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Si/Cu_2O Nanowires Heterojunction as Effective Position-Sensitive Platform

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Abstract: Cu_2O nanowires (Nws) network-based heterojunction was observed to have a position-sensitive photovoltaic characteristic. Its amplitude of the photovoltage (V_{ph}) varied regularly with the position of incidence of the 532nm laser radiation onto the Cu_2O NWs surface. The V_{ph} of this platform varies with the light position described as $\Delta V_{ph}/\Delta x$ is approximate ~14 mV/mm. Besides, the photoresponse of this device is very stable. This position-sensitive platform is expected to serve as a convenient device as easily to be fabricated, high performing photodetector.

Keywords: Position-Sensitive Photodetector, Cu_2O NWs Network, Heterojunction, Photovoltage

1. Introduction

Nano-sized one-dimensional (1D) structures, such as nanorods and nanowires, have great potential in sensor applications due to their excellent opto-electrical and mechanical properties [1-2]. Compared to the same sensing devices which are made from thin film or bulk structures, its' extraordinary performance is often attributed to their inherently high surface-to-volume ratio of nanostructure. As size and morphology have strong effects on physical and chemical properties, much effort has been devoted to the synthesis of nanocrystals.

Generally speaking, the detector was prepared by individual nano-units requires the use of high-cost and highly specialized equipment. However, the preparation of sensor involving disordered nanostructures network is not complicated [3]. In addition, nanostructure network device is beneficial to better light trapping and suppressed reflection [4-5].

Cu_2O, a p-type semiconductor with a direct band gap of about 2.17 eV, has been widely employed in gas sensors [6], catalysts [7], solar energy conversion [8-9], and magnetic storage devices [10]. Furthermore, Cu_2O is inexpensive, plentiful, and good environmental acceptability, which favors the fundamental and practical research on Cu_2O [11]. In this regard, Cu_2O nanowire (NW) network-based devices can function as highly effective photodetectors capable of sensing laser position. Recently, we successfully fabricated Cu_2O nanowire (Nws) platform on Si substrate and got a Si/Cu_2O Nanowire heterojunction. We observed the junction has a position-sensitive photovoltaic characteristic. Its amplitude of the photovoltage (V_{ph}) varied regularly with the position of incidence of the 532nm laser radiation onto the Cu_2O NWs surface. The V_{ph} of this platform varies with the light position described as $\Delta V_{ph}/\Delta x$ is approximate to ~14 mV/mm. These results demonstrated that Cu_2O NWs/Si hetero-junction can be served as low-cost, attractive, high performing and easily fabricated photodetector.

2. Experimental

The Synthesis of Cu_2O Nanowires. All of the chemical reagents used in this experiment were analytical grade. Cu_2O nanowires were synthesized as follows [12]: 257.3 mg of Cu (Ac) 2 was dissolved in 85 ml of deionized water, which was dissolved with a ultrasonic oscillator. Afterward, to this solution was added some of an aqueous solution of o-anisidine, which invokes the reaction mixture to become dark green owing to the coordination of Cu^{2+} and o-anisidine. The reaction mixture was transferred to a 90 ml autoclave. The autoclave was sealed and maintained at 140°C for 10 h and subsequently cooled to ambient temperature naturally. And the precipitate was filtered, washed with distilled water several times, and dried in a vacuum oven at 60°C for 3 h [12].

The surface morphology of the as-prepared Cu_2O nanowires was characterized by a field emission scanning electron microscopy (SEM). The structure and crystal orientation of Cu_2O nanowires were analyzed with X-ray diffraction.

The preparation of Cu_2O/Si heterojunction. Taking a certain amount of Cu_2O nanowires dissolved in some of absolute ethyl alcohol, which was dissolved with an ultrasonic oscillator. Afterward, this solution was natural deposited on silicon wafer which was cleaned by 10% hydrofluoric acid. Then, the junction prepared was transferred to a tube furnace and maintained at 350°C for 30min under the vacuum condition.

