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Vertical MgZnO Schottky ultraviolet photodetector with Al doped MgZnO transparent electrode

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ABSTRACT

In this paper, we report a vertical Schottky ultraviolet photodetector based on the MgZnO:Al transparent electrode. The vertical MgZnO:Al/MgZnO/Au photodetector was fabricated on the sapphire substrate, which shows a good Schottky contacting character. The transparent and conducting MgZnO:Al thin film was developed by magnetron sputtering and annealed to fit the request of our detection. The device is structured vertically in an order of sapphire/MgZnO:Al/MgZnO/Au. The device shows a good Schottky contacting character. The maximum responsivities of the photodetector are 0.0266 mA/W at 0 V bias and 13.31 mA/W under 10 V backward bias, respectively. The peak response wavelength is located at 340 nm and cut-off is at the wavelength of 355 nm. The turn-on voltage is 2.0 V and the breakdown voltage is 40 V. The leakage current is less than 70 pA at a reverse bias of 15 V.

1. Introduction

MgZnO alloy materials have received more and more interests due to their multiple applications in the ultraviolet photon detection field [1–3]. As we know, the attenuation of ultraviolet emission increased in a large degree even when it propagates in a short length in the atmosphere. Therefore, multiplication effect is necessary in ultraviolet (UV) photodetector. Generally speaking, photodetectors based on p–n junctions usually have relatively high sensitivity and low noise. However, fabrication of the stable p-type MgZnO is still a challenge at present. In order to realize the high performance ultraviolet photodetectors, Schottky junction device is a good candidate [4–6]. Most ZnO based Schottky UV detectors realized by the metal–semiconductor-metal structures [5,8–10], albeit the Schottky junction cannot be established easily, because they are easily influenced by the surface state of the active layer of the devices. As we know, Schottky junction works based on the barrier between the metal and semiconductor when they are connected [7]. The horizontal structure devices with digital electrodes on the same side would be highly affected by surface state and suffer from a non-uniform field distribution, which makes it breakdown easily [7]. A vertical structure UV detector, with a transparent and conductive layer may resolve these problems.

The MgZnO can be modified by doping this material with various elements [11–13]. The MgZnO:Al layer was chosen as a practicable transparent electrode for MgZnO based UV detectors. The absorption edge of this layer should be shorter than that of the active layer to make sure that the wastage of incident light can drop to a contented level. A resistivity about 10^{-3} Ω-cm level is also asked [14,15]. In this work, we fabricated applicable MgZnO:Al layer and our device shows a good rectifying effect and visible–blind detection performance.

2. Experimental details

The MgZnO:Al thin film was grown on a commercial c-plane sapphire substrate by using radio frequency (RF) magnetron sputtering technique. A ceramic target with 45 wt.% MgO, 54.81 wt.% ZnO and 0.19 wt.% Al_2O_3 was used. The ceramic target was made by the Northeast Normal University. The sputtering rate is about 5 nm/min and the chamber pressure was maintained at 1.8 Pa. Oxygen with 20 sccm flow rate and argon with 40 sccm flow rate were used as the sputtering gas. Growth temperature was 400 °C and the RF power was 90 W. The thickness of the as-grown film was 300 nm. Then the as-grown MgZnO:Al films were vacuum annealed for 1 h in different temperatures to reduce the resistivity of the MgZnO:Al thin film, in order to meet the requirement of the device.

