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Ultraviolet photoconductive detector based on Al doped ZnO films prepared by sol–gel method

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Abstract

We report a study on the fabrication and characterization of ultraviolet photodetectors based on ZnO:Al films. Using sol–gel technique, highly *c*-axis oriented ZnO films with 5 mol% Al doping were deposited on Si(1 1 1) substrates. The photoconductive UV detectors based on ZnO:Al thin films, having a metal–semiconductor–metal (MSM) structure with interdigital (IDT) configuration, were fabricated by using Au as a contact metal. The characteristics of dark and photocurrent of the UV detector and the UV photoresponse of the detector were investigated. The linear current–voltage (*I–V*) characteristics under both forward and reverse bias exhibit ohmic metal–semiconductor contacts. Under illumination using monochromatic light with a wavelength of 350 nm, photo-generated current was measured at 58.05 μA at a bias of 6 V. The detector exhibits an evident wide-range spectral responsivity and shows a trend similar to that in transmittance and photoluminescence spectrum.

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Keywords: Sol–gel; ZnO:Al; Photoconductive UV detector; Ohmic contact; Photoresponsivity

1. Introduction

Many of the important applications of ultraviolet (UV) detection are in space research, missile warning systems, high temperature flame detection, air quality monitoring, gas sensing, accurate measurement of radiation for the treatment of UV irradiated skin, etc. [1,2]. The most common detectors currently in use are the photomultipliers (PMT's) and the silicon photodetectors, but they are not blind and require costly filters to attenuate unwanted and infrared radiation. With the use of wide band-gap semiconductors such as GaN, diamond and ZnO, the need for these filters would be eliminated. In the past a few years, GaN-based UV detectors have made a remarkable progress [3]. On the other hand, material having the similar crystal structure and optical properties as those of GaN, ZnO is an attractive alternative for such applications [4,5].

Ability to detect and process signals at different wavelengths simultaneously is central in today's photonics technology. It is known that by mixing MgO (band gap 7.8 eV) with ZnO, one can have an effect of broadening the optical band gap [6]. Even ultraviolet photoconductive detector based on ZnMgO alloy films by molecular beam epitaxial has been observed by Koike et al. [7]. On the other hand, compared to $Mg_xZn_{1-x}O$ thin films, Al doped ZnO thin films also can obtain a tunable band gap. Especially, ZnO:Al thin films with high *c*-axis orientated crystalline structure along (0 0 2) plane are potential device applications in broadband UV photodetectors with high tunable wavelength resolution [8,9]. So far, there is no report on UV detector using chemically synthesized ZnO:Al film, to the best of our knowledge. In this letter, we firstly report photoconductive UV detector based on a metal–semiconductor–metal (MSM) structure on sol–gel synthesized ZnO:Al thin film.

2. Experiment

The thin films deposition was performed by spin-coating technique on the Si(1 1 1) substrate. As a starting material, zinc acetate dihydrate was used. 2-Methoxyethanol and monoethanolamine (MEA) were used as a solvent and stabilizer,

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respectively. Zinc acetate dehydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$) was first dissolved in a mixture of 2-methoxyethanol and MEA solution. The molar ratio of MEA to zinc acetate was maintained at 1.0 and the concentration of zinc acetate was 0.5 M. The molar ratio of dopant (aluminum nitrate) in the solution, [Al/Zn], was 5%.

The solution was dropped onto Si(1 1 1) substrates, which were rotated at 4000 rpm for 30 s. After being deposited by spin coating, the films were dried at 300 °C for 15 min to evaporate the solvent and remove organic residuals. The procedures from coating to drying were repeated 10 times until the desired thickness of the films was reached. The total thickness of the films was in the range of 400–450 nm. Then the films were inserted into a furnace and annealed at 550 °C for 60 min. UV photodetectors were designed and fabricated based on interdigital (IDT) MSM circular structures. The device material is made up of 5 mol% ZnO grown on Si(1 1 1) substrates. Au was used as the contact metal because of its electron negativity. A 100-nm-thick Au film electrodes was patterned on sol–gel synthesized ZnO:Al surface with a shadow mark by thermal evaporation at 250 °C.

The crystalline structure was analyzed by X-ray diffraction (XRD, BEDE-DI). The spectral photoresponse was measured using Xe lamp UV light source. The photoluminescence spectra were measured at room temperature by the fluorescence spectrophotometer (SHIMADZU, RF-5301). The optical properties were tested by UV–vis–NIR double beam spectrophotometer (SHIMADZU, UV-2550).

