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FAST TRACK COMMUNICATION

MgNiO-based metal–semiconductor–metal ultraviolet photodetector

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Abstract
In this study, we report the growth of $Mg_xNi_{1-x}O$ thin films on quartz substrates by electron beam evaporation. The absorption edge shows a blue shift from 340 nm to 260 nm with increase in the Mg content from 0.2 to 0.8. A metal–semiconductor–metal structured photodetector is fabricated from the $Mg_{0.2}Ni_{0.8}O$ film. At a bias of 5 V, the dark current of the photodetector is about 70 nA. The maximum responsivity is about 147.3 $\mu A\,W^{-1}$ at 320 nm. In addition, the ultraviolet (UV) (320 nm) to visible (400 nm) rejection ratio is nearly two orders of magnitude. Based on these results, it is proposed that $Mg_xNi_{1-x}O$ is a potential candidate for application in UV photodetectors.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Ultraviolet (UV) photodetectors have attracted much interest due to their potential application in many fields, such as UV radiation monitoring, ultra-high temperature flame detection and airborne missile warning systems, etc [1–5]. UV detectors based on different materials, such as Si, SiC, GaN, AlGaN, ZnO and $Mg_xZn_{1-x}O$ [6–8], have been reported. Among these materials, AlGaN and MgZnO are two most promising candidates [9–11]. However, the high dislocation density of AlGaN materials hinders the realization of high-performance photodetectors, although some significant progress has been made. For $Mg_xZn_{1-x}O$ films, phase-separation tends to occur when the Mg composition is in the range from 37% to 62%, because ZnO and MgO have different crystalline structures [12], which degrades the performance of the photodetectors fabricated from these materials. Both NiO and MgO are stabilized in rock-salt structure and have very similar lattice constants (0.4209 nm for MgO and 0.4177 nm for NiO), and solid solutions of NiO and MgO can cover the whole mole-fraction range (with $0 \leqslant x \leqslant 1$, where x is the MgO mole fraction) [13–16], which assures that high quality $Mg_xNi_{1-x}O$ alloys can be obtained. Since the band-gaps of MgO and NiO are 7.8 and 3.6 eV, respectively [17, 18], the cutoff wavelength of the photodetectors fabricated from $Mg_xNi_{1-x}O$ alloys may be extended from 160 to 350 nm. Therefore, $Mg_xNi_{1-x}O$ can be a potential candidate for application in UV photodetectors. Nevertheless, no report on the photodetectors fabricated on $Mg_xNi_{1-x}O$ can be found to the best of our knowledge. Even in the film growth field, only a few studies on $Mg_xNi_{1-x}O$ thin film were reported [19].

In this letter, $Mg_xNi_{1-x}O$ alloy films have been grown by electron beam evaporation (EBE), and a metal–semiconductor–metal (MSM) structured photodetector was fabricated based on a $Mg_{0.2}Ni_{0.8}O$ film. The response characteristics of the photodetector have been studied.

2. Experiments

The $Mg_xNi_{1-x}O$ films were grown on quartz substrates by an EBE system. Sintered ceramic targets with the composition of $(MgO)_{0.2}(NiO)_{0.8}$, $(MgO)_{0.5}(NiO)_{0.5}$ and $(MgO)_{0.83}(NiO)_{0.17}$

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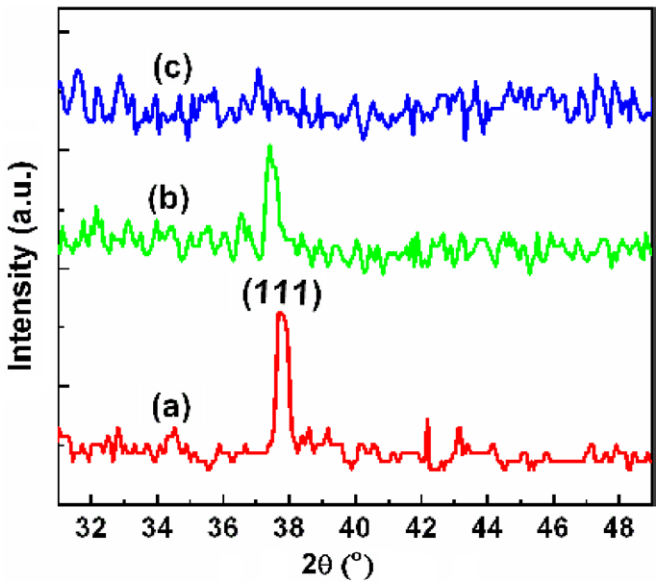

Figure 1. XRD spectra of the $Mg_xNi_{1-x}O$ thin films grown on quartz with different Mg concentrations. (a) $Mg_{0.2}Ni_{0.8}O$, (b) $Mg_{0.5}Ni_{0.5}O$ and (c) $Mg_{0.83}Ni_{0.17}O$.

