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Fabrication and characterization of an individual ZnO microwire-based UV photodetector

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ABSTRACT

In this paper, a single ZnO microwire-based photodetector for the monitoring of ultraviolet (UV) radiation is described. Single crystal ZnO microwires were synthesized using a chemical vapor deposition (CVD) on the Si or Al_2O_3 substrate. The UV photodetector was fabricated by using in-situ lift-out method in a focused ion beam system to manipulate individual zinc oxide microwire. The photodetector prototype consists of a single ZnO microwire (20 μm in length) and exhibits a response of ~10 mA/W for UV light (365 nm) under 1 V bias. The transient response measurements revealed relatively fast response. The effect of oxygen adsorption and of different relative humidity conditions on the electronic transport through individual microwire is explored and discussed.

1. Introduction

In the past decade, ultraviolet rays reaching the earth's surface have intensified due to increasing stratospheric ozone depletion, and they may cause adverse effects on the human body, like high skin cancer rates, etc. In this connection there is a strong motivation for the development of small, low-cost, robust, and efficient ultraviolet (UV) detectors able to work in diverse conditions and that can be installed in different customer electronic devices easily. Besides this, UV photodetectors found wide applications in flame sensing, missile plume detection, chemical/biological analysis and advanced optical communications. For further developments a number of requirements and constrains like radiation hardness, reliability, light weight, minimal power consuming and order-of-magnitude performance advances in detectors and enabling technologies must be met.

II–VI semiconducting oxide materials have been regarded as promising materials due to their potential application in ultraviolet radiation detectors [1–10]. In this context, zinc oxide has been reported extensively for different UV detection applications [1–4], due to its radiation resilient properties [5,6], wide band gap of 3.36 eV that makes ZnO a strong candidate for high temperature electronic devices with reliable operation in space and other harsh environments. ZnO can emit laser light in the ultraviolet range up to room temperature, thus it can be used in highly-efficient miniaturized light sources (e.g. optical storage, microanalysis and in combination with a phosphor as bright white-light-source displays). Based on multiple advantages of ZnO for device applications in comparison with other wide band gap semiconductor materials, such as GaN, SiC, diamond, it is suitable for fabrication of long lifetime devices. Recent reports demonstrate fabrication of UV photodetectors using ZnO nano/microrods and wires [1–4].

To this date, ZnO materials have been grown by a variety of methods such as pulsed laser deposition, vapor phase transport process, chemical vapor deposition method, hydrothermal and aqueous solution deposition [1–12]. However, the nano-size makes

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the ZnO sensing devices not strong enough to survive under extreme environments or in consumer electronics. In order to develop reliable ZnO-based optical devices, the high quality zinc oxide structures with micrometer size are required to optimize the UV light sensing performance. Also, for UV photodetector applications, the presence of impurities in material will decrease the UV to visible rejection ratio. We employed chemical vapor deposition method to synthesize high quality ZnO microwires and employed photoluminescence and Raman spectroscopy to investigate their optical properties.

In this work, we demonstrate a method to fabricate single ZnO microwire-based UV detector and its characteristics under different relative humidity regimes that may lead to a next generation of micron size photodetectors for a wide area of applications.

2. Experimental

The growth of ZnO structures was carried out in a horizontal furnace with an argon/oxygen flow. A mixture of ZnO (99.99%) and graphite (99.999%) powders at molar ratio of 1:1 was used as source material. A temperature profile was set in the furnace with the maximum of 1030 °C at the place of the source material and 1000 °C at the Si or Al_2O_3 substrate. The growth process was performed in 1–2 h.

The morphology of the products was analyzed using a VEGA TS 5130MM scanning electron microscope (SEM) equipped with Energy Dispersion X-ray Spectrometer (EDX). Transmission electron microscopy (TEM) was performed with a FEI Tecnai F-30 microscope operating at 300 kV. The continuous wave PL was excited by the 351.1 nm line of a SpectraPhysics Ar^+ laser and analyzed with a double spectrometer ensuring the spectral resolution better than 0.5 meV. The samples were mounted on the cold station of a LTS-22-C-330 optical cryogenic system. The Raman scattering (RS) measurements were carried out at room temperature with a MonoVista CRS Confocal Laser Raman System in the backscattering geometry under the excitation by a 532 nm DPSS laser. An in-situ lift-out technique was used for the photodetector fabrication in a focused ion beam (FIB) instrument. The UV sensitivity was measured using a two-terminal ZnO microwire device. Current–voltage (*I*–*V*) characteristics were measured using a semiconductor parameter analyzer with input impedance of 2.00×10^8 Ω [1–3]. The fabricated single ZnO microwire-based photodetector was put in a test chamber to detect ultraviolet light. The readings were taken after a UV light was turned on. The UV source is an Hg-lamp with an incident peak wavelength of 365 nm and power output of 0.1 mW with online conductivity monitoring in ambient air.