Ag contacts were fabricated using silver pastes on either end of the nanomaterial layer serving as the left (L) and right (R) electrodes for subsequent, current-voltage (I-V) and photovoltaic measurement. The sample assembly was then placed in a dark housing with a small front aperture to introduce a light source to the sample while eliminating any external optical and electrical noise. A 532 nm semiconductor laser was used as a constant-wave illumination source. The light was sent through an optical chopper rotating with a predetermined frequency. A small area of 1 mm in diameter light spot was irradiated perpendicularly on the heterojunction surface by the light beam with energy density ~0.15W/mm2. The photovoltaic and lateral photovoltaic waveforms between two electrodes was measured and recorded by a 350 MHz sampling oscilloscope terminated into 1 MΩ for open circuit photovoltage at ambient temperature [13].

3. Results and Discussion

The typical XRD pattern of the as-prepared Cu_2O Nws is given in Figure 1. In order to clearly show the peaks of the Cu_2O nanoparticles, the peaks of Si substrate were removed from the pattern. Several diffraction peaks in the 2θ range of 20^0-70^0 observed in the Cu_2O Nws can be assigned respectively to the (110), (111), (200) and (220) planes of Cu_2O structure according to their positions and the relative intensity (JCPDS card no. 5-667). According to the diffraction intensity in the corresponding XRD pattern, Cu_2O nanocrystalline mainly grow along (220) orientation, which indicates that there is a relatively slow growth rate along the (220) facet. The ex-situ XPS tests showed that the top of the nanowires contain copper in its Cu^+ oxidation state (not shown). Therefore, the results prove that Cu_2O is the only product, and it excludes the existence of impurities in the deposits.

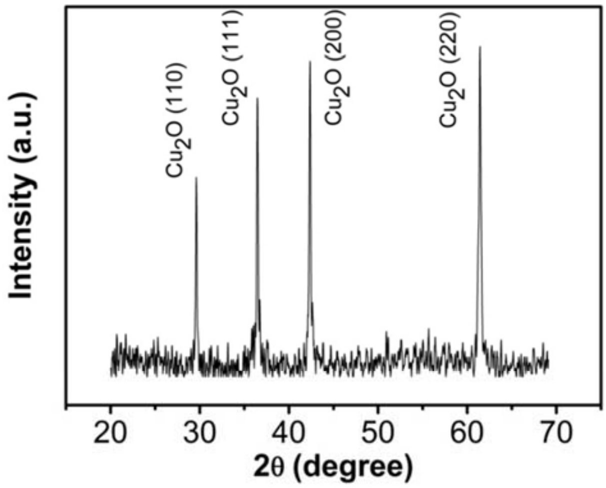


Figure 1. *The XRD pattern of a sample of Cu_2O nanowires.*

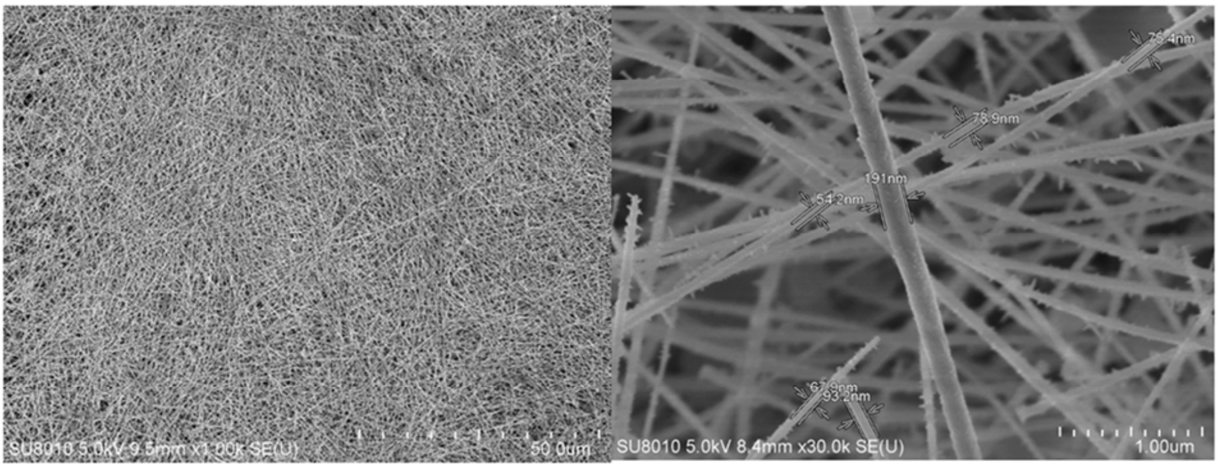


Figure 2. *SEM images of a sample of Cu_2O nanowires.*

Figure 2 shows a typical SEM image of as-prepared Cu_2O nanowires with a high aspect ratio. SEM overviews reveal that the morphology of the Cu_2O sediments are long, straight nanowires. It can be seen that the diameter of these Cu_2O nanowires is about (50-200) nm and their lengths range from tens of micrometers to more than a hundred micrometer.

