

Fabrication of ZnO:Zr Film Deposited on Flexible Substrate by RF Magnetron Sputtering

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Abstract: Zirconium-doped zinc oxide (ZnO:Zr) transparent conducting thin films with high transmittance, low resistivity and good adhesion were firstly prepared on water-cooled polyethylene glycol terephthalate flexible substrates by RF magnetron sputtering. X-ray diffraction and scanning electron microscopy show that the ZnO:Zr films are polycrystalline with a hexagonal structure and a preferred orientation parallel to the substrate. The lowest resistivity obtained in our experiment is $1.55 \times 10^{-3} \Omega \cdot \text{cm}$. The average transmittance of the films is over 90% in the wavelength range of the visible spectrum.

Key words: ZnO:Zr films; flexible substrates; magnetron sputtering; transparent conducting films

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1 Introduction

Transparent conducting thin films deposited on flexible substrates have many applications. They are widely used in flexible electro-optical devices, flexible liquid crystal displays, plastic thin film solar cells, transparent electromagnetic shielding materials and unbreakable heat reflecting mirrors^[1]. In recent years, Sn-doped In_2O_3 (ITO) and Al-doped ZnO (ZnO:Al) on flexible substrates have been extensively studied^[2-7]. But in our knowledge, no report was published for ZnO:Zr films prepared on flexible substrates up to now. Comparing with ITO, ZnO:Zr films have many advantages of source abundance, low cost, innocuity and good stability (in plasma). Comparing with ZnO:Al, ZnO:Zr films present higher transmittance and better hot stability. Poly-ethylene glycol terephthalate (PET) is a Promising flexible substrate due to its high optical transmittance, high melting point (about 200 °C)

and low chemical reactivity. In this letter, we firstly report the preparation and properties of ZnO:Zr films deposited on water-cooled PET substrates by RF magnetron sputtering

2 Experiments

ZnO:Zr films were deposited on various flexible substrates in a GJP500C2 model RF magnetron sputtering system with a basic pressure of 3.4×10^{-4} Pa. A sintered ceramic with a mixture of ZnO (99.99% purity) and ZrO_2 (99.99% purity) were employed as source materials. The content of ZrO_2 added to the ZnO target was 5% (mass fraction). The distance between the substrate and the target was about 50 mm. During the process of deposition, the pressure of Ar was controlled at 1.5 Pa, the sputtering RF power was maintained at 100 W for 40 min and the substrate was water-cooled at room temperature. Under these conditions, high quality ZnO:Zr films with good adhesion, high

transmittance and low resistivity were obtained without damage to the flexible substrates. The structure and morphology properties of the films were analyzed with a D8 ADVANCE XRD using $\text{CuK}\alpha_1$ radiation ($\lambda=0.154\,06\text{ nm}$) and a Sirion 200 SEM. The optical transmittance measurements were performed with a TU-1901 UV-vis spectrophotometers.

3 Results and Discussion

3.1 X-ray Diffraction Analysis

Fig. 1 shows the X-ray diffraction spectrum of a typical $\text{ZnO}:\text{Zr}$ film deposited on water-cooled PET substrate at room temperature and 100 W for 40 min. The $\theta-2\theta$ scan data of the $\text{ZnO}:\text{Zr}$ film only exhibits a strong peak at $2\theta=31.13^\circ$, which is very close to the preferred orientation of the standard ZnO crystal (31.38°) and corresponding to the (100) peak. This indicates that the $\text{ZnO}:\text{Zr}$ film is polycrystalline with a hexagonal structure and a preferred orientation parallel to the substrate. A previous study showed that the preferred orientation for $\text{ZnO}:\text{Zr}$ films was dependent on the experimental conditions^[8]. The full-width at half-maximum (FWHM) of the (100) diffraction peak is calculated as 0.66° , and then the crystallite size is calculated as 13.9 nm according to the Scherre formula $D=0.89\lambda/(B\cos\theta)$. Thus we can conclude that the $\text{ZnO}:\text{Zr}$ film deposited on PET substrate is nano-structural crystal.

