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ZnO nanowire array ultraviolet photodetectors with self-powered properties

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ABSTRACT

A ZnO nanowire (NW) array ultraviolet photodetector (PD) with Pt Schottky contacts has been fabricated on a glass substrate. Under UV light illumination, this PD showed a high photo-to-dark current ratio of 892 at 30 V bias. Interestingly, it was also found that this PD had a high sensitivity of 475 without external bias. This phenomenon could be explained by the asymmetric Schottky barrier height (SBH) at the two ends causing different separation efficiency of photogenerated electron–hole pairs, which resulted in the formation of photocurrent. It is anticipated to have potential applications in self-powered UV detection field.

1. Introduction

As a direct wide-gap semiconductor with a band gap of 3.37 eV and a large exciton binding energy of 60 meV, ZnO has good photoconductivity and excellent radiation hardness and can be synthesized at low temperatures [1,2]. So, ZnO is a promising photoelectric material for optoelectronics in UV range, such as light-emitting diodes, laser diodes, and photodetectors [3–5]. To date, ZnO-based UV PDs mainly fall into two categories: film type [6,7] and NW type [8,9]. Compared with the film type, the NW type counterparts are expected to exhibit better performances due to their distinct properties such as carrier confinement and high surface-to-volume ratio [10]. Monocrystalline NWs provide direct passageways for electrons, which promotes the photoresponse speed. High surface-to-volume ratio and high density of surface states increase the photoconductivity gain, resulting in a high photosensitivity [11]. Many previous studies have focused on the single NW UV PDs, which were built using sophisticated, costly and low-yield techniques [12–14]. Alternatively, due to the well-defined growth method, simple configuration and controllability of the nanostructure [5,15], ZnO NW arrays combined with metallic contacts provide a new approach to integrate single NWs into practical devices. Nevertheless, how to improve the sensitivity (photo-to-dark current ratio) and shorten the response time of these devices is still a challenge. In this study, we optimized the structure of ZnO NW array UV PDs so that they had high-performance.

On the other hand, the problem of energy shortage is sustainably worsening nowadays. It is highly desired that PDs can not only detect the signals but also be powered by these detected signals, which means saving lots of energy. Although UV PDs based on ZnO nano-materials have been widely investigated, there are few reports about the self-powered ones. In this paper, we present a UV PD based on the ZnO NW array fabricated by hydrothermal synthesis on the glass substrate. With or without external bias, the fabricated device can have high sensitivity to UV light illumination. The possible mechanism was also investigated.

2. Experimental procedure

Fig. 1 shows the schematic structure of the fabricated ZnO NW array PD. First, a 400 nm-thick ZnO seed layer was prepared by spin-coating a sol–gel precursor on the substrate, followed by an annealing treatment. After that two 50 nm-thick-Pt electrodes were deposited onto the two sides of the seed layer and served as Schottky contacts. The Pt electrodes were 10 mm long and 5 mm wide with 5 mm spacing. So, the area of uncovered ZnO seed layer

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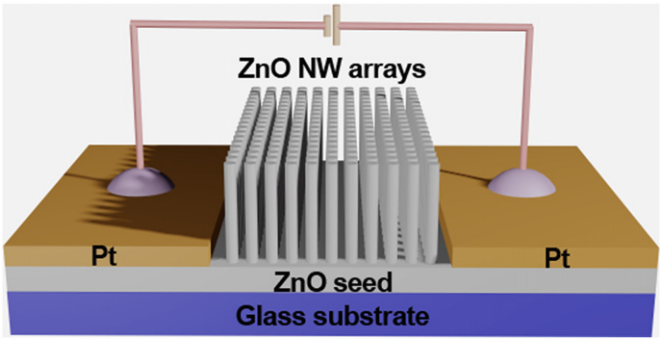

Fig. 1. The schematic diagram of the ZnO NW array UV PD.

that could promote the growth of NW arrays was 0.5 cm^2. Then, the ZnO NW arrays were synthesized using the hydrothermal method that has been reported a lot in the literature [5]. Finally, two copper wires were attached on the surface of the Pt electrodes using silver conductive adhesive.

3. Results and discussion

Fig. 2a and b shows top-view and cross-sectional FESEM images of the ZnO NW arrays, respectively. It can be seen that the vertically-aligned ZnO NW arrays are made on the glass substrate. The average length and diameter of the ZnO NWs are about 1.2 μm and 100 nm, respectively.

