Research Result

Influence of Thickness Effect on the Optical and UV detection Properties of Al-Doped ZnO Nanocrystalline Films

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ABSTRACT

The $Zn_{0.99}Al_{0.01}O$ nanocrystalline films with thickness of 160, 200, and 240 nm were fabricated on the Corning glass for UV-VIS-NIR transmittance ratio and UV photodetection properties investigation. Three different thickness of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films were deposited by repeating sol-gel spin-coating method for 8, 10, and 12 times to obtain 160, 200, and 240 nm films, respectively. The transmittance spectrums of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films measured by the UV-VIS-NIR spectrophotometer shows the transmittance ratio decreases with the increase of film thickness. Based on transmittance ratio, the optical energy gap Eg can be deduced by Tauc Plot Method. The results showed the energy gap Eg slightly increase with the increase of thickness. Finally, the I-V curves were measured in the dark and under UV illumination separately. The results show a decrease of current variation ratio defined as $(I_{photo}-I_{UV\text{-}dark})/I_{UV\text{-}dark}$ with increasing the thickness of $Zn_{0.99}Al_{0.01}O$ nanocrystalline films. However, the current variation ratios of all ZnO nanocrystalline films are at least above 88% which all exhibit sufficient UV light photodetection characteristics which may be possible for future high-performance UV photodetection application.

KEYWORDS

ZnO, thickness effect, transmittance ratio, current variation ratio, UV photodetection.

1. INTRODUCTION

Recent studies have focused on the development of highly efficient, flexible process, and highly sensitive ultraviolet (UV) photodetectors with various wide band-gap materials. Therefore, a variety of wide-band gap nanomaterials have been utilized for UV detection research to achieve higher performance photosensitivity [1]. The II-VI compound semiconductor ZnO with a wide bandgap of 3.37 eV along with the advantages of high thermal stability, low-cost and Silicon process compatibility makes itself become one of the most important photonic materials for UV photodetection application [2]. Meanwhile, zinc oxide (ZnO) based nanomaterials have attracted significant attention due to their miscellaneous properties such as piezo-phototronic and pyro-phototronic effects, which allow the fabrication of high-performance and low power consumption-based photodetectors for industrial application [3]. For the past few years, researchers further declared that synthesis, characterization, and practice industrial applications of the ZnO-based compound including ZnO doped with Group I, II, III and other transition metals have been comprehensive objects due to their brilliant electrical, optical, and chemical properties [4]. A great deal of studies has been focused their research on the metal-doped ZnO-based UV photodetectors with nano-scale thin films. In this study, Al has been chosen as doped element due to its environment friendly nature and high *n*-type Zn-substitution rate. The light doped of Al in ZnO ($Zn_{0.99}Al_{0.01}O$) nanocrystalline films are fabricated on the Corning glass substrates with various thickness separately by the sol-gel spin-coating method for the investigation of the influence on the optical properties. Besides, the possibility of the Al-doped ZnO nanocrystalline films for the application for UV photodetection is also discussed.

2. EXPERIMENTAL PROCEDURE

The $Zn_{0.99}Al_{0.01}O$ nanocrystalline films with thickness of 160, 200, and 240 nm were fabricated on the Corning glass substrates separately by sol-gel spin-coating method. The precursor solutions were prepared by zinc acetate dihydrate $Zn(C_2H_3O_2)_2{\cdot}2H_2O$, aluminum acetate dihydrate $Al(C_2H_3O_2)_3{\cdot}2H_2O$, 2-methoxyethanol $C_3H_8O_2$, and 2-aminoethanol C_2H_7NO. Zinc acetate dihydrate and aluminum acetate dihydrate with 0.99:0.01 mole ratio was firstly dissolved in 2-methoxyethanol with Zn/Al ions concentration keeping at 0.5 M. Then, 2-methoxyethanol as a stabilizer was added into the solutions to form stable precursor solutions. Transparent solutions were obtained after stirring at 150°C for 1 hour on a hotplate. Then, the solution was left at room temperature for 72 hours to obtain a clear solution. After that, the $Zn_{0.99}Al_{0.01}O$ films were deposited on the Corning glass substrates separately with the solution by spin-coating method. The precursor solution was dropped on the Corning glass substrate and initially spun at 1000 rpm for 10 seconds and accelerated to 3000 rpm for 30 seconds. Then, the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films were preheated on the hotplate at 300°C. The coating processes will be repeated for 8, 10, and 12 times separately to obtain the films with thickness 160, 200, and 240 nm. After that, the samples of $Zn_{0.99}Al_{0.01}O$ nanocrystalline films were annealed by a high temperature quartz tube furnace at 500°C in air for 5 hours. The flow-chart of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films deposition processes by using spin-coating method us shown as Fig. 1.