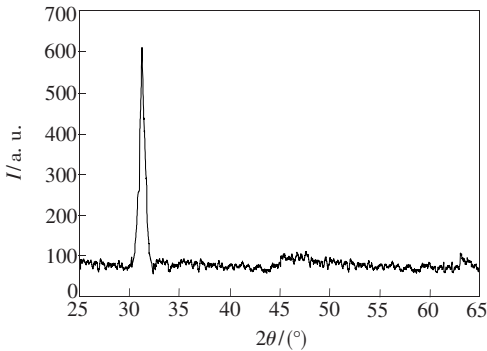


Fig. 1 XRD spectrum for a $\text{ZnO}:\text{Zr}$ film deposited on PET substrate

3.2 SEM Analysis

Fig. 2 shows the scanning electron microscopy(SEM) image of a typical $\text{ZnO}:\text{Zr}$ film deposited on water-cooled PET substrate at room temperature and 100 W for 40 min. The $\text{ZnO}:\text{Zr}$ film consists of some flat structural grains, representing a preferred orientation parallel to the substrate, which agrees with the X-ray diffraction(XRD) results.

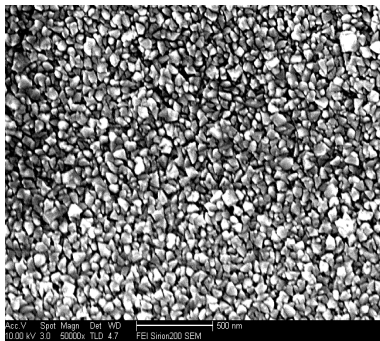


Fig. 2 SEM image of a $\text{ZnO}:\text{Zr}$ film deposited on PET substrate

3.3 Optical Transmittance

The optical transmittance as a function of the wavelength for the same sample of about 200 nm thickness was measured, as shown in Fig. 3. The average transmittance in the range of 400~800 nm wavelength is over 90%. The adhesion to the substrate for high quality films was good, no breakup and fall-off were observed when the films were folded many times.

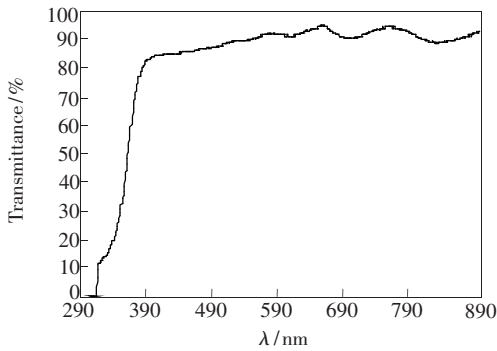


Fig. 3 Optical transmittance as a function of the wavelength for the same sample

3.4 Electrical Resistivity

The electrical resistivity of $\text{ZnO}:\text{Zr}$ films

deposited on water-cooled PET substrates lies on the experimental conditions. In our experiment, the lowest resistivity achieved is $1.55 \times 10^{-3} \Omega \cdot \text{cm}$ with a thickness of about 200 nm at the optimized conditions of 100 W, 1.5 Pa and 40 min.

4 Conclusion

ZnO:Zr films with high transmittance, low resistivity and good adhesion were firstly prepared on flexible substrate PET by RF magnetron

sputtering. XRD and SEM show that the ZnO:Zr films are polycrystalline with a hexagonal structure and a preferred orientation parallel to the substrate. The lowest resistivity obtained in our experiment is $1.55 \times 10^{-3} \Omega \cdot \text{cm}$. The average transmittance of the film is over 90% in the wavelength range of the visible spectrum. This result may be useful for inaugurating the potential applications of ZnO:Zr films in flexible devices.

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利用射频磁控溅射法在柔性衬底上 制备 ZnO:Zr 透明导电薄膜

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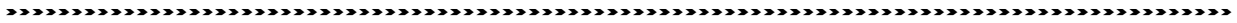
摘 要

利用射频磁控溅射法首次在室温水冷柔性衬底 PET 上制备出了可见光透过率高、电阻率低的掺锆氧化锌(ZnO:Zr)透明导电薄膜。X 射线衍射和扫描电子显微镜表明,ZnO:Zr 薄膜为六角纤锌矿结

构的多晶薄膜,且具有平行于衬底方向的择优取向。实验获得 ZnO:Zr 薄膜的最小电阻率为 $1.55 \times 10^{-3} \Omega \cdot \text{cm}$ 。实验制备的 ZnO:Zr 薄膜具有良好的附着性能,其可见光区平均透过率超过 90%。

关 键 词: ZnO:Zr 薄膜;柔性衬底;磁控溅射;透明导电薄膜

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