Optics Communications 346 (2015) 43–46

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

A practicable route to improve the responsivity of $Mg_{0.2}Zn_{0.8}O$ ultraviolet photodetectors

Rusheng Liu [a], Dayong Jiang [a,*], Maiyu Zhou [b], Guang Yang [b], Long Sun [a], Chunguang Tian [a], Shang Gao [a], Qingcheng Liang [a], Jianxun Zhao [a], Jianhua Hou [a]

[a] School of Materials Science and Engineering, Changchun University of Science and Technology, Changchun 130022, China
[b] Special Service Department, Aviation University of Air Force, Changchun 130000, China

ARTICLE INFO

Article history:
Received 11 December 2014
Received in revised form
30 January 2015
Accepted 10 February 2015
Available online 11 February 2015

Keywords:
Ultraviolet photodetector
Thermal annealing
Responsivity

ABSTRACT

The paper reports a study of the thermal annealing effects on $Mg_{0.2}Zn_{0.8}O$ ultraviolet photodetector with sequential annealing temperature (500, 600, 700 and 800 °C). As for the single hexagonal phase photodetector, the responsivity suddenly increases from 600 to 700 °C, which has been interpreted in terms of a qualitative model considering the thermal effects on the surface film. These results reveal a practicable route to improve the responsivity of $Mg_{0.2}Zn_{0.8}O$ ultraviolet photodetector via the device thermal annealing.

1. Introduction

Wurtzite ZnO, environment friendliness and direct bandgap materials, is very popular for its applications in ultraviolet (UV) photodetectors (PDs) [1]. Additionally, alloying with rock salt MgO provides a possibility to increase the band gap from 3.37 to 7.80 eV [2,3]. Although, metal–semiconductor–metal (MSM) structured UV PDs based on $Mg_xZn_{1-x}O$ have been extensively demonstrated in recent years [4–6], it is still a significant challenge to improve the responsivity at present [7,8], which fall short of the high performance prerequisite.

In attacking this problem not only depends on manufacturing operation [9], but also on post-heat treatments such as thermal annealing. The annealing on $Mg_xZn_{1-x}O$ PDs is conducive to enhancing the metal–semiconductor contact and optimizing the surface film structure [10]. Consequently, it is an easy and straightforward way to raise the device performance, which has become a necessary process in production. However, a systematic study about thermal annealing on $Mg_xZn_{1-x}O$ UV PDs is still immature. Particularly, the surface film, as an essential part of the device, does not be ignored during the annealing process. In this communication, we expose the thermal annealing effects on the performance of $Mg_{0.2}Zn_{0.8}O$ UV photodetector, especially the enhanced responsivity results from the annealed surface film.

2. Experimental

Firstly, the vacuum chamber had been initially evacuated to 5×10^{-4} Pa, then Ar and O_2 were introduced into the chamber with a flow ratio of 50:15 sccm. Subsequently, the $Mg_{0.2}Zn_{0.8}O$ film grown on the quartz substrate with a total pressure of 4 Pa, a sputtering power of 130 W and a rotational speed of 10 rpm for 2 h. To reduce the film defects, the $Mg_{0.2}Zn_{0.8}O$ thin film was annealed at 550 °C for 30 min in the open air. Finally, the top Au finger electrodes, 500 μm long and 5 μm wide with 5 μm spacing, were constructed through conventional UV photolithography and wet etching route.

After the device fabrication, thermal annealing was performed in a tube furnace. To perform the changes of the film structure, relative high annealing temperature (500, 600, 700 and 800 °C) was perform in the open air for 30 min. The phase identification of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector was characterized by the Rigaku Ultima VI X-ray diffractometer (XRD) with Cu Kα radiation ($\lambda=1.54184$ Å) at 40 kV and 20 mA. A PerkinElmer Lambda 950 UV/VIS Spectrometer was used for absorbance spectra in the wavelength range from 200 to 500 nm. The responsivity characteristics (Zolix DR800-CUST) and the current–voltage (*I–V*) (Agilent 16442A Test Fixture) under dark were recorded after each annealing cycle at room temperature.

3. Results and discussion

The XRD patterns of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector annealed at different temperatures are shown in Fig. 1. The

* Corresponding author.
E-mail address: dayongjiangcust@126.com (D. Jiang).

http://dx.doi.org/10.1016/j.optcom.2015.02.020
0030-4018/

diffraction peaks of Au and In come from the contact electrodes, the schematic illustration of the photodetector shown in the inset of Fig. 5. The diffraction peak (002) at around 34.80° indicates that the photodetector was wurtzite structure and single-phase after being annealed at 500, 600 and 700 °C. While two diffraction peaks at ~34.71° and ~35.46° are obtained at 800 °C, which is assigned to the (002) plane of hexagonal MgZnO and the (111) plane of cubic MgO, respectively. Such phase segregation phenomenon has been generally observed in MgZnO with high Mg content [11–14]. But today, we just discuss the photodetector with a single-phase due to the Au finger electrodes were broken at 800 °C.

