Applied Physics Letters

MgxZn1−xO-based photodetectors covering the whole solar-blind spectrum range

Z. G. Ju, C. X. Shan, D. Y. Jiang, J. Y. Zhang, B. Yao et al.

Citation: Appl. Phys. Lett. **93**, 173505 (2008); doi: 10.1063/1.3002371
View online: http://dx.doi.org/10.1063/1.3002371
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v93/i17
Published by the American Institute of Physics.

Related Articles

Tuning the dynamic properties of electrons between a quantum well and quantum dots
J. Appl. Phys. 112, 043702 (2012)

High responsivity near-infrared photodetectors in evaporated Ge-on-Si
Appl. Phys. Lett. 101, 081101 (2012)

Dual-color ultraviolet photodetector based on mixed-phase-MgZnO/i-MgO/p-Si double heterojunction
Appl. Phys. Lett. 101, 081104 (2012)

Enhanced performance of photodetector and photovoltaic based on carrier reflector and back surface field generated by doped graphene
Appl. Phys. Lett. 101, 073906 (2012)

Gallium free type II InAs/InAsxSb1-x superlattice photodetectors
Appl. Phys. Lett. 101, 071111 (2012)

Additional information on Appl. Phys. Lett.

Journal Homepage: http://apl.aip.org/
Journal Information: http://apl.aip.org/about/about_the_journal
Top downloads: http://apl.aip.org/features/most_downloaded
Information for Authors: http://apl.aip.org/authors

ADVERTISEMENT

Downloaded 11 Sep 2012 to 159.226.165.151. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions

APPLIED PHYSICS LETTERS **93**, 173505 (2008)

$Mg_xZn_{1-x}O$-based photodetectors covering the whole solar-blind spectrum range

Z. G. Ju,[1,2] C. X. Shan,[1] D. Y. Jiang,[1,2] J. Y. Zhang,[1,a)] B. Yao,[1] D. X. Zhao,[1] D. Z. Shen,[1] and X. W. Fan[1]

[1]*Key Laboratory of Excited State Processes, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, No.16 East South-Lake Road, Changchun 130033, People's Republic of China*

[2]*Graduate School of the Chinese Academy of Sciences, Beijing 100039, People's Republic of China*

(Received 2 September 2008; accepted 29 September 2008; published online 29 October 2008)

A series of $Mg_xZn_{1-x}O$ thin films has been prepared by metalorganic chemical vapor deposition and metal-semiconductor-metal structured ultraviolet photodetectors are fabricated from these films. The cutoff wavelengths of the photodetectors can cover the whole solar-blind spectrum range (220–280 nm) by varying Mg content in the $Mg_xZn_{1-x}O$ thin films. As a representative, the photodetector fabricated from $Mg_{0.52}Zn_{0.48}O$ shows an ultraviolet/visible rejection ratio of about four orders of magnitude, and the dark current is 15 pA at 10 V bias. These results demonstrate that high-performance photodetectors operating in the whole solar-blind spectrum range can be realized in $Mg_xZn_{1-x}O$ films. © *2008 American Institute of Physics*. [DOI: 10.1063/1.3002371]

Photodetectors working in solar-blind spectrum range (220–280 nm) have very high sensitivity since the interference from the solar irradiation is greatly suppressed. Therefore, there has been great interest in the development of solar-blind photodetectors in the past years.[1–4] The interest comes partly from the versatile applications of such photodetectors in many areas such as flame detection, missile plume sensing, and convert space-to-space communications.[5–10] In this subject, wide band gap semiconductors have been the strongest candidates because they can offer facilities with neat size, high efficiency, and low cost.[11,12] Among the frequently studied wide band gap semiconductors, GaAlN alloys have been highlighted for their tunable band gaps and high absorption coefficient.[13–15] However, the lack of lattice-matched substrate and relatively high defect density limit the further development of GaAlN based photodetectors.[16] MgZnO possesses unique figures of merits for application in ultraviolet (UV) photodetectors such as large tunable band gap (3.3–7.8 eV) and low growth temperature (100–750 °C).[17] In addition, the environmental-friendly and biocompatible characters make MgZnO alloys more attractive. However, only one report on the MgZnO-based photodetectors operating in solar-blind range can be found to the best of our knowledge.[18] The cutoff wavelength of the photodetector is at 230 nm, and the UV/visible rejection ratio, which reflects the signal/noise ratio of photodetectors, is only one order of magnitude, revealing that the performance of such photodetector has much room to be improved.

