ZnSe-BASED SOLAR-BLIND ULTRAVIOLET PHOTODETECTORS WITH HYBRID Ag-NANOWIRE AND Ni/Au CONTACTS

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OUTLINE

- **Introduction / Motivation**
- **Experimental**
- **Results**
- **Conclusion**
- **Acknowledgements**

Motivation (1)

Ultraviolet Photodetectors have wide range of applications:

- Medicine and biology,
- space and telecommunication,
- ozone layer monitoring,
- high temperature flame detection,
- personal UV exposure dosimetry

Conventional UV photodetectors based on Si and GaAs have some disadvantages:

- They require a filter to eliminate visible and infrared light,
- the intense UV radiation induces aging effects in Si-based photodetectors which leads to their degradation.

Motivation (2)

Conventional **UV Photodetectors** usually based on the one of the following type of structures:

- Planar Schottky diode,
- Vertical Schottky diode,
- p-i-n photodiode,
- 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.

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.

Advantages of wide bandgap materials for fabrication of **UV photodetectors**:

ZnSe is attractive semiconductor materials due to their large bandgap energy (2.67 eV at 300 K), high electric field strength of breakdown (~ 1 MV/cm), as well as high resistance to intense UV and X-ray radiation.

We present the results of the characterization of fast **near-UV metal-semiconductor-metal (MSM) photodetectors** based on **bulk ZnSe** with **Cr/Au, Ni/Au,** and **hybrid Ag-nanowire** and **Ni/Au** contacts.

These devices have a high responsivity caused by the mechanism of internal multiplication of carriers due to the avalanche effect.

Experimental (1)

•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.

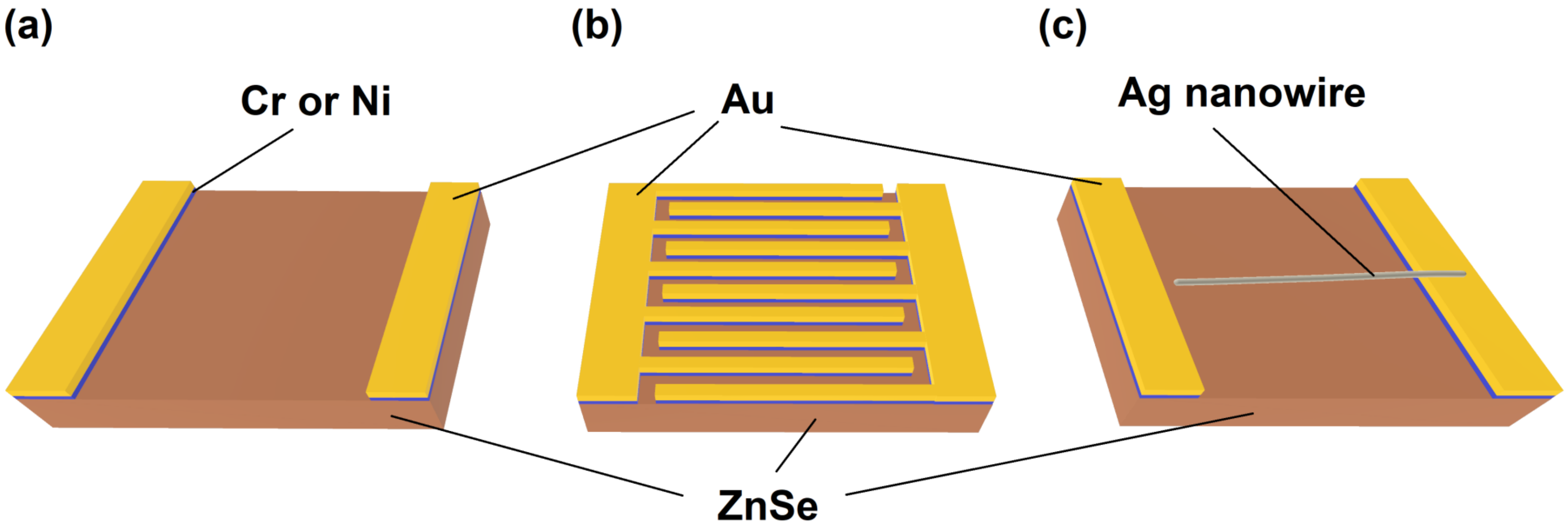


Fig. 1. Schematic structure of ZnSe-based metal-semiconductor-metal UV photodetector with different contacts design: (a) conventional contacts ; (b) interdigital contacts; (c) hybrid Ag-NW contacts

Experimental (2)

- The Schottky contacts were fabricated by by thermally evaporating of **25 nm Cr** (or **25 nm of Ni** by e-beam sputtering) 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.

