APPLIED PHYSICS LETTERS **98**, 103506 (2011)

$Mg_{0.55}Zn_{0.45}O$ solar-blind ultraviolet detector with high photoresponse performance and large internal gain

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(Received 3 November 2010; accepted 15 February 2011; published online 10 March 2011)

A Schottky type metal-semiconductor-metal solar-blind ultraviolet detector was fabricated on high quality wurtzite $Mg_{0.55}Zn_{0.45}O$ epitaxial film. Photoresponse spectra show a responsivity peak of 22 mA/W under 130 V bias. A sharp cutoff was recognized at a wavelength of 270 nm, and a temporal response measurement indicates a fast decay time of less than 500 ns. A large internal gain was observed and interpreted by a reduced Schottky barrier height model, which fits well with the experimental data. © *2011 American Institute of Physics*. [doi:10.1063/1.3563705]

Recently, solar-blind ultraviolet (UV) detectors operating in the spectrum region of 220–280 nm have been attracting more and more attention due to their huge potential for applications in missile plume early warning, flame/engine control, air/water purification, covert space-to-space communications, etc.[1–3] MgZnO alloy with a tunable band gap extending from that of wurtzite ZnO (~3.37 eV) to that of cubic MgO (~7.8 eV) is a promising candidate for solar-blind UV detectors. However, researchers have found it difficult to obtain a single-phase wurtzite MgZnO (W-MgZnO) with high Mg content due to the well-known phase segregation problem in wide band gap ternary alloys.[4] In this case, it is impossible to shorten the cutoff wavelength into the deep UV region.[5,6] Some researchers have realized solar-blind UV detection by cubic MgZnO components with high Zn content.[7,8] However, the detailed photoresponse performance of the device, especially the temporal response, was unsatisfactory or was not even explored yet.

In this letter, we report the fabrication of Schottky type interdigital metal-semiconductor-metal (MSM) solar-blind UV detectors on W-$Mg_{0.55}Zn_{0.45}O$ epitaxial film, which was grown on c-plane sapphire substrate by radio-frequency plasma assisted molecular beam epitaxy (rf-MBE).[9] Current-voltage (*I-V*) characteristics show that the detectors can work at a bias of hundreds of volts with low leakage current, and we observed ultrafast photoresponse, a high rejection ratio of solar-blind UV to visible light, and a sharp deep-UV cutoff, as well as a large internal gain. To explore the gain mechanism, a reduced Schottky barrier height (SBH) model was adopted, which fits our observations well.

The epilayer was synthesized on sapphire (0001) substrate by rf-MBE, employing a unique "quasihomo" MgZnO buffer with a low Mg content. More details of the growth conditions, as well as the structural and optical properties of the film can be found elsewhere.[9,10] The $Mg_{0.55}Zn_{0.45}O$ solar-blind UV photodetector was designed and fabricated using a Schottky type interdigital MSM structure. Ti (10 nm)/Au (50 nm) was deposited to form finger electrodes, with 2 μm width, 300 μm length, and 2 μm gap (as shown in the inset of Fig. 1). Semiconductor parameter analyzers (Keithley 6487 and 4200) were employed for *I-V* characterization. Photoresponse measurements were performed using the SpectraPro-500i (Acton Research Corporation) optical system with a Xe-arc lamp combined with a monochromator as the light source. The temporal response of the detector was recorded by a digital oscilloscope with a resolution better than 5 ns, and a KrF excimer laser (248 nm) with a pulse width of 20 ns at a repetition rate of 1 Hz was applied as the optical excitation source.

Figure 1 shows the *I-V* curve of the $Mg_{0.55}Zn_{0.45}O$ MSM Schottky photodetector. The well-defined symmetrical rectifying behavior indicates the back-to-back Schottky contacts of the non-alloyed Ti/Au on high-Mg-content MgZnO. No saturation or sharp breakdown of the current was observed in the scan range from −400 V up to 400 V, suggesting the diode could work in high-power circuits. The knee voltage is 0.4 V with a current of about 1.4×10^{-12} A, indicating a large SBH of about 0.80 eV estimated by the Richardson–Dushman equation. The deviation from the theoretical value of 1.04 eV, calculated by the Schottky–Mott model using the ratio of the band expansion of $\Delta E_c : \Delta E_v = 9:1$ for $Mg_xZn_{1-x}O$ alloys to ZnO,[11] is due to the structural differ-

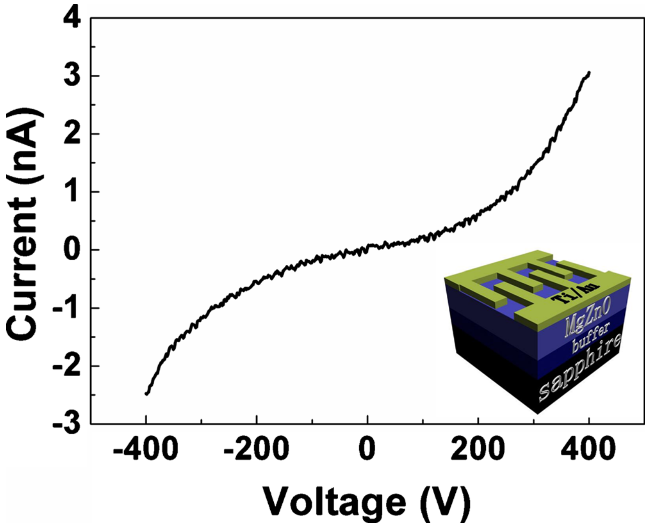

FIG. 1. (Color online) Dark *I-V* characteristic of the $Mg_{0.55}Zn_{0.45}O$ solar-blind UV detector measured from −400 V to 400 V (the inset is a schematic of the detector structure).

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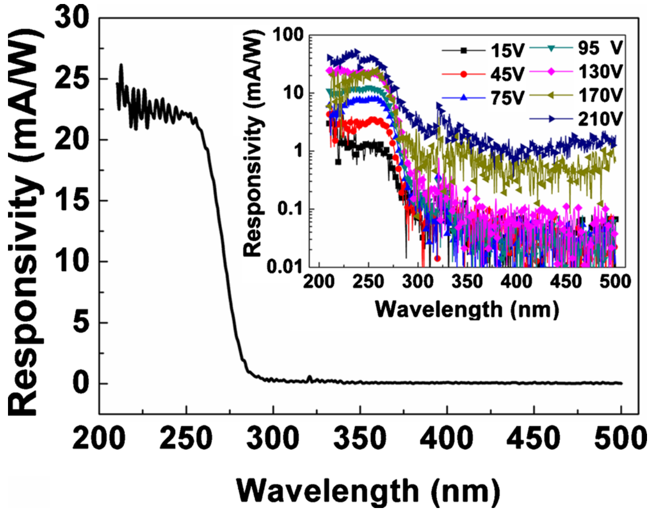

FIG. 2. (Color online) Spectral photoresponse of the $Mg_{0.55}Zn_{0.45}O$ solar-blind UV detector at 130 V bias (the inset is photoresponse spectra at different biases).

ence between MSM and Schottky diodes. The dark current at 130 V bias was found to be as low as 3×10^{-10} A. Once the applied voltage exceeds 130 V, the dark current increases fast due to hole injection from the forward-biased junction.[12]

The spectra-photoresponse of the detector is shown in Fig. 2. The sharp cutoff observed at 270 nm agrees well with the $Mg_{0.55}Zn_{0.45}O$ band gap energy of 4.55 eV.[9] The maximum responsivity is about 22 mA/W at 260 nm under 130 V bias, corresponding to an external quantum efficiency (EQE) of 10.49%. Note that the rejection ratio of solar-blind UV to visible light is more than two orders of magnitude, demonstrating the high crystal quality and good performance of the high-Mg-content MgZnO component. Responsivity increases rapidly in the UV region when the bias increases. On the other hand, the responsivity in the visible light region changes little until the voltage exceeds 130 V, which decreases the aforementioned rejection ratio. (In the inset of Fig. 2, the peak at 320 nm is induced by the exchange action of two gratings in the testing system.)

Figure 3 shows the temporal response of $Mg_{0.55}Zn_{0.45}O$ solar-blind UV detector. The 10% to 90% fall time is less than 500 ns and after reaching 90% the photocurrent quickly decays to the initial value (the value before laser illumination). No persistent photoconductivity was observed, which is rarely reported for MgZnO solar-blind UV detectors, suggesting a low density of interface defects and deep level defects.[13,14]

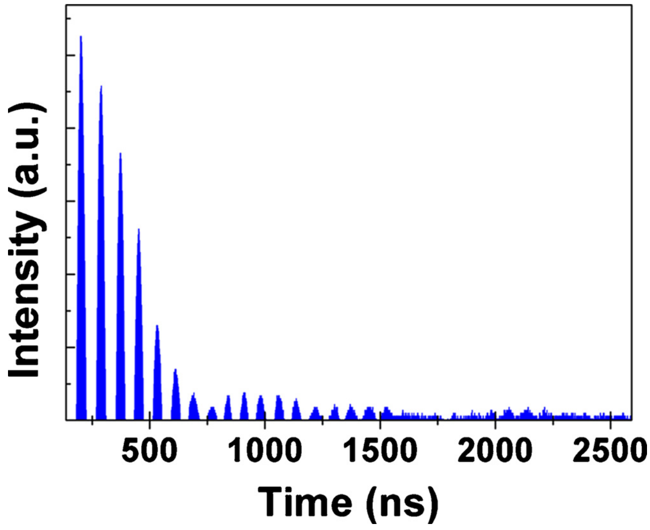

FIG. 3. (Color online) Temporal response of the $Mg_{0.55}Zn_{0.45}O$ solar-blind UV detector.

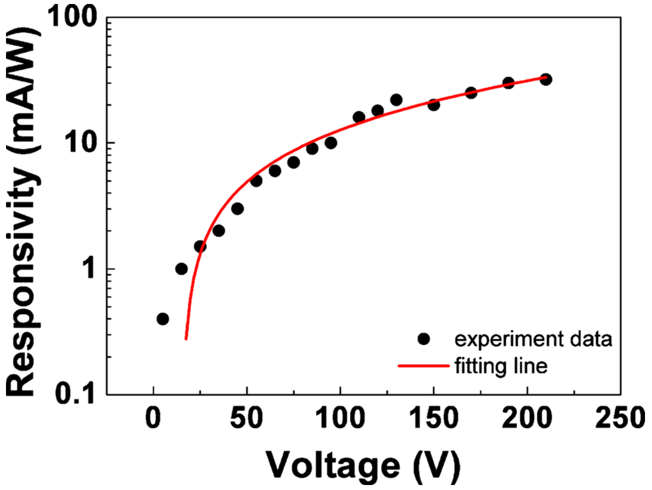

FIG. 4. (Color online) Dependence of the maximum responsivity on the external bias. Note the black circles indicate the experimental data, while the line is the fitting curve.

The peak responsivity at 260 nm increases exponentially with applied bias from 0.4 mA/W at 15 V to 32 mA/W at 210 V, as shown in Fig. 4 (the black circles), corresponding to an increase in EQE from 0.19% to 15.26%, which indicates a large internal gain. Such gain cannot be generated by the photoconductive gain mechanism, for the latter follows a linear relation.[15] Until now, we only found one paper regarding the internal gain in MgZnO UV detectors.[16] Their maximum Mg fraction is 18%, and the SBH should be much lower than our $Ti/Au-Mg_{0.55}Zn_{0.45}O$ Schottky junction. However, the transport behavior of conducting carriers depends a lot on SBH, and the large SBH in wide band gap semiconductor device decides the optoelectronic properties.

To explain the gain mechanism in our MgZnO solar-blind UV photodetector, a reduced-SBH model was adopted.[13,17] Here the remnant photocarriers lower the built-in potential and thus the Schottky barrier, which allows the electrodes to emit more electrons, leading to a large internal gain. The SBH reduction, $\Delta\Phi_b$, can be inferred from the rejection ratio, $R/R_{dark}\approx\exp[(\Delta\Phi_b/kT)]-1$. Since R/R_{dark} is more than two orders of magnitude, $\Delta\Phi_b$ is more than 119 meV. It can be seen that the SBH decreased greatly from its initial value of 0.80 eV, yielding a large gain. By this model, the theoretical plot fits the experimental data well, as shown in Fig. 4.

In conclusion, MSM solar-blind UV detectors were fabricated on high quality W-$Mg_{0.55}Zn_{0.45}O$ films. The devices can bear high voltage with a low leakage current. The maximum photoresponsivity is 22 mA/W under 130 V, with a cutoff at 270 nm. The detector shows a fast response—less than 500 ns—and a good rejection ratio of solar-blind UV to visible light of more than two orders of magnitude. Great internal gain was observed and explained by a reduced-SBH model, which was considered applicable to gain mechanisms in Schottky type MgZnO photodetectors.

This work was supported by the National Science Foundation (Grant Nos. 61076007, 50532090, and 60606023), the Ministry of Science and Technology of China (Grant Nos. 2007CB936203, 2009CB929400, 2009AA033101, and 2011CB302002), and the Chinese Academy of Sciences.

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