As we know, the lattice constant c of nanocrystal is a key parameter to phase stability, which can be described as the following equation:

$$c = \frac{\lambda}{2\sin\theta}\sqrt{\frac{4}{3(a/c)^2}(h^2 + hk + k^2) + l^2}, \quad (1)$$

where h, k, l are Miller exponents, λ and θ is X-ray wavelength (λ=1.54184 Å) and Bragg angle, respectively. As shown in Fig. 2, the (002) peak extended to the large angle with increasing the annealing temperatures up to 600 °C. According to the Eq. (1), the c-axis length decreased which should be attributed to the bonding of Mg–O was strengthened leading to better crystallinity [15]. However, the diffraction angle of (002) peak start to decrease from 700 °C, which means the increase of the c-axis length. We speculate that the orderly wurtzite structure was destroyed by the thermal annealing. To exclude the possible influence of Au and In diffusion into the $Mg_{0.2}Zn_{0.8}O$ films during the annealing process, the $Mg_{0.2}Zn_{0.8}O$ films without Au/In electrodes have been prepared and performed. The XRD patterns and diffraction angles of the $Mg_{0.2}Zn_{0.8}O$ films are plotted in the inset of Fig. 2. The similar variation trend, diffraction angles start to decrease with increasing the annealing temperatures after reaching maximum, agrees well with the photodetector annealing which performed a good repeatability and excluded the diffusion influence of Au and In.

The absorption spectra of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector are shown in Fig. 3, which were tested on the same condition without the substrate contribution. It should be noteworthy that the absorption of the photodetector annealed at 500–600 °C is nearly the same, indicating the band-gap does not change in the temperature range. While the absorption edge of 700 °C shows a little red-shift and two absorption edges are observed at 800 °C. The phenomena may be due to the fact that the trend of phase separation appeared at 700 °C and phase separation has occurred at 800 °C. The results are in good agreement with the values deduced from the XRD patterns.

The photoresponse spectra of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector annealed at different temperatures were recorded under a fixed bias voltage of 30 V shown in Fig. 4. It is fairly clear that the responsivity almost keeps constant after the photodetector was annealed at 500 to 600 °C. However, the responsivity dramatically increases when the annealing temperature up to 700 °C, which peak located at around 291 nm and cutoff wavelength is about 360 nm. By means of precise count, the responsivity is increasing from 3.95 to 87.94 mA/W, corresponding to the annealing temperature is 500 and 700 °C. The dark I–V characteristics of the photodetector annealed at different temperatures are shown in Fig. 5. The nonlinear I–V characteristics indicate that Schottky metal–semiconductor contacts were achieved. Obviously, there is no significant change in the value of the dark currents from 500 to 600 °C, which is about −51.78 pA under −15 V shown in the inset of Fig. 5. However, the dark current obviously increases to −120 pA at 700 °C.

Three possible reasons are proposed as the cause the reduction of Schottky barrier height which results in the enhanced responsivity and dark current: the inter-diffusion, oxygen vacancies induced by interface-alloying and the Zn interstitial shallow donors. Firstly, the inter-diffusion in metal–semiconductor contact is gradualness during the annealing process [16]. However, the responsivity and dark current are almost the same from 500 to 600 °C and dramatically increase at 700 °C (as shown in Figs. 4 and 5), indicating the big change should be attributed to some other reasons. Secondly, oxygen vacancies induced by interface-alloying which could reduce the Schottky barrier height. Besides, the responsivity of the device should obey a nonlinear relation with bias voltage [17,18]. However, the peak responsivity of the device (annealed at 700 °C) exhibited an almost linear increase with the

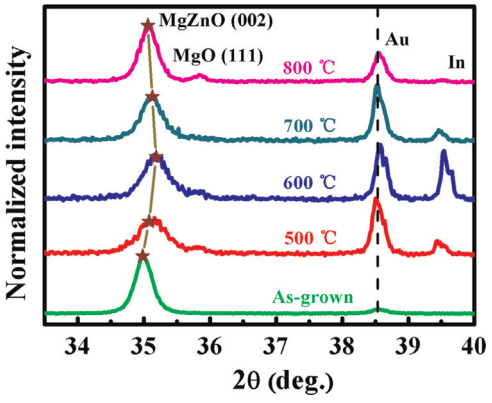

Fig. 1. Normalized XRD patterns of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector annealed at different temperatures (as-grown, 500, 600, 700 and 800 °C).

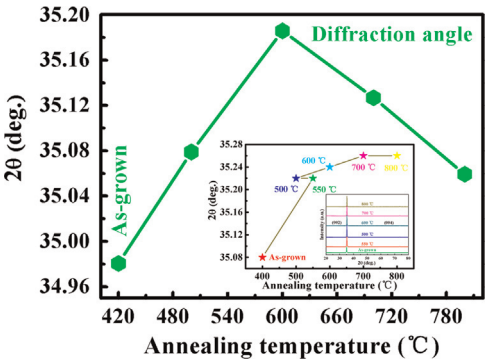

Fig. 2. Diffraction angles of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector as a function of annealing temperatures. The inset shown the diffraction angles and normalized XRD patterns of the $Mg_{0.2}Zn_{0.8}O$ film at different annealing temperatures (as-grown, 550, 500, 600, 700 and 800 °C).

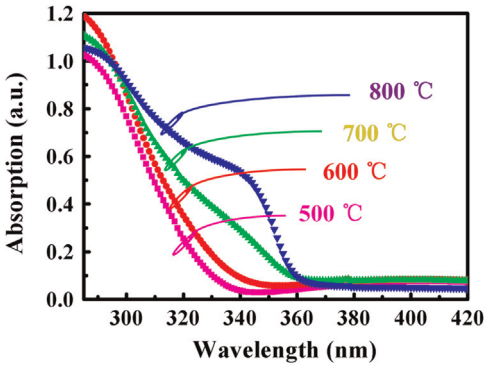

Fig. 3. The absorption spectra of the $Mg_{0.2}Zn_{0.8}O$ UV photodetector annealed at different temperatures.