- A simple spin coating method was used to distribute a commercially available Ag-NWs over the ZnSe substrate. The alignment of the Ag-NWs has been performed using dielectrophoresis method. The investigated photodetector had a nanowire diameter of 120 nm and a tip-tip gap of 1 μm.

- For all types of photodetectors the active area is **10 μm × 10.5 μm**.

Experimental (3)

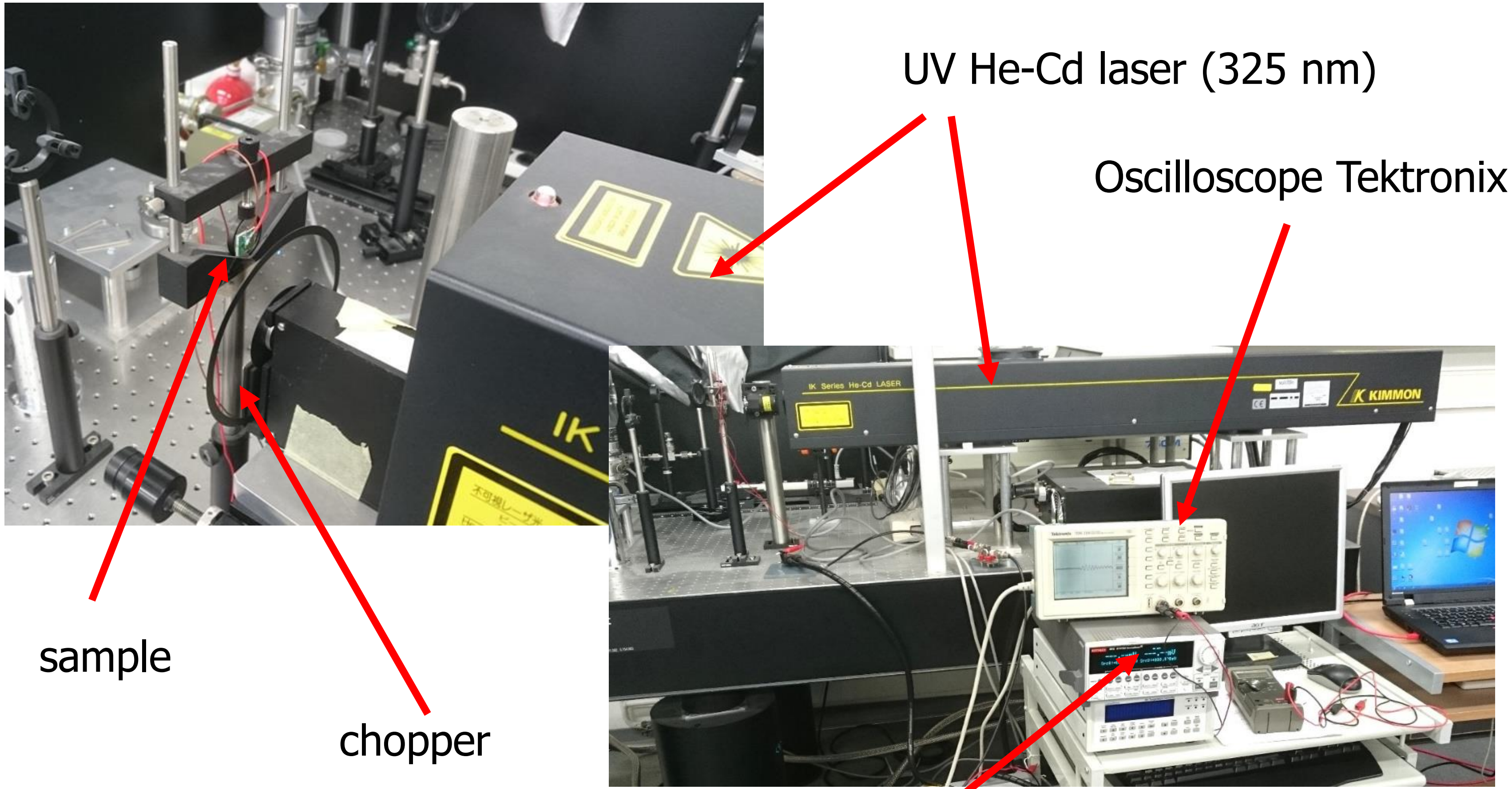
- The current-voltage characteristics of fabricated UV photodetectors in the dark and under UV illumination were measured using a Keithley 2612 multimeter. The applied bias voltage was varied from 0 V to 15 V.

- 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.

