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Ultrafast and High Sensitive UV/IR Photodetector Based on a Single SnO_2 Nanowire

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Abstract Tin oxide, SnO_2 has potential applications in many research areas. Using a chemical vapor deposition CVD method, high-quality single crystalline SnO_2 nanowire (NW) was synthesized on a large scale. Individual SnO_2 nanowire based ultraviolet photodetector was fabricated by simply transferring individual nanowire to Pt interdigital electrodes. The photodetector exhibited excellent photoconductive performance in terms of high sensitivity to the ultraviolet 375 nm and infrared 750 nm UV illuminations, fast response and recovery time. It also has perfect stability and reliability, revealing n-type semiconducting behaviour of the tin oxide ultraviolet and infrared photodetecors as an excellent material not only for fabricating highly sensitive photodetecors but also valuable additives that provide new functionality in photodetecors, which will enable the development of high-performance photodetecors.

Keywords SnO_2 nanowires, Chemical vapor deposition, UV/IR photodetector

1. Introduction

One dimensional (1-D) nanostructures had a great potential for applications in the fields of the optoelectronic and sensor device. Tin oxide (SnO_2) is an n-type semiconductor with a wide-band gap (Eg = 3.62 eV, at 300 K). Furthermore, because of the wide-band gap, very large surface to volume ratios, low cost, high responsive, strong radiation hardness and high chemical stability. Photodetectors can be used for a variety of applications in the military, scientific, civil applications, security, medicine, industrial, automotive areas and communications. Common applications using UV/IR detectors include rail safety, gas leak detection, flame detection, alcohol level testing for DUI's, anesthesiology testing, petroleum exploration, space operations, temperature sensing, water and steel analysis [1] [2] [3].

Several approaches to fabricating photodetector based on a single nanowire have been reported; among them, the use of single indium phosphide nanowires for photodetection with highly polarized photoluminescence (Jianfang Wang et al.) [4], high sensitive and ultrafast UV photodetector based on ZrO_2 single crystals (Xing Jie et al.) [5], high-performance ultraviolet photodetectors based on an individual Zn_2SnO_4 single crystalline nanowire (Yanjun Zhang et al.) [6], single p-type/intrinsic/n-type silicon nanowires as nanoscale avalanche photodetectors (Chen Yang et al.) [7], single nanowire-based UV photodetectors for fast switching (Kamran ul Hasan et al.) [8] …ect.

In this paper, we reported a fabrication of UV photodetector based on a single SnO_2 nanowire. SnO_2 nanowires were synthesized by CVD method. High photocurrent to dark current ratio was achieved. Fast response and recovery time were observed for the device under ultraviolet 375 nm and infrared 750 nm UV illuminations. Light measured at room temperature in air atmosphere. The mechanism that determines the photoresponse is analyzed and discussed.

2. Experimental

SnO_2 nanowires were fabricated by a chemical vapor deposition process in a horizontal tube furnace. The source material is 0.3g SnO_2 powder, which was put in an alumina boat at the center of the tube furnace. A silicon (100) substrate was placed on the alumina boat. The distance between the tin powder and the substrate was about 0.5 cm. The pressure in the quartz tube was maintained at the standard atmospheric pressure. The temperature of the system was raised to 900°C at 10°C/min at a fixed flow rate of 100 sccm nitrogen, kept at that temperature (900°C) for 1 h under a mixed gas of nitrogen (98.5-99.5 sccm) and oxygen (1.5-0.5 sccm) with a total flow rate of 100 sccm, and then cooled to room temperature without any O_2 being introduced and a white layer of product was found on the silicon substrate.