Subsequently, 500 nm MgZnO film was deposited onto it in a metal organic chemical vapor deposition (MOCVD) technique as the active layer of photodetector. The precursors were dicyclopentadienylmagnesium ($(MeCp)_2Mg$), diethylzinc (DEZn) and high pure oxygen (99.999%). Nitrogen was used as carrier gas. The deposition temperature is 450 °C, and the chamber pressure is fixed at 2×10^{-3} Pa. The flow rates of DEZn, $(MeCp)_2Mg$ and O_2 were kept at 20 ml/min,

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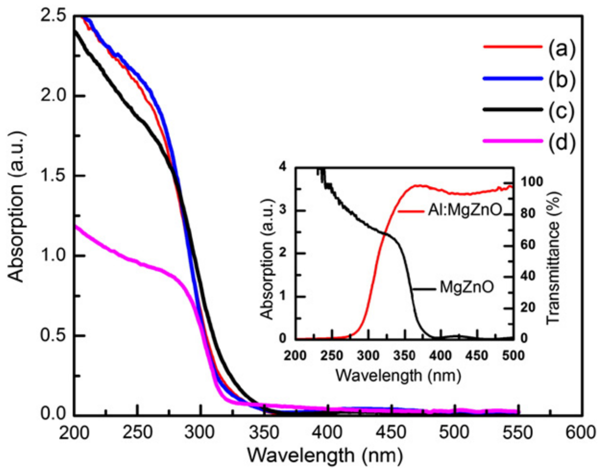

Fig. 1. Room temperature absorption spectrum of the MgZnO:Al film (a) unannealed, (b) annealed at 500 °C (c), annealed at 600 °C and (d) annealed at 700 °C; inset is the absorption spectrum of MgZnO film and the transmittance spectrum of Al:MgZnO film.

7.5 ml/min, and 550 ml/min, respectively. The MgZnO film showed an n-type conduction with an area of almost 0.2 cm^2. Subsequently, Au (99.99%) was evaporated onto the MgZnO active layer under a pressure of about 2×10^{-3} Pa using a vacuum evaporation method as top electrode to form Schottky contact, and Al (99.99%) electrode was fabricated on and bottom MgZnO:Al layer to form ohmic contact using the same method.

The absorption spectrum of the MgZnO:Al films was measured in a Shimadzu UV-3101PC ultraviolet visible spectrophotometer. To measure the influence of annealing temperature to the Al-doped MgZnO films, emission scanning electron microscope S-4800 made by HITACHI Company was used to get the images at 5 kV voltage. The Hall effect measurements and the current–voltage curve of the device were carried out by Lakeshore Company and the model of the system is VSM7707. The photoresponse spectra of the vertical detector at 0 V bias and 10 V backward bias were observed by DSR100 produced by Zolix Company.

3. Results and discussion

Fig. 1 shows the absorption spectrum of MgZnO:Al films. We used UV3101 UV visible spectrophotometer to get the spectrum. The four curves show the absorption spectrum of MgZnO:Al film before and after annealing at different temperatures, respectively. Notably, the absorption intensity is descending gradually with an increase in the annealing temperature, especially in the case of 700 °C. This is due to the fact that thickness of the film decreased during the annealing process in vacuum. It will be illustrated by the images from scanning electronic microscopy (SEM) in Fig. 2 later. The absorption edge of MgZnO:Al film is located at about 310 nm and almost shows little shift with the different annealing temperatures. The insets in Fig. 1 show the absorption spectrum of MgZnO film which is fabricated as the active layer of our detector, and the transmittance spectrum of MgZnO:Al film. Notably,

