Rapid Thermal Oxidation of Zinc Nitride Film

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Abstract

In this work, a zinc nitride (ZnN) film was deposited at room temperature and subjected to pulse mode rapid thermal oxidation. Then a p-type conductive zinc oxide (ZnO) material was obtained by oxidizing ZnN (i.e. RTO_ZnN). A rectified p-type RTO_ZnN/n-type ZnO diode and linear resistor made of RTO_ZnN were achieved. The carrier concentration, mobility and resistivity of RTO_ZnN film in this study were 6.49×10^{18} cm⁻³, 12.9 cm²/ V · s and 0.7 Ω -cm, respectively.

1. Introduction

Recently, the realization of stable p-type ZnO has long been the bottleneck for ZnO-based materials applications [1]. There were several issues limit the preparation of p-type ZnO including low dopant solubility, deep acceptor level, and the "self-compensation" of shallow acceptors.[2] The atomic nitrogen (N) was thought as an acceptor for ZnO. However, J. L. Lyons et al. [3] proposed that N atom may act as deep acceptor in ZnO. In this study, we used pulse mode rapid thermal oxidation (PRTO) to oxidize a sputter deposited ZnN film and achieve stable p-type conduction. Through of rapid thermal process, some N atoms within ZnN film were replaced by O atoms. Then the processed film was converted into a p-type ZnO material containing N atoms.

2. Experimental Procedure

The preparation of RTO_ZnN film is described as follows. First, a 300-nm-thick ZnN film is deposited on substrates by sputtering the Zn target (99.995% purity) with 3 sccm nitrogen (N₂) gas flow. The deposition temperature, power and pressure were 27 °C, 50 W and 5×10^{-2} Torr, respectively. Next, the as-deposited ZnN film is subjected to pulse mode rapid thermal annealing process at O₂, 500 °C for 5 pulses (the duration time was 5 s/pulse). Then the preparation of RTO_ZnN is completed.

3. Results and Discussion

Figure 1 compares the Raman spectra of RTO_ZnN, ZnO and bare Si. The signal of 437 cm⁻¹ in RTO_ZnN showed that O atoms diffuse into the processed film and form Zn-O bonds. In addition, A. Kaschner et al. proposed that the local vibration signals of 275 and 580 cm⁻¹ are related to the presence of N atom in N-doped ZnO. [4] It was found that the spectrum of RTO_ZnN is similar to that of N-doped ZnO. [5] Meanwhile, no N-related signals were observed in ZnO film. The signals of 275.1, 437 and 579.5 cm⁻¹ in the processed film showed that ZnN may be doped with O atoms. Thus a material composed of Zn, O and N was prepared. In words, rapid thermal oxidation provides an alternative to produce N-doped ZnO film.

Fig. 2 shows the cross-sectional SEM images of as-deposited ZnN and oxidized ZnN films processed with different temperatures. It was found that the crystallinity of processed film is improved with oxidation temperature.

Typically, the XRD image of ZnO crystal exhibits a signal of 34.44° corresponding to preferential orientation of (002). [6] As shown in Fig. 3, RTO_ZnN film also possessed a similar signal of 34.38°, which reflects that the rapid thermal oxidation modifies the physical structure of ZnN film approaching that of ZnO.

Table I lists the electrical properties of different RTO_ZnN films. The 500 °C processed RTO_ZnN film shows the p-type conduction repeatedly. The carrier concentration, mobility and resistivity of RTO_ZnN film in this study were 6.49×10^{18} cm⁻³, 12.9 cm²/ V · s and 0.7 Ω -cm, respectively.

Finally, the electrical characteristics of p-type RTO_ZnN were evaluated in Fig. 4 and 5, respectively. A rectified I-V curve with turn-on voltage of only 0.75 V was obtained in RTO_ZnN/ZnO diode (Fig. 4) and the Al/ RTO_ZnN /Al structure showed a linear I-V characteristic with resistance of 0.71 Ω (Fig. 5).

4. Conclusions

We have successfully oxidized ZnN by using rapid thermal process. The oxidized ZnN film showed p-type conduction and its physical structure was similar to that of N-doped ZnO. Since the rapid thermal process resulted in some N atoms within ZnN film being replaced by O atoms. Thus it can be implied that the processed film is converted into ZnO material containing N atoms. The proposed oxidation can not only produce the p-type ZnO material but also drive the processed film being crystallized. The carrier concentration, mobility and resistivity of p-type oxidized ZnN were 6.49×10^{18} cm⁻³, 12.9 cm²/ V · s and 0.7 Ω -cm, respectively.

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Table I. Electrical properties of various RTO_ZnN films.

	Carrier Concentration (cm ⁻³)	Mobility (cm²/V • s)	Resistivity (Ω-cm)
500 °C RTO_ZnN	6.498×10^{18}	12.9	0.7
475 ℃ RTO_ZnN	$-7.438 imes 10^{18}$	25.4	0.032
450 ℃ RTO_ZnN	$-6.219 imes 10^{18}$	27.7	0.036
as-deposited ZnN	$-6.566 imes 10^{18}$	91.3	0.01
ZnO	-2.258×10^{16}	3.53	78.2



Fig. 1 Raman spectra of RTO_ZnN, ZnO and Si, respectively.



Fig. 2 Cross sectional views of RTO_ZnN oxidized with different temperatures.



Fig. 3 XRD images of RTO_ZnN and ZnO, respectively.



Fig. 4 I-V curve of RTO_ZnN/ZnO diode.



Fig. 5 I-V curve of Al/RTO_ZnN/Al structure.