

Schottky structures *n*ZnSe(O,Te)/Ni as candidates for selective ultraviolet detectors

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Received October 30, 2007

Data on optical and electrophysical properties of photosensitive structures with Schottky barrier of *n*ZnSe(O,Te)/Ni type are presented. The photoreceivers of this type have current sensitivity S_λ = 0.1–0.15 A/W for λ = 420–440 nm, and at λ = 250–270 nm S_λ is 0.02 A/W; the threshold sensitivity is ~10^{-12} W·cm^{-1}·Hz$^{-1/2}$. For separation of various UV spectrum regions showing photobiological activity, light filters have been developed intended for use thereof in detecting devices.

Представлены данные по оптическим и электрофизическим свойствам фоточувствительных слоев с барьерами Шоттки *n*ZnSe(O,Te)/Ni и показаны перспективы их использования в качестве УФ фотоприемников. Фотоприемники такого типа имеют токовую чувствительность S_λ = 0.1–0.15 А/Вт для λ = 420–440 нм; для λ = 250–270 нм S_λ = 0.02 А/Вт; пороговая чувствительность ~10^{-12} Вт·см$^{-1}$·Гц$^{-1/2}$. Разработаны светофильтры для выделения различных фотобиологически активных областей УФ спектра, предназначенные для использования их в детектирующих устройствах.

The growing interest to the problem of UV radiation detection in various scientific, technological and social fields, such as medicine (physiotherapy, blood autotransfusion, protection from carcinogenic radiation, prevention of catarrhal respiratory diseases), monitoring of "ozone holes" formation above the Earth, synthesis of D_2 and D_3 vitamins, etc., stimulates the development of new semiconductor photoconverters (SPC) for the UV spectral region. Recently, the development of SPC mainly followed the way to create structures with a potential barrier. Those have high impedance and can function at high frequencies, are compatible with microchip technologies, have high efficiency, low weight and small size, are insensitive to magnetic fields, show the ability for charge accumulation and to integration of the detection signal. Of a special interest for the UV range are Schottky diodes, since the absorbing region of short-wave radiation is located close to semiconductor surface, in the space charge layer, where a strong electric field is present and, consequently, surface recombination does not substantially affect the photoconversion process [1].

Recent studies have shown that doped crystals ZnSe(X), where X = Te, O, can be effectively used as components of "semiconductor-metal" UV photosensitive structures with a Schottky barrier [2, 3]. The Schottky barrier height for those structures is ~1.0–1.1 eV and is defined by the difference between the work function of the metal electrons Φ_m ~ 5.2 eV and the semiconductor electron affinity χ ~ 4.1 eV. However, as a rule, the Schottky structures obtained in practice are not ideal and contain an inter-

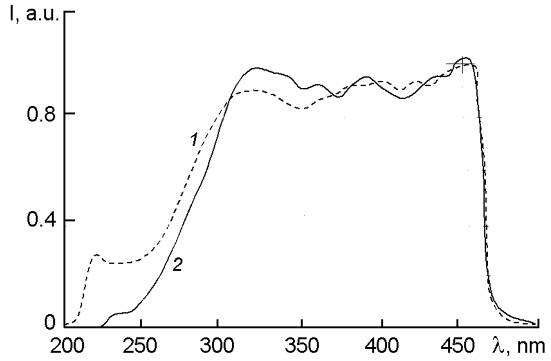

Fig. 1. Photosensitivity spectrum of nZnSe(O,Te)/Ni structures without (*1*) and with (*2*) additional quartz window.

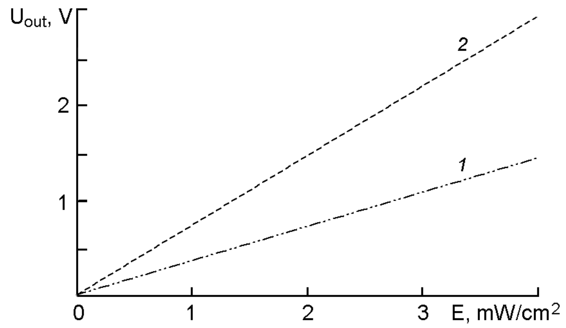

Fig. 2. Output signal of the nZnSe(O,Te)/Ni as a function of illuminance in 330–390 nm spectral range under irradiation: Hg lamp (*1*); natural solar illumination (*2*).

mediary dielectric layer. In this case, the barrier height would also depend upon the density of surface states in the semiconductor D_s, its dielectric constant ε_s, the dielectric layer thickness δ, etc.

This work was aimed at studies of principal peculiar features of nZnSe(O,Te)/Ni Schottky structures, as well as detectors on their base, including development of optical filters for separation of various biologically relevant regions in the UV spectrum.

For our studies, we have prepared samples of surface-barrier structures involving zinc selenide crystals activated with tellurium and oxygen (ZnSe(O,Te)) as semiconductor substrate, and nickel as the metal layer. The sample preparation procedure included the following main stages: preparation of crystals, including mechanical treatment of the surface and its chemical purification by etching; application of indium ohmic contacts by melting; application of a rectifying contact by vacuum deposition of a semi-transparent nickel layer of specified thickness (70–90 nm); preparation of the electric contact circuit; placing the obtained structure in an appropriate housing. The effective area of the photoreceivers was 0.16 cm^2. The sensitivity distribution was measured using an MDR-23 monochromator, DDS-30 hydrogen lamp and FEU-100 calibrated photoreceiver. A Keithley/SCS 4200 semiconductor analyzer with temperature-controlled box was used to measure the current-voltage characteristic at various temperatures. The experiments on sensitivity measurement of UV detector based on nZnSe(O,Te)/Ni structure as a function of the angle between the incident light beam and normal to the detector surface were carried out to test the influence of light scattering direction with respect to the detector surfaces (cosine factor).

In these structures, the predominant mechanism is formation of electron-hole pair followed by its separation by the space charge field, being realized at photon energy $h\nu > E_g$. Such process is more important as compared to generation of electrons in the metal with followed by transfer thereof to the semiconductor at energy $q\varphi_b < h\nu < E_g$. Therefore, the photosensitivity spectrum of such transitions is located in the energy range above the band gap width and is characterized by a sharp fall at $h\nu < E_g$ (Fig. 1). The total output signal as a function of illuminance is increased linearly, at least, up to the values of 4 mW/cm^2, both under artificial (Hg-lamp) and natural solar illumination (Fig. 2).

The current-voltage characteristic (IVC) for various samples can be different, thus suggesting a complex character of the build-up of Schottky barriers formed in such systems under real conditions. Fig. 3 demonstrates IVC for two types of real Schottky barriers. The differences in current-voltage characteristics in the region of transition between the direct and cut-off directions can be supposed to be related both with different carrier concentration in semiconductor substrates and with different defectness degrees of their surfaces that causes different mechanisms of dark current flow through the barrier.

Temperature dependences of photocurrent obtained at different bias voltages and different irradiation levels (Fig