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Optical waveguide and 1.54 μm photoluminescence properties in RF sputtered Er/Yb-doped ZnO thin films

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ABSTRACT

The erbium-doped ZnO films were deposited on SiO_2 glass and MgO crystal substrates by RF-magnetron sputtering and were characterized by the use of photoluminescence, X-ray diffraction, Rutherford backscattering spectrometry and field emission scanning electron microscopy. The results show that the films fabricated on SiO_2 glass substrate are highly c-axis oriented. The Er-doped films emit photoluminescence spectra centered at 1.54 μm, and the emission intensity is strongly related with substrate temperature. The waveguiding properties of the Er-doped ZnO film on SiO_2 glass substrate are demonstrated by prism coupling. Both TE and TM modes are measured at 633 nm.

1. Introduction

Rare-earth doped materials, especially erbium-doped, have attracted researchers' attention due to their wide range of applications. The optical properties of these materials are desired in amplifiers, lasers and NIR-to-visible up-converters applications [1–3]. The 1.54 μm emission comes from the intra-4*f*-transition $^4I_{13/2}$–$^4I_{15/2}$ of Er^{3+}, which is within a wavelength range of a minimum loss for silica optical fiber [4]. The emission spectrum of Er^{3+} is independent of host materials, but the intensity and efficiency mainly depend on the host materials. A great deal of work has been carried out in order to enhance the Er-related emission. It has been reported that the Er-related 1.54 μm emission could be effectively enhanced by oxygen co-doping and selecting wide bandgap oxide materials as hosts [5,6]. Therefore, ZnO is expected to be one of the profitable candidates which fulfill both conditions of wide-band-gap and inherent oxygen. Moreover, ZnO has high electrical conductivity, which becomes one of the most promising materials for the next generation optoelectronic devices [7,8].

Several ways have been investigated for Er doping, such as bulk doping, ion implantation and Er-containing thin film [9–11]. Compared with the other ways, Er-containing thin films deposited on a low-refractive-index substrate will allow strong confinement of light and ultra compact photonic devices, which is a favorable feature of the waveguide in systems of integrated optics [12–14].

In the present work, we present the deposition of Er/Yb-doped ZnO thin films on SiO_2 glass and MgO crystal substrates by radio frequency (RF) magnetron sputtering technology. The sputtered erbium-doped thin films have been characterized by X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM) and Rutherford backscattering spectrometry (RBS). The Er^{3+} related photoluminescence (PL) and the optical waveguiding properties of the Er/Yb: ZnO films have also been studied.

2. Experimental

Er/Yb-doped ZnO thin films were sputtered by an RF-magnetron sputtering system (FJL56) on SiO_2 glass and MgO crystal substrates. The ZnO target was co-doped with 1 wt.% Er_2O_3 and 4 wt.% Yb_2O_3. The deposition of Er/Yb: ZnO film was carried out in a vacuum chamber evacuated to a base pressure of 10^{-4} Pa and backfilled with an Ar: O_2 ambient. The chamber pressure was maintained at a constant value of 0.7 Pa. The substrates were rotated at the speed of 20 rpm, and substrate temperature varied from room temperature (RT) to 800 °C.

The structural properties of the films were analyzed by X-ray diffraction (XRD, Rigaku, MiniFlex600). The surface morphology of the film was investigated with field emission scanning electron microscopy (FESEM, JEOL, JSM-6700F). The composition and thickness of the films were determined by Rutherford backscattering technique using 2.022-

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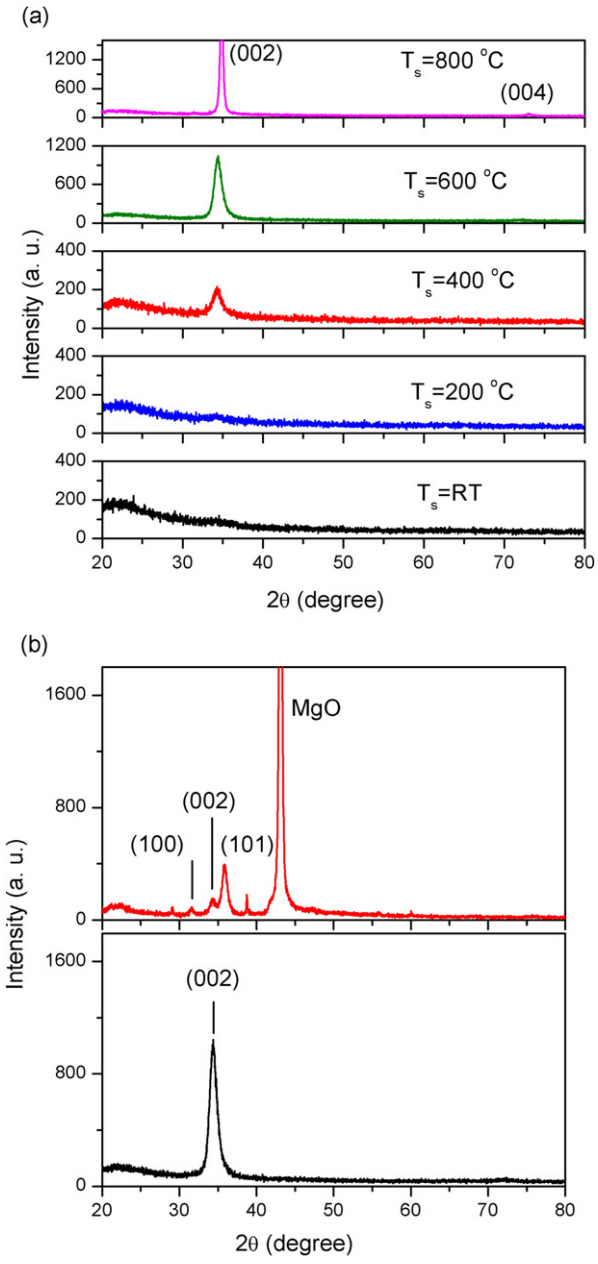

