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ZnO nanowire photodetectors based on Schottky contact with surface passivation

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ABSTRACT

Performance characteristics, such as dark current and response time, of ZnO nanowire (NW) photodetectors are usually degraded by H_2O/O_2 adsorption on the NW surfaces. In this work, ZnO NW photodetectors based on Au Schottky contact through passivating surface states were investigated. ZnO NW photodetectors were fabricated with a lateral electrode structure, in which Au served as Au/ZnO Schottky contact and semi-transparent top electrode. Specifically, passivation of the surface states of ZnO NWs by using highly intensive UV irradiation effectively improved the photoresponse. A physical model based on surface band theory was developed to understand the origin of the performance improvement of the photodetector. The present device architecture prevents ZnO NWs photodetector from H_2O/O_2 adsorption in air and efficiently extracts photogenerated carriers across a diametrical direction.

1. Introduction

Semiconductor nanowires (NWs) have been studied intensively as potential active materials in optoelectronics and electronics because of their beneficial characteristics in structure, function, and fabrication [1–6]. Among these NWs, ZnO is an important wide-gap semiconductor with a band gap of 3.3 eV, which demonstrates strong absorption in ultraviolet (UV) light, thereby leading to evident electronic transitions from valence band to conduction band. ZnO NW photodetectors exhibited promising properties, specifically ultrahigh photocurrent gain [7,8]. To date, ZnO NWs are often exposed in air for light transmission in most photodetectors, unavoidably resulting in H_2O/O_2 adsorption on the NW surface, which increases surface-trapped charge; consequently, this charge increases dark current, delays response time, and finally degrades the performance of ZnO UV photoresponse [4,7,9,10]. It leads to the increase of surface charge which rises the dark current and increases the decay time, finally affects ZnO UV photodetectors performances [11]. Therefore, overcoming the influence of surface states to improve the performance of a photodetector is a current critical issue. Various efforts, such as Schottky contact [4,12,13], lateral electrode structures [3,14,15], and NWs coated with functionalized materials [16–19], have been contributed to address this problem.

The integrated architecture of NW-based optoelectronic devices with lateral electrodes prevents air exposure, in which the top and bottom electrodes are located on the opposite lateral sides of NWs, similar to that of a thin-film planar device. Moreover, this architecture is significantly beneficial in transporting carriers across diametrical direction and electronic injection/extraction. Our previous work proposed an effective method to fabricate the lateral electrodes on NWs [15], in which NWs were structurally matched with alumina insulation by using selective anodic oxidation, and lateral electrodes were fabricated by directly evaporating metallic atoms onto the opposite sides. In the present work, we further investigated the photoresponse characteristics of ZnO NWs based on Au Schottky contact through passivating surface states. Our work provides a new alternative to address the problem of H_2O/O_2 adsorption on ZnO NW surfaces.

2. Experimental details

The current ZnO NW photodetector was fabricated as described in the previous work [15]. ZnO NW arrays were directly grown on a GaN/sapphire substrate via a vapor transport process and dispersed directly to a Si slice by using a mechanically printed slide. An Al film was evaporated on the NW ensemble to form an

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electrical contact (bottom electrode) on one lateral side. A structurally matched alumina layer with 40 nm thickness was formed through a transfer step and selective anodic oxidation. Importantly, the alumina film layer insulated the two contacts and separated each NW. Prior to the fabrication of Au Schottky contact on another lateral side, various surface treatments were performed, such as highly intensive UV irradiation in oxygen atmosphere for a long duration. Finally, patterned SiO_2 beneath Au was used to configure the window of one cell. The morphology of the photodetector was observed under an optical microscope and a scanning electron microscope (SEM JOEL 7000F). Current–voltage (I–V) and photoresponse were measured using a Semiconductor Parameter Analyzer (Agilent 4156C) at room temperature.

3. Results and discussion

Fig. 1 shows the schematic and microscopic image of a ZnO NW photodetector cell. One cell unit contains several tens of NWs (Fig. 1c and d). Au Schottky contact also serves as a semi-transparent electrode, which renders good transmittance among metal materials [20]. Incident UV light transmits via the top electrode and excites electron–hole pairs in ZnO NWs. The dark current forms a Schottky contact because of the work functions between Au (5.1 eV) and ZnO (4.15 eV). By contrast, Al (4.1 eV) and ZnO exhibit almost no barrier between them.

