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Self-powered ultraviolet photodetector based on ZnO nanorod arrays decorated with sea anemone-like CuO nanostructures

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ABSTRACT

ZnO nanorod arrays decorated with sea anemone-like CuO nanostructures were synthesized by hydrothermal method. A ultraviolet photodetector was fabricated based on the CuO/ZnO hierarchical nanostructures and exhibited good stability and reproducibility of self-powered photoresponse properties. The sensitivity and responsivity of the fabricated device were 120 and 0.272 mAW^{-1}, respectively. The photoresponse mechanism at zero bias was discussed through the energy band theory.

1. Introduction

In recent years, ultraviolet (UV) photodetectors (PDs) have been paid more and more attentions, due to their various potential applications in many fields, including space communications, flame detection, ozone layer monitoring and missile warning system, etc [1–4]. ZnO has been regarded as one of the most important candidates for UV PDs and solar cells because of its large exciton binding energy (60 meV) and wide direct band gap (3.37 eV) [5–7]. Meanwhile, ZnO based Schottky junction, p-n junction and heterojunction have been extensively studied for application as UV PDs [8,9]. As is known, most of the PDs require additional power supply to provide the potential difference [10]. There is an urgent demand for high performance UV PDs without consuming external power. Thus, self-powered UV PDs driven by a built-in potential difference have been attracting increasing interests.

In this paper, we reported a facile synthesis method for the CuO/ZnO hierarchical nanostructures consisted of ZnO nanorod arrays (ZnO NRAs) and sea anemone-like CuO nanostructures (CuO SANs). A novel self-powered UV PD based on CuO/ZnO hierarchical nanostructures and its photoresponse properties were presented. The possible mechanism was also discussed.

2. Experimental methods

UV PDs based on ZnO NRAs decorated with CuO SANs were fabricated on SiO_2/Si substrates (thermal oxide thickness is 300 nm) with Au interdigitated electrodes. Cr/Au (10/100 nm) contact electrodes were deposited by thermal evaporation, and patterned with interdigitated structures by using photolithography and dry etching. ZnO NRAs were hydrothermal grown on interdigitated finger regions by using kapton tape masks [11]. After ZnO NRAs growth, the ZnO NRAs sample was immersed in a mixture of 1 mM $Cu(NO_3)_2$ and 10 mM $C_6H_{12}N_4$ for 1 h and the solution temperature was held at 60 °C. Then, the as-prepared sample was cleaned by deionized water, and dried. The morphology of the samples was examined using a field emission scanning electron microscope (FE-SEM, SU8010, HITACHI). The crystal structure was measured by using an X-ray diffractometer (XRD, D8 Advance, Bruker Axs). A transmission electron microscope (TEM, Tecnai G2 F20, FEI Company) equipped with energy dispersive X-ray spectroscopy (EDS) was also used for further determination of the morphology and structure. The current-voltage (I-V) characteristics were measured using Keithley 2450 Source Meter.

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The self-powered photoresponsivity of the devices were measured at zero bias under dark and UV illumination (365 nm) with a power density of 2.5 mW/cm^2.

3. Results and discussion

SEM measurements have been performed on the samples to investigate their morphologies. The SEM image of ZnO NRAs is shown in Fig. 1(a), it can be seen that well-aligned ZnO nanorod arrays are approximately vertically grown on the substrates and very closely packed. Fig. 1(b) is the image of ZnO NRAs decorated with CuO SANs. It can be clearly observed that the top surface of ZnO nanorods is decorated by uniform sea anemone-like nanostructures with a size of about 1 μm. The corresponding partially enlarged image is shown in Fig. 1(c), it can be found that each sea anemone-like nanostructure is self-assembled by many densely packed nanotentacles. Fig. 1(d) shows the XRD patterns of the samples. For the ZnO NRAs, all the diffraction peaks can be indexed to hexagonal wurtzite structure of ZnO (JCPDS No. 36-1451). For the CuO-decorated ZnO NRAs, the diffraction peaks at 35.5° and 38.6° are corresponding to the (−1 1 1) and (1 1 1) planes of monoclinic CuO (JCPDS No. 80-1916). No peaks related to Cu, Cu_2O or $Cu(OH)_2$ phases are observed.

Morphology and structure analysis were further performed by TEM. A typical TEM image of an individual ZnO nanorod decorated with CuO SANs is shown in Fig. 2(a). It is clearly seen that sea anemone-like nanostructure is located at the end of the nanorod, indicating the CuO SANs adhere to ZnO NRAs robustly. High-resolution TEM (HRTEM) images for the nanorod and CuO SANs are shown in Fig. 2(b) and (c). Two groups of lattice fringes exhibit the d-spacing of 0.26 and 0.25 nm, corresponding to the (0 0 2) plane of wurtzite ZnO and the (−1 1 1) plane of monoclinic CuO, respectively [12]. Furthermore, Fig. 2(d) and (e) illustrate EDS collected from the nanorod and CuO SANs, further confirming the successful synthesis of CuO/ZnO heterojunction.