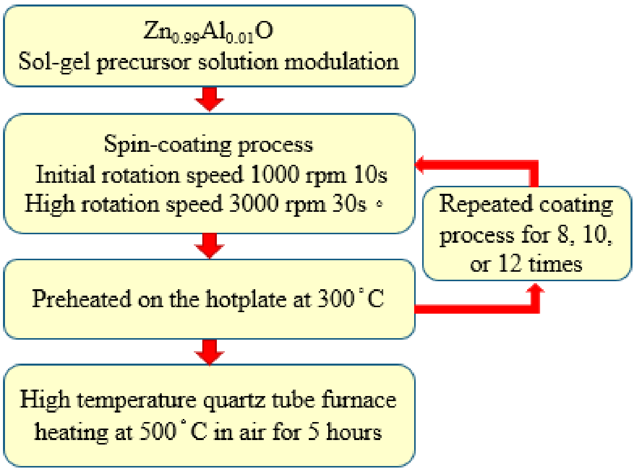


Figure 1. Flow-chart of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films deposition processes by using spin-coating method.

The UV-VIS-NIR Transmittance Spectrometer with model Jasco V-670 was utilized to measure the optical properties of all $Zn_{0.99}Al_{0.01}O$ nanocrystalline films. Finally, the current-voltage (I-V) curves of all ZnO nanocrystalline films with the bias voltage from -5 V to +5 V were performed to measure the I-V curves under dark and UV illumination using the two-point probe holder in a black isolated chamber with a Keithley 2400 source meter.

3. RESULTS AND DISCUSSION

The UV-VIS-NIR transmittance spectra in the wavelength range from 300 to 800 nm of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films grown on the Corning glass substrates with thickness 160, 200, and 240 nm were measured separately to observe the transmittance ratio. As shown in Fig. 2, the transmittance ratio of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films are all above 90% within VIS-NIR (400 to 800 nm wavelength) range which shows excellent transparent nature for visible and infrared light.

For further study on the micro-crystallinity, it is a common method to judge from the value of the optical energy gap (Eg). On of the most promise method to evaluate the Eg value is the Tauc plot method [5]. The first step is to find out the absorption coefficient (α) from the relationship between the transmittance (T) and absorption coefficient (α), $\alpha=(1/d)\ln(1/T)$, where d is the thickness of the ZnO films. And then, the equation of the relationship between the α and the Eg of the ZnO nanocrystalline films is $(\alpha h\upsilon)^2=A(h\upsilon-Eg)$, where A is a constant and hυ is the photon energ. The relationship is used to find the Eg of all $Zn_{0.99}Al_{0.01}O$ nanocrystalline films. Tauc plots of the ZnO nanocrystalline films with thickness 160, 200, and 240 nm are shown as Fig. 3.

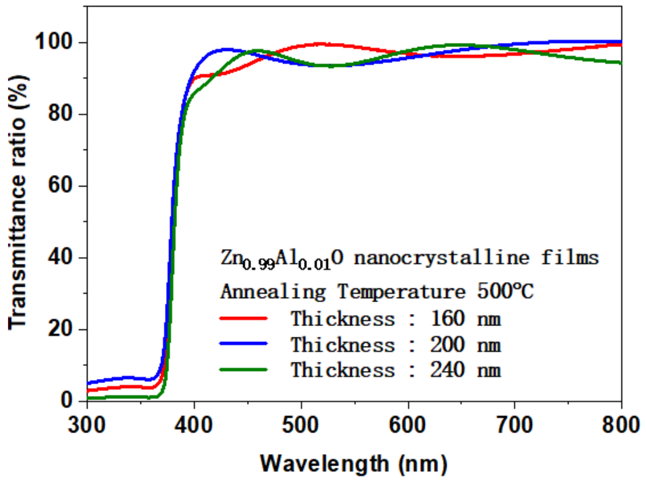
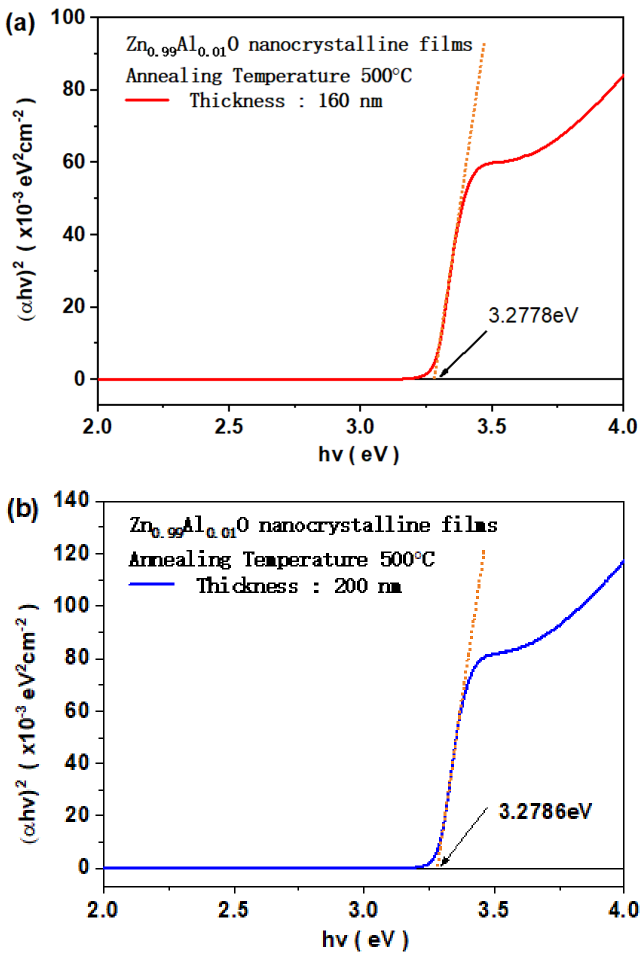