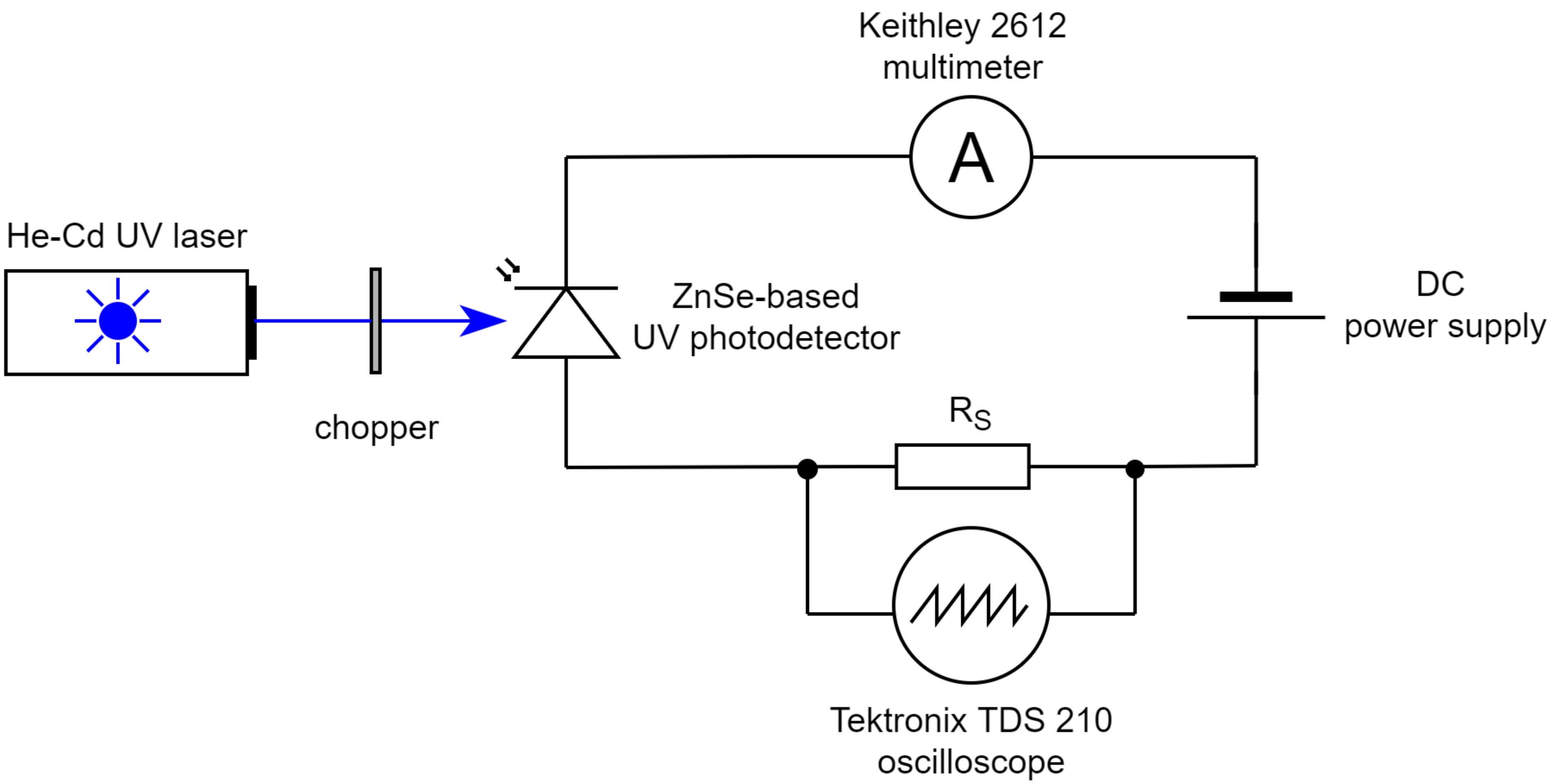
- For the measurements of time-dependent characteristics of the photocurrent, the UV laser light was modulated by chopper with a frequency range of 20 Hz-1kHz, a load resistance of 9.9 MΩ was connected in series with the fabricated ZnSe-based MSM UV photodetector and DC voltage source of 15 V.

- The relaxation curves of voltage from load resistance were measured by Tektronix TDS 210 oscilloscope.

Experimental (4) / Experimental setup



Experimental (5) / Experimental setup



Experimental (6)

The performance of the UV photodetectors was characterized by its responsivity *R*, normalized detectivity *D**, and noise equivalent power (NEP) which are defined as follows:

$$R = \frac{I_{photo} - I_{dark}}{P_{ill}}, \qquad D^* = \frac{R\sqrt{A}}{\sqrt{2eI_{dark}}}, \qquad NEP = \frac{\sqrt{2eI_{dark}}}{R}$$

where I_{photo} is the photocurrent of the photodetector under UV illumination, I_{dark} is the dark current, P_{ill} is the illumination power on the photodetector, *A* is the active area of the photodetector, and *e* is elementary charge.