In order to investigate the current-voltage (I-V)

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characteristics of SnO_2 nanowire, we fabricated a simple device based on a single SnO_2 nanowire, as shown in Figure 3. The SnO_2 nanowires were grown initially dispersed in ethanol with assistance of ultrasonic, and then an individual nanowire was carefully transferred through a self-made micro-manipulating system onto a SiO_2/Si substrate provided with interdigitated Pt electrodes (20μm gap) on the insulating side. The SnO_2 nanowire has a length between 40 to hundred microns and a diameter between 300 nm to 600 nm. In order to remove the residual ethanol and to ensure a good adherence of the SnO_2 nanowire to the substrate; the device was heated in a tube furnace at 180℃ for 2 h. The electrical measurement was performed by an Agilent B1500A semiconductor device analyzer at room temperature and air atmosphere.

3. Results and Discussion

Figure 1 is a typical electronic microscopy image of the as-synthesized SnO_2 nanowires. These have diameters of 400–600 nm and are several hundreds of micrometers in length. The schematic diagram is shown in figure 2, whereas the SnO_2 nanowire based UV sensor with the similar configurations can be found in the previous studies [9], as well. It can be confirmed from the electronic microscope image in figure 1 that the grown SnO_2 nanowire has sufficient length to bridge the gap between two pads. The high magnification electronic microscope image in figure 3 shows that the single nanowire is contacted to form the photoconductive SnO_2 nanowire channel [10].

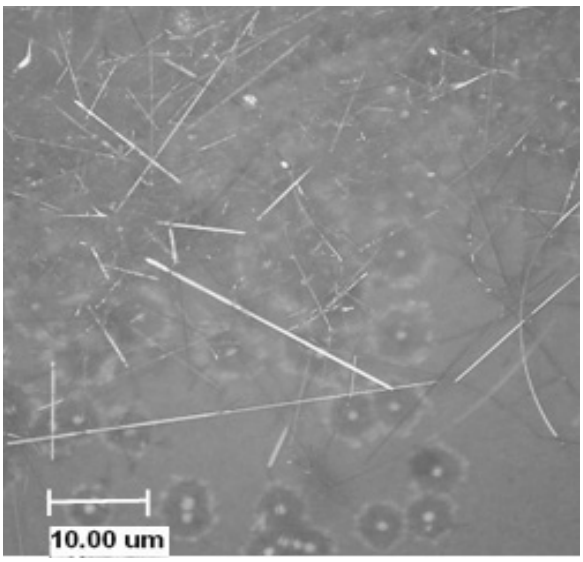

Figure 1. The electronic microscopy image of SnO_2 nanowires

To study the influence of the surface on the electrical and photon-sensing properties of the as-prepared nanowires, an equivalent circuit for a fabricated SnO_2 based photodetector was constructed, as shown in figure 2 [11].

The current-voltage (I-V) characteristics for the single SnO_2 nanowire device measured at room temperature in ambient condition with bias from −10 V to 10 V in the dark and under UV illumination 375 nm. Figure 4 is typical I-V curves of the device before and after irradiated with UV lights with wavelengths of 375 nm. From the curves, we can clearly see that, upon UV illumination, the photodetector exhibited a remarkable increase in the current which is indicated that the obtained SnO_2 nanowires UV photodetector has the characteristic of high-sensitivity [12]. Both the I–V curves, both in the dark and under UV illumination, resulting in the nonlinear I–V curves, indicating that good an Ohmic contact was made is caused by the Schottky barriers formed between the semiconductor and the metal electrodes [13][14].

