A Zinc Oxide Nanoparticle Photodetector

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Abstract
A zinc oxide (ZnO) ZnO nanoparticles photodetector was fabricated with a simple method. With 5V applied bias, it was found that dark current and photocurrent of our ZnO nanoparticles photodetectors were 1.98\times10^{-8} and 9.42\times10^{-7} A, respectively. In other words, we achieved a photocurrent to dark current contrast ratio of 48. With an incident lightwavelength of 375 nm and a 5-V applied bias, it was found that the measured responsivities were 3.75 A/W for the ZnO nanoparticles photodetector. On the other hand, the 3.75 A/W responsivity measured from the ZnO nanoparticles PD corresponds to detector efficiency significantly larger than 100%. Such a result indicates that there exists a large photoconductive gain in the ZnO nanoparticles PD.

Index Terms—Zinc Oxide, Nanoparticle, Photodetector

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I. INTRODUCTION

As the number of scaled-down components being developed gradually becomes abundant, it is apparent that the high-quality wide bandgap one-dimensional (1D) semiconductor nanostructures such as nanowires (NWs) [1-6], nanotubes [7,8], and nanoribbons [9,10], will most likely become the promising functional components for the next-generation nanometer-scale photonic and electronic devices. During the past years, semiconductor nanocrystals and NWs have been utilized for fabricating photoelectric devices due to their large surface-to-volume ratio and tunable feature size [11-15]. Accordingly, the presence of deep level surface trap states in NWs greatly prolongs the photocarrier lifetime and the reduced dimensionality of the active area in NW devices shortens the carrier transit time. While the surface and feature size of NWs can provide the similar benefits associated with nanocrystals, better extraction of photo-generated carriers, however, is only achievable through the high mobility NW core, leading to a substantial photoconductive gain.

Among those semiconductor materials available, ZnO is one of the most appealing candidates due to its large exciton binding energy of 60 meV, wide bandgap energy of 3.37 eV at room temperature, excellent chemical and thermal stability and biocompatibility [16, 17]. In the past decade, the demonstration of a large variety of functional ZnO nanowire (NW) devices such as field effect transistors [14,18], optically pumped lasers [19,20], UV detectors [21-23], and chemical and biological sensors [24-28] have aroused growing interest in this material. Law et al. [11] have reported the use of aligned ZnO NWs in dye-synthesized solar cells to enhance extraction of generated carriers, leading to higher external quantum efficiencies. In this work, ZnO nanoparticles UV photodetectors were fabricated. The details of the ZnO nanoparticles growth and the UV detectors fabrication are discussed. The electrical and optical of the fabricated photodetectors are also measured and analyzed.
II. Experiments

The well-dispersed nano-scale ZnO suspensions were fabricated by a ball milling equipment. The milling conditions were set on 3500 rpm and 24 hrs. Then the prepared ZnO nanoparticles was coated on the Al$_2$O$_3$ substrate by spin coating technique. The coated film of ZnO nanoparticles was dried at 60°C in an oven. The baked film and substrate were annealed at 800°C for 1 h in air. The ZnO nanoparticles thin films would be analyzed by SEM, XRD, PL equipment. A JEOL JSM-7000 F field emission scanning electron microscope operated at 10 keV was then used to characterize structural properties of the ZnO nanoparticles film. For the fabrication of nanoparticle photodetector, a thick Ni–Au (20/100 nm) film was deposited through an interdigitated shadow mask onto the nanoparticle thin film to serve as contact electrodes. We designed the pattern on the metal mask so that fingers of the interdigitated electrodes were 2 mm wide and 2.2 mm long with a finger spacing of 0.2 mm. It should be noted that the nanoparticles thin film shown in Fig. 1 could provide electrical paths for the two interdigitated electrodes. Current–voltage (I–V) characteristics of the fabricated PDs were then measured by an HP 4156 semiconductor parameter analyzer at room temperature. Spectral-responsivity measurements of the PDs were also performed at room temperature by a JOBIN-YVON SPEX System with a 300-W xenon arc lamp light source (PERKINELMER PE300BUV) and a standard synchronous detection scheme.

