ZnO films which may compensate the intrinsic donors causing increase in sheet resistance. The PL studies revealed that the emission region spreads all over the visible region, leaving a chance of white luminescence. Also the crystalline nature of films deposited in N_2 ambient was poor. The film deposited in O_2 ambient has 96% of transmission which proves it to be a very good candidate for transparent conducting electrodes. The band gaps were determined for both the samples from $(\alpha h\nu)^2$ vs hν plot and found that both films exhibit direct type transitions at 3.47 and 3.35 eV respectively

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