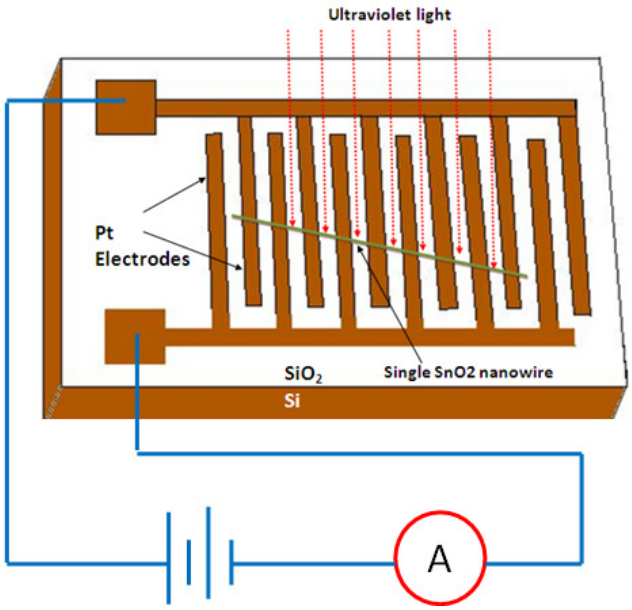

Figure 2. Schematic diagram of the fabricated photodetector based on a single nanowire SnO_2

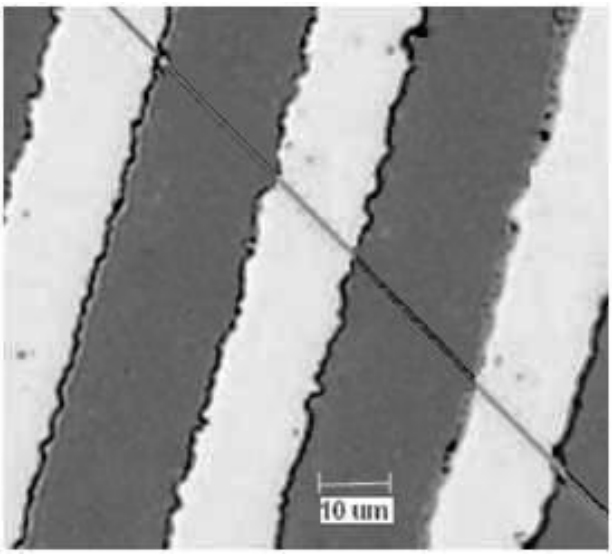

Figure 3. Image of the fabricated photodetector based on a single nanowire SnO_2

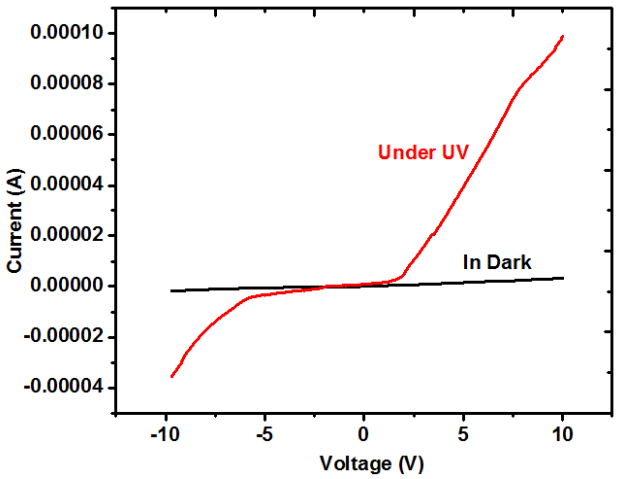

Figure 4. I-V characteristics of the fabricated photodetector based on a single nanowire SnO_2 in dark and under UV light

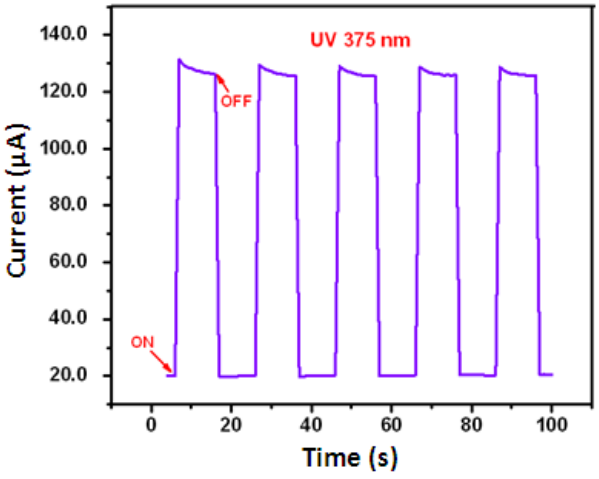

Figure 5. Photoresponse characteristics of a single SnO_2 nanowire photodetector with a 375 nm illuminating UV

