



Erbium containing ZnO prepared by ion beam sputtering deposition and thermal annealing mixing

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ABSTRACT

Erbium containing ZnO was prepared by ion beam sputtering deposition and thermal annealing. Alternate ZnO and erbium layers were deposited on silicon substrates at room temperature. Annealed sample shows mixing of erbium and ZnO layers, while strong 980 nm emission was observed under the excitation of a 325 nm laser which is due to the inner 4f transition of Er^{3+} from $^4\text{I}_{11/2}$ to $^4\text{I}_{15/2}$. Under the optimized annealing condition, more than 80% of oxygen atoms are still located in stoichiometric ZnO matrixes. X-ray diffraction analysis shows a shift of ZnO (0 0 2) diffraction peak position to the larger angle value, indicating an elongated *c*-axis and suggesting the incorporation of erbium ions into ZnO. Variable temperature photoluminescence analysis indicates that the emission at 980 nm is due to energy transfer from defect-related deep level emission of host ZnO to erbium ions.

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1. Introduction

Erbium is an essential element in optical telecommunication technology due to its 1.54 μm emission at which silica-based fiber has minimum attenuation and near zero dispersion. Beside the 1.54 μm emission, near infrared emission at ~ 980 nm from erbium may also find valuable medical applications [1]. The incorporation of erbium into semiconductor materials, especially silicon, has been intensively studied [2] that the integration of opto-electronic integrated circuits may become a reality. However, erbium doped silicon is plagued with low equilibrium solubility ($\sim 10^{18}$ atoms/ cm^3) and thermal quenching effects [3] that useful emission from erbium doped Si has not been achieved. On the other hand, erbium doped ZnO have shown promising results [4–14]. Erbium doped ZnO have been prepared by laser ablation [7], ion implantation [8,9], sol–gel [10], thermal evaporation [11,12], and RF magnetron sputtering [13], while the luminescence efficiency of 1.54 μm is greatly enhanced by the incorporation of nitrogen [4] or Li [14]. In this article, we report the growth and characterization of erbium containing ZnO by ion beam sputtering deposition utilizing a capillaritron ion source. Capillaritron ion source is a versatile ion source that does not require sophisticated power supply systems. Capillaritron ion sources are capable of operating between 4 and 20 kV for almost any gases which makes it suitable for ion beam sputtering [15] and ion implantation applications [16]. In this study, alternate layers of ZnO and erbium

are deposited on silicon (1 0 0) substrates at room temperature and the mixing of erbium with ZnO is achieved through post-growth annealing. This approach excludes the use of expensive compound oxide targets and simplifies the thin film growth procedure.

2. Experimental

Erbium containing ZnO was prepared by ion beam sputtering deposition utilizing a capillaritron ion source [15]. Erbium (99.99%) and ZnO (99.99%) targets were positioned on opposite side of a target holder which was mounted on a rotational feedthrough. A capillaritron ion source was positioned at 30 mm away from the center of the target holder and was positioned at an angle of 30° relative to the normal of the target. Silicon (1 0 0) substrates were positioned at 30 mm away from the target and were positioned almost parallel to the target. Alternate layers of erbium and ZnO were deposited on silicon substrates with a total period of 10 by rotating the target holder in vacuum. The sputtering time was 10 min for each target that result in a total film thickness of ~ 100 nm. The base pressure and growth pressure were 4×10^{-6} and 5×10^{-4} Torr, respectively. The anode current and anode voltage of the capillaritron ion source were fixed at 350 μA and 10 kV, respectively. The target current density was measured by a Faraday cup and was found to be 0.2 mA/ cm^2 . The effect of annealing on the properties of ZnO thin films without erbium layers was first characterized by photoluminescence (PL) and X-ray photoelectron spectroscopy (XPS). PL study was performed utilizing a 35 mW He–Cd laser at 325 nm as the excitation light source and the spectra were dispersed by a Horiba Jobin Yvon iHR 550 spectrometer and detected by a Symphony CCD detector

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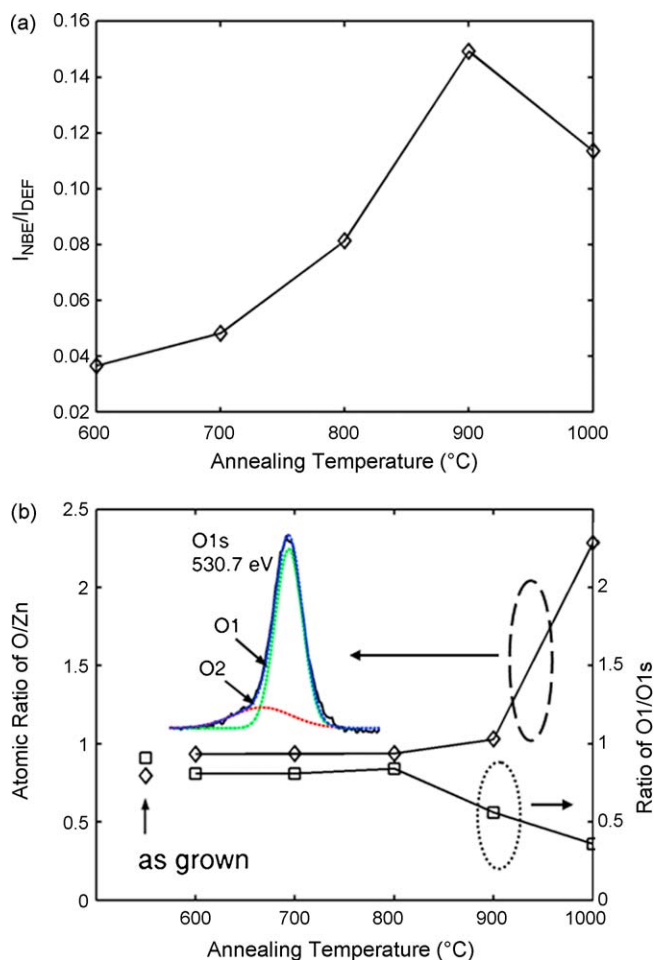


Fig. 1. (a) Ratio of $I_{\text{NBE}}/I_{\text{DEF}}$ after annealing and (b) atomic percentage ratio of O/Zn and the deconvolution area ratio of O1/O1s.