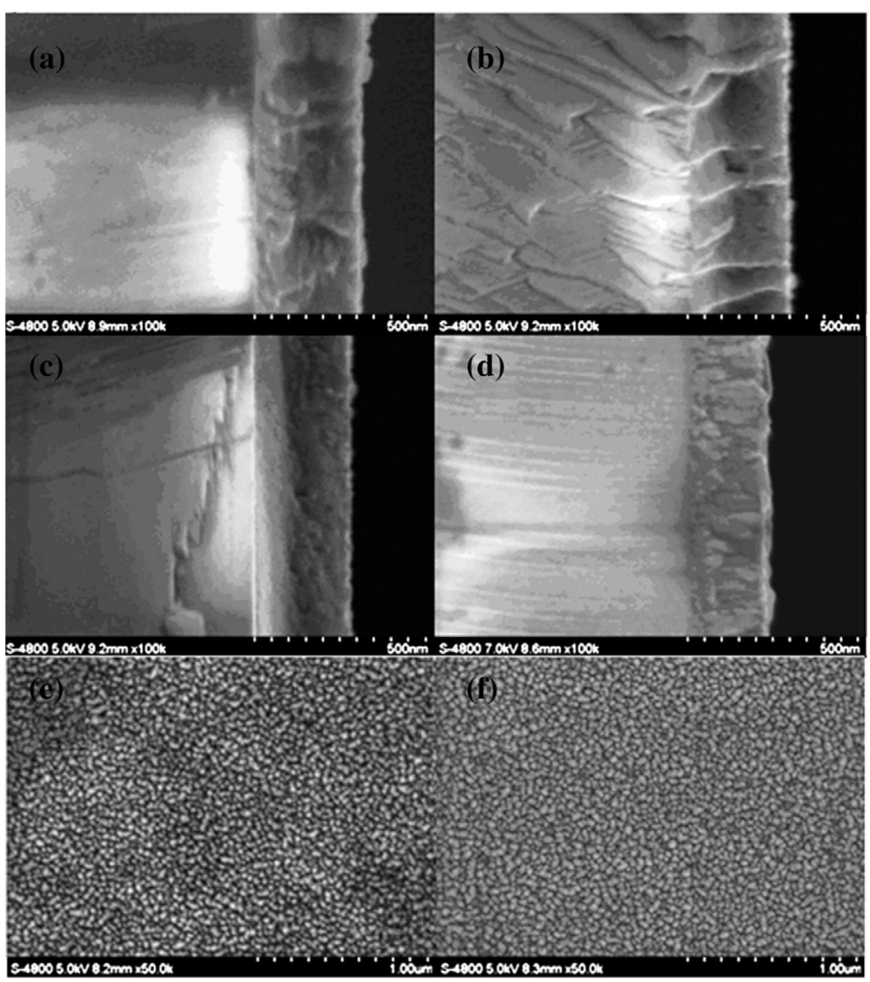

Fig. 2. Section SEM images of MgZnO:Al thin films (a) before and (b) after annealing at 500 °C, (c) 600 °C, and (d) 700 °C; surface SEM images of the MgZnO:Al thin films (e) before and (f) after annealing at 600 °C.

the absorption edge of MgZnO film is located at 355 nm where the MgZnO:Al film is almost completely transparent. Consequently the MgZnO:Al film as transparent electrode is available for a vertical device.

Fig. 2 is SEM image. In this paper, we used field emission scanning electron microscope S-4800 to observe the images at 5 kV voltage. In Fig. 2, the letters (a), (b), (c), and (d) are on behalf of Al-doped MgZnO films unannealed and annealed at different temperatures. We can find a reduction of thickness of the film with the increasing annealing temperature. The thickness of the film lessens gradually, especially in the case of 700 °C, it was scaled down to 280 nm. Fig. 2(e) shows the section images of the as grown MgZnO:Al thin film, and Fig. 2(f) shows the section images of the 600 °C-annealed MgZnO:Al thin film. The grain uniformity was a little improved while the grain compactness was highly promoted after the vacuum annealing, which maybe arise from the migration of atoms.

The Hall effect measurements were employed to measure the electronic properties of the MgZnO:Al thin film. The measurement system used in this work was VSM7707. The resistivity of the as-grown MgZnO:Al film is 9.7 Ω-cm, while the MgZnO:Al films annealed at 500 °C, 600 °C, and 700 °C is 1.2×10^{-2} Ω-cm, 4.7×10^{-3} Ω-cm and 2.9×10^{-1} Ω-cm, respectively. The resistivity reaches its minimum of 4.7×10^{-3} Ω-cm after annealing at 600 °C, however, it shows a certain increase when annealing at 700 °C. Thus, the reduction of film thickness is still considered as an important factor to reduce the resistivity of the MgZnO:Al film and the MgZnO:Al film annealed at 600 °C was the most qualified to be the transparent electrode for the UV detector.