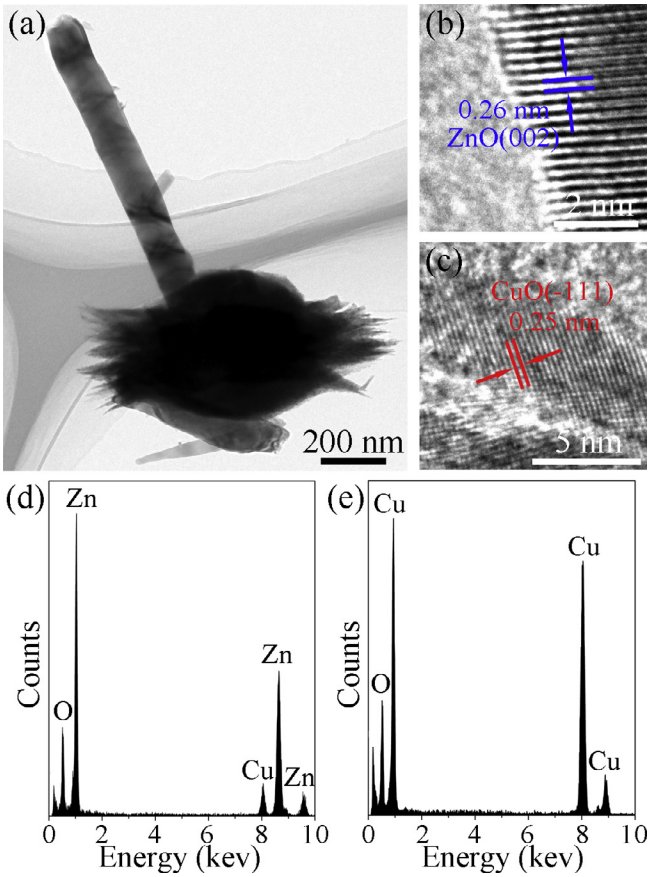

Fig. 2. (a) TEM image of an individual ZnO nanorod decorated with CuO SANs, HRTEM images of (b) the ZnO nanorod and (c) CuO SANs. EDS spectrums of (d) the nanorod and (e) CuO SANs.

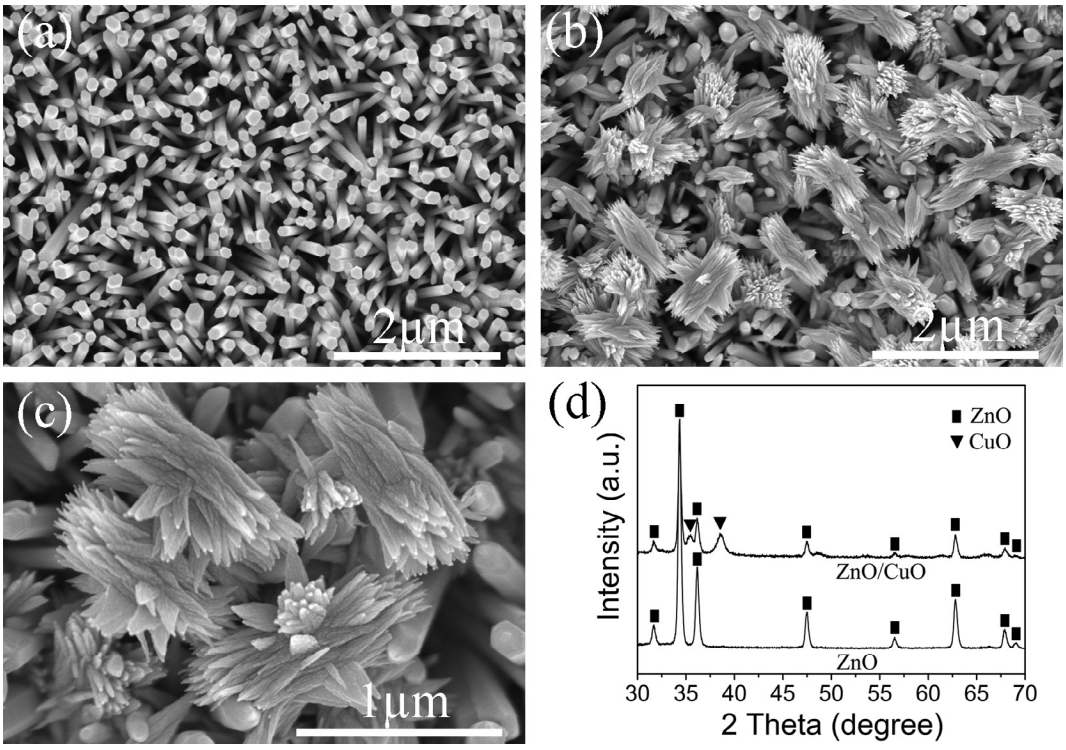

Fig. 1. (a) SEM images of ZnO NRAs, (b) ZnO NRAs decorated with CuO SANs and (c) corresponding partially enlarged image. (d) XRD patterns of ZnO NRAs and ZnO NRAs decorated with CuO SANs.