Figure 2. The transmittance spectra from 300 to 800 nm of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films grown on the Corning glass substrates with thickness 160, 200, and 240 nm.

From Tauc plots of Fig. 3, Eg can be obtained by using extrapolation method in the plots. From the results of Fig. 3, the Eg slightly increase form Eg=3.2778eV for 160 nm, Eg=3.2786eV for 200 nm, to Eg=3.28075eV for 240 nm, which was resulted from the enhancement of grain crystallization induced by increasing film thickness.



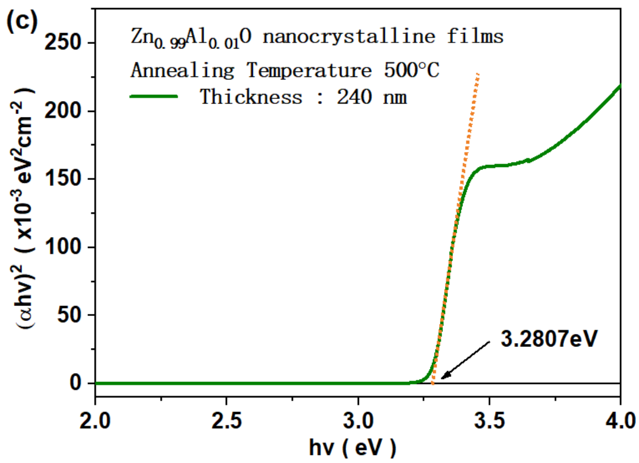
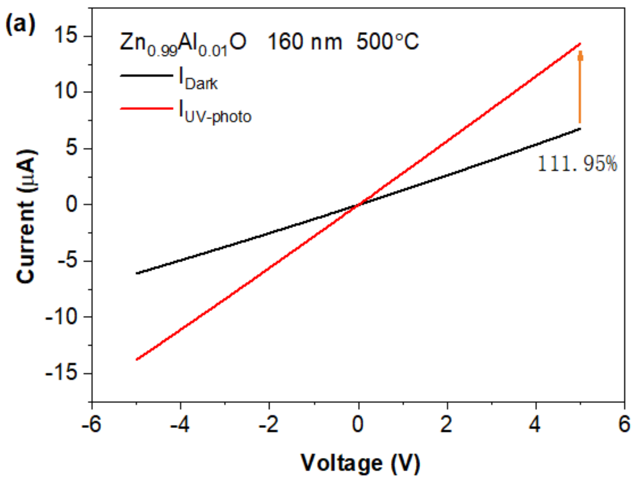
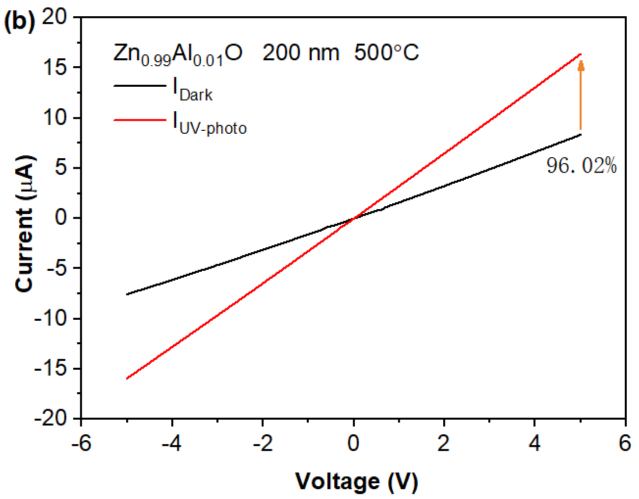


Figure 3. The Tauc plots of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films grown on the Corning glass substrates with thickness (a) 160, (b) 200, and (c) 240 nm.