Figure 1 Schematic diagram of the fabricated ZnO nanoparticles photodetector.
III. RESULTS AND DISCUSSION

Figure 2 The SEM image of the ZnO nanoparticles film on Al₂O₃ substrate after annealing at (a) 400 °C, (b) 600 °C, (c) 800 °C.
Figure 2(a) has shown the SEM images of ZnO nanoparticles annealed at 400°C. It could be seen clearly that the shape of ZnO nanoparticles were sphere and column like. The average grain size of ZnO nanoparticles were about 100 nm. These ZnO nanoparticles were contacted closely with neighboring nanoparticles to form continuous film. The thickness of ZnO nanoparticles film was about 500 nm that we could observe. Figure 2(b) has shown the SEM images of ZnO nanoparticles annealed at 600°C. The grain size was maintained at about 150 nm and the shape of the nanoparticles were sphere and column like. Figure 2(c) has shown the SEM images of ZnO nanoparticles annealed at 800°C. It could be observed clearly that the ZnO nanoparticles were contacted more closely and melted with each other. Because of the high temperature annealing, the properties of crystallize was much better than at low temperature. Figure 3(a) shows the XRD spectrum of ZnO nanoparticles film on Al₂O₃ substrate. It is found that all the diffraction peaks of ZnO nanoparticle and Al₂O₃ could be indexed to the wurtzite structure ZnO and Al₂O₃ according to the standard JCPDS (no.897716
& no.751526) card. Figure 3(b) shows the ranges of EDX spectrum detection in ZnO nanoparticles film. We would sure that ZnO nanoparticles contains 31.5% in Zinc, 34.14% in oxygen, 21.96% in aluminum, 7.35% in platinum and 5.04% carbon at the percentage of weight. The platinum (Pt) signals are originated from the deposited platinum thin film which was utilized for increasing electric conductivity when we use the SEM. Because the thick of nanoparticles film is 500nm, the elements of aluminum and oxygen were attributed to Al$_2$O$_3$ substrate. By subtracting the compound of oxygen in Al$_2$O$_3$, the ratio of zinc to oxygen was still about 1:1.

![Figure 4 I-V characteristics of the fabricated ZnO nanoparticles photodetector after annealing 800°C.](image)

Figure 4 I-V characteristics of the fabricated ZnO nanoparticles photodetector after annealing 800°C.
Figure 5 Transient response of the measured current by turning the UV light on-and-off.

Figure 4 shows the current–voltage (I–V) characteristics between the two neighboring electrodes bridges by ZnO nanoparticles film measured in the dark and UV light illuminated. With 5V applied bias, it was found that dark current and photocurrent of our ZnO nanoparticles photodetectors were $1.98 \times 10^{-8}$ and $9.42 \times 10^{-7}$ A, respectively. In other words, we achieved a photocurrent to dark current contrast ratio of 48. At room temperature, when the sample is irradiated with UV light, the conductance rises as can be noticed in fig. 5 at the first time the ZnO nanoparticle film is irradiated, there is a shift in the dark conductivity which is maintained at the following irradiations. As shown in Fig. 5, it was found that dynamic response of the ZnO nanoparticles PD was stable and reproducible with an on/off current contrast ratio of around 160. It was found that photocurrent decayed rapidly and could be well described by the stretched-exponential function. It should be noted that the current decrease rate is determined by the speed of oxygen molecules absorbed on ZnO nanowire surface to capture excess electrons. Thus, turn-off speed should be much slower than the turn-on speed for our ZnO UV photodetector.
Figure 6 shows room-temperature spectral responses of the fabricated ZnO nanoparticles photodetector using a 300-W Xe lamp dispersed by a monochromator as the excitation source. During these measurements, the monochromatic light calibrated with a UV-enhanced Si diode and an optical power meter was modulated by a mechanical chopper and collimated onto the front-side (i.e., metal-side) of the fabricated devices using an optical fiber. The photocurrent was then recorded by a lock-in amplifier. It should be noted that photoresponses of the fabricated photodetector were flat in the short-wavelength region while sharp cutoff occurred at 375 nm. With an incident lightwavelength of 375 nm and a 5-V applied bias, it was found that the measured responsivities were 3.75 A/W for the ZnO nanoparticles photodetector. On the other hand, the 3.75 A/W responsivity measured from the ZnO nanoparticles PD corresponds to detector efficiency significantly larger than 100%. Such a result indicates that there exists a large photoconductive gain in the ZnO nanoparticles PD. Previously; Chen et al. observed an ultrahigh photoconductive gain from a single GaN NW, which was three orders of magnitude larger than that of GaN film PD [24]. It has also been shown that the large photoconductive gain is originated from carrier multiplication and the electron-hole spatial separation induced by strong surface band bending. Similar phenomenon should also occur in our ZnO nanoparticles PD. The result suggest that the 1D lateral ZnO nanoparticles photodetector reported in this study is potentially useful for UV light sensing.
IV. CONCLUSION

In summary, a zinc oxide (ZnO) ZnO nanoparticles photodetector was fabricated with a simple method. With an incident lightwavelength of 375 nm and a 5-V applied bias, it was found that the measured responsivities were 3.75 A/W for the ZnO nanoparticles photodetector. On the other hand, the 3.75 A/W responsivity measured from the ZnO nanoparticles PD corresponds to detector efficiency significantly larger than 100%. Such a result indicates that there exists a large photoconductive gain in the ZnO nanoparticles PD.

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REFERENCES