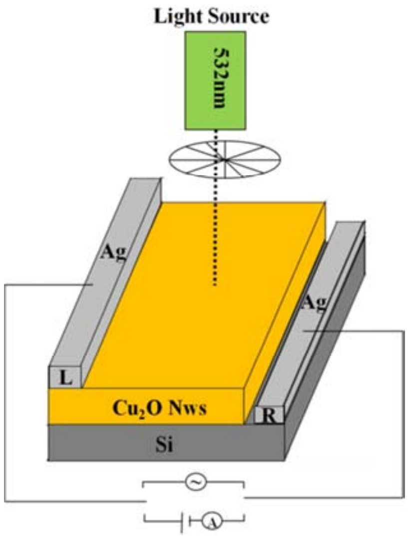
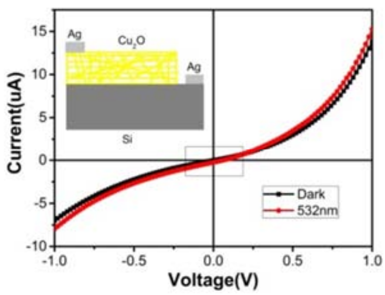
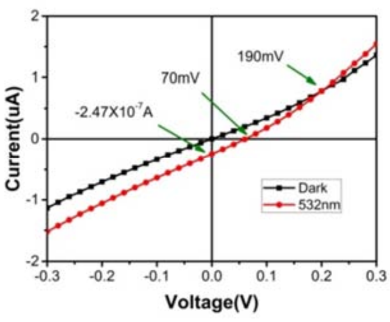


Figure 3. *Schematic diagram of overall photoelectric measurement setup.*



(a)

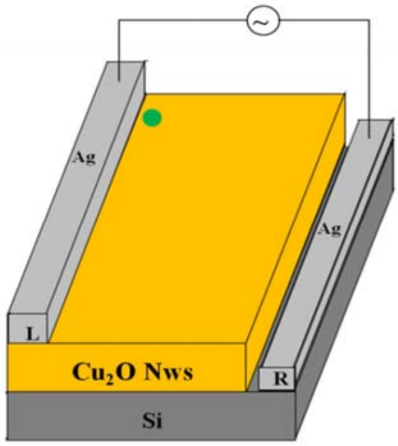


(b)

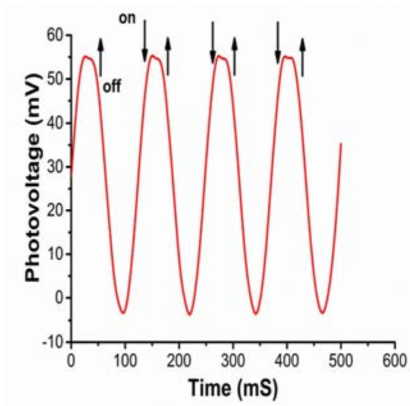
Figure 4. *(a) Typical current versus voltage (I-V) plot is shown for Cu_2O NWs. (b) displays a magnified view of the black squared region in the I-V curve in (a).*

Our overall experimental scheme for the nanomaterial network photoelectric measurements is displayed in Figure 3. The current-voltage (I-V) characteristics of Si/Cu_2O heterojunction were studied under dark and illumination. And I-V measurements were carried out by sweeping the L-R voltage from -1 to 1 V with an increment of 20 mV. The light source used for the I-V characteristics was the 532 nm semiconductor laser. Figure 4 (a) displays the resulting I-V characteristics of the Cu_2O NW devices. The heterojunction exhibits good rectifying I-V behavior.