3. Results and discussion

The XRD spectrum of 5 mol% Al doped ZnO thin film on Si(1 1 1) substrates which annealed at 550 °C is shown in Fig. 1. It is found that the thin film has a preferential *c*-axis orientation. This indicates that the *c*-axis of the grains becomes uniformly perpendicular to the substrate surface. The *c*-axis orientation in ZnO:Al films is due to a self-texturing mechanism as discussed by Deng et al. [10]. No other crystalline phase was observed though the concentration of Al was 5 mol%, which means that the impurity does not change the crystal structure and most Al atoms in the ZnO thin films are substituted in the Zn site. The surface roughness mean square (rms) of the film is 3.68 nm, as measured by the atomic force microscopy. These results indicate that sol–gel-synthesized ZnO thin film with 5 mol% Al doping is suitable to be fabricated to UV detectors.

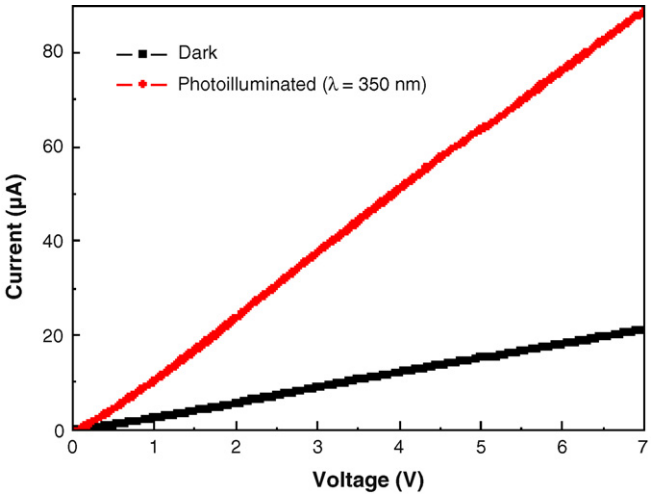

Fig. 2. Dark and photoilluminated currents of Au/ZnO:Al/Au photoconductive detector.

The Au/ZnO:Al/Au MSM structure with IDT configuration was used to evaluate the UV detector performance. The measured dark and photoilluminated *I–V* characteristics are shown in Fig. 2. The linear *I–V* relations under both forward and reverse bias exhibit ohmic metal–semiconductor contacts. The detector operates in the photoconductive mode. Under 6 V bias, the measured average dark current was 18 μA. The low dark current is helpful to enhance the detector's signal to noise (S/N) ratio. Under illumination using monochromatic light with a wavelength of 350 nm, photo-generated current was 58.05 μA at a bias of 6 V.

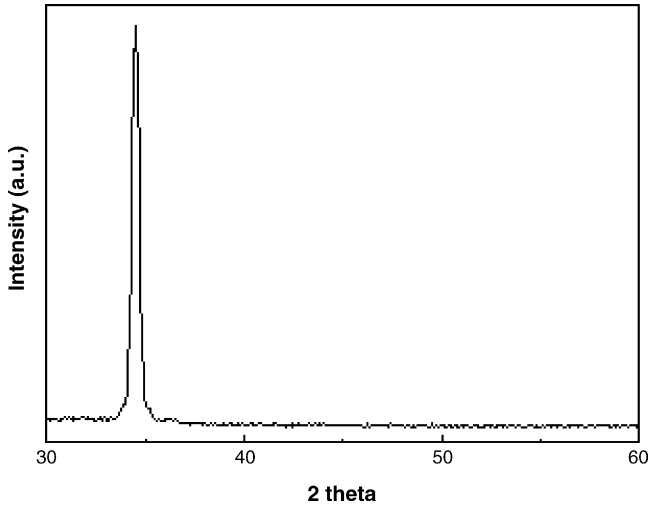

Fig. 1. XRD pattern of 5 mol% Al doped ZnO thin film.

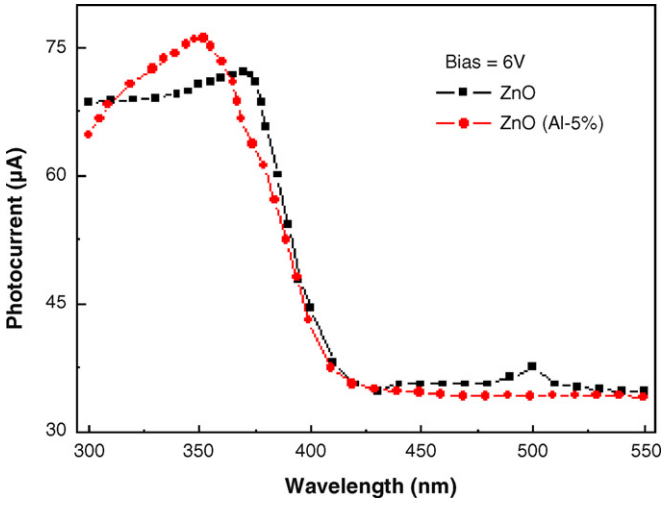

Fig. 3. Photocurrent spectrum of Au/ZnO:Al/Au photoconductive detector.