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RAPID RESEARCH LETTER

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Ultraviolet Photodetectors
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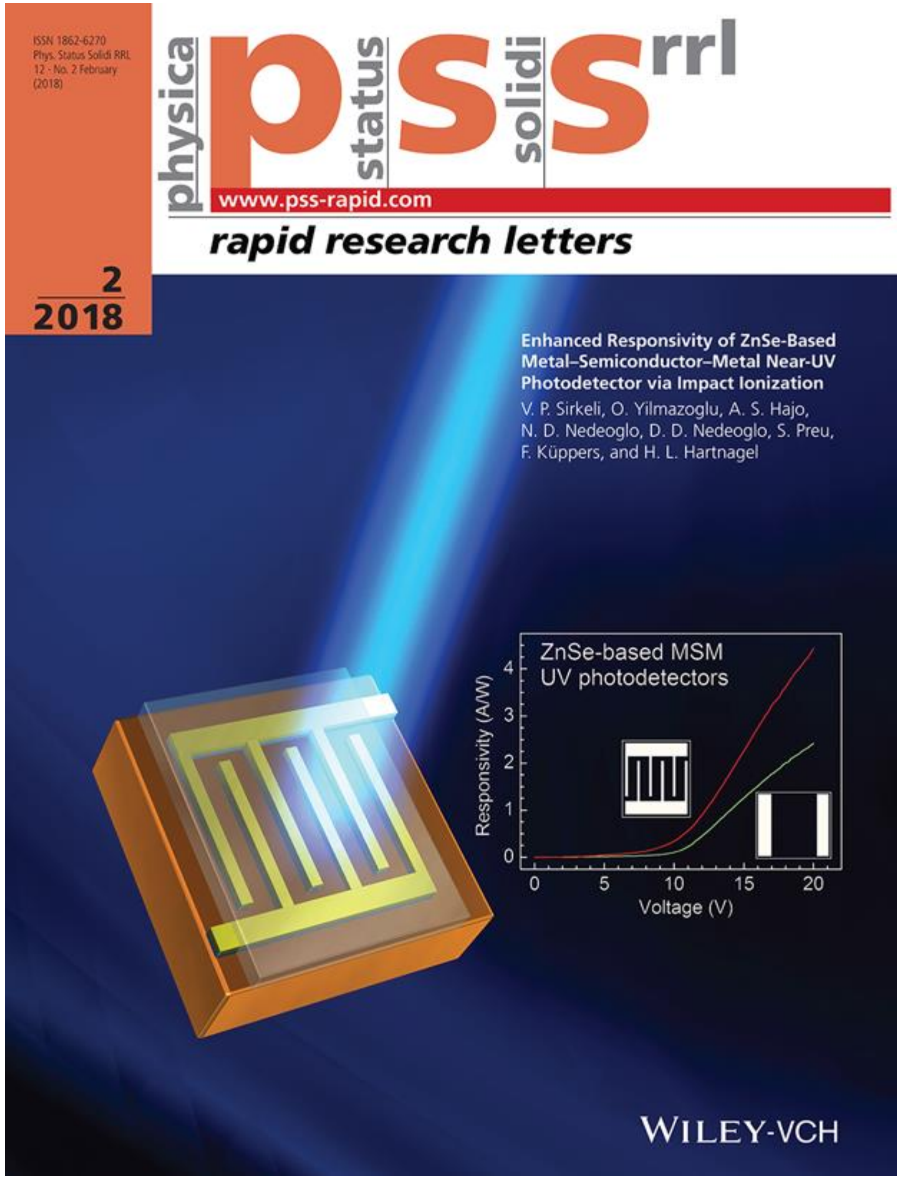
Enhanced Responsivity of ZnSe-Based Metal–Semiconductor–Metal Near-Ultraviolet Photodetector via Impact Ionization

