Photoconducting Properties of ZnO microwhiskers

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Key words : ZnO, micro whisker, photoconductivity

1. Introduction

As a wide band gap (3.3 eV) semiconductor with large exciton binding energy (60 meV), ZnO has been widely used in various devices such as surface acoustic wave (SAW) devices, pyroelectric devices, gas sensors, varistors and transparent electrodes. Moreover, ZnO has potential for light-emitting diodes (LEDs), laser diodes (LDs) and ultraviolet (UV) detecting devices in the UV range [1–4]. For example, ZnO is extremely resistant to room temperature MeV proton irradiation compared to other semiconductors [5] and can undergo harsh radiation for much longer time and be used for space applications. zinc oxide has a number of advantages, such as high resistance to radiation damage, high breakdown strength and temperature stability, low cost and simplicity of device fabrication [6-7].

Till today, there are few reports on the photo response of metal–semiconductor–metal (MSM) detectors on ZnO. In addition, many papers were mostly concerned with the preparation of ZnO and investigation of their structural and optical properties, but their optoelectronic properties need more attention.

It is known that both fast and slow components are observed [8–10] in ZnO photo response. The slow component that takes tens of minutes is due to photo desorption of oxygen from crystal surface [8–11]. In this case, the rise in conductivity under illumination results from the return to the crystal of equilibrium electrons captured earlier by oxygen atoms. This process is studied in detail and is used in gas sensors [8–11]. For photo-detection, the fast component is important. This component that takes fractions of second is due to generation of photo carriers and their following radiative and nonradiative recombination through local centers. It is the recombination process that defines photosensitivity [8, 9].

In ZnO, however, the photosensitivity process has been weakly studied and the role of different electronic processes in photoconductivity has not been established. For the realization of ZnO in optoelectronic properties the effect of light illumination on the conductivity is important.

In the present work, we report the photoconductive properties of ZnO microwhiskers grown through carbothermal method.

2. Experimental Procedure

A conventional horizontal tube furnace was used for the synthesis of ZnO nanowires. Mixture of ZnO and graphite in 1:1 ratio (by weight) was used as a source material. It was loaded on a quartz boat and placed in the center of 1 m long quartz tube. High purity gases were introduced through one side of the furnace and other side of the quartz tube was connected to a water bubbler. The flow of gases was controlled with rotameters. The material was heated to 1100°C under a constant flow of 500sccm argon. On stabilizing the temperature, the gas atmosphere was switched to 98% argon and 2% oxygen at same flow rate. The furnace was maintained under these conditions for 30 mins and then cooled to room temperature at a rate of 6ºC/min. The transparent colorless needles shaped micro crystals with hexagonal cross-section were found to grow in the up flow direction of the gas. The cross-sectional diameter and average length of whiskers are 10 μm and 5 mm respectively. The photoconductivity of micro whiskers was measured at room temperature. The conductivity of ZnO single crystal was measured based on metal–semiconductor–metal planar structures over a SiO_2/Si substrate. The photoconductivity transients were measured with applying 1 μA direct electric current

3. Results and Discussion

The Figure 1 shows a ZnO micro whisker on a SiO_2/Si substrate with indium contacts in MSM planar structure.

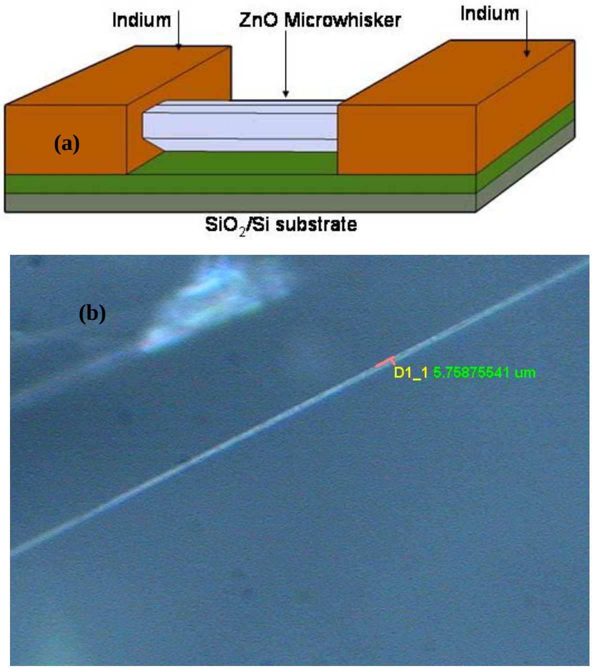

Fig. 1 (a) Schematic of MSM planar structure of ZnO micro whisker fabricated over a SiO2/Si substrate using indium contacts (b) optical image of ZnO micro whisker of 15 μm diameter.

The measured dark and photo illuminated I–V characteristics Ag-electrode on ZnO micro whisker are depicted in Figure 2.