The open circuit voltage (V_{oc}) and short circuit current (I_{sc}) were also obtained from the I-V curves shown in Figure 4 (a). These results can be clearly seen in the zoomed-in I-V plots of Figure 4 (b). The open-circuit voltage (Voc) and short-circuit current (Isc) upon illumination are determined as 70 mV and 2.47×10^{-7}A, respectively. Under the dark condition, no significant V_{oc} or I_{sc} is measured. However, the Cu_2O NW device exhibits well photovoltaic effect when the laser illuminated on the left near the electrode.



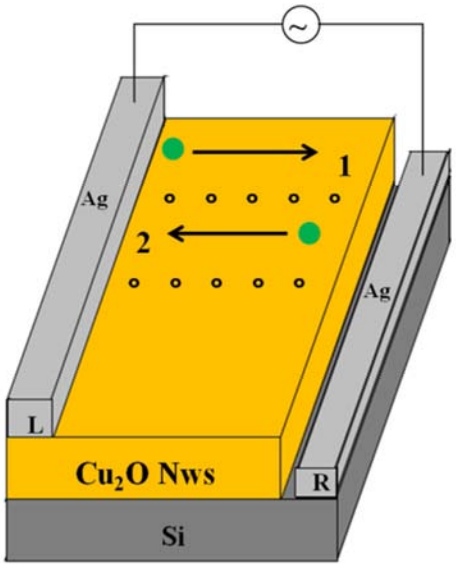
(a)



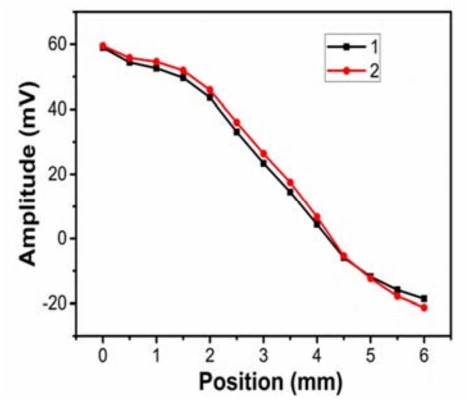
(b)

Figure 5. *Typical photovoltage acquired from Cu_2O NWs while illuminating the device with a 532 nm laser through an optical chopper is shown.*

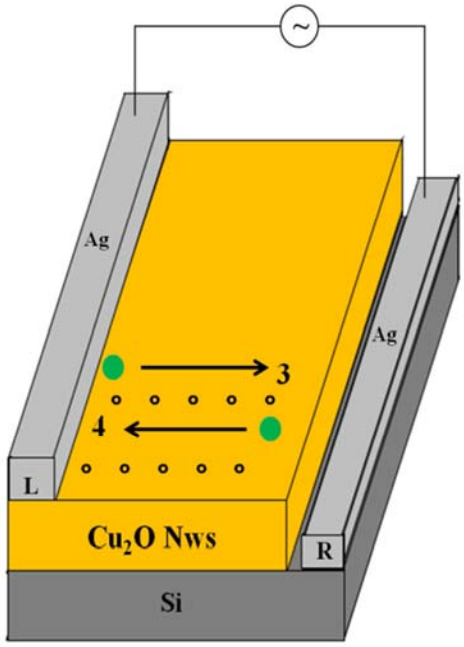
The device schematic provided in Figure 5 (a) displays a typical sample configuration involving networks of Cu_2O NWs. Figure 5 (b) displays a representative voltage response obtained from Cu_2O NWs, showing a maximum photovoltage (V_{ph}) value of 58 mV. The laser position of incidence is located in the left electrode. Down (up) arrows inserted in Figure 5 (b) indicate the time when the 532 nm laser directed to the sample is on (off) through a 10 Hz chopper wheel.