The properties of electrical transport and UV photoresponse are characterized as the bias voltage applied to the Au electrode against the Al electrode. Fig. 2 shows the I–V curves measured in the dark and under a 175 μW cm^{-2} and 365 nm UV illumination. The photoresponsivity is estimated to be 1 A/W at –1 V bias. The effective illumination area of ZnO NWs is approximately 10% (Fig.1a). Hence, the real photoresponsivity of ZnO NWs is very high. The photodetector in Fig. 2a was fabricated through a normal process, whereas that in Fig. 2b was treated with an intensive UV irradiation prior to the formation of Au Schottky contact. The process through passivating surface states effectively reduced the dark current from 20 pA to 2 pA at −1 V bias and increased the on/off ratios with more than one order. The rectified current in the dark indicates the typical Schottky transport with strong rectification [21]. Under UV illumination, the current increased rapidly at a higher reverse bias. The photogenerated electron–hole pairs

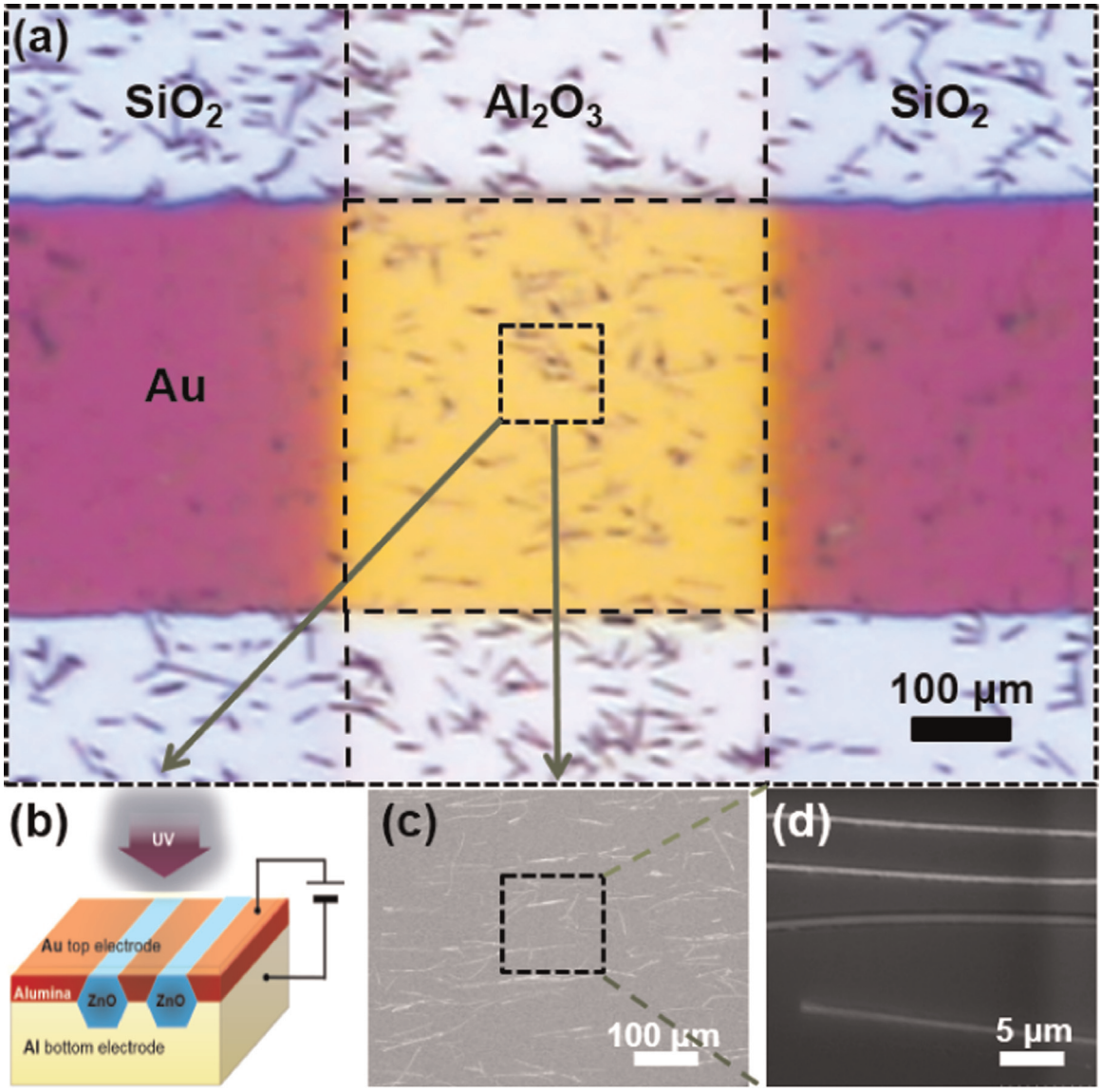

Fig. 1. (a) Optical microscopic image of one cell of ZnO NW photodetector. (b) Schematic of ZnO NW photodetector structure. (c) and (d) SEM images of ZnO NWs with different scales.

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