A LATERAL ZNO NANOWIRE UV PHOTODETECTOR PREPARED ON ZNO:GA/GLASS TEMPLATE

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Introduction

In the past decade, a significant amount of research and development activities have been focused on the synthesis, structural characterization and physical phenomena of nano-structured materials. Due to their peculiar characteristics and size effect, these materials often exhibit novel physical properties that are different from those of the bulk. This has attracted great interests both for fundamental research and potential nano-device applications. Among the various nano-structured materials, wide bandgap one-dimensional (1D) ZnO nanowire is a promising functional material. With room temperature bandgap energy of 3.37 eV and exciton binding energy of 60 meV, ZnO emits short-wavelength light, conducts transparently and is piezoelectric. Recently, it has been shown that ZnO nanowires can also be used as (UV) photodetectors, chemical sensors and biological sensors.

On the other hand, glass substrates are transparent and low cost. Large-area glass substrates are also commercially available. Thus, glass is an ideal substrate material for large size optoelectronic devices. If we can grow ZnO nanowires on glass substrates, we should be able to realize various novel optoelectronic devices, such as ZnO-based light emitters, photodetectors and field emission displays (FEDs). ZnO nanowires can be synthesized by various methods. However, it is difficult to grow ZnO nanowires on glass substrates since glass substrates are amorphous and weak at high temperatures. Previously, *Huang et al.* [1] reported the successful gas phase synthesis of ZnO nanowires on patterned Au catalyst by vapor-liquid-solid (VLS) reaction at high temperatures (i.e. 900-925°C). *Geng et al.* [2] modified this VLS technology and successfully grew ZnO nanowires on Si substrate. Very recently, *Tseng et al.* developed a low-temperature self-catalyzed vapor-liquid-solid (VLS) process at 550°C and reported the growth of vertical single crystalline ZnO nanowires on ZnO:Ga/Si_3N_4/SiO_2/Si template [3]. Using the same method, *Hsu et al.* reported similar growth of vertical single crystalline ZnO nanowires on ZnO:Ga/glass template and demonstrated ZnO nanowire UV photodetectors by flipping the sample so that tips of the vertical ZnO nanowires were contacted directly with a patterned ITO/glass substrate [4]. However, such a simple scheme is not suitable for practical applications since tips of the vertical ZnO nanowires were contacted softly with the underneath ITO/glass. This work reports the lateral growth of ZnO nanowires on ZnO:Ga/glass template by VLS process. A UV photodetector was also fabricated using the laterally grown nanowires. The fabrication process and the properties of the fabricated photodetector will also be discussed.

Experimental

Prior to the growth of ZnO nanowires, we first deposited a 50-nm-thick Ga-doped ZnO thin film onto glass substrates by RF magnetron sputtering. X-ray diffraction (XRD) measurement showed that the sputtered ZnO:Ga film was oriented along the (002) direction. Using four-point resistivity measurement, we found that sheet resistance of the sputtered ZnO:Ga film was around 200 Ω/sq. We then used standard photolithography to partially etch away the ZnO:Ga film and define the comb-like pattern. During wet etching, the template was dipped in 2% HCl for 3 min to remove the exposed ZnO:Ga. As shown in figure 1, we designed our etching mask so that fingers of the comb-like pattern were 5 μm wide and 80 μm long with a spacing of 5 μm. We subsequently used two small pieces of glass to cover the two electrodes of the patterned ZnO:Ga film so that no ZnO nanowires will be grown in these regions. To grow the ZnO nanowires, we placed the patterned ZnO:Ga/glass template and Zn powder on an alumina boat, and inserted them into a quartz tube. The zinc vapor source was Zn metal powder with a purity of 99.9%, obtained from Strem Chemicals. The evaporation process was performed in the quartz tube located in a horizontal tube furnace. A JEOL JSM-6500F field emission scanning electron microscope (FESEM) operated at 5 KeV and a MAC MXP18 X-ray diffractometer (XRD) were then used to characterize structural properties of the as-grown ZnO nanowires. Room temperature current-voltage (I-V) characteristics of the fabricated devices were then measured both in dark and under illumination by an HP4156 semiconductor parameter analyzer. It should be noted that the I-V measurements were performed in a box so that the dark currents were measured in total darkness. The transmission spectrum was measured using a high-intensity UV light source (Hamamatsu, 150 W, at wavelengths from 115 to 400 nm).