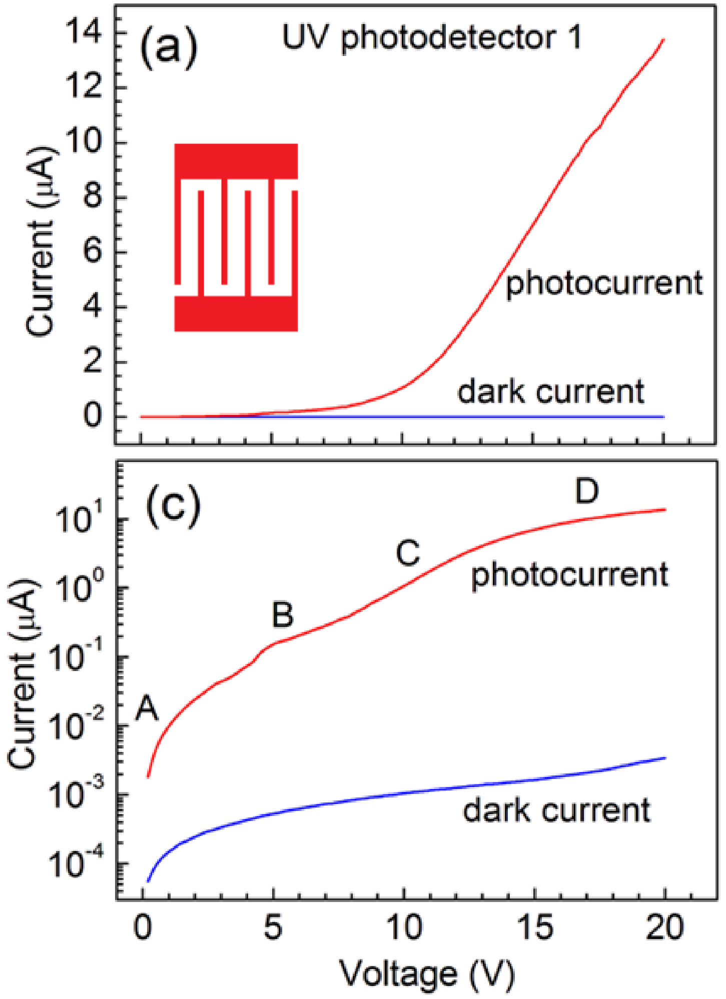
Vadim P. Sirkeli, Oktay Yilmazoglu, Ahid S. Hajo, Natalia D. Nedeoglo, Dmitrii D. Nedeoglo, Sascha Preu, Franko Küppers, and Hans L. Hartnagel*

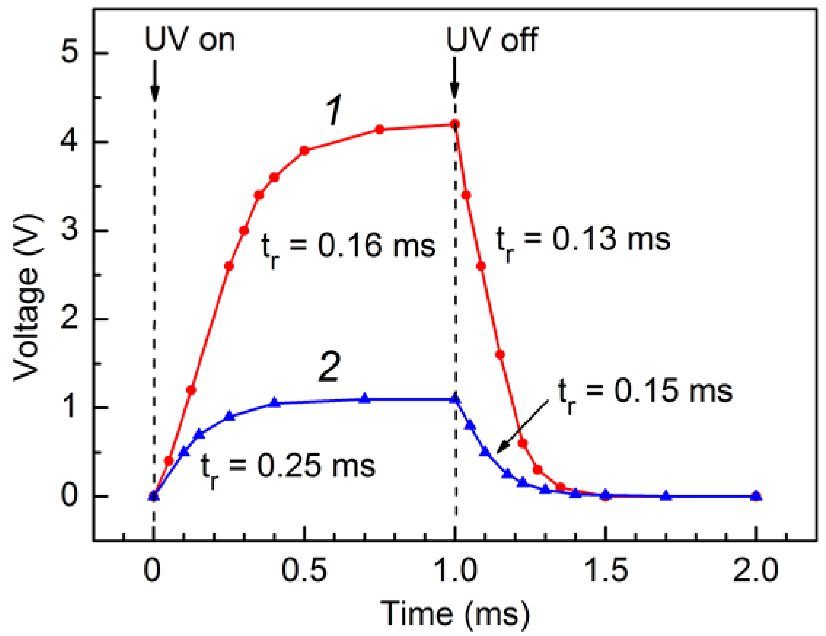
We report on high-responsivity, fast near-ultraviolet photodetectors based on bulk ZnSe employing a metal–semiconductor–metal structure with and without interdigital contacts. A very high responsivity of 2.42 and 4.44 A W^{-1} at 20 V bias voltage and high rejection rate of 7900 and 4810 for the light with a wavelength of 325 nm is obtained for photodetectors without and with interdigital contacts, which indicates an internal gain. The mechanism of internal gain is attributed to the impact ionization of ZnSe atoms under high internal electric field strength of 133 kV cm^{-1}. 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 is achieved for the device with interdigital contacts at room temperature.

energy (ZnSe: $E_g = 2.67$ eV at 300 K[3,4]), high electric field strength of breakdown (≈1 MV cm^{-1}[5]), as well as high resistance to intense UV and X-ray radiation. The UV detectors are usually based on the following structure types: planar Schottky diode, vertical Schottky diode, p–i–n photodiode, or metal–semiconductor–metal (MSM) photodiode. The last MSM structure is of special interest since it could be used for monolithical integration with field effect transistors. MSM UV photodetectors are unipolar devices with two back-to-back Schottky metal/semiconductor junctions



Results (2) / Performance characteristics of ZnSe-based MSM UV photodetectors with Cr/Au conv. and interdigital contacts





The response times are equal to 0.25 ms and 0.15 ms for a UV photodetector with conventional contacts, and are equal to 0.16 ms and 0.13 ms for a UV photodetector with interdigital contacts, respectively.