were used as the evaporation sources. Prior to the evaporation, the substrates were cleaned using acetone and ethanol for 5 min in an ultrasonic bath, followed by rinsing with de-ionized water. The background vacuum in the reaction chamber is 2.5×10^{-3} Pa. The substrate temperature and electric beam current were kept at 400 °C and 35 mA in the deposition process. In this way, three samples with different Mg compositions were prepared, and they are labelled samples (a), (b) and (c). The thickness of the films is about 300 nm. A Ringaku O/max-RA x-ray diffractometer (XRD) with Cu Kα radiation ($\lambda = 0.1541$ nm) was used to evaluate the crystalline properties of the $Mg_xNi_{1-x}O$ films in θ–2θ scan mode. The composition of the films was characterized by an energy-dispersive spectrometer (EDS). Optical absorption spectra were recorded using a Shimadzu UV-3101PC scanning spectrophotometer. A MSM structured photodetector was fabricated on a $Mg_{0.2}Ni_{0.8}O$ film by depositing interdigital Au electrodes on the film. The current–voltage (I–V) curve of the photodetector was measured by an HMS 7707 Hall measurement system (Lakeshore). A standard lock-in amplifier was employed for the spectral response measurements, where the irradiation source is a 150 W Xe lamp.

3. Results and discussion

Figure 1 shows the XRD spectra of the $Mg_xNi_{1-x}O$ films. It is noticed that only one broad $Mg_xNi_{1-x}O$ (1 1 1) peak can be observed. The diffraction peaks of samples (a), (b) and (c) are located at 37.70°, 37.31° and 37.07°, respectively. With increasing Mg content, the peak shifts to the small-angle side, and the intensity decreases. The shift can be attributed to the replacement of Ni ions (with an atom radius of 0.083 nm) by Mg ions which have a slightly larger atom radius (0.086 nm).

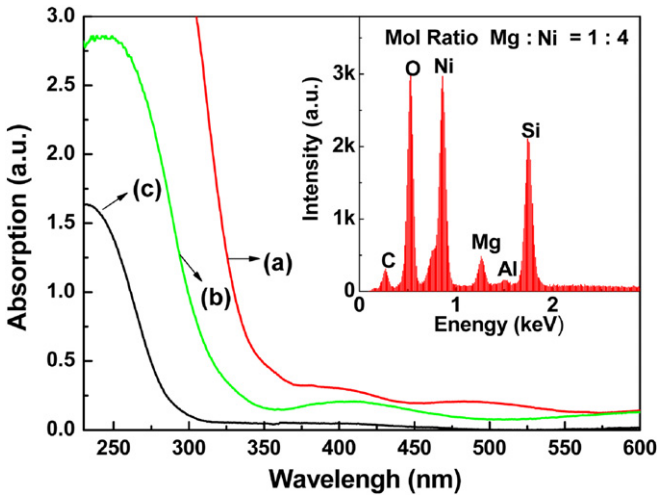

Figure 2. Absorption spectra of $Mg_{0.2}Ni_{0.8}O$ (a), $Mg_{0.5}Ni_{0.5}O$ (b), and $Mg_{0.83}Ni_{0.17}O$ (c). The inset shows a typical EDS spectrum of the $Mg_{0.2}Ni_{0.8}O$ film.

Shown in figure 2 are the optical absorption spectra of the $Mg_xNi_{1-x}O$ films with different Mg compositions. The inset shows a typical EDS spectrum of sample (a), and the Mg/Ni atom ratio is about 1 : 4 as revealed by the EDS spectrum (the detection limit of EDS is 1%). Simultaneously, the atomic concentrations of Mg in the $Mg_xNi_{1-x}O$ films obtained from their EDS spectra are 0.2, 0.5 and 0.83 for samples (a), (b) and (c), respectively, which is in good agreement with the composition of the source target. The absorption edge shows a clear blue shift from 340 to 260 nm as the Mg concentration increases from 0.2 to 0.83, as shown in figure 2. Theoretically, the band-gap E_g of $Mg_xNi_{1-x}O$ alloys can be expressed by the following formula [17]:

$$E_g(Mg_xNi_{1-x}O) = xE_g(MgO) + (1-x)E_g(NiO), \quad (1)$$

where E_g (MgO) and E_g (NiO) are the band-gap of MgO and NiO, respectively. Therefore, the band-gap of $Mg_xNi_{1-x}O$ with Mg concentrations of 0.2, 0.5 and 0.83 can be derived to be 4.43 eV, 5.69 eV and 7.09 eV (corresponding to absorption edges of 280 nm, 218 nm and 175 nm), respectively. However, the absorption edges observed in figure 2 are all longer than the derived values from equation (1). In our experiments, we thought that this may be due to the following facts: the mobility of Mg atoms and O atoms on the substrate is relatively slow at low growth temperature, which results in the nonuniformity of Mg content in the films. There might be many Mg-rich areas in the $Mg_xNi_{1-x}O$ alloy. Because of the very small difference in the lattice constants of MgO and NiO, the nonuniformity may not be detected by XRD. As is well known, composition fluctuation frequently existed in alloy semiconductors [20, 21]. The precipitated nanograins have a higher Mg concentration and the host has a higher Zn concentration coexisting in the $Mg_xZn_{1-x}O$ film, which has been confirmed [22]. Therefore, we deduced that our samples exist the similar case, some Mg radicals may be in the form of clusters, which does not contribute to the absorption spectrum, but to the EDS data in this paper. As a result, the $Mg_xNi_{1-x}O$ with low Mg content in the films plays a major part in the band-gaps of the thin films,