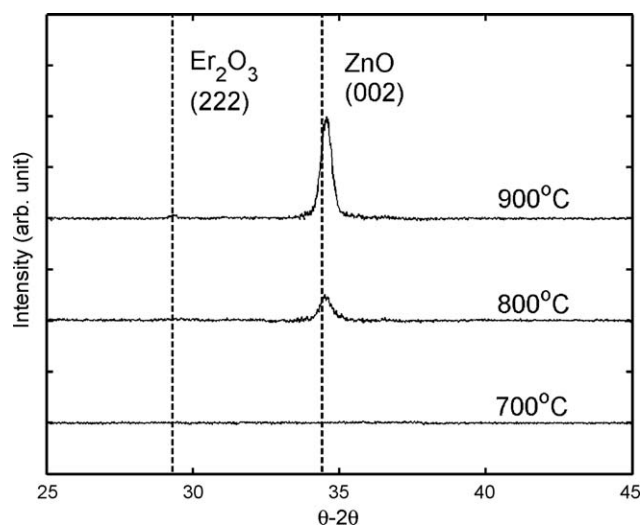


Fig. 2. X-ray diffraction pattern of ZnO/Er multilayer structures after annealing at 700, 800 and 900 °C, all for 30 min in an atmospheric environment.

cooled to -70°C . Variable temperature PL was obtained by mounting the sample on a close-cycled helium cold finger. Annealing of ZnO single layer or ZnO/Er multilayer structures were performed in atmospheric environment from 600 to 1000 °C. XPS analysis was performed in a VG ESCA[®] Scientific Theta Probe system using an Al $K\alpha$ source at 1486.4 eV with an X-ray probe spot size of 400 μm . Before XPS analysis, samples were etched with a 5 keV argon ion beam for 5 min to remove surface contamination. The crystallinity of the ZnO/Er multilayer structures was analyzed by X-ray diffraction (XRD) utilizing a 12 kW Rigaku D/MAX 8 X-ray diffractometer (Cu $K\alpha$, $\lambda = 0.1541\text{ nm}$), while cross-sectioning morphology of the film was investigated utilizing a field emission scanning electron microscope (FE-SEM, JEOL[®] JSM-6500F) operating at 15 keV. Secondary ion mass

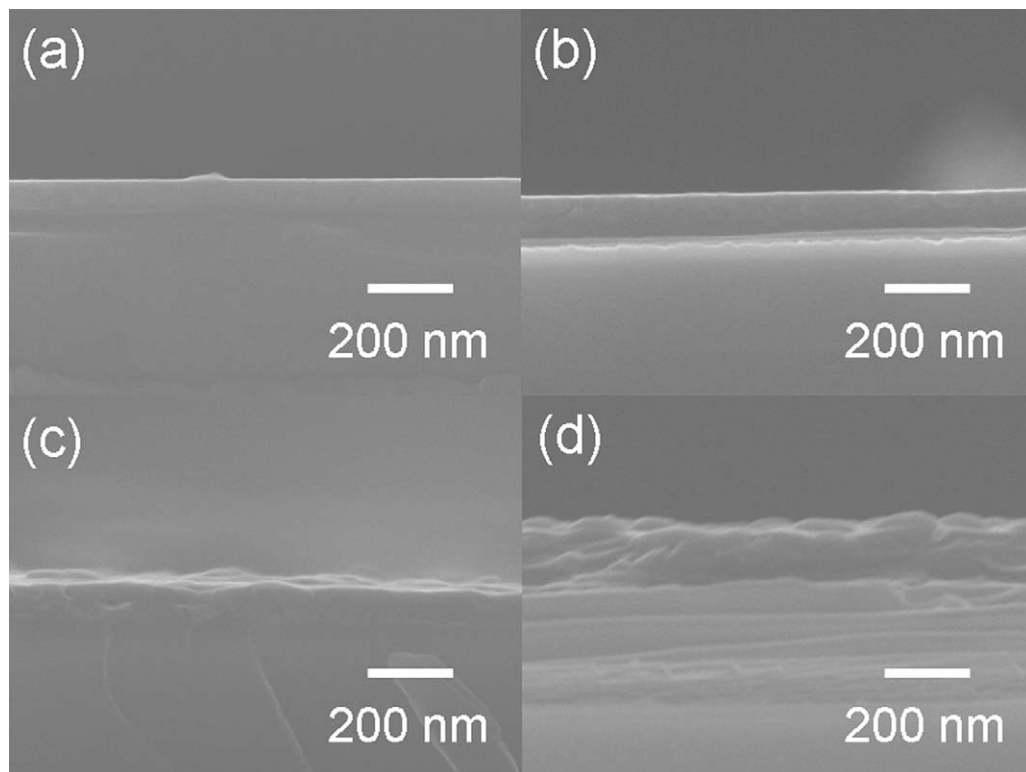


Fig. 3. Cross-sectioning FE-SEM micrograph of ZnO/Er multilayer structures annealed at (a) 700, (b) 800, (c) 900 and (d) 1000 °C, all for 30 min in an atmospheric environment.

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