In this letter, the authors report on the fabrication of a series of $Mg_xZn_{1-x}O$ metal-semiconductor-metal (MSM) structured photodetectors, and their cutoff response wavelength can be varied from 225 to 287 nm by changing the Mg content in the alloy films. Namely the response of the photodetectors fabricated from MgZnO can cover the whole solar-blind spectrum range. As a representative, the photodetector with Mg content of 52% shows a high rejection ratio of four orders of magnitude, and the dark current is 15 pA at 10 V bias, comparable to the corresponding values reported in GaAlN photodetectors.

The $Mg_xZn_{1-x}O$ thin films were prepared on sapphire substrates in a metalorganic chemical vapor deposition (MOCVD) technique. Diethylzinc, biscyclopentadienyl-Mg, and oxygen were employed as the precursors, and high purity nitrogen act as a carrier for the precursors. The growth temperature was fixed at 450 °C and the pressure at 2×10^4 Pa. $Mg_xZn_{1-x}O$ with different Mg content $(0.5<x<0.7)$ was obtained by changing the mole ratio of Zn and Mg precursors. The thickness of thin films is about 350 nm. Without any surface treatment, a 100 nm Au layer was evaporated onto the MgZnO films using a vacuum evaporation method. MSM structured photodetectors were fabricated based on these films through conventional UV photolithography and wet etching route.

The composition of the $Mg_xZn_{1-x}O$ thin films was measured by energy dispersive x-ray spectrometer. The structure characterizations were carried out in a D/max-RA x-ray diffraction (XRD) (Rigaku) with Cu Kα 0.154 nm line as the radiation source. The transmission spectra were recorded us-

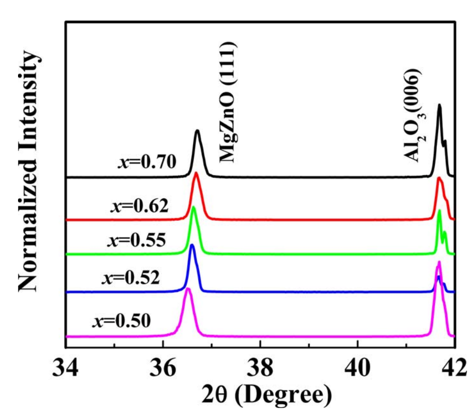

FIG. 1. (Color online) XRD patterns of the $Mg_xZn_{1-x}O$ films with Mg compositions of 0.50, 0.52, 0.55, 0.62, and 0.70, respectively.

a)Electronic mail: zhangjy53@yahoo.com.cn.

 © 2008 American Institute of Physics

Downloaded 11 Sep 2012 to 159.226.165.151. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions

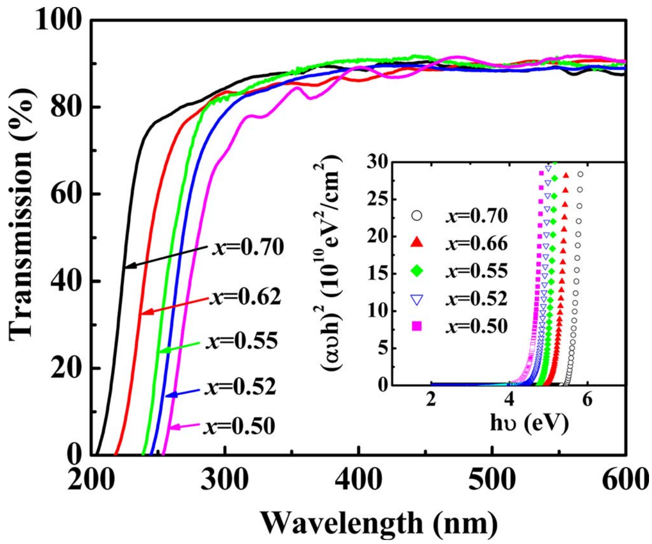

FIG. 2. (Color online) Transmission spectra of $Mg_xZn_{1-x}O$ thin films (x=0.50, 0.52, 0.55, 0.62, and 0.70). The inset is a plot of $(\alpha h\nu)^2$ vs $h\nu$ that gives the band gaps of these films.

ing a Shimadzu UV-3101PC scanning spectrophotometer. The spectral responsivity of the photodetectors was measured using a 150 W Xe lamp, monochromator, chopper (EG&G 192), and lock-in amplifier (EG&G 124A). The dark current was measured by a Hall measurement system (Lake Shore 7707).

