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Full Length Article

Single fiber UV detector based on hydrothermally synthesized ZnO nanorods for wearable computing devices

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ABSTRACT

There has been increasing interest in zinc oxide (ZnO) based ultraviolet (UV) sensing devices over the last several decades owing to their diverse range of applications. ZnO has extraordinary properties, such as a wide band gap and high exciton binding energy, which make it a beneficial material for UV sensing device. Herein, we show a ZnO UV sensing device fabricated on a cylindrical Polyethylene terephthalate (PET) monofilament. The ZnO active layer was synthesized by hydrothermal synthesis and the Cu electrodes were deposited by radio frequency (RF) magnetron sputtering. Cu thin film was deposited uniformly on a single PET fiber by rotating it inside the sputtering chamber. Various characteristics were investigated by changing the concentration of the seed solution and the growth solution. The growth of ZnO nanorods was confirmed by Field Emission Scanning Electron Microscopy (FESEM) to see the surface state and structure, followed by X–ray Diffraction (XRD) and X–ray photoelectron spectroscopy (XPS) analysis. Also, current–voltage (I–V) curves were obtained to measure photocurrent and conductance. Furthermore, falling response time, rising response time, and responsivity were calculated by analyzing current-time (I–t) curves.

1. Introduction

Due to the tremendous growth of the internet and electronic devices, various technologies have been combined and integrated. Internet of Things (IOT) technology has emerged as the best application of combined high–tech industries because it collects enormous quantity of data through the internet, sensor networks, and computing devices [1,2]. By collecting data from our everyday life through sensor networks, especially through smart textiles, big data is being created in numerous ways [3–6]. Smart textiles are fabrics that respond to environmental changes thanks to embedded electronic materials [7]. The responding features contribute smart textiles perform as various types of sensors and actuators. Plenty of devices have been fabricated which react to temperature [8,9], humidity [10,11], pressure [12,13] and ultraviolet (UV) [14]. Among these diverse devices, UV sensing devices have been actively developed and have appeared in markets over the past decades.

Nitride based materials such as GaN, AlGaN, InN $In_xGa_{1-x}N$ have been widely researched for UV detectors [15]. Recently, zinc oxide (ZnO) has become one of the most promising and ideal metal oxides for UV sensing device owing to the large surface area to volume ratio, wide bandgap of 3.37 eV, high exciton binding energy of 60 eV, and photo–absorption in UV range [16–19]. Due to these advantages, nano–scaled ZnO particles have wide applications in such devices as solar cells [20,21], gas sensors [22], nanogenerators [23], and light emitting diodes [24]. Furthermore, ZnO is well suited to being a semiconducting layer due to the low cost and numerous different synthesis methods, including the sol–gel method, solvothermal method, and hydrothermal method. Different kinds of ZnO nanostructures are created based on the synthesis methods, such as nanoparticle, nanorod, nanoneedle, nanowire, nanobelt, nanotube, and nanoflower.

This present work focused on ZnO nanorods and nanowires, which were synthesized in situ via hydrothermal synthesis using seed solution and growth solution. Plenty of resources exist which detail this two–step ZnO synthesis. First, a substrate is coated by a seed layer consisting of ZnO precursors, commonly by spin coating on a Si substrate, and then ZnO nanorods are grown hydrothermally. Zinc acetate dehydrate can be used as a precursor for the seed solution while Zinc nitrate hexahydrate and HMT can be used for the growth solution precursor [25–27]. This method is appropriate for synthesizing ZnO on a planar substrate; therefore, our research group used dip–coating to create the seed layer coating on a non–planar PET monofilament. Hexamethylenetetramine (HMT) was also used in the growth solution in this work to grow ZnO into a rod–shape.