The photoresponse is observed with periodic switching of UV/IR light illumination at room temperature and air atmosphere. Remarkably, photocurrent was measured under applied bias voltage of 5 V as shown in the figure 5 (UV 375 nm) and figure 6 (IR 750 nm). A reducing current is seen during each illumination. This phenomenon is involved with the oxygen-adsorption process in the dark and oxygen-desorption process upon UV/IR illumination are generally thought to be associated with the generation of free carriers [15]. In ambient conditions, oxygen molecules are absorbed onto the nanowire surface and capture free electrons from the nanowire, making a low-conductivity depletion layer near the surface. When SnO_2 nanowire is illuminated by UV light, it is likely that electron–hole pairs are generated, and the holes can neutralize the negatively charged oxygen molecules which then desorb at the surface of the SnO_2 nanowire. The holes migrate to the surface to desorb the oxygen adsorbates, resulting in a reduction in the depletion barrier thickness and an increase in the free-carrier concentration. Hence, photocurrent increases dramatically upon the UV/IR light illumination. After turning off the UV/IR illumination, oxygen molecules readsorb on the nanowire surfaces, returning the nanowires to their initial low-conductivity state. Given the absorbed oxygen on the SnO_2 nanowire, the Schottky contact of the photodetector device is affected by the interfacial states [16] [17].

Photoluminescence is believed to be an effective way to study the optical properties of semiconducting nanostructures. Room-temperature photoluminescence (PL) spectra of the SnO_2 nanowires were studied and shown agood results to infrared light with a peak wavelength position of around 750 nm (corresponding to 1.65 eV) is dominantly observed. The infrared light emission is known to be related to defecting levels within the band gap of SnO_2, associated with oxygen vacancies or Sn interstitials that have formed during the the growth of the SnO_2 nanowires [18-20]. A similar work has been reported in the case of room-temperature PL spectra of the as-prepared Zn-doped SnO_2 nanorods and the pure SnO_2 nanorods [21], Laser-Ablation Growth and Optical Properties of Wide and Long Single-Crystal SnO_2 Ribbons [18], SnO_2 nanorods synthesized by solution phase growth [19], Synthesis and low-temperature photoluminescence properties of SnO_2 nanowires [22], Raman spectroscopic and photoluminescen ce study of single-crystalline SnO_2 nanowires [23], Direct growth of oxide nanowires on CuOx thin film [24], nanobelts and direct growth of SnO_2 nanowires on WOx thin films [25], and Ultrahigh responsivity UV/IR photodetectors based on pure CuO nanowires [26]. This finding indicates that the SnO_2 nanowires were sensitive to UV/IR illumination intensity as is shown in figure 5 and figure 6.

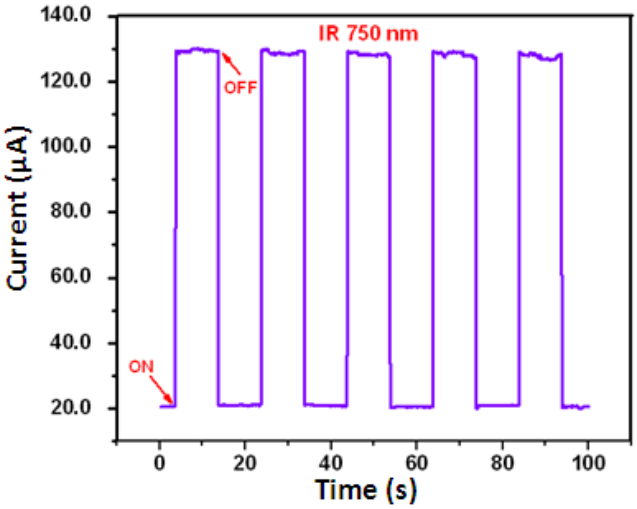

Figure 6. Photoresponse characteristics of a single SnO_2 nanowire photodetector with a 750 nm illuminating IR