The structural properties of the $Mg_xZn_{1-x}O$ thin films (with x=0.50, 0.52, 0.55, 0.62, and 0.70) assessed by XRD and the diffraction patterns of the films are shown in Fig. 1. Besides the peak from the sapphire substrate, only one peak located at around 37° can be observed for all the samples, and this peak can be attributed to the diffraction from (111) facet of cubic MgZnO alloys (JCPDS Card No. 87–0653).[19] With increasing Mg content, the (111) peak shifts to large-angle side, indicating the incorporation of Mg into the lattice of ZnO.[20] The absence of the characteristic peaks of wurtzite

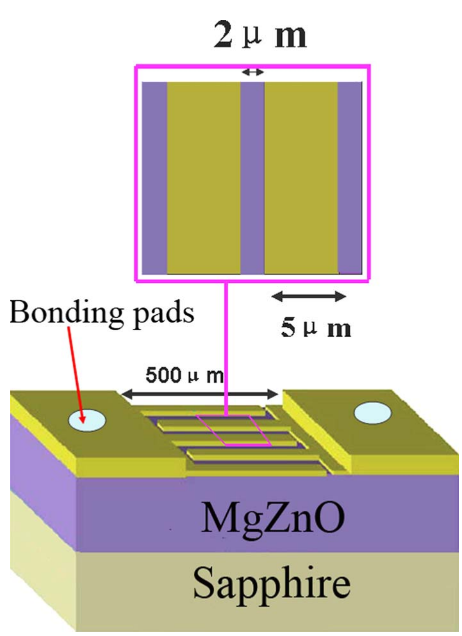

FIG. 3. (Color online) Schematic of MSM structured $Mg_{0.52}Zn_{0.48}$ photodetector. The Au fingers are 500 μm long and 5 μm wide, and the interelectrode spacing is 2 μm.

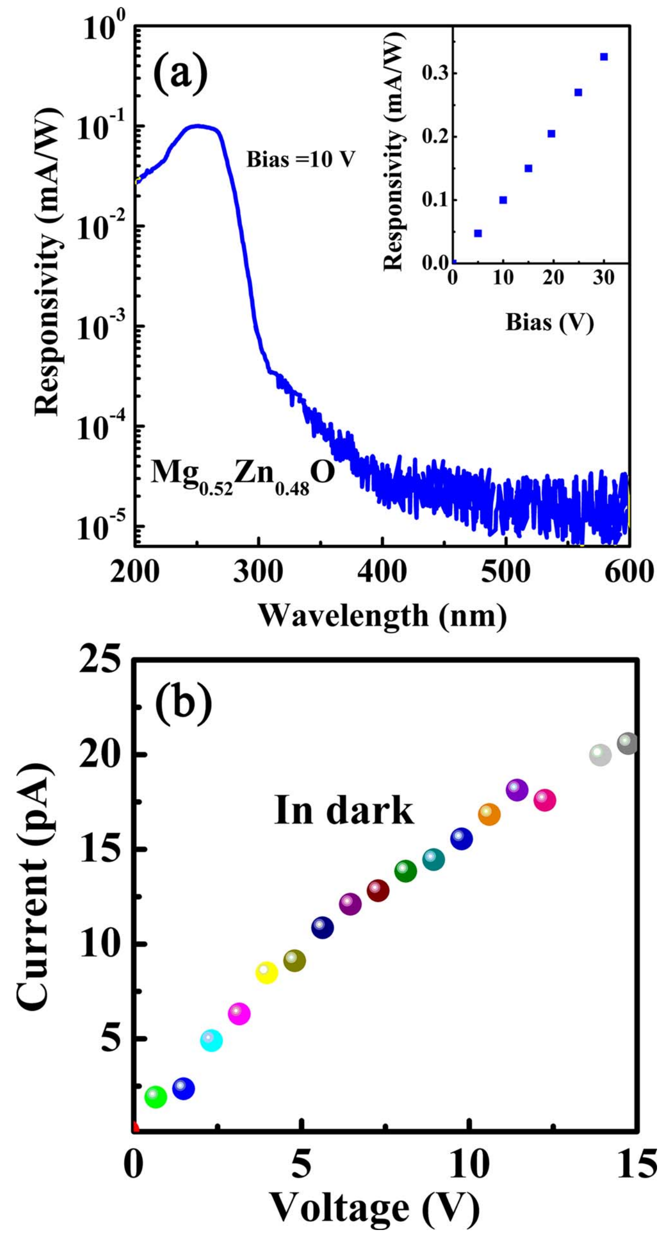

FIG. 4. (Color online) (a) Response spectrum of $Mg_{0.52}Zn_{0.48}O$ solar-blind photodetector under 10 V bias, the inset shows the responsivity as function of bias voltage under 250 nm light illumination. (b) Dark current of the $Mg_{0.52}Zn_{0.48}O$ photodetector as a function of bias voltage.

structure indicates that the films have preferred (111) orientation without phase separation.

