A Single ZnO Nanosheet-based UV Photodetector

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***Abstract*— In this work, an individual zinc oxide (ZnO) nanosheet was integrated into a sensor device for detection of UV light with ultra-high photosensitivity. Three-dimensional (3-D) and two-dimensional (2-D) highly porous ZnO micro- and nanostructures networks were synthesized via a simple oxidation of Zn metal powder in a furnace. The ultra-high photosensitivity (I_{UV}/I_{dark} ~ 220) of the individual ZnO nanosheet was explained based on to the dominance of the polar (0001) surfaces and the adsorption and desorption of the ambient gas molecules on these surfaces.**

***Keywords*—ZnO nanosheet, SEM, UV photodetector, nanosensor.**

I. Introduction

Since it is relatively easy with ZnO to achieve various nano- and microscale morphologies (including 3-D, 2-D and 1-D), during the recent three decades, there has been growing interest towards ZnO nano- and microstructures [1]. It was demonstrated that the structural morphology of metal oxide nano- and microstructures plays a crucial role in the performances of sensors and especially of nanosensors [2-5]. Recently, a simple approach on the synthesis of 3-D highly porous ZnO nano- and microstructure networks with four different arm morphologies in the same process was reported [2]. The difference in the morphologies of the obtained structures was understood on the basis of synthesis temperature variations, content of Zn vapor and oxygen in the furnace at different locations, which result in different growth rates along the ZnO *c*-axis and formation of 2D structures like nanosails, respectively [2].

In this work, the individual ZnO nanosheet (NS) was integrated into nanosensor devices in order to fabricate a UV photodetector with ultra-high photosensitivity. The importance of exposed facets was revealed, demonstrating that the dominance of the polar (0001) surfaces leads to a higher amount of adsorbed oxygen species.

II. Experimental part

The free-standing 3-D and 2-D highly porous ZnO micro- and nanostructures networks were synthesized via an oxidation process of Zn metal powder (Sigma Aldrich, <10 μm, ≥98%, CAS#: 7440-66-6) in a furnace [2]. More details on the synthesis process are presented in our previous work [2]. The elaborated approach gives the possibility to simultaneously grow interconnected networks of nano-ZnO-tetrapods (T), ZnO-T with complex arm morphologies, ZnO-T-nanosheets, and ZnO nanowires (NW)-T [2]. For this study, only the ZnO-T-nanosheets were used. The UV measurements were performed as was previously described in normal ambient conditions at room temperature (relative humidity ~ 30%) [2].

III. Results and Discussions

Figure 1 shows an SEM image of highly porous ZnO micro- and nanostructures networks. It can be observed that a high amount of ZnO tetrapods exhibit large sheets with nanoscale thickness on their legs. These sheets can grow up to 5 μm in width [2]. They also can grow not only on an individual leg, but also between two legs of the same tetrapod, forming airplanes – like structures [6]. The discussions on growth mechanism are presented in our previous work [2].

Such individual ZnO NSs were integrated into nanosensor devices using the method elaborated by Lupan *et al.* [7] in FIB/SEM system. The SEM image of the device is presented in **Fig. 2a**, while UV response to three pulses of UV light (intensity of 15 - 20 mW/cm^2) is presented in **Figure 2b**. As can be observed, the ZnO NS with a surface area of about 12 μm^2 was connected to Au electrodes using Pt-complex contacts.

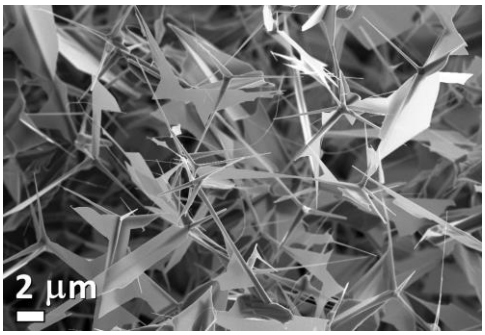

Fig. 1. SEM image of highly porous ZnO micro- and nanostructures networks formed of ZnO-T-nanosheets.

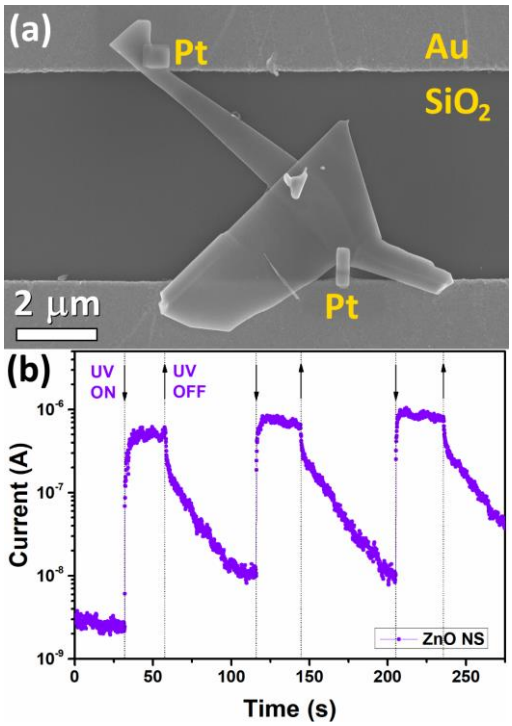

Fig. 2. (a) SEM image of the device fabricated based on individual ZnO nanosheet. (b) The room temperature dynamic photoresponse of device to UV ligth (λ = 365 nm).

The UV response of device to three consecutive pulses of UV light (intensity of 15 - 20 mW/cm^2) is presented in **Figure 2b.** The applied bias voltage was 5 V. The calculated UV response (defined as ratio of device current under UV illumination and in the dark, i.e. I_{UV}/I_{dark}) is ~ 220, which is much higher compared to an individual ZnO NW [8]. This can be explained as follows. Under exposure in ambient air, oxygen molecules will adsorb on the surface of ZnO by capturing free electrons [8]:

$$O_2(g) + e^- \rightarrow O_2^-(ads) \quad (1)$$

This will create an electron-depleted layer with low conductivity at the surface [8]. Under UV illumination, the electron-hole (e^- + h^+) pairs are generated in ZnO, and are separated by the built-in electric field in the electron-depleted layer [8]. The photo-generated holes migrate to the surface of ZnO to decrease the width of the electron-depleted layer and to discharge adsorbed oxygen ions by the surface electron-hole recombination [8]:

$$h^+ + O_2^-(ads) \rightarrow O_2(g) \quad (2)$$

The ZnO NW have more (10-10) exposed crystal planes, while ZnO nanoplates/nanosheets have more (0001) exposed crystal planes [1, 9]. The adsorption and desorption of oxygen molecules (Eq. (1)) at room temperature should occur more actively on the polar (0001) surface of ZnO nanoplates [1]. The (0001) facet is terminated with Zn^{2+} ions which are capable of seizing atmospheric oxygen (O_2) through physical/chemical absorption due to unsaturated oxygen coordination [9]. As a result, the (0001) facet has the highest chemisorption ability, i.e. higher UV response [1, 9]. Therefore, the photoelectric properties of ZnO nanosheets can be significantly improved compared to ZnO nanowires [1].

IV. Conclusions

In this work, an individual ZnO nanosheet was integrated in premiere into a UV nano-photodetector achieving an ultra-high UV response at room temperature of ~ 220. The much higher UV response of ZnO NS compared to ZnO NW was explained based on presence of more (0001) facets for ZnO NS, which has the highest chemisorption ability, i.e. higher UV sensing abilities. These results demonstrate the importance of exposed crystal facets on sensing performances of ZnO micro- and nanostructures.

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