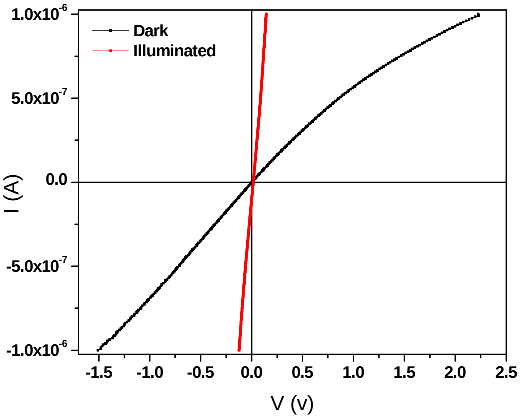

Fig. 2 The measured dark and photo-illuminated I–V characteristics of ZnO micro whisker

As shown in the Fig.2 there is a drastic change in the I-V characteristics measured in dark and in photo-illumination. In dark it shown non linear behavior while under photo illumination it show good ohmic linear behavior with enhanced conductance.

The effect of the photo illumination on the conductivity of the ZnO microwhiskers was studied by applying 1μA the electric current across the MSM structure and measured the voltage drop across the structure under photo illumination and dark in period of 60 sec at room temperature. The change in the conductivity as a result of photo illumination is calculated using equation given as:

$$\sigma\ \% = \frac{\sigma_{light}}{\sigma_{dark}} \times 100$$

This percentage change in the conductivity is plotted in Fig.3. As shown in the figure 3, the conductivity increases suddenly with the photo illumination and thus the photoconductivity increases with increasing the photo intensity. With the photo illumination the conductivity of the micro whisker rises to 90% with in 3-4 s and falls to 80% within 2-3 s depending upon the photo intensity.

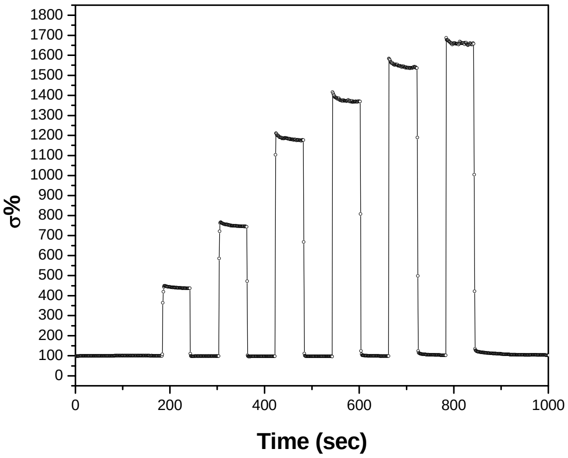

Fig. 3 the percerntage change in conductivity of ZnO microwhisker with increasing photo intensity

The photo-response of ZnO consists of two parts: a rapid process of photo-generation and recombination of electron–hole pairs, and a slow process attributed to the oxygen adsorption and photo desorption on the ZnO surface. The slight oxygen-deficient crystal always show a steady decrease in the conductivity due to the adsorption of oxygen near the surface.

Once irradiated with light, pair of electron and hole are produced:

$$h\nu = h^{+} + e^{-},$$

where h is the Planck constant, h^+ is the hole. Photo generated holes discharge the negatively charged oxygen

ions and the oxygen is desorbed:

$$h^{+} + O_2^{-} = O_2(g)$$

Conductivity is a product of the carrier density and mobility. On one hand, a large amount of photo generated electrons increase the carrier density, and the conductivity of the ZnO increases quickly, which is a rapid process. On the other hand, photo generated holes are captured by the negatively charged oxygen ions, and the photocurrent increases by excess conduction-band electrons with the same density as the captured holes. In this process, the oxygen photo desorption depletes most photo generated holes, and prohibits holes to recombine with conduction band electrons. The carrier density increases. The oxygen photo desorption also increases the carrier mobility by means of lowering the barriers height. Consequently, the conductivity increases. The generation of electrons is accompanied with the recombination of electron–hole pairs. As long as the generation rate of electrons is larger than the electron–hole pairs recombination rate, the photocurrent may increase steadily. But with the decrease of the chemisorbed oxygen, the rate of carrier recombination increases. When the rate of the carrier generation and recombination are equal, the photoconductivity reaches the peak value, which is a steady dynamic equilibrium state.

4. Conclusion

ZnO microwhiskers were grown through carbothermal reduction process. Metal-semiconductor-metal (MSM) type planar structure was fabricated with semiconducting ZnO microwhiskers on SiO_2/Si substrate using indium metal contacts. Photo illumination show a drastic change on the behavior of I-V characteristics, as it converted from non linear behavior to linear ohmic behavior. The photoconductivity measurement show that the conductivity increases suddenly with the photo illumination and thus the photoconductivity increases with increasing the photo intensity. With the photo illumination the conductivity of the microwhisker rises to 90% with in 3-4 s and falls to 80% within 2-3 s depending upon the photo intensity. These observations were explained on the basis of oxygen sorption and desorption mechanism.

Acknowledgment

This work was supported by National Research Foundation of Korea Grant (2009-0087091) and the research grant of the Jeju National University in 2009.

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