The photoluminescence (PL) spectra (Fig. 3a) of the ZnO NW arrays were measured by using a He–Cd (325 nm, 5 mW) laser as the excitation source at room temperature. A strong UV emission at 380 nm and a weak green emission at 580 nm were observed. The broad visible emission is related to the surface states, oxygen vacancies, and some structural defects [16]. While compared with the sharp UV emission, the weak emission in visible region is almost negligible, which can account for the formation of the high crystal quality ZnO NW arrays. Fig. 3b shows the absorption spectra of the ZnO NW arrays at room temperature. There is a sharp absorption peak at 378 nm, which is consistent with the wavelength of the PL maximum in Fig. 3a.

In order to probe the photoelectric properties of the fabricated ZnO NW array PD, the current–voltage (I–V) characters were measured in dark (black curve) and 365 nm UV light illumination (violet curve) with an intensity of 0.47 mW cm^{-2}, as shown in Fig. 4a. The nonlinear I–V characters in dark demonstrate realization of Schottky contacts between Pt and ZnO. While under UV light illumination, the I–V curve becomes linear as the violet line shows. The reasons for the differences between the dark current and photocurrent are as follows: (i) electron–hole pairs are generated in the ZnO NWs on illumination at photon energy larger than the bang gap. Along the potential gradient in outer shell of the ZnO NWs, some holes drift to the surfaces and discharge the adsorbed oxygen anions [$h^+ + O_2^-(ad) = O_2(g)$], increasing the concentration of free electrons and decreasing the width of the depletion layer [17]. The free electrons in the NWs diffuse into the ZnO seed layer, which contribute to the decrease of system resistance; (ii) the other holes are trapped by the surface states, which changes the SBH of Pt/ZnO. The SBH (Φ) can be expressed as [18]:

$$\phi = qV_{bi} + E_{cf} = \frac{Q_i^2}{2N_s\varepsilon S^2} + E_{cf} \quad (1)$$

where V_{bi} is the build-in potential in the depletion layer, E_{cf} is the deviation between the conduction band and Fermi energy of ZnO, Q_i is the concentration of charges on the interface of Pt/ZnO, N_s is

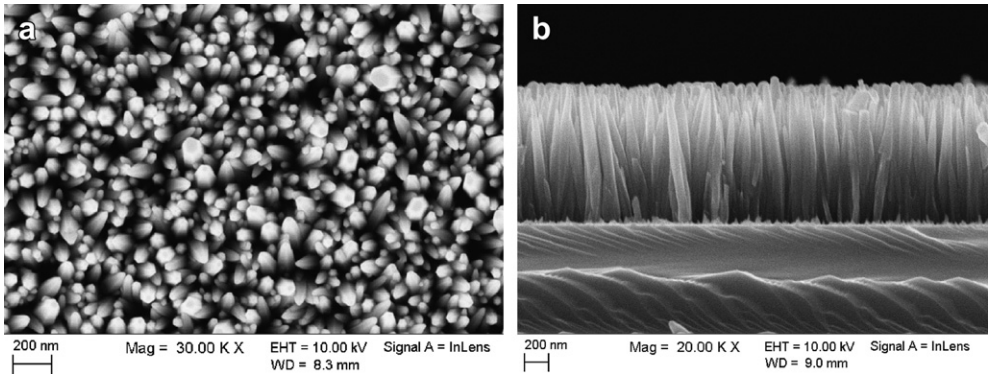

Fig. 2. (a) The top-view FESEM image and (b) the cross-sectional FESEM image of the ZnO NW arrays.

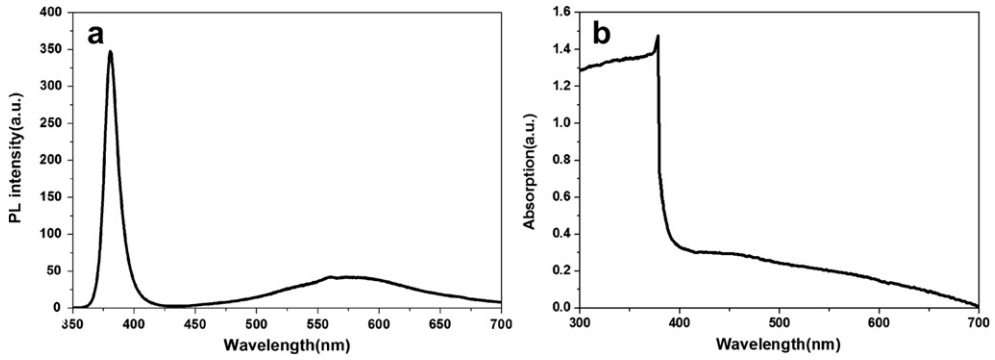

Fig. 3. (a) The PL spectra and (b) the absorption spectra of the ZnO NW arrays.