Fig. 1. XRD patterns of Er/Yb: ZnO films (a) on SiO_2 glass substrate at different temperature, (b) on SiO_2 glass and MgO crystal substrates at 600 °C.

MeV He ion beam and a detection angle of 165°. Photoluminescence (PL) measurements were carried out at room temperature. The Ar-ion laser operating at 514 nm was used as a pump source. The luminescence signal was detected using a Fourier transform infrared spectrometer (Nicolet 860) equipped with an InGaAs detector with resolution of 8 cm^{-1}. Optical waveguide properties were studied by prism coupling method (Metricon Model 2010 prism coupler). In the prism coupling experiment, a TiO_2 (rutile) prism and Otto configuration were used.

3. Results and discussion

Fig. 1(a) shows the XRD patterns of the Er/Yb: ZnO films fabricated on SiO_2 substrate for 7 h at different substrate temperatures. As can be observed, the films fabricated at RT do not show obvious diffraction peak, which indicates a poor crystallinity. When the temperature of the substrate is 200 °C, the diffractogram contains a contour of diffraction peak at 34.0°, which suggests that the film begins to crystallize. With the increase of the substrate temperature in the range of 400–600 °C, only one strong ZnO (002) peak is exhibited, which indicates the completely c-axis oriented growth. This suggests that the oriented growth begins to be noticeable at substrate temperature higher than 200 °C. When the substrate temperature is increased to 800 °C, in addition to a strong (002) peak, a weak ZnO (004) peak at 72.9° appears. It can be found from Fig. 1(a) that the intensity of (002) peak increases with the increase of substrate temperature. In addition,

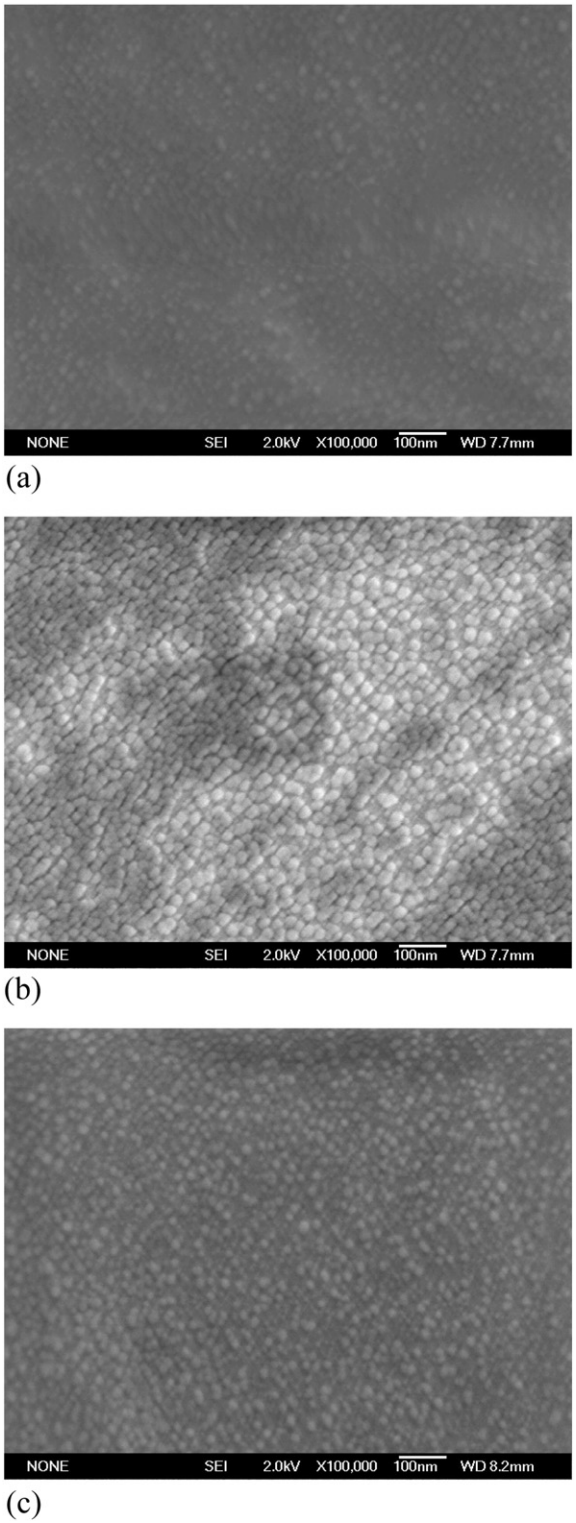

Fig. 2. FESEM micrographs of the Er/Yb: ZnO films (a) on SiO_2 glass substrate at room temperature, (b) on SiO_2 glass substrate at 600 °C and (c) on MgO crystal substrate at 600 °C.