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Growth and characterization of heteroepitaxy ZnO thin film on sapphire substrate with ion implantation followed by thermal oxidation-some preliminary results

Tu Anh TRINH*, In Seok HONG, Hwa Ryun LEE, Yong Sub CHO
PEFP, KAERI, P.O.Box 105, Yuseong, Daejeon, Korea
**Corresponding author: tuanh@kaeri.re.kr*

1. Introduction

ZnO thin film is one of the metal oxide semiconductors which are widely used in light emitting/ laser applications. Recently, ZnO has gained a new substantial interest primarily because of its potentialities for spintronic, as predicted by Dielt et. al. [1]. Methods for fabricating ZnO include metal-organic chemical vapor deposition, pulsed laser deposition, electron beam physical vapor deposition, molecular beam epitaxy, ion implantation, etc. Among them, ion implantation has several advantages such as easy and precise control of the dopant concentration, elimination of the contamination and avoidance of the secondary phase. In the previous studies, ZnO films were formed in transparent insulators such as silica glass SiO_2 [2], MgO [3] by several methods. In the present research, we employed ion implantation method combined with thermal oxidation to fabricate ZnO thin film on sapphire substrate. X-ray diffraction (XRD) and Auger Electron Spectroscopy (AES) were applied to characterize the structure of these films.

2. Method

(001) α-Al_2O_3 single crystals were implanted by 50 keV zinc ions with a dose up to 1.5×10^{17} ions cm^{-2}, confirmed by proton induced X-ray emission (PIXE) method. The sapphire substrate was treated by acetone for 10 minutes before being loaded into the chamber. The Zn^+ beam current density was 2 $\mu A\ cm^{-2}$ to keep the substrate temperature below 100^0C during the implantation process. The samples were tilted off-axis by 7° to avoid channeling effect. The implanted samples were annealed in a conventional furnace in air at different temperatures from 500^0C to 800^0C with a step of 100^0C in 2 hours. XRD was carried out by Rigaku system using a Cu-X ray source.

3. Results and Discussion

Figure 1 shows x-ray diffraction XRD scans for the ZnO films grown on sapphire (001) at different annealing temperatures. The peak at $2\theta = 34.42^0$ corresponds to (002) direction of the hexagonal ZnO structure, the others refer to the sapphire substrate. When the annealing temperature was as low as 500^0C, the intensity of ZnO peak was low (Fig. 1a), indicating just a small fraction of ZnO was formed. However, after being annealed at higher temperature, Zn^+ ions in the substrate were totally oxidized and formed ZnO phase, which can be seen in Fig. 1b and 1c. This can be explained as following: when annealing temperature was much higher than 419^0C, the melting point of Zn in the bulk (700^0C, for example), the pressure of Zn steam was high making a diffusion of Zn atoms into the substrate's surface during thermal oxidation process and forming ZnO. Therefore, annealing temperature is an important key to form the ZnO films.

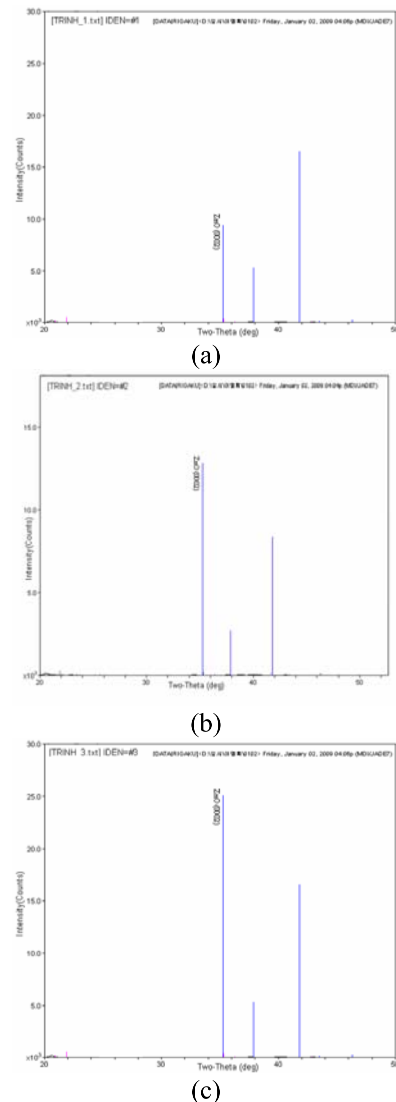

Fig 1 XRD spectra for annealing Zn-implanted sapphire substrate sample at different temperatures (a) 500^0C, (b) 700^0C, and (c) 800^0C in 2 hours.

The average grain size of the ZnO films can be determined by applying the Scherrer equation [4] to the full width at half maximum (FWHM) of the (002) peaks, as given by:

$$D = \frac{57.3 \times K\lambda}{\beta \cos\theta} \qquad (1)$$

where K is the particle shape factor and taken as 0.9, λ is the wavelength of Cu Kα radiation (0.154056 nm), β is the calibrated half intensity width of the selected diffraction peak in radians and θ is the Bragg angle (half of the peak position angle). The smaller FWHM in the single-crystal ZnO films indicates that the concentration of defects in the ZnO films is low and the quality of these films is high. As shown in Fig. 2, the FWHM of (002) diffraction peaks, correspondingly the grain size of films, decrease with an increasing in annealing temperature. It is observed that the grain size greatly increases from 17 to 23 nm on increasing the annealing temperature from 500^0C to 800^0C

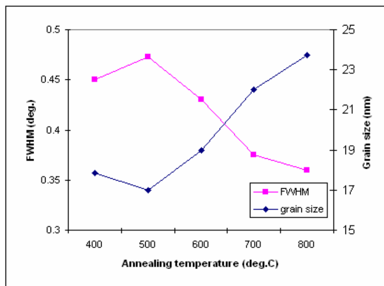

Fig. 2 The FWHM and grain size of ZnO on sapphire substrate as a function of annealing temperature.

The composition and thickness of the ZnO thin films grown on sapphire substrates were investigated by an AES measurement. Fig. 3 shows that ZnO films consisted of zinc, oxygen, and carbon at the surface and of zinc and oxygen at a depth of 50nm. The carbon impurities at the ZnO surface might originate from contamination due to diffusion pump and the carbon plasma chamber. According to AES spectra, the ZnO was deposited at the surface of sapphire with a thickness of approximately 50nm. This result agrees with the calculation of SRIM.

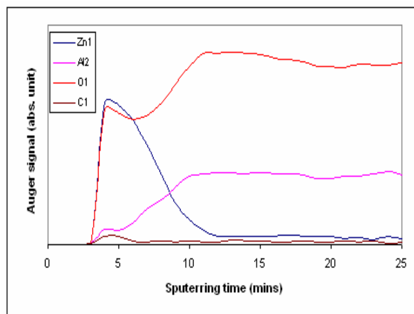

Fig. 3 Auger electron spectra obtained from a ZnO/ sapphire (001) heterostructure

3. Conclusions

Zn-ion implantation followed by thermal oxidation was used to fabricate ZnO in sapphire substrate. A sapphire substrate was implanted with Zn^+ ions of 50 keV up to 1.5 $x10^{17}$ ions/ cm^2, and was annealed in air at elevated temperatures. After annealing at 700^0 C for 2 h, ZnO which shows the peak on XRD spectra at 34.42^0 were formed on the surface of the sapphire substrate. The grain size of ZnO increased from 17nm to 23nm with the gain of annealing temperature. AES spectrum shows that the film thickness was 50nm.

Acknowledgement

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