Result and discussion

As shown in figure 1, it can be clearly seen that some of the lateral ZnO nanowires bridged across two neighboring fingers to provide electrical paths. With these lateral ZnO nanowires, the two neighboring electrodes were no longer electrically open. We could thus determine resistivity of the sample by applying a constant voltage across the two electrodes and measure the corresponding current. Figure 2 shows I-V characteristics of the sample with lateral ZnO nanowires measured in dark (dark current) and under illumination (photo current). During photocurrent measurements, a 150W deuterium (D_2) lamp was used as the UV light source. It can be seen that measured current increased linearly with the applied bias. It was also found that resistivity of the crabwise ZnO nanowires bridged the two neighboring electrodes was as high as 226 Ω-cm. With 2 V applied bias, it was found that dark current and photo current were 4.1 x 10^{-9} and 5.0 x 10^{-8} A, respectively. In other words, the detector current was increased by more than 12 times upon UV illumination.

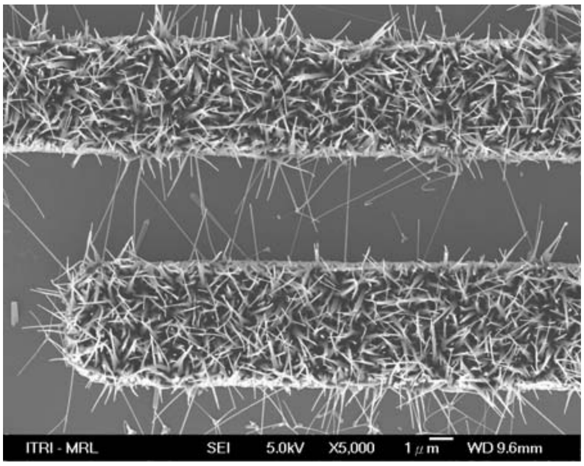

Fig.1 Top-view SEM micrograph of the ZnO nanowires grown with an oxygen flow rate of 0.4 sccm.

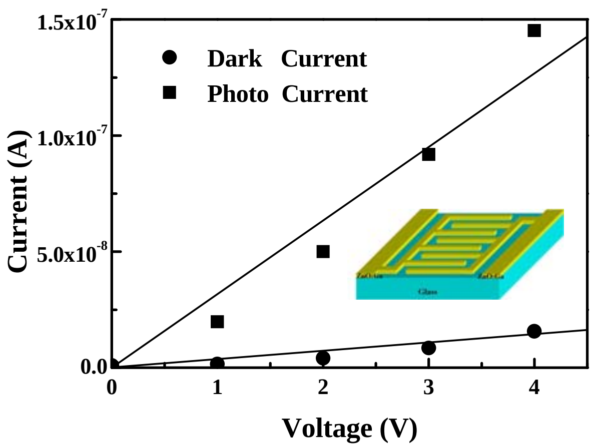

Fig.2: I-V characteristics of the sample with lateral ZnO nanowires. (Insert Schematic diagram of the patterned ZnO:Ga/glass template.)

Figure 3 shows transient response of the measured current by turning off the UV excitation. It should be noted that the current decreasing rate is determined by the speed of oxygen molecules absorbed on ZnO nanowire surface to capture excess electrons. As shown in figure 6, it was found that turn-off transient can be fitted well by the exponential curve shown as follows:

$$I(t) = I_d + (I_p - I_d)\exp[-(t/\tau)] \quad \textbf{(Eq. 1)}$$

where I(t) is the transient current, I_d is the current measured in dark, I_p is the current measured under UV illumination, t is the time after turn-off and τ is the corresponding time constant. From the data plotted in figure 3, it was found that the corresponding time constant for our lateral ZnO nanowire photodetector was around 452 mSec. The faster response indicates that the lateral ZnO nanowire photodetector is suitable for high speed operation.

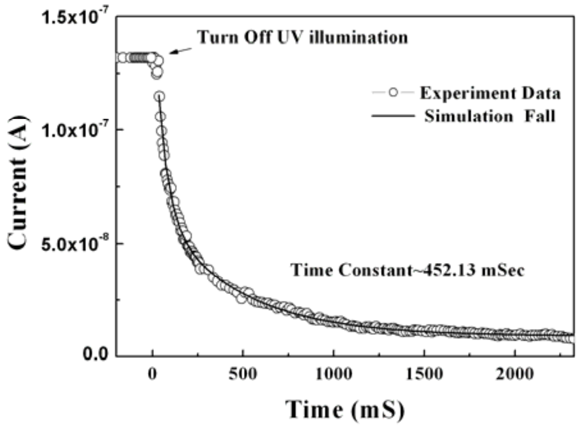

Fig. 3: Transient response of the measured current by turning off the UV excitation.

Conclusion

In summary, we reported the lateral growth of ZnO nanowires on ZnO:Ga/glass template and the fabrication of UV photodetector. With 2 V applied bias, it was found that dark current and photo current of the fabricated detector were 4.1 x 10^{-9} and 5.0 x 10^{-8} A, respectively. It was also found that the corresponding time constant of our lateral ZnO nanowire photodetector was around 452 mSec.

References

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