These values of response time are about 2-4 orders of magnitude lower than reported response times for photodetectors based on bulk and nano-ZnSe or ZnO/ZnSe nanowires.

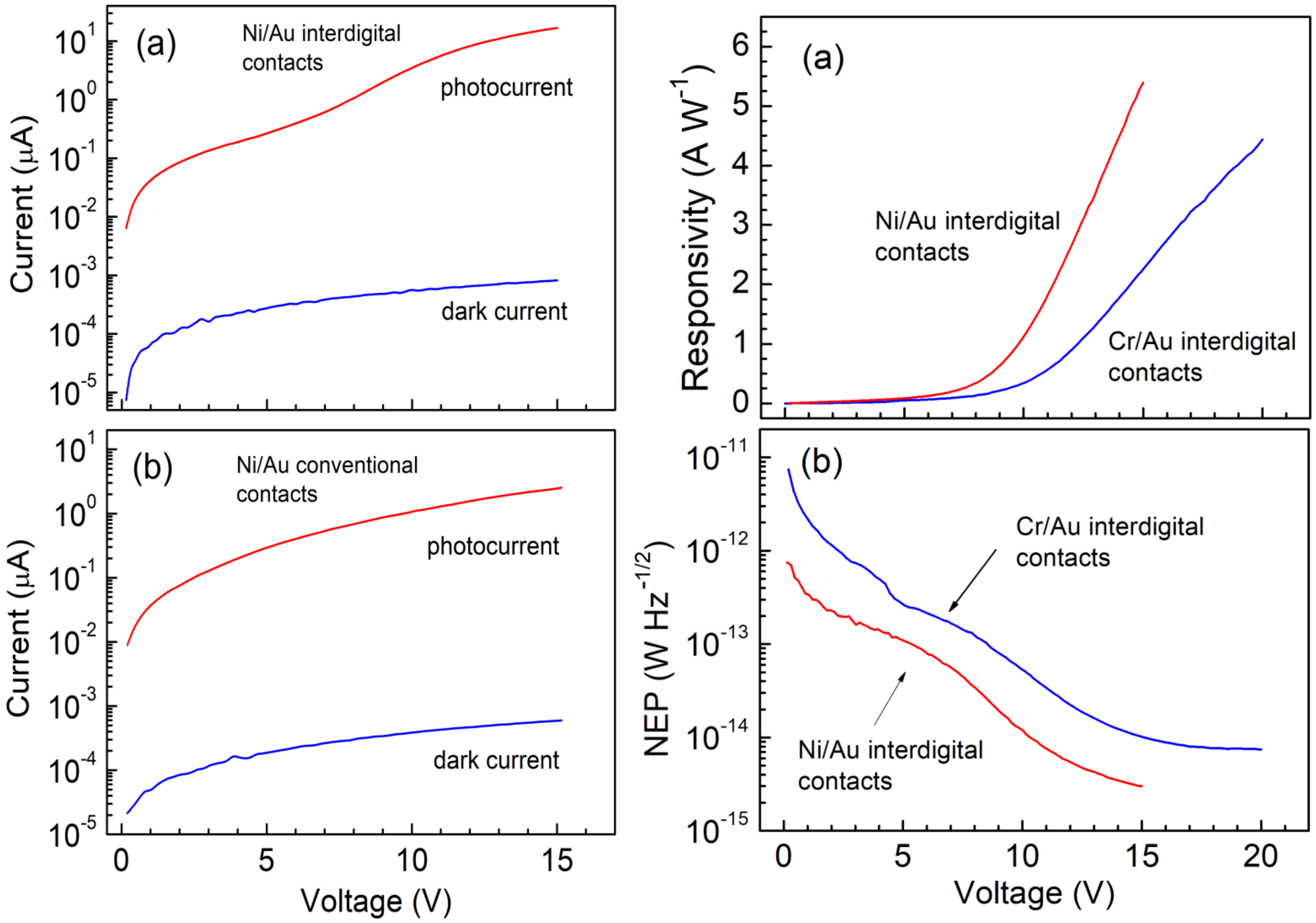
Avalanche effect

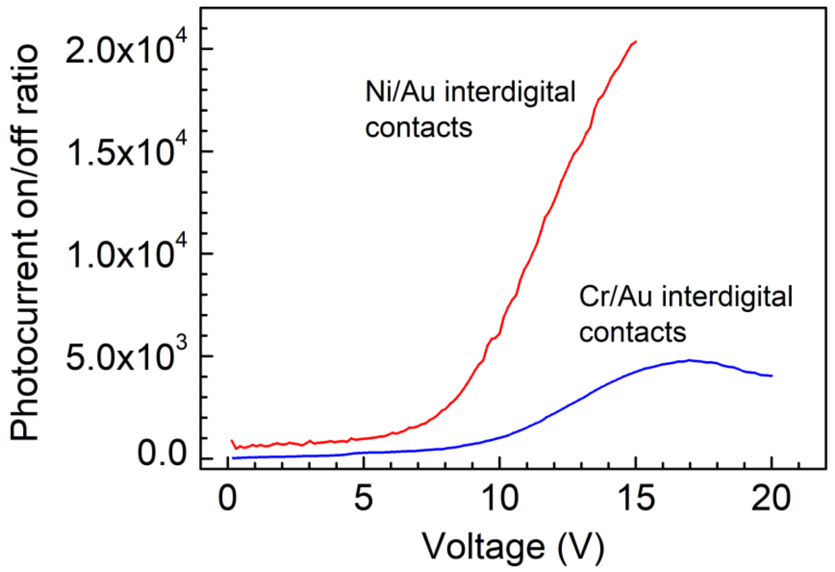
- When a voltage is applied to ZnSe-based MSM photodetector, one of the two back-to-back connected Schottky contacts is forward biased, while the other one is reverse biased. The internal electric field is concentrated in the depletion region of the reverse biased Schottky contact. When the applied bias voltage is increased, the internal electric field strength in the depletion region is also increased.

- The charge carriers, generated in the ZnSe active layer under illumination of UV light, are accelerated in the depletion region due to the high electric field strength, and their kinetic energy also increases.

- While travelling, these accelerated non-equilibrium photo-carriers will collide with ZnSe atoms and impart some of the kinetic energy to valence electrons. Due to this additionally acquired energy, these valence electrons will break their covalent-ionic bonds and jump into the conduction band to become free conduction. These newly generated free electrons will get accelerated. They will knock out some other valence electrons by means of collision. This phenomenon is called carrier multiplication or internal gain. This effect leads to the drastically non-linear increase of current with increasing applied voltage.

Results (4) / Performance characteristics of ZnSe-based MSM UV photodetectors with Ni/Au and Cr/Au interdigital contacts