The device structure is sketched in Fig. 3. We chose Al doped MgZnO film as the electrode layer of the vertical device to reduce the lattice mismatch with the MgZnO active layer. Moreover, the MgZnO:Al film is transparent at the absorption edge of MgZnO film, so that the maximum responsivities of the photodetector would be hardly influenced by the electrode layer. To confirm the Schottky contact of the vertical structure, current–voltage curve was measured on the VSM 7707 system. As shown in Fig. 3, the device shows a typical rectifying behavior, which exhibits a good Schottky behavior. The breakdown voltage is as high as 40 V, the turn-on voltage is 2 V and the diode leakage current is less than 70 pA under a reverse bias of 15 V.

Fig. 4 shows the photoresponse spectra of the vertical detector at 0 V bias and 10 V backward bias. The response spectral measurement system used in this work was DSR100. The peak response is located at 340 nm and the responsivities are 0.0266 mA/W and 13.31 mA/W under 0 V bias and 10 V backward bias, respectively. The cut-off wavelength is at 355 nm. Under 10 V backward bias voltage, the UV (R 340 nm)/visible (R 450 nm) rejection ratio of the device is three orders of magnitude, which shows a good visible blind performance. The response at 0 V bias indicates that the devices work based on Schottky effect. Additionally, the response is originated from the MgZnO layer rather than the MgZnO:Al electrode layer. Thus, the MgZnO:Al thin film is a good transparent electrode material for the MgZnO based vertical UV detectors.

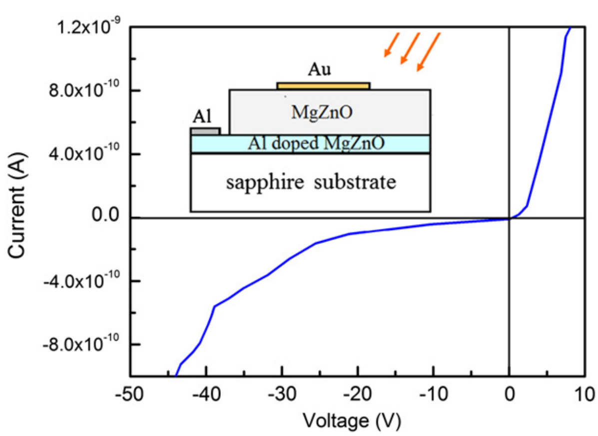

Fig. 3. Typical *I–V* curve of the device. The inset is the structure sketch of the vertical device.

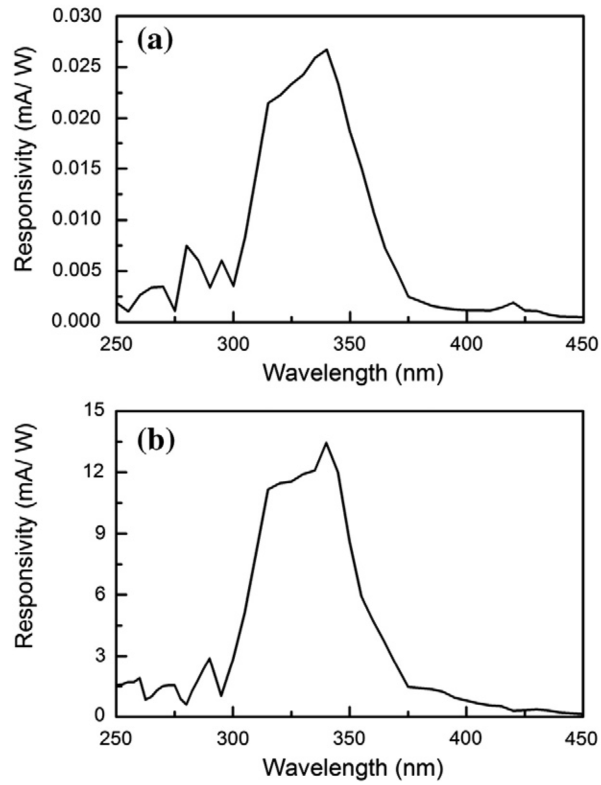

Fig. 4. Spectral responses of the vertical MgZnO Schottky detector at (a) 0 V bias and (b) 10 V bias.

