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ZnO Ultraviolet photodiodes With Pd Contact Electrodes

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With the advancement of optoelectronic devices fabricated on wide direct band gap materials, it becomes possible to produce high-performance solid-state photodetectors that are sensitive in the ultraviolet (UV) region. For example, GaN-based UV photodetectors are already commercially available. ZnSe-based UV photodetectors have also been demonstrated.

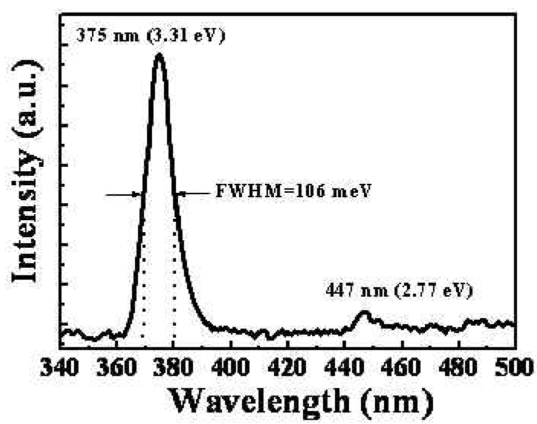
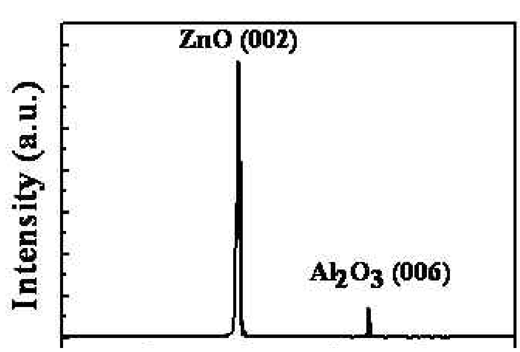


Figure 1、Room temperature PL spectrum of epitaxial ZnO films.

ZnO is another wide direct bandgap material that is sensitive in the UV region. At room temperature, the bandgap energey of ZnO is near 3.37 eV. Besides, ZnO has the similar wurtzite structure with GaN. Furthermore, comparing with GaN, ZnO has larger exciton binding energy of 60 meV than GaN (24 meV). It makes ZnO a promising photonic material for applications such as light emitting diodes (LEDs), laser diodes (LDs) and UV photodetectors. Indeed, ZnO has attracted much attention in recent years. High quality ZnO epitaxial layers can be grown by metalorganic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE) and pulsed laser deposition (PLD) on top of ZnO substrates, sapphire substrates and epitaxial GaN layers.

ZnO sensors detecting in the UV region have also been demonstrated. There are many kinds of photodetectors, such as Schottky-type photodiodes, metal-semiconductor-metal (MSM) photodetectors, p-n junction, p-i-n photodetectors and heterojunction structures. Among these structures, MSM UV photodetectors have attracted much interest due to their simplicity and high responsivity. MSM structures can also be used in optoelectronic-integrated-circuits (OEICs) due to ease of integration, potential for high speed, and compatibility with filed effect transistor (FET) process technologies.



MSM sensors consist with interdigitated Schottky contacts deposited on top of an active layer. To achieve high performance MSM UV photodetectors, it is important to achieve large Schottky barrier height at metal-semiconductor interface. A large barrier height leads to small leakage current and high breakdown voltage which could result in improved responsivity and photocurrent to dark current contrast ratio. To achieve a large Schottky barrier

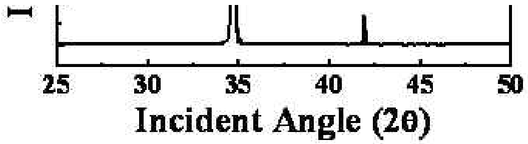


Figure 2、XRD spectrum of the epitaxial ZnO films prepared on sapphire substrate.

height on ZnO, one can choose metals with high work functions. However, many of the high work function metals are not stable at high temperatures. In other words, severe inter-diffusion might occur at metal-ZnO interface. Palladium (Pd) is an interesting metal that has recently been used as stable Schottky contact of wide bandgap GaN. Pd is also a good conductor with superior thermal and chemical stabilities. GaN-based UV PDs and Schottky diodes with Pd contact electrodes have also been demonstrated. Although the study of the ZnO schottky diodes with Pd contact electrodes had been reported. However, neither the properties of ZnO-based MSM photodetectors with Pd contacts nor the detectivity of the devices could be found in the literature to our knowledge. So, this causes our research motivation.

Samples used in this study were grown by radio frequency (rf) plasma-assisted MBE (Omni Vac) on sapphire (0001) substrates. The base pressure in the growth chamber was ~$1 \cdot 10^{-10}$ Torr. From Hall measurement, it was found that carrier concentration of the as-grown ZnO films was 1.71×10^{16} cm^{-3} at room temperature. Figure 1 shows room temperature PL spectrum of these ZnO epitaxial films. It was found that we observed a strong excitonic related PL peak at 375 nm and a very weak green band emission at around 447 eV. The green luminescence band may be due to the oxygen vacancy as the defect. It was also found that full-width-half-maximum (FWHM) of the excitonic related PL peak was only 106 meV. Figure 2 shows measured XRD spectrum of the 1000-nm-thick ZnO epitaxial film prepared on sapphire substrate. The peak occurred at $2\theta = 41.9^{o}$ in the spectrum was originated from the (006) plane of sapphire substrate. We also observed a ZnO (002) XRD peak at $2\theta = 34.3^{o}$ with a FWHM of 0.18^{o}. Such a result indicates that the ZnO film was preferentially grown in c-axis direction. The small FWHM of the ZnO (002) XRD peak again indicates good crystal quality of our samples.