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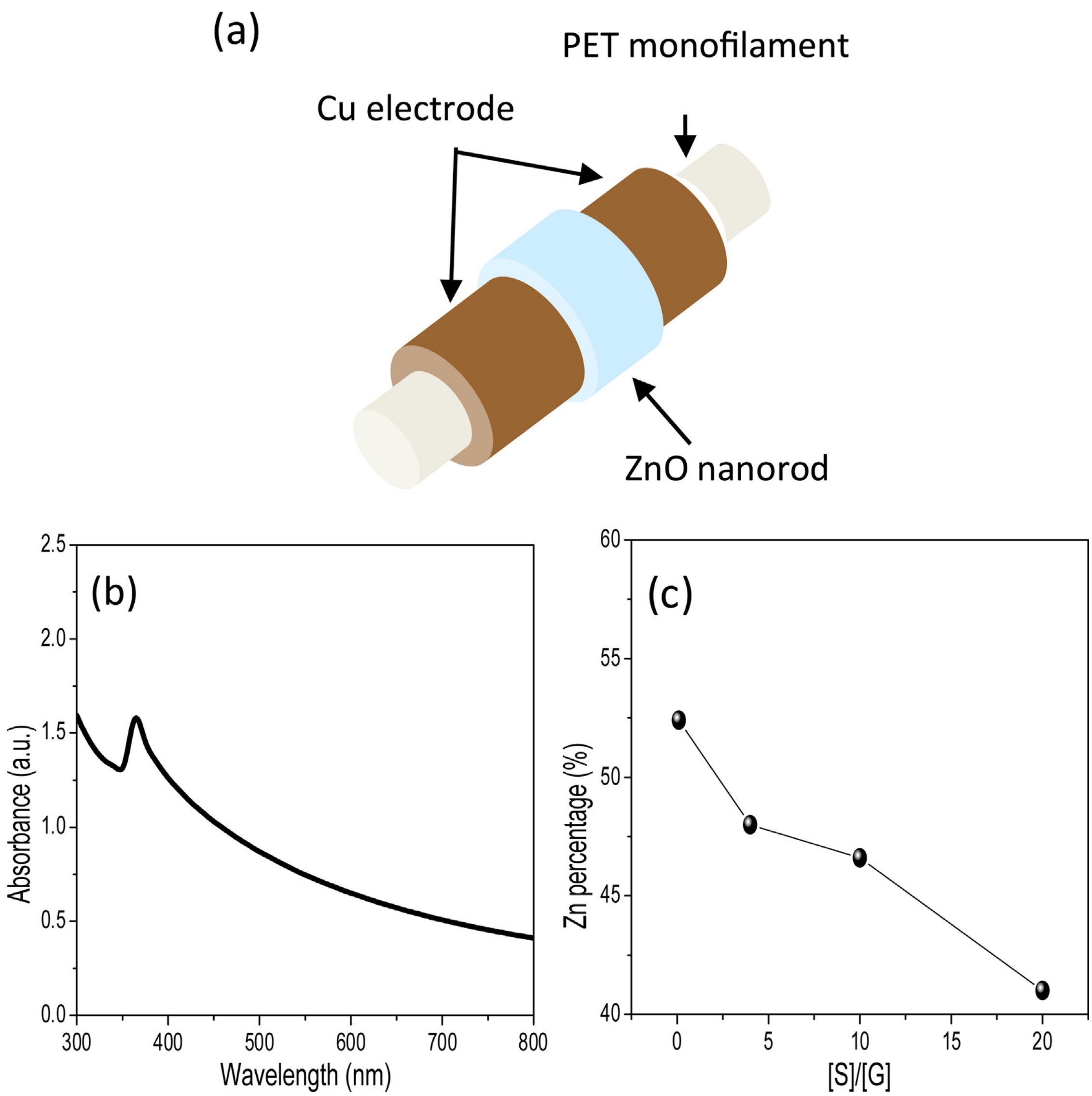

Fig. 1. (a) Schematic diagram of ZnO nanorod based UV sensing device (b) absorbance spectrum of ZnO nanorod (c) effect of [S]:[G] ratio on atomic percentage of Zn based on EDS spectrum.

Due to the variety of synthesis methods, ZnO has been synthesized on diverse substrates in the literature. Several researchers have fabricated flexible ZnO UV detectors on polymer and fiber substrates. Zhang et al. reported a ZnO UV detector based on flexible poly urethane (PU) fibers; however, the PU fibers were woven together, resulting in a rough surface and low photocurrent [28]. Athauda et al. introduced ZnO nanowires grown hydrothermally on nylon fibers [29]. Similarly, these nylon fibers were also woven together. Liu et al. synthesized ZnO on Kevlar fibers for UV sensing devices. ZnO nanowires were synthesized vertically in a furnace; however, the temperature of the furnace was extremely high, ranging from 380 °C to 510 °C [30]. These are the constraints of woven fiber devices. Single fibers, such as a PET monofilament, are required for wearable devices. However, deposition of thin films on cylindrical fibers remains a problem. Several methods, such as electroless plating, have been used to deposit an electrode layer on a PET fiber, but the surface was less smooth than sputtering deposition [31]. Jang et al. deposited ZnO seed layer by RF magnetron sputtering on a carbon fiber [32]. Also, Ag nanowires were coated by spray coating method which were used as electrode. However, without any rotation device, the uniformity of ZnO seed layer could not be fine. In addition, the characterization of the device was performed after placing bundle of fibers laterally. The deposition of Cu thin films in our work was performed by a process that our research group designed to apply thin metal films to various sensors [33–36]. Various metal thin films were deposited uniformly on a PET monofilament by rotating the filament sequentially during the sputtering process. Also, the measurement of electrical features was held by a single fiber which is appropriate for wearable computing devices.

In this work, our research group successfully synthesized ZnO nanorods grown on a flexible PET monofilament. The PET fiber was maintained as a single fiber with high thermal stability. A Cu thin film electrode was deposited by radio frequency (RF) magnetron sputtering. The whole PET monofilament was immersed in a seed solution followed by vertical growth in a growth solution. The molecular concentration of both the seed and growth solutions varied between 4 different values, expressed as [S]:[G], and the results demonstrated the effect of the molecular ratio of seed solution and growth solution. The surface of the ZnO nanorods was investigated by FESEM, and various UV sensing properties were studied using I–V and I–t characteristic curves.