Development of Ultra-Violet Sensing Devices with Zinc-Oxide Thin-Films on Oxidized Nano-Porous-Silicon Substrates

Kuen-Hsien Wu, Chia-Chun Tang and Sheng-Chun Lin
Department of Electro-Optical Engineering, Southern Taiwan University of Science and Technology
No. 1, Nan-Tai Street, Yungkang Dist., Tainan City 710, Taiwan R.O.C.
E-mail: khwu@mail.stust.edu.tw

The II-VI compound material zinc oxide (ZnO) with an optical band gap of 3.3eV is considered a promise candidate for ultra-violet (UV) detecting applications [1]. However, there were no suitable substrates for the growth of ZnO thin films nowadays. It was due to the large differences in the lattice constants as well as in the thermal expansion coefficients between ZnO and the substrates, the film quality of these deposited ZnO materials cannot be improved [2]. In recent researches, some materials grown on nano-porous-Si (NPS) got better film crystallinity and film quality than those directly grown on silicon substrates [3]. This paper mainly reported the preparation of ZnO thin films on NPS for development of low-cost UV optical-sensing devices.

In this work, heavily doped (3~5 mΩ·cm) (100) p⁺-Si wafers were used as the starting substrates. NPS layers were prepared by an electrochemical anodic etching method. Then the NPS layers were transformed into oxidized nano-PS (ONPS) through a 60-s, 800°C rapid thermal oxidation (RTO) process. Thereafter, ZnO thin-films were sputtered on ONPS surface layers and annealed under different temperatures in N₂ ambient. Finally, Al electrodes were deposited on the top of the samples by an e-beam evaporator to complete a metal-semiconductor-metal (MSM) photodiode structure of the ZnO/ONPS UV optical sensing devices.

Figure 1 showed the SEM images of samples with the as-deposited ZnO thin films on ONPS substrates. From the figure, we can observe that a uniform and smooth 100-nm thick ZnO thin-film with grain sizes of about 20nm~30nm was successfully deposited on a 3.5-µm ONPS substrate. Fig.2 showed X-ray diffraction (XRD) patterns of the deposited ZnO on ONPS for different annealing temperatures. We found that the crystallinity of the ZnO films improved with a higher annealing temperature.

Figure 3 show the photo-response spectra of ZnO devices on nano-porous silicon (NPS) and oxidized nano porous silicon (ONPS) substrates. It was found that developed ZnO-on-ONPS device obtained higher 300~400nm UV responsivity and greatly suppressed visible-light response as compared with ZnO-on-NPS devices. It is important to prevent visible-light response for an UV sensing devices in most applications. Fig.4 illustrated the current-voltage characteristics of the ZnO-on-ONPS photodiode with and without UV illumination. The photocurrent was measured under incident light with wavelength of 375nm and power of 0.08mW/cm². The photocurrent was 4.74mA/cm² and the dark current was 4.56×10⁻²mA/cm² measured at a 5-V bias. The photo-to-dark current ratio was calculated up to about 104.

ZnO thin-films with smooth and uniform grain structures had been successfully deposited on NPS or ONPS substrates. Experimental results demonstrated that ZnO-on-ONPS was a very potential approach for development of low-cost UV photodetectors.

Reference
Fig. 1. SEM images of the as-deposited ZnO thin-film on an ONPS substrate.

Fig. 2. X-Ray diffraction patterns of ZnO films deposited on ONPS substrates for different annealing temperatures.

Fig. 3. Photoresponse spectra of ZnO photodiodes prepared on NPS and ONPS substrates. The photoresponse of a bare NPS layer was also included.

Fig. 4. Current-voltage characteristics of the developed ZnO-on-ONPS photodiodes with and without illumination.