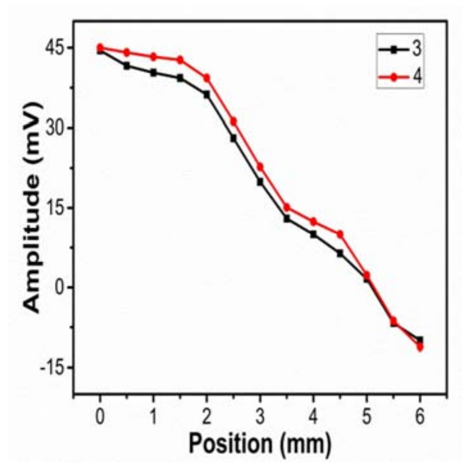
(a)



(b)



(c)



(d)

Figure 6. *Voltage signal changes depending on the laser position as indicated in the schematic. Illumination positions along the middle of the device spanning one electrode to the other.*

The photovoltaic signal, obtained when the Cu_2O NWs film is irradiated by a laser pulse, is plotted as a function of position. The magnitude of V_{ph} varies on the same sample devices depending on the laser position. Different signals for different positions of incidence of laser pulse are presented. Figure 6 (b) shows that the amplitude of the signal versus the position of incidence when varying the laser position along a line spanning from one electrode to the other (marked as L and R electrodes in the schematics) on the back side (marked as B in the schematics) of Si/Cu_2O NW device. It can be seen from Figure 6 (b) that in the range of 1-5 mm, the V_{ph} value varies almost linearly with the position of incidence of the laser irradiation. And the amplitude varies more gently near the electrodes at both ends. V_{ph} varies with the light position on the line between the L and R electrodes with $\Delta V_{ph}/\Delta x$ of approximately 14 mV/mm for Si/Cu_2O NWs.

For a more accurate and detailed investigation of V_{ph} dependence on the laser spot position, the focused laser scanned along the lines on the front side (marked as B in the schematics) of device, as shown figure 6 (c). The V_{ph} values, plotted as a function of the laser spot position are shown in figure 6 (d). It is clear that the V_{ph} still varies almost linearly with the distance between the electrodes. Besides, it can be seen from figure 6 (b) and figure 6 (d) that the photoresponse characteristics are very stability. The curve of V_{ph} varies is almost coincident when varying the laser position along a line spanning from one electrode to the other circularly.

Figure 7 summarizes the distribution of the V_{ph} in the plane of the Cu_2O surface. The voltage sign reversal is obtained when the laser position moves between the two contacts L and R. It is clear that the signal is asymmetric in a plane. It is known that light-induced carrier gradients in PN junctions can produce a photovoltage through photovoltaic effect. The existence of the carrier gradient caused the diffusion of carriers to L and R electrodes when the laser spot is positioned on the Cu_2O surface. And the probability of recombination closed to L electrodes is lowest and shows similar gradient increasing as the laser position along a line varying from L electrode to R electrode because of the intrinsic defects of Cu_2O [14]. Based on this conception, the result is easily understood.

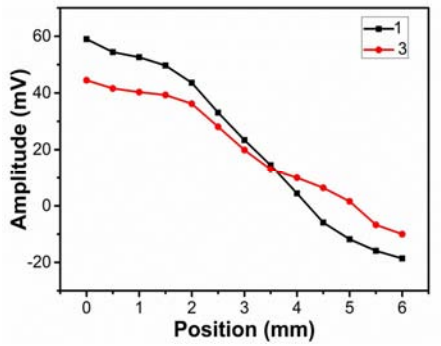


Figure 7. *The distribution of the V_{ph} in the plane of the Cu_2O surface.*

Asymmetric photoresponse signals are observed, which has been reported previously on single nanomaterial devices. It can be deduced that the position-sensitive this composite film should have a certain relationship with its microstructure or some other properties [3]. The devices are governed by a barrier-dominated transport mechanism. The L and R electrodes in NW mesh configuration form different contact barriers at the interface due to variations in contact conditions, yielding asymmetric photoresponse characteristics. Besides, Cu_2O NWs arranged on the surface of the silicon substrate are non-uniformity of the network. At the same time, NW-NW junction barriers existing in the NW mesh configuration may also contribute to the asymmetry of the photoresponse curves. Further studies are still in progress.

4. Conclusions

In summary, Cu_2O NWs configured in a network format can be effectively used as high performing position photodetector. The Cu_2O NW mesh-based devices yield substantial photovoltage of 58 mV under illumination with a 532 nm laser. The photodetector is simple and straightforward to construct without the need of complicated fabrication steps involving highly specialized instrumentations. Therefore, that Cu_2O NW network-based photodetector can serve as a convenient alternative to commercial or single NW-based devices as easily assembled, high performing photodetector.

Acknowledgments

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