4. Conclusion

In conclusion, a vertical MgZnO Schottky photodetector with MgZnO:Al transparent electrode has been fabricated. The resistivity of the sputtered MgZnO:Al was decreased significantly by annealing in vacuum, and was used as the transparent electrode. The vertical structured photodetector shows a good Schottky behavior. It demonstrated that the annealing MgZnO:Al film as a transparent electrode is a feasible way to improve the properties of the metal/semiconductor contact and the photon detectors. The results reported in this paper provide a facile route to realize high performance vertical structured Schottky behavior, which may also lay a solid ground for the future applications of this kind of MgZnO-based UV photodetectors.

Acknowledgments

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References

[1] D. Jiang, J. Qin, X. Zhang, Z. Bai, D. Shen, Mater. Sci. Eng. B 176 (9) (2011) 736.
[2] W.W. Liu, B. Yao, B.H. Li, Y.F. Li, J. Zheng, Z.Z. Zhang, C.X. Shan, J.Y. Zhang, D.Z. Shen, X.W. Fan, Solid State Sci. 12 (9) (2010) 1567.
[3] R. Schmidt-Grund, M. Schubert, B. Rheinlander, D. Fritsch, H. Schmidt, E.M. Kaidashev, M. Lorenz, C.M. Herzinger, M. Grundmann, Thin Solid Films 455 (2004) 500.
[4] M. Brandt, H. von Wenckstern, G. Benndorf, H. Hochmuth, M. Lorenz, M. Grundmann, Thin Solid Films 518 (4) (2009) 1048.
[5] L.K. Wang, Z.G. Ju, C.X. Shan, J. Zheng, D.Z. Shen, B. Yao, D.X. Zhao, Z.Z. Zhang, B.H. Li, J.Y. Zhang, Solid State Commun. 149 (45–46) (2009) 2021.

[6] H. Endo, M. Sugibuchi, K. Takahashi, S. Goto, S. Sugimura, K. Hane, Y. Kashiwaba, Appl. Phys. Lett. 90/12 (2007).
[7] Simon M. Sze, Kwok K. Ng, Physics of Semiconductor Devices, third ed. Wiley-Interscience, New Jersey, 2007.
[8] E. Budianu, M. Purica, F. Iacomi, C. Baban, P. Prepelita, E. Manea, Thin Solid Films 516 (7) (2008) 1629.
[9] Y. He, W. Zhang, S. Zhang, X. Kang, W. Peng, Y. Xu, Sensors Actuators A Phys. 181 (2012) 6.
[10] Z.Q. Xu, H. Deng, J. Xie, Y. Li, X.T. Zu, Appl. Surf. Sci. 253 (2) (2006) 476.
[11] W. Wei, C. Jin, J. Narayan, R.J. Narayan, Solid State Commun. 149 (39–40) (2009) 1670.
[12] K. Maejima, H. Shibata, H. Tampo, K. Matsubara, S. Niki, Thin Solid Films 518 (11) (2010) 2949.
[13] K. Koike, K. Hama, I. Nakashima, S. Sasa, M. Inoue, M. Yano, K. Koike, K. Hama, I. Nakashima, S. Sasa, M. Inoue, M. Yano, Jpn. J. Appl. Phys. 1 (44/6A) (2005) 3822.
[14] V. Bhosle, A. Tiwari, J. Narayan, J. Appl. Phys. 100/3 (2006).
[15] M. Lorenz, E.M. Kaidashev, H. von Wenckstern, V. Riede, C. Bundesmann, D. Spemann, G. Benndorf, H. Hochmuth, A. Rahm, H.C. Semmelhack, M. Grundmann, Solid State Electron. 47 (12) (2003) 2205.