Photoluminescence properties of N-doped and nominally undoped p-type ZnO thin films

Hu-Jie Jin, Yun-Hwan Jeong and Choon-Bae Park[a]
School of Electrical Electronic and Information Engineering, WRISS, Wonkwang University

Abstract: The realization and origin of p-type ZnO are main issue for photoelectronic devices based on ZnO material. N-doped and nominally undoped p-type ZnO films were achieved on silicon (100) and homo-buffer layers by RF magnetron sputtering and post in-situ annealing. The undoped film shows high hole mobility of 1201 $cm^2V^{-1}s^{-1}$ and low resistivity of 0.0454Ω·cm with hole concentration of $1.145x10^{17}cm^{-3}$. The photoluminescence(PL) spectra show the emissions related to FE, DAP and defects of V_{Zn}, V_O, Zn_O, O_i and O_{Zn}..

Key Words: N-doped p-type ZnO film; Undoped p-type ZnO film; Photoluminescence property.

1. Introduction

The merits of ZnO include large excitonic binding energy (60 meV), ease of wet etching and availability of large-area bulk substrates. The light emitting efficiency of fabricated LEDs is low [1]. The problem originates from poor-quality p-type ZnO films. To realize high quality p-type ZnO, origins of p-type carrier and defects should be analyzed. We realized N-doped and nominally undoped p-type ZnO films on homo-buffer layer and Si by RF magnetron sputtering and then analyzed PL spectra in detail. It was found that near bnad edge emissions were related to FE, FA and DAP and defect transitions were related to V_{Zn}, V_O, O_i and O_{Zn}.

2. Experiment

We prepared ZnO films on n-Si (001) and homo-buffer layer template by RF magnetron sputtering. The buffer layer template was fabricated on n-Si (001) by RF magnetron sputtering in the mixed ambient of Ar and O_2 with ratio of 4:1 at 100^0C and 15mTorr for 30min with RF power of 120W. N-doped ZnO films were prepared in an ambient of N_2 and O_2 with ratio of 3:2 at 450^0C for 180 min with power of 210W and in-situ annealing was carried out in pure O_2 at 10Torr and 800^0C for 5min. We also fabricated a nominally undoped ZnO film on the buffer layer template in pure O_2 with the other conditions being the same as the case of the N-doped film.

3. Results and discussion

Table 1 shows that buffer layer facilitates hole formation. The undoped film on buffer layer has the highest carrier concentration of $1.145x10^{17}$ cm^{-3} and mobility of $1201cm^2V^{-1}s^{-1}$, and the lowest resistivity of 10^{-2}cm of the three films.

Table 1. XRD spectra of buffer layer, N-doped films and undoped film

sample	N-doped film on Si	N-doped film on buffer	undoped film on buffer
type	p	p	p
concent. (cm^{-3})	$7.84x10^{13}$	$9.46x10^{14}$	$1.145x10^{17}$
mobility ($cm^2V^{-1}s^{-1}$)	1054.6	91.5	1201
resist. (Ω·cm)	75.26	72.2	0.0454

Fig. 1 shows the PL spectrum of N-doped film on Si. Four peaks show at the positions of 3.3826, 3.3109, 3.2413 and 3.1658 eV, respectively, being ascribed to free exciton [FE], 1LO, 2LO and donor-acceptor pair transition (DAP). In visible region, two peaks are at 3.0516 and 1.9229 eV, and three shoulders are at 2.36, 1.13 and 1.72 eV respectively. The peak of 3.0516 eV is assigned to zinc vacancy (V_{Zn}), and 1.9229 eV is approximate to 1.937 eV which is ascribed to oxygen interstitial (O_i). Low shoulder at about 2.36 eV is attributed to oxygen vacancy (V_O). There are two other shoulders at about 2.13 and 1.72 eV that are not found in any references explicitly.

Fig. 2 shows the PL spectrum of nominally undoped film on buffer layer. The peaks at 3.3023 and 3.2175 eV are attributed to the transition of free electron to acceptor level (FA) and donor-acceptor pair (DAP) respectively. The peak at 3.0860 and 1.9806 eV are ascribed to zinc vacancy (V_{Zn}) and oxygen interstitial (O_i) respectively. There are also two uncertain shoulders at about 1.76 and 2.26eV.

Comparison of Fig. 1 with Fig. 2 reveals approximation of two patterns at deep level defect emissions. The peak positions at 1.76, 1.9806, 2.26 and 3.0860 eV in Fig. 4 seem to correspond to those at 1.72, 1.9229, 2.13 and 3.0516 eV in Fig. 3. In Fig. 3, the intensity of shoulder at 1.72 eV is lower than

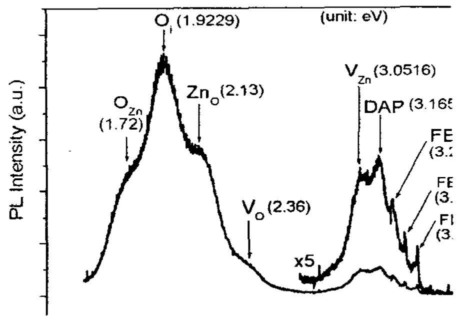

Fig. 1 PL spectrum of N-doped film on Si.

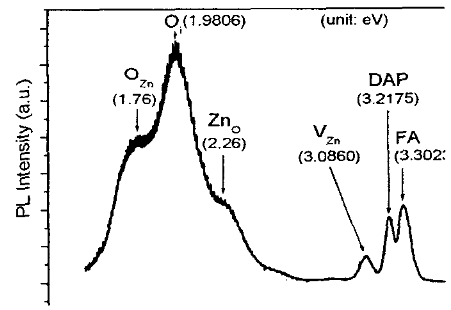

Fig. 2 PL spectrum of undoped film on buffer layer.

that at 2.13 eV, but in Fig. 4, the intensity of shoulder at 1.76 eV is higher than that at 2.26 eV. If we take the shoulder at 1.72 eV in Fig. 3 and 1.76 eV in Fig. 4 as emission associated with oxygen antisite on zinc (O_{Zn}) and take shoulder at 2.13 eV in Fig.3 and 2.26 eV in Fig.4 as emission associated with zinc antisite on O (Zn_O), the phenomena can be interpreted. At the condition of high pressure of oxygen, the intensity related to Zn_O gets low and that related to O_{Zn} gets high.

4. Conclusion

DAP, V_{Zn}, Zn_O, O_i and O_{Zn} were shown in PL spectra. Low hole density on N-doped p-type ZnO film was attributed to molecular N_2 on O site instead of atomic N. In N-doped processing the buffer layer facilitates p-type conductivity in ZnO films.

Acknowledgement

This research was supported by SMBA through the Enterprise Attached Research Institute.

References

[1] Y. Ryu, T. Lee, J.A. Lubguban, H.W. White, B. Kim, Y. Park, C. Youn, Appl. Phys. Lett. Vol. 88, pp. 241108, 2006