ZnO MSM photodetectors were then fabricated. Prior to the deposition of contact electrodes, wafers were dipped in acetone and methanol to clean the surface. 100-nm-thick Pd film was subsequently deposited onto the sample surface by e-gun evaporation to serve as metal contacts. Standard lithography and etching were then performed to define the interdigitated contact pattern. The structure of the fabricated ZnO MSM photodetectors shows in figure 3.

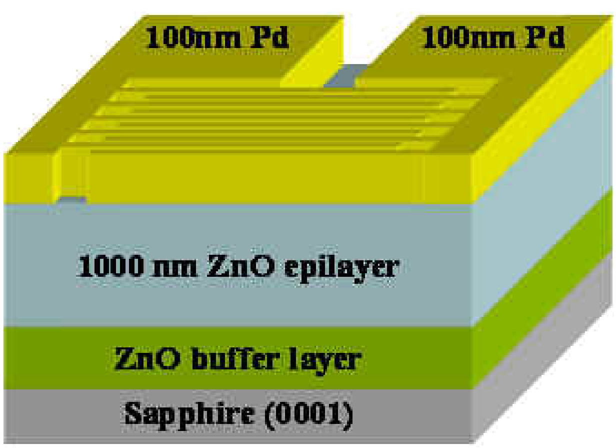


Figure 3、The structure of the ZnO MSM photodetector

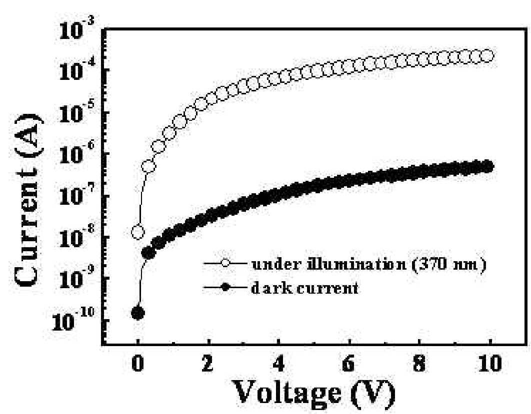


Figure 4、I-V characteristics of the fabricated Pd/ ZnO/Pd MSM photodiodes measured in dark (dark current) and under 370 nm illumination (photocurrent).

Figure 4 shows current-voltage (I-V) characteristics of the fabricated ZnO MSM photodetectors with Pd electrodes measured in dark and under illumination (370 nm). It was also found that dark current and photocurrent of the fabricated photodiode biased at 1V were 1.19×10^{-8} and 3.83×10^{-6} A, respectively. In other words, we achieved a photocurrent to dark current contrast ratio of only 322.

Figure 5 shows measured spectral responsivities of the fabricated Pd/ZnO/Pd MSM photodetectors. As shown in figure 5, it was found that the photodetector responsivities were nearly constants in the below bandgap UV region (300-370 nm) while sharp cutoffs with a drop of 2 orders of magnitude occurred at approximately 370 nm. With an incident wavelength of 370 nm and 1 V applied bias, it was found that the maximum responsivities for the fabricated Pd/ZnO/Pd MSM photodetectors was 0.051 A/W, which corresponds to a quantum efficiency of 11.4 %. Figure 6 shows the noise equivalent power (NEP) increased and detectivity (D*) decreased monotonically with the applied bias. This is due to the fact that increase in responsivity is much smaller than the increase of total noise current power as the applied bias increased for our detectors. Thus, NEP and D* of our detectors were both dominated by the total noise current power.

In this research topic, we successfully fabricated the ZnO MSM photodetectors by using Pd contact electrodes. It was found that our devices show good performance. These results will facilitate the further development of short-wavelength photodetectors.

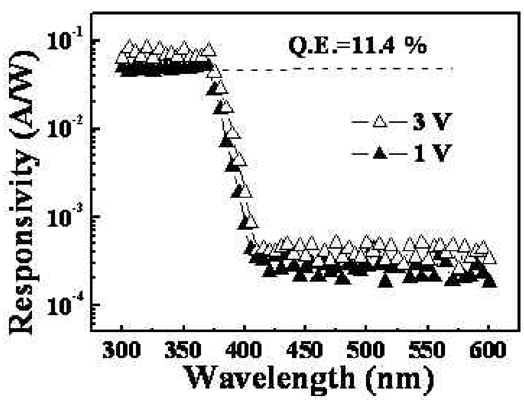


Figure 5、Measured spectral responsivites of the fabricated Pd/ZnO/Pd MSM photodiodes.

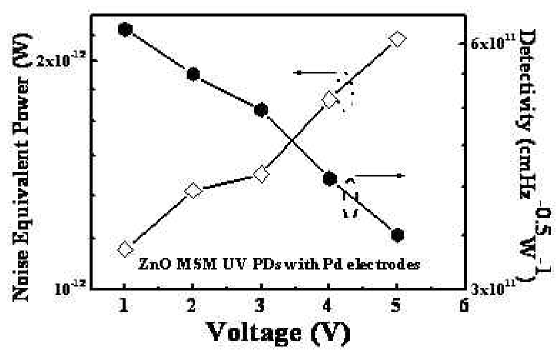


Figure 6、The noise equivalent power and detectivity as functions of applied voltage.