Figure 2 shows the transmission spectra of the $Mg_xZn_{1-x}O$ films. The inset is a plot of $(\alpha h\nu)^2$ versus $h\nu$ from which the band gaps of the films can be derived. All the samples show sharp absorption edge and high transmittance of about 90% in the visible spectrum region. With decreasing Mg content, the absorption edge shifts from 220 to 260 nm. No multi-absorption-edge, a typical characteristic of phase separation, is observed for all the samples, which confirms that phase separation that is frequently observed in MgZnO alloys with high Mg content does not occur in our case. The absence of phase separation promises that high-performance photodetectors can be obtained on these films. The exact reason for the absence of phase separation is not clear, but it may be related to the fact that MOCVD is a nonequilibrium growth technique, the relatively low growth temperature em-

Downloaded 11 Sep 2012 to 159.226.165.151. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions

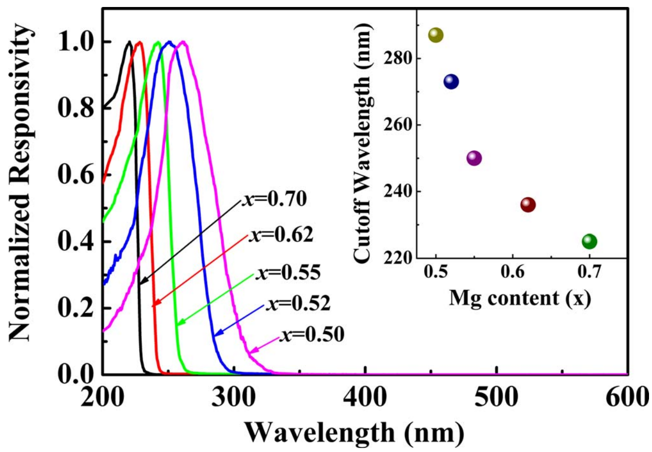

FIG. 5. (Color online) Normalized response spectra of $Mg_xZn_{1-x}O$ photodetectors with $x=0.50$, 0.52, 0.55, 0.62, and 0.70. The inset shows the cutoff wavelength of the photodetectors as a function of Mg content.

ployed (450 °C) makes kinetics instead of thermodynamics dominate the growth process. In this case, most radicals do not have enough time to reach their energy-minimum sites. As a result, single-phased metastable cubic MgZnO films have been obtained.

Figure 3 shows a schematic of the MSM structured photodetectors made from the MgZnO films. Interdigital Au fingers are deposited onto the MgZnO films as electrodes. The Au fingers are 500 μm in length and 5 μm in width, and the interelectrode spacing is 2 μm. In order to characterize the performance of the photodetectors, $Mg_{0.52}Zn_{0.48}O$ photodetector is selected as a representative. The typical responsivity curve of the $Mg_{0.52}Zn_{0.48}O$ photodetector is shown in Fig. 4. The peak responsivity is about 0.1 mA/W at 250 nm, and the cutoff wavelength is located at 273 nm. The inset in Fig. 4(a) shows the responsivity of the photodetector as a function of bias voltage. A linear relationship is observed from 0 to 30 V, indicating no carrier mobility saturation or sweep-out effect occurs up to 30 V bias.[21] In addition, the UV/visible rejection ratio (R250 nm/R400 nm) of the photodetector is about four orders of magnitude, as shown in the response spectra, which indicates that the photodetector exhibits relatively high signal-to-noise ratio. The dependence of the dark current on the bias applied is shown in Fig. 4(b). It is shown that the dark current is 15 pA under 10 V bias, which is comparable to the corresponding value reported in MSM structured GaAlN solar-blind photodetector (10 pA at 30 V bias).[22]

The response spectra of the $Mg_xZn_{1-x}O$ photodetectors with different Mg content are shown in Fig. 5. It is noted that all the photodetectors have an UV/visible rejection ratio of about four orders of magnitude. For clarity, all the spectra have been normalized. The inset shows the cutoff wavelength of the photodetectors as a function of the Mg content. As shown in the figure, the cutoff wavelength can be varied from 225 to 287 nm by changing the Mg content from 0.50 to 0.70, which covers the whole solar-blind spectrum range.

