Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp729-730

Selectivity lateral grown ZnO nanowire UV Photodetectors on glass substrate

Wen-Yin Weng[1], Ting-Jen Hsueh[2], Shoou-Jinn Chang[1], Cheng-Liang Hsu[3]

[1] Institute of Microelectronics and Department of Electrical Engineering
Center for Micro/Nano Science and Technology
Advanced Optoelectronic Technology Center
National Cheng Kung University, Tainan 701, Taiwan, ROC
Phone: (+886) 6-2757575-62400-1208 E-mail: weng.wenyin@gmail.com
[2] National Nano Device Laboratories, Tainan 741, Taiwan, ROC
[3] Department of Electronic Engineering
National University of Tainan, Tainan 700, Taiwan, ROC

1. Introduction

Ultravioletu (UV) photodetectors (PDs) are important devices that have a wild range of commercial and military applications. In recent years, ZnO has attracted much attention due to the facts that it is an n-type semiconductor with large exciton binding energy of 60 meV and wide bandgap energy of 3.37 eV at room temperature. The optoelectronic properties make ZnO a promising material for UV PDs applications. The planar ZnO UV detectors have already been demonstrated [1]. Other than planar films, it is also possible to fabricate ZnO nanowires. One-dimensional (1D) semiconductor nanowires have attracted great attention because of their potential applications in nanoscale devices. Compared with bulk or thin film-based devices, 1D ZnO-nanowire PDs should provide a high internal photoconductivity gain due to the surface-enhanced electron-hole separation efficiency [2]. These 1D ZnO-nanowire PDs can be achieved by dispersing a single nanowire onto pre-fabricated electrodes [3, 4] or use electron-beam lithography to define the electrical contacts [5]. However, these two method both require tedious and time consuming processing steps. In contrast, fabrication of lateral ZnO nanowires PDs is simpler [6]. Compared with Si, glass substrates are transparent and low cost. Large area glass substrates are also commercial available. Thus, glass is an ideal substrate material for UV PDs. In this study, we report the fabrication of lateral ZnO nanowires PDs on glass substrate. Physical and electro-optical properties of the fabricated PDs will also be discussed.

2. Experimental

Fig.1 schematically depicts the growth and processing steps used in this study. Prior to the growth of ZnO nanowires, we first deposited a Cr/Au (5/100 nm) film onto a glass substrate by e-beam evaporation. Standard photolithography and lift-off were then performed to define the two contact electrodes. For the growth of ZnO nanowires, the patterned substrate and Zn powder which placed on an alumina boat were both inserted into a quartz tube. Evaporation was carried out in the quartz tube located in a horizontal tubular furnace [7]. Argon and oxygen gases were then introduced into the furnace. It should be noted that the positions of the substrate, the Zn metal powder and the alumina boat were carefully controlled so that they were on the same horizontal level and heated to the same temperature. During the growth, we kept the growth pressure and the growth time at 10 torr and 60 min, respectively.

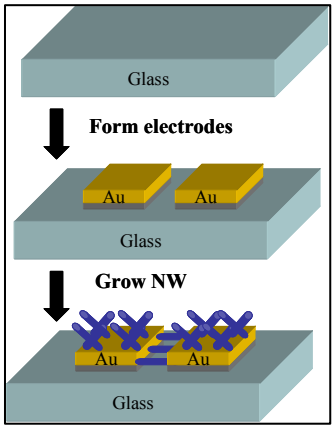

Fig.1 Growth and processing steps used in this study.

3. Results and Discussion

Fig.2 shows measured XRD spectrum of the as grown sample. It was found that only one strong ZnO (002) XRD peak could be observed at $2\theta = 34.5°$. It was also found that full-width at half-maximum (FWHM) of the XRD peak was about 0.167°. These results indicate that the as-grown ZnO nanowires were all well oriented with pure wurtzite structure and with a reasonably good crystal quality.

Fig.3 shows top-view SEM micrograph of the ZnO nanowires prepared in this study. It can be seen that high-density ZnO nanowires were selectively grown on the Cr/Au electrodes while no nanowires could be grown directly on glass. It was also found that average length and diameter of the ZnO nanowires were around 5 μm and 75 nm, respectively. The inset shows an enlarged top-view SEM micrograph of the same sample taken from the center of the two contact electrodes. It can be seen that the ZnO nanowires prepared in this study were grown laterally. Furthermore, it was found that some of these laterally-grown ZnO nanowires bridged across the two

Cr/Au electrodes to provide electrical paths. Thus, the two electrodes were no longer electrically open. We can thus determine resistance of the sample by simply applying a voltage across the two electrodes and measure the corresponding current.

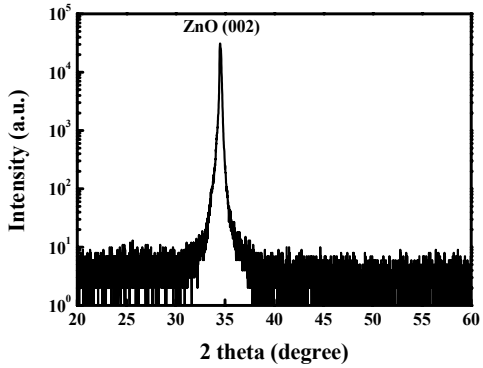

Fig.2 Measured XRD spectrum of the as grown sample.