3. Results and discussion

3.1. Structural characteristics

Fig. 1 shows a SEM micrograph of ZnO microwires. The average length and diameter of these ZnO microwires are 20–200 μm and 1–3 μm, respectively. It was also found that the cross-section of the ZnO microwires are well-defined hexagons, reflecting the wurtzite structure of ZnO. The energy dispersion X-ray spectroscopy (EDX) analysis of the produced structures demonstrates a stoichiometric ZnO composition. We found that the Zn:O ratios in our nanostructures correspond to 1:1 atomic ratio in all samples within the limits of the sensitivity of the EDX system of around 0.1 at.% (Fig. 1b). However, one should note that deviation from stoichiometry at the level of 0.1 at.% could generate a large amount of defects which seriously affect the electrical parameters of the material.

High resolution transmission electron microscopy (HRTEM) was employed to characterize the as-grown ZnO microwires. To prepare TEM samples, some of the ZnO microwire crystals were mechanically broken to generate atomic sharp edges for TEM examination. Fig. 2 shows the HRTEM images taken from one broken edge of the ZnO microwires. It can be observed that the ZnO crystal lattice is well oriented and no defects were evidenced in the examined region. The lattice spacing of 0.52 nm was calculated from the TEM image. The selected-area electron diffraction (SAED) pattern of the ZnO microwire materials are shown in the insert of Fig. 2. According to the SAED results, the microwire is grown along [0001] direction of ZnO, which corresponds to the HRTEM result.

3.2. Optical studies of ZnO microwires: PL and Raman

Fig. 3 shows the PL spectrum at 10 K from a ZnO microwire sample synthesized with CVD technique. It is dominated by the emission related to the recombination of donor bound excitons (D^0X) with I_4, I_8, and I_9 lines [12–14] and free excitons (FX). The D^0X emission is accompanied by LO phonon replica. The I_4, I_8, and I_9 lines are related to H, Ga, and In residual impurities with donor binding energy of 46, 55, and 63 meV, respectively [12]. These

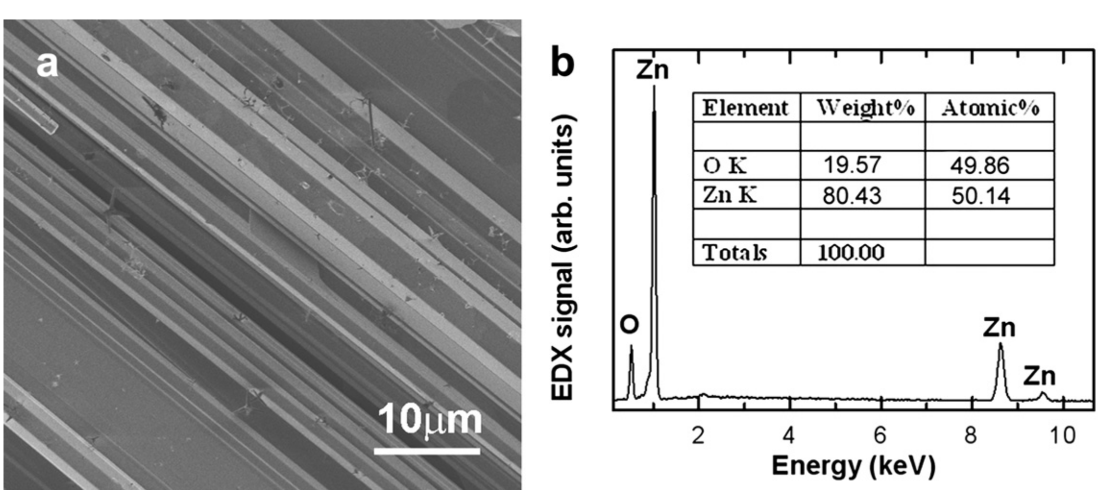

Fig. 1. SEM image of the CVD synthesized ZnO microwires (a) and the EDX analysis of the ZnO wire (b).