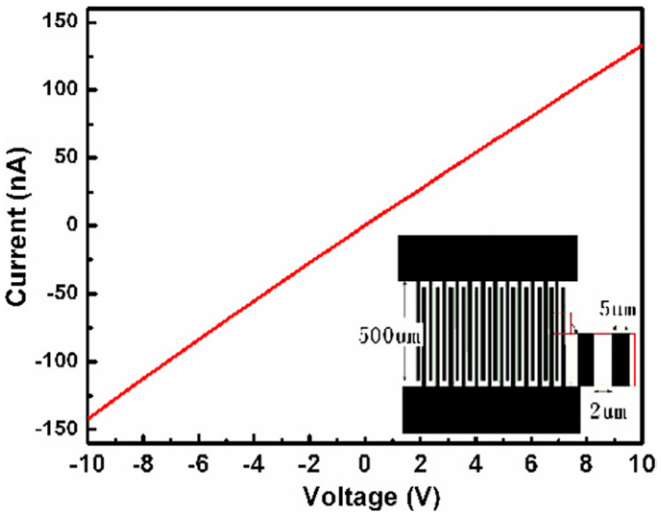

Figure 3. I–V characteristics of the $Mg_{0.2}Ni_{0.8}O$ MSM photodetector. The inset shows the interdigitated electrode configuration of the device.

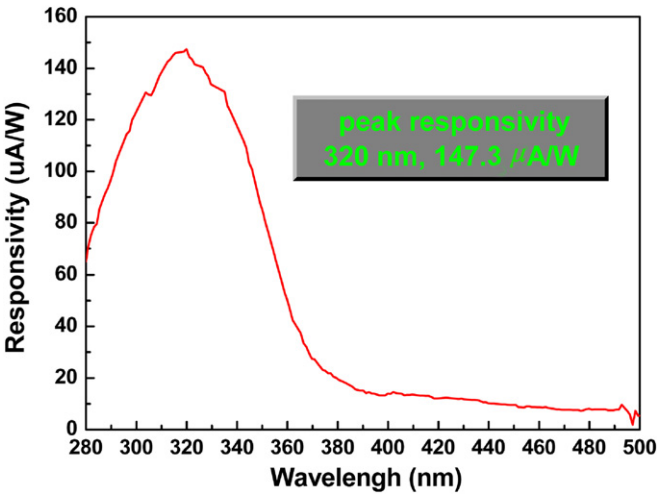

Figure 4. Spectral responsivity of the photodetector fabricated from $Mg_{0.2}Ni_{0.8}O$ at a bias of 5 V.

and the induced band-gaps derived from absorption spectra are smaller than the values calculated from the EDS data.

Figure 3 shows the I–V curve of the $Mg_{0.2}Ni_{0.8}O$ photodetector. The inset shows the schematic illustration of the interdigital Au electrodes deposited onto the $Mg_{0.2}Ni_{0.8}O$ thin films, in which the black and white parts are the Au electrode and $Mg_{0.2}Ni_{0.8}O$ area, respectively. The interdigital metal electrodes, which were defined on a 200 nm Au layer by conventional UV photolithography and lift-off procedure, are 500 μm long and 5 μm wide, with 2 μm spacing. There are 24 fingers in this structure, including 12 up and 12 down. In this way, an MSM structured photodetector has been prepared. As shown in figure 3, the dark current of this photodetector is about 70 nA at 5 V bias.

The spectral response of the $Mg_{0.2}Ni_{0.8}O$ photodetector is shown in figure 4. At 5 V bias, the photodetector has a peak responsivity of 147.3 $\mu A\,W^{-1}$ at 320 nm. The cutoff wavelength is about 340 nm, which is in agreement with the absorption edge of the $Mg_{0.2}Ni_{0.8}O$ shown in figure 2. Meanwhile, the UV (320 nm)/visible (400 nm) rejection ratio (the ratio of photoresponsivity with illuminated light at 320 nm to 400 nm) of the device is more than two orders of magnitude.

We note that the method used for the $Mg_xNi_{1-x}O$ films growth is the EBE system, which is much cheaper and simpler than other systems such as molecular beam epitaxy, metal–organic chemical vapour deposition or pulsed laser deposition. Therefore, the photodetector obtained in this paper prevails in expense over that prepared using other methods. Additionally, by optimizing the growth conditions of the alloys, $Mg_xNi_{1-x}O$ based photodetectors with better performance could be attainable.

4. Conclusion

In conclusion, $Mg_xNi_{1-x}O$ films have been grown on quartz substrates by the EBE method, and a prototype photodetector was fabricated on the $Mg_{0.2}Ni_{0.8}O$ film. The peak responsivity of the photodetector is located at 320 nm and the cutoff wavelength at 340 nm. The results indicate that $Mg_xNi_{1-x}O$ can be a promising candidate material for ultraviolet photodetectors.

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