For Pt electrode and SnO_2 nanowire photodetector, there is additional conducting mechanism that is contributing to the UV/IR response and recovery. The mechanism for the metal semiconductor metal structured Pt electrode and SnO_2 nanowire photodetector can be attributed to the Schottky contact at the Pt electrode and SnO_2 nanowire interfaces [27]

Generally, the Pt electrode and SnO_2 nanowire can form a schottky contact. When the photodetector is exposed to UV/IR light illumination, photogenerated electrons and hole in the schottky barriers interface region are separated by the strong electric field there. The electron-hole recombination rates decrease and the carrier lifetime increase and the schottky barriers height between semiconductor and the metal electrode decreases, resulting in an increase in free carrier density [28]. However, the schottky barriers play an important role in the high UV/IR photo response and rapid response time. To investigate the device speed, we recorded the signals over a time interval 0.002 second in our measurement system. Table 1 illustrates recorded signals of the response and recovery time from a single ON/OFF cycle at the rise and fall points to clarify the device speed. Figure 7 shows fast response and recovery characteristics with a response time ≈ 0.001 second and a recovery time ≈ 0.001 second in average, knowing that Agilent B1500A has zero-second delay time [29].

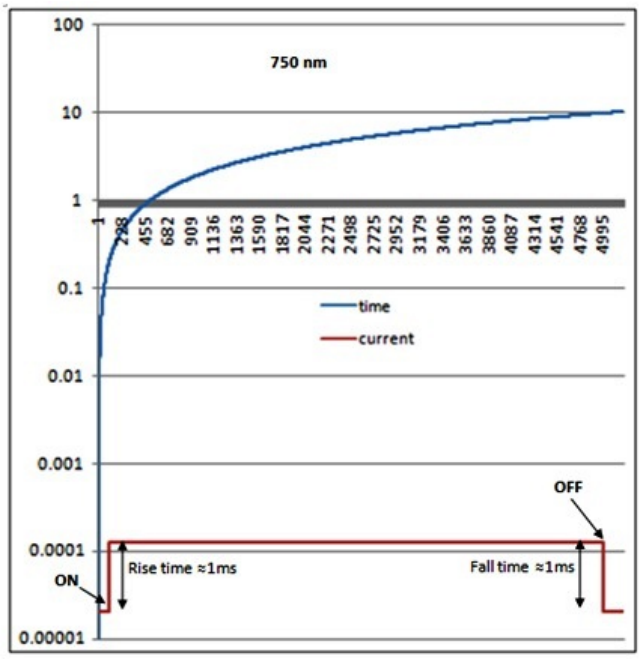

Figure 7. Enlarged view of a single ON/OFF cycle

Table 1. Illustrates the response and recovery times

Response Time		Recovery time	
Time (S)	Current (A)	Time (S)	Current (A)
0.19	2.11E-05	9.996	1.29E-04
0.192	2.11E-05	9.998	1.29E-04
0.194	2.11E-05	10	1.29E-04
0.196	2.11E-05	10.002	2.11E-05
0.198	2.11E-05	10.004	2.11E-05
0.2	1.29E-04	10.006	2.11E-05
0.202	1.29E-04	10.008	2.11E-05
0.204	1.29E-04	10.01	2.11E-05

4. Conclusions

In conclusion, we have fabricated the highly sensitive and ultrafast UV/IR photodetectors based on single SnO_2 nanowire. We have successfully synthesized SnO_2 nanowires via chemical vapor deposition method. I–V curves under dark and light response were studied. Upon UV/IR illumination, the UV/IR photodetectors based on single SnO_2 nanowire exhibits high sensitivity under (UV 375 nm and IR 750 nm) illumination light with low voltage bias 5V at room temperature in the air atmosphere, fast response and recovery time. It also has perfect stability and reliability.

ACKNOWLEDGEMENTS

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