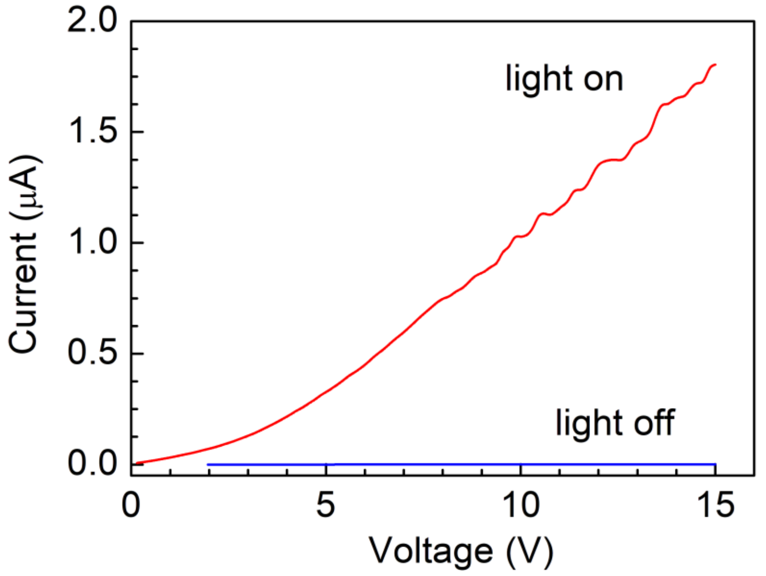


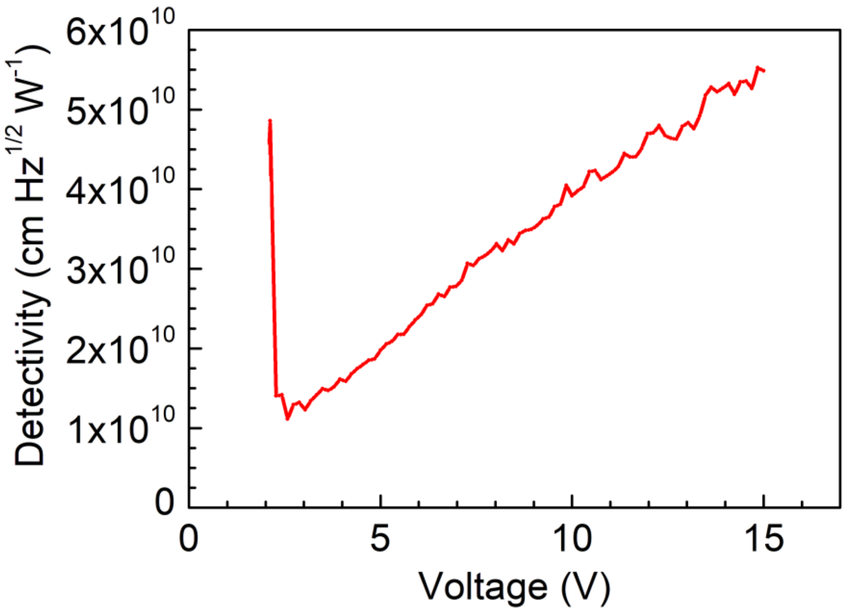


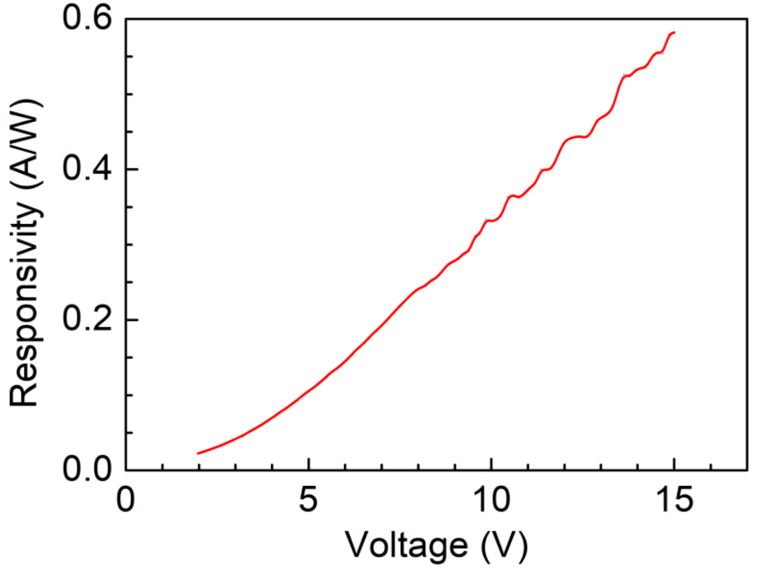
A maximum Responsivity of 5.40 A W^{-1} at 15 V and 1.64 A W^{-1} at 15 V is found for the ZnSe-based MSM UV photodetectors with Ni/Au and Cr/Au interdigital contacts, respectively.

A maximum photocurrent on/off ratio is 20342 at 15 V is found for UV detectors with Ni/Au interdigital contacts.

Results (5) / Performance characteristics of ZnSe-based MSM UV photodetectors with hybrid Ag-NW and Ni/Au contacts







When the bias voltage of 15 V is applied, the maximum dark current is equal to 0.36 nA.

Maximum value of responsivity of 0.58 A W^{-1} at bias voltage of 15 V for light with a wavelength of 325 nm is found for this device.

A maximum value of detectivity of ~ 5.49 × 10^{10} cm $Hz^{1/2}$ W^{-1} at 15 V was obtained for this device.

Results (6) / The characteristics of all fabricated ZnSe-based UV photodetectors with different contacts

Sample No.	Contacts type	Bias voltage of 15 V @ 325 nm			
		Dark current (nA)	Photocurrent on/off ratio	Responsivity (A W^{-1})	Detectivity 10^{10} (cm $Hz^{1/2}$ W^{-1})
#1	**Ni/Au interdigital**	0.82	**20342**	**5.40**	**33.7**
#2	Ni/Au conventional	0.59	4140	0.79	5.80
#3	Cr/Au interdigital	1.64	4219	2.23	9.86
#4	Cr/Au conventional	0.71	5418	1.25	8.35
#5	**Ag-NW – Ni/Au hybrid**	**0.36**	**5006**	**0.58**	**5.49**

Conclusion

- ZnSe-based MSM UV photodetectors with hybrid Ag-NW and Ni/Au contacts have been fabricated and investigated.
- Among all fabricated ZnSe-based photodetectors, the better one is the device with Ni/Au interdigital contacts due to the high Schottky barrier height (1.49 eV) of Ni-ZnSe.
- The device with hybrid Ag-NW contacts have the lowest value of dark current (0.36 nA) and have lowest capacitance due to the small footprint of the nanowire contact. This device with Ag-NW contact could be attractive for high-speed UV telecommunications and UV-Tomography applications.
- This device with hybrid Ag-NW contact at bias voltage of 15 V has a maximum photocurrent on/off ratio of 5006 and a maximum responsivity of 0.58 A W^{-1}, respectively. The measured response times of all fabricated UV photodetectors is in the μs-range and is limited by the *RC*-time of the measurement system.

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Thank you for your attention!