In conclusion, metastable cubic $Mg_xZn_{1-x}O$ thin films with Mg content from 0.5 to 0.7 have been prepared by MOCVD. A series of solar blind UV photodetectors with their cutoff wavelength varying from 225 to 287 nm has been realized based on these thin films. The representative solar-blind photodetector shows a UV/visible rejection ratio of about four orders of magnitude and a dark current of 15 pA under 10 V bias. The results reported in this letter indicate that high performance photodetectors with cutoff wavelength covering the whole solar-blind range can be realized on $Mg_xZn_{1-x}O$ by proper adjusting the Mg content.

This work is supported by the Key Project of National Natural Science Foundation of China under Grant No. 50532050, the "973" Program under Grant Nos. 2006CB604906 and 2008CB317105, and the Knowledge Innovation Program of the Chinese Academy of Sciences, Grant No. KJCX3.SYW.W01.

[1] M. Razeghi and A. Rogalski, J. Appl. Phys. **79**, 7433 (1996).
[2] A. Osinsky, S. Gangopadhyay, B. W. Lim, M. Z. Anwar, M. A. Khan, D. V. Kuksenkov, and H. Temkin, Appl. Phys. Lett. **72**, 742 (1998).
[3] D. Walker, X. Zhang, P. Kung, A. Saxler, S. Javapor, J. Xu, and M. Razeghi, Appl. Phys. Lett. **68**, 2100 (1996).
[4] E. Monroy, F. Calle, J. L. Pau, F. J. Sanchez, E. Munoz, F. Omnes, B. Beaumont, and P. Gibart, J. Appl. Phys. **88**, 2081 (2000).
[5] T. Tut, T. Yelboga, E. Ulker, and E. Ozbay, Appl. Phys. Lett. **92**, 103502 (2008).
[6] T. Tut, M. Gokkavas, A. Inal, and E. Ozbay, Appl. Phys. Lett. **90**, 163506 (2007).
[7] H. Jiang and T. Egawa, Appl. Phys. Lett. **90**, 121121 (2007).
[8] M. Y. Liao, Y. Koide, and J. Alvarez, Appl. Phys. Lett. **90**, 123507 (2007).
[9] V. Adivarahan, G. Simin, G. Tamulaitis, R. Srinivasan, J. Yang, M. A. Khan, M. S. Shur, and R. Gaska, Appl. Phys. Lett. **79**, 1903 (2001).
[10] V. V. Kuryatkov, H. Temkin, J. C. Campbell, and R. D. Dupuis, Appl. Phys. Lett. **78**, 3340 (2001).
[11] T. Tut, M. Gokkavas, B. Butun, S. Butun, E. Ulker, and E. Ozbay, Appl. Phys. Lett. **89**, 183524 (2006).
[12] R. M. Clintock, A. Yasan, K. Minder, P. Kung, and M. Razeghi, Appl. Phys. Lett. **87**, 41123 (2005).
[13] C. Sevik and C. Bulutay, Appl. Phys. Lett. **83**, 1382 (2003).
[14] C. J. Collins, U. Chowdhury, M. M. Wong, B. Yang, A. L. Beck, R. D. Dupuis, and J. C. Campbell, Appl. Phys. Lett. **80**, 3754 (2002).
[15] D. Walker, V. Kumar, K. Mi, P. Sandvik, P. Kung, X. H. Zhang, and M. Razeghi, Appl. Phys. Lett. **76**, 403 (2000).
[16] V. V. Kuryatkov, B. A. Borisov, and S. A. Nikishin, J. Appl. Phys. **100**, 096104 (2006).
[17] S. Choopun, R. D. Vispute, W. Yang, R. P. Sharma, T. Venkatesan, and H. Shen, Appl. Phys. Lett. **80**, 1529 (2002).
[18] W. Yang, S. S. Hullavarad, B. Nagaraj, I. Takeuchi, R. P. Sharma, T. Venkatesan, R. D. Vispute, and H. Shen, Appl. Phys. Lett. **82**, 3424 (2003).
[19] JCPDS Card No. 87–0653.
[20] R. Ghosh and D. Basak, J. Appl. Phys. **101**, 113111 (2007).
[21] W. Yang, R. D. Vispute, S. Choopun, R. P. Sharma, and T. Venkatesana, Appl. Phys. Lett. **78**, 2787 (2001).
[22] J. L. Pau, E. Muñoz, M. A. Sánchez, and E. Calleja, Proc. SPIE **4650**, 104 (2002).

Downloaded 11 Sep 2012 to 159.226.165.151. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions