High-performance near-ultraviolet avalanche photodetectors based on ZnSe

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***Abstract*—This We report on high-responsivity, fast near-ultraviolet avalanche photodetectors based on bulk ZnSe employing a metal-semiconductor-metal structure. A very high responsivity of 2.42 A/W and 4.44 A/W at 20 V bias voltage for light with a wavelength of 325 nm was obtained for photodetectors without and with interdigital contacts, which indicates an internal gain. The mechanism of internal gain is attributed to the avalanche effect in ZnSe under high internal electric field. Also a low dark current of ~ 3.4 nA and high detectivity of ~ 1.4×10^{11} cm $Hz^{1/2}$ W^{-1} at a voltage of 20 V was achieved for the device with interdigital contacts at room temperature.**

***Index Terms*—Zinc selenide, ultraviolet photodetectors, avalanche effect.**

I. Introduction

Ultraviolet (UV) photodetectors have a wide range of applications in medicine, biology, space and telecommunication, including ozone layer monitoring, high temperature flame detection and personal UV exposure dosimetry [1, 2]. Most commercial UV-photodetectors are based on Si or GaAs semiconductors, which require a filter to eliminate visible and infrared light. Moreover, the intense UV radiation induces aging effects in Si-based photodetectors, which leads to their degradation. Wide-bandgap semiconductors such as ZnSe are attractive semiconductor materials due to their large bandgap energy (2.67 eV at 300 K [3]), high electric field strength of breakdown (~ 1 MV/cm [4]), as well as high resistance to intense UV and X-ray radiation. The UV photodetectors are usually based on the Schottky diode, p-i-n photodiode, or metal-semiconductor-metal (MSM) structures. The UV photodetectors with MSM structures feature a very low capacitance in the fF-range, and thus could operate at high frequencies. Moreover, due to their structure MSM photodetectors have a high resistivity, and a high bias voltage can be applied. This opens up the possibility to enhance the responsivity of photodetectors using internal gain mechanisms employing the avalanche effect. ZnSe-based UV-photodetectors reported up to now are based on an epitaxial ZnSe active layer grown on a GaAs substrate by molecular beam epitaxy or metallo-organic chemical vapor deposition techniques. At intense UV radiation this thin epitaxial ZnSe layer could be damaged. Therefore, bulk ZnSe is a more suitable material for the fabrication of photodetectors for intense UV radiation. In this paper we report on the characterization of fast near-UV MSM photodetectors based on bulk ZnSe with and without interdigital contacts, which have a high responsivity caused by the mechanism of internal multiplication of carriers due to the avalanche effect. It is established that both types of MSM photodetectors with and without interdigital contacts show improved performance compared to those reported in the literature.

II. Experimental

High resistivity (10^{10} – 10^{12} Ω cm) ZnSe crystals with monocrystalline blocks of several millimeters and grown by the vapour phase method were used as active layer of UV photodetectors. The Schottky contacts were fabricated by thermally evaporating 25 nm Cr followed by 140 nm Au, and performing standard photolithographic and lift-off processes. A 500 nm dielectric Si_xN_y passivation layer was placed above the metallic structure in order to prevent electric breakdown under applied high bias voltage to the samples [5]. Two types of UV photodetectors were fabricated as shown in Fig. 1: with interdigital contacts (Fig. 1(a)) and without interdigital contacts (Fig. 1(b)). For both types of photodetectors the active area is 10 μm × 10.5 μm. The UV MSM photodetector with interdigital contacts consists of 6 pairs of 0.5 μm wide metallic finger contacts with a distance of 1.5 μm between fingers as shown in Fig. 1(a). The current-voltage characteristics of fabricated photodetectors in the dark and under UV illumination were measured using a Keithley 2612 multimeter. The applied bias voltage was varied from 0 V to 20 V. The photocurrent was excited by a 325-nm Cd-He laser with output optical power of 56.5 mW and beam spot diameter of 1.56 mm. For the measurements of time-dependent characteristics of the photocurrent, the UV laser light was modulated by a chopper with a frequency range of 20 Hz – 1 kHz. The relaxation characteristics of the photocurrent were measured by a Tektronix TDS 210 oscilloscope.

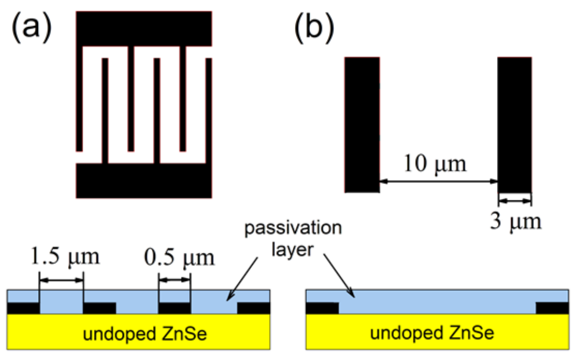

Fig. 1. Schematic structure of ZnSe-based metal-semiconductor-metal UV photodetectors: (a) photodetector with interdigital contact, (b) photodetector without interdigital contacts.

III. Results and Discussion

The current-voltage (I-V) characteristics of the two ZnSe-based MSM UV photodetectors (with and without interdigital contacts) in the dark and under illumination of UV light are shown in Figs. 2(a) and 2(b). It can be seen that for both samples the dark current practically linearly increased with increasing bias voltage. Maximum values of dark current are equal to 3.4 nA and 1.1 nA at bias of 20 V for photodetectors with and without interdigital contacts, respectively. Under UV illumination the behaviour of I-V characteristics showed significant changes and became non-linear: at first, the photocurrent increased almost linearly with applied voltage for U < 8 V, and significantly increased when the applied voltage is > 10 V, which is caused by the avalanche effect. The sensitivity of the investigated photodetectors, defined as ratio of photocurrent to the dark current, is linearly increased with increasing voltage for both types of UV photodetectors and achieved a maximum value at 20 V, which is equal to 4810 and 7900 for photodetectors with and without interdigital contacts, respectively. These peak values of sensitivity are more than 1-2 orders of magnitude higher than the values of sensitivity reported earlier for UV-photodetectors based on bulk ZnSe and ZnSe-, and ZnSe/ZnO-based nanostructures [1, 2, 6, 7]. From the I-V characteristics the Schottky barrier height was estimated to be 1.26 eV for our devices. This value is close to the half bandgap energy of ZnSe, which is the optimal condition for obtaining the lowest dark current and better performance of Schottky diodes [2].

The responsivity of fabricated photodetectors was measured under applied voltage from 0 V to 20 V and is presented in Fig. 3(a). The behaviour of responsivity dependences has a similar character to the photocurrent dependences of respective photodetectors (Figs. 1(a) and 1(b)). At voltages < 8 V the responsivity increases linearly with increasing applied bias voltage, and increases exponentially at voltages > 10 V. A maximum value of responsivity of 4.44 A/W and 2.42 A/W at a bias of 20 V for light with a wavelength of 325 nm is found for the photodetectors with and without interdigital contacts, respectively. These values are significantly higher than the maximum value of 0.13 A/W at 450 nm reported by Vigue et al. [2] for different types of ZnSe-based photodetectors. Taking into account the experimentally-obtained External Quantum Efficiency (EQE) for a ZnSe MSM photodetector at 450 nm of 35 % [2], we have estimated the maximum internal gain of photocurrent to be equal to 50 for a photodetector with interdigital contacts. The internal gain effect is attributed to the avalanche effect in ZnSe due to the high electric field strength.

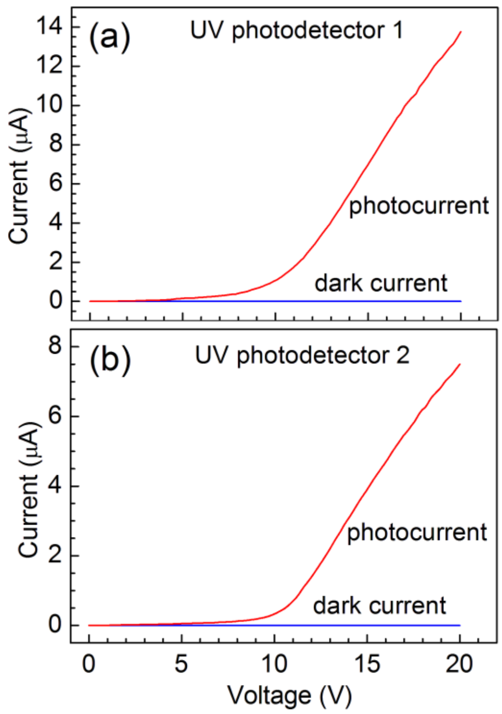

Fig. 2. Schematic structure of ZnSe-based metal-semiconductor-metal UV photodetectors: (a) photodetector with interdigital contact, (b) photodetector without interdigital contacts.

The detectivity dependences of the UV photodetectors were calculated from I-V characteristics and are shown in Fig. 3(b). This dependence of detectivity vs. applied bias voltage practically repeats the behavior of responsivity curves shown in Fig. 3(a): the detectivity is linearly increased with increasing bias voltages up to 8 V, and then significantly exponentially increased when applied voltage is > 10 V with tendency to saturation at voltages > 18V. A maximum value of detectivity of ~ 1.4 × 10^{11} cm $Hz^{1/2}$ W^{-1} at 20 V was obtained for a photodetector with interdigital contacts. This value is comparable with detectivity values for ZnSe-based UV photodetectors reported earlier [1, 2, 6, 7].

From the time-dependent characteristics of the photocurrent the response times were estimated to be 0.13 ms and 0.15 ms for UV photodetectors with and without interdigital contacts, respectively. These values are about 2-4 orders of magnitude lower than reported response times for photodetectors based on bulk and nano-ZnSe or ZnO/ZnSe nanowires [1, 2, 6, 7].

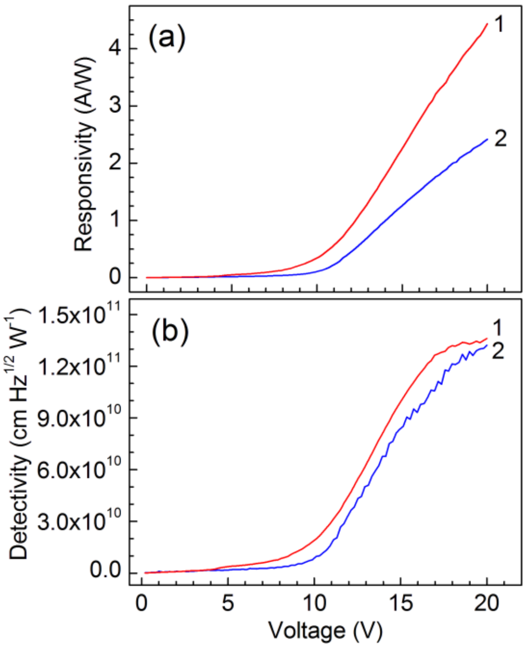

Fig. 3. Responsivity (a) and detectivity (b) of ZnSe-based MSM UV photodetectors as function of applied bias voltage. Curves: 1 – photodetector with interdigital contacts, 2 – photodetector without interdigital contacts.

IV. Conclusion

Near-UV avalanche photodetectors based on bulk ZnSe with and without interdigital contacts have been fabricated and investigated. Low values of dark current of 1.1 nA and 3.4 nA at 20 V were achieved for photodetectors without and with interdigital contacts, respectively, which indicates the high quality of Cr/Au Schottky contacts. A very high responsivity of 4.44 A/W and high sensitivity of 4810 at 20 V for light with a wavelength of 325 nm was obtained for A MSM UV photodetector with interdigital contacts, which indicates high internal gain of 50. The mechanism of internal gain is attributed to the avalanche effect in ZnSe under high internal electric field strength. The measured response times of UV photodetectors is in the microseconds range and is limited by the *RC* time of the measurement system.

Acknowledgment

V.P.S. gratefully acknowledges financial support from the Alexander von Humboldt Foundation. N.D.N. and D.D.N. acknowledges financial support from the RM Grant 15.817.02.27F.

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