Photoluminescence property of Al,N-codoped p-type ZnO films by dc magnetron sputtering

Hu-jie Jin, Yan-Yan Liu, Bok-Kee Park, and Choon-Bae Park[a]
Wonkwang Univ. WRISS, School of Electrical Electronic and Information Engineering.

Abstract

In this study, high quality (Al,N)-codoped p-type ZnO thin films were obtained by DC magnetron sputtering. The film on buffer layer grown in 80% N_2 ambient shows highest hole concentration of $2.93\times10^{17}cm^{-3}$. The films show hole concentration in the range of 1.5×10^{15} to 2.93×10^{17} cm^{-3}, resistivity of 131.2 to 2.864 Ωcm, mobility of 3.99 to 31.6 $cm^2V^{-1}s^{-1}$. The films on Si show easier p-doping in ZnO than those on buffer layer. The film on Si shows the highest quality of optical photoluminescence (PL) characteristics. The donor energy level (E_d) of (Al,N)-codoped ZnO films is about 50 meV and acceptor energy level (E_a) is in the range of 63 to 71 meV. It will help to improve p-type ZnO films.

Key Words : (Al,N)-codoped, DC magnetron sputtering, p-type ZnO, PL property

1. Introduction

Theoretically, N is the best dopant of group Velements to dope ZnO p-type[1]. However, it is hard to obtain p-type ZnO with N as p-type dopant due to deep acceptor level and its low solubility. To solve these problems, proposed the theory of codoping group Vand Ⅲ elements with ratio of 2:1 was proposed[2]. In this study, to grow high quality p-type ZnO films, ceramic ZnO mixed with 2wt% Al_2O_3 was used as target, and Al in ceramic N_2 as co-dopant source. To ignite DC sputtering plasma, home-made sputtering instrument was used. Optical analysis was carried out through PL spectra of (Al,N)-codoped ZnO film and other analysis were also performed. The acceptor level and donor level of (Al,N)-codoped ZnO films were obtained by the analysis of PL spectra.

2. Experimental process

(Al,N)-codoped ZnO films were fabricated on n-Si and homo-buffer layer. The detail was listed Table 1. Homo-buffer layer was fabricated on n-Si with ZnO films with RF power.

Table 1. Condition of (Al,N)-codoped ZnO films

parameter	condition
target	ZnO 5N
substrate	n-Si, buffer layer
base pressure	7×10^{-6}Torr
working pressure	15 mTorr
DC power	340Vx0.1A
growth temp.	450°C
ambient gases	$N_2:O_2$=2:3,3:2,4:1
pre-sputtering time	10 min
growth time	120 min (570 nm)

3. Results and discussion

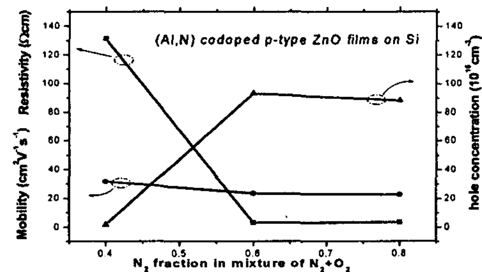
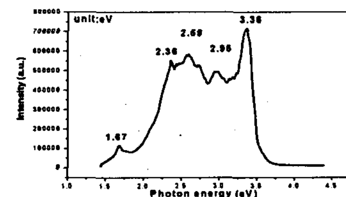
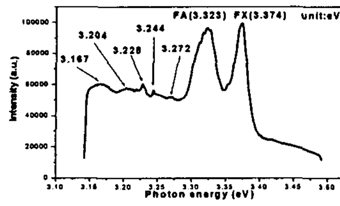


Fig. 1 Electrical property of films on Si at 450°C and 15 mTorr in different N_2 fraction.

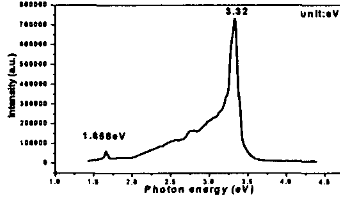
Fig. 1 shows that (Al,N)-codoped ZnO films grown on Si at 15 mTorr have p-type conduction. The film grown in N_2 fraction of 60% in N_2 and O_2 exhibits highest hole concentration of 9.35×10^{16} cm^{-3}, lowest resistivity of 2.864 Ωcm and moderate mobility of 23.3 $cm^{-2}V^{-1}s^{-1}$. Too much or too little N_2 content reduces hole concentration and increases the resistivity of films. The film grown in N_2 80% shows p-type conduction with hole concentration of 2.97×10^{17} cm^{-3}, mobility of 3.99 $cm^2V^{-1}s^{-1}$ and resistivity of 5.35 Ωcm.



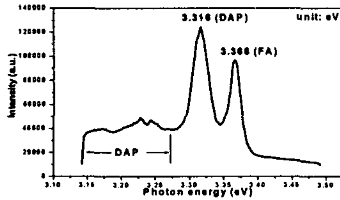
(a)



(b)



(c)



(d)

Fig. 2 PL spectra at 6K of full range and NBE of the films on buffer and Si at 450°C and 15 mTorr in N_2 80% on (a) (b) buffer and (c) (d) on Si.

Fig. 2 shows PL spectra at 6 K of broad region and high resolution near band edge of p-type films grown in N_2 80% shows deep defect levels at 1.67, 2.36, 2.59 and 2.95 eV (c); 1.66 eV (e), and near band edge levels at 3.374 and 3.304 eV (d); 3.366 and 3.316 eV (f). The peaks of 3.374, 3.323 eV in (d) and 3.366 and 3.316 eV (f) are ascribed to FA and DAP respectively.

The emission energy of DAP at low temperature is

$$h\nu = E_g - E_a - E_d + \frac{e^2}{4\pi\epsilon r}$$

And the emission energy of FA at low temperature is

$$h\nu = E_g - E_a$$

The peak energy difference of 50 meV in Fig. 3 (f) and of 51 meV in Fig. 3 (d) are the depth of donor levels (E_d). The E_d is at the range of 50 and 51 meV. The depth of Al donor level in Al-monodoped ZnO is 65 meV. For the case of (Al,N)-codoping in ZnO, the Al donor level is made shallower by 15 meV. The low temperature bandgap of ZnO is about 3.437 eV. Thus the acceptor level in ranged at 63 to 71 meV, less than 100 meV.

4. Conclusion

High quality (Al,N)-codoped p-type ZnO thin films were obtained by DC magnetron sputtering on Si in N_2 80% fraction. The Ea and Ed of films grown in 80% N_2 are determined.

Acknowledgement

This research was supported by the Small and Medium Business Administration (SMBA) through the Enterprise Attached Research Institute.

References

[1] C.H. Park, S.B. Zhang, and S.H. Wei, "Origin of p-type doping difficulty in ZnO:The impurity perspective", Phys. Rev. B, Vol. 66, No. 7, p. 073202, 2002.

[2] T. Yamamoto, "Codoping for the fabrication of p-type ZnO", Thin Solid Films Vol. 420-421, p. 100-106, 2002.