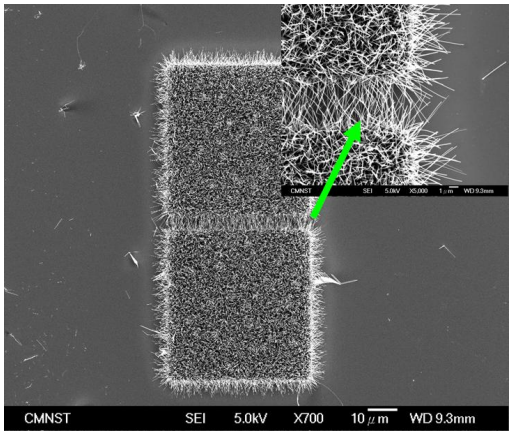

Fig.3 Top-view SEM micrograph of the ZnO nanowires prepared in this study. The inset shows an enlarged top-view SEM micrograph of the same sample taken from the center of the two contact electrodes.

Fig.4 shows spectral responses of the laterally-grown ZnO nanowires PD measured with three different applied biases (i.e., 0.1, 0.3 and 0.5 V). The inset shows I-V characteristics of the laterally-grown ZnO nanowires PD measured in dark. It should be noted that the photo responses of the fabricated PD were reasonably flat over the short-wavelength region while cutoff occurred at ~ 360 nm. With an incident light wavelength of 350 nm and an applied bias of 0.1 V, it was found that measured responsivity of the PD was 6.04×10^{-3} A/W. It was also found that the transition region of the laterally-grown ZnO nanowires PD was only 30 nm. As we increased the bias voltage to 0.5 V, it was found that measured responsivity increased to 3.04×10^{-2} A/W. The significant increase in responsivity with applied bias suggests that there exists a large photoconductive gain in the laterally-grown ZnO nanowires PD. It is known that photoconduction of ZnO nanowires is governed by desorption and adsorption of oxygen [5]. In the dark, oxygen molecules on surface of nanowires carry negative charges by capturing free electrons from the n-type ZnO. Thereby, it creates a depletion layer with low conductivity near the surface. UV light absorption generates electron-hole pairs. The photo-generated holes oxidize the adsorbed negatively charged oxygen ions on the surface while the remaining electrons in the conduction band increase the conductivity. These oxygen-related hole-trap states at the nanowires surface prevent charge-carrier recombination and prolong the photo-carrier lifetime. Thus, we can achieve the high internal photoconductivity gain [4]. Here, we define UV-to-visible rejection ratio as the responsivity measured at 350 nm divided by the responsivity measured at 420 nm. With such a definition, it was found that we achieved a UV-to-visible rejection ratio larger than 600 when biased at 0.1 V.

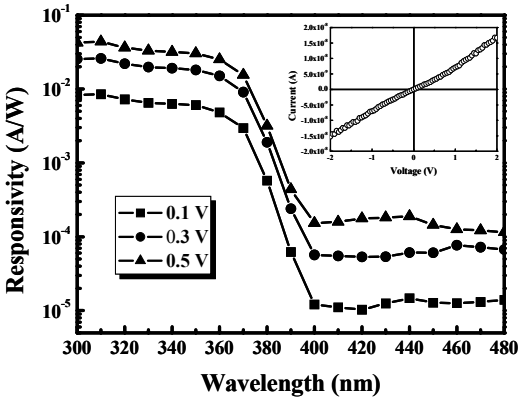

Fig.4 Spectral responses of the laterally-grown ZnO-nanowires PD measured with three different applied biases. The inset shows I-V characteristics of the same sample.

4. Conclusions

In summary, we propose a simple method to fabricate laterally-grown ZnO nanowires PDs on glass substrates by self-catalyzed VLS process. It was found that cutoff of the fabricated PD occurred at ~ 360 nm with a transition region of 30 nm. With an incident light wavelength of 350 nm and an applied bias of 0.1 V, it was found that measured responsivity of the PD was 6.04×10^{-3} A/W with a UV-to-visible rejection ratio larger than 600.

References

[1] T. K. Lin, S. J. Chang, Y. K. Su, B. R. Huang, M. Fujita and Y. Horikoshi, J. Cryst. Growth. **281** (2005) 513.
[2] C. Soci, A. Zhang, B. Xiang, S. A. Dayeh, D. P. R. Aplin, J. Park, X. Y. Bao, Y. H. Lo and D. Wang, Nano Lett. **7** (2007) 1003.
[3] H. Kind, H. Yang, B. Messer, M. Law and P. Yang, Adv. Mater. **14** (2002) 158.
[4] J. Suehiro, N. Nakagawa, S. Hidaka, M. Ueda, K. Imasaka, M. Higashihata, T. Okada and M. Hara, Nanotechnol. **17** (2006) 2567.
[5] Y. W. Heo, B. S. Kang, L. C. Tien, D. P. Norton, F. Ren, J. R. La Roche and S. J. Pearton, Appl. Phys. A **80** (2005) 497.
[6] J. B. K. Law and J. T. L. Thong, Appl. Phys. Lett. **88** (2006) 133114.
[7] T. J. Hsueh, C. L. Hsu, S. J. Chang and I. C. Chen, Sensors and Actuators B **126** (2007) 473.