Fig. 4 shows the I-V curves of all $Zn_{0.99}Al_{0.01}O$ nanocrystalline films with thickness of 160, 200, and 240 nm grown on the glass substrates, respectively. The I-V curves were measured in the dark (dark-current, noted as I_{dark}) and under UV illumination (photo-current, noted as $I_{UV\text{-}photo}$), respectively, for the purpose of the UV photodetection investigation as shown in the Fig. 4. To prevent noise interference, all I-V measurements are performed in an isolated black chamber.





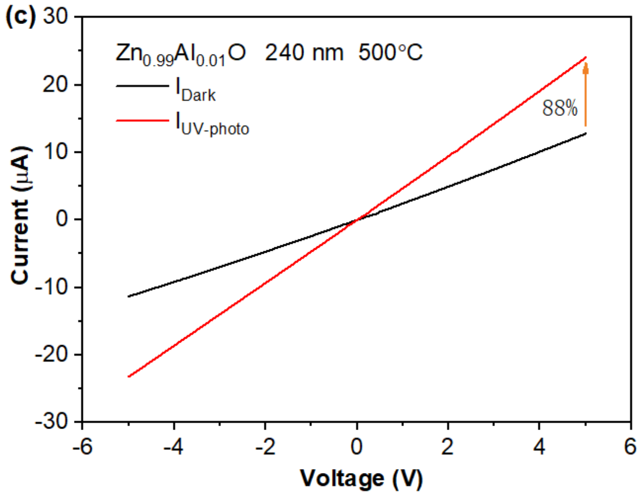


Figure 4 The I-V curves with applied voltage from -5V to 5V of the ZnO nanocrystalline films grown on the glass substrate with thickness of (a) 160 nm, (b) 200 nm, and (c) 240 nm.

As listed in TABLE 1, the I_{dark} and $I_{UV\text{-}photo}$ current values measured at +5V along with UV photo-induced current variation ratio (I%) of the ZnO nanocrystalline films with thickness of 160, 200, and 240 nm. The I_{dark} of the ZnO nanocrystalline films grown on the glass substrate increases from 6.7630, 8.3645, to 12.7869 μA with the increase of the film thickness from 160, 200, to 240 nm, respectively. Meanwhile, the $I_{UV\text{-}photo}$ also increases from 14.3340, 16.3958, to 24.0393 μA with the increase of the film thickness from 160, 200, to 240 nm, respectively. The reason of current increasing is due to both the increase of film thickness and grain size. Besides, an obvious increase of current in the dark than under UV illumination is observed. The I% is defined as $(I_{dark}\text{-}I_{UV\text{-}photo})/I_{dark}$ with current measured at 5V bias voltage to evaluate the UV photosensing property characteristic. Due to the obviously increase of I_{dark} than that of $I_{UV\text{-}photo}$ with the increase of the film thickness, the I% decreases from 111.95%, 96.02%, to 88.00% with the film thickness increases from 160, 200, to 240 nm, respectively. As a result, we obtain a decreased of UV photo-induced I% with the increase of film thickness. However, the high UV photo-induced I% above 88% of all samples show the well possibility for UV photodetection application.

TABLE 1. The I_{dark}, $I_{UV\text{-}photo}$ and I% measured at +5V bias voltage of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films with thickness of 160, 200, and 240 nm.

Film thickness (nm)	*$I_{UV\text{-}photo}$ (μA)*	*I_{dark} (μA)*	*I%*
160	*14.3340*	*6.7630*	*111.95%*
200	*16.3958*	*8.3645*	*96.02%*
240	*24.0393*	*12.7869*	*88.00%*

4. CONCLUDIONS

The influence of thickness effect on the optical properties of the $Zn_{0.99}Al_{0.01}O$ nanocrystalline films with various thickness and the corresponding UV-VIS-NIR transmittance ratio and UV photodetection properties are investigated in this study. Observed from transmittance measurements, the transmittance ration of all $Zn_{0.99}Al_{0.01}O$ nanocrystalline films are above 90% in the VIS-NIR wavelength range showed excellent transparent characteristic. The slightly increase of optical bandgap shows the enhancement of crystallization with increase of film thickness. From the I-V curve measurements, the UV photo-induced current variation ratio decreases from 141.84%, 123.53%, to 118.99% with the film thickness increases from 160, 200 to 240 nm, respectively. However, high UV photo-induced current variation ratio above 88% of all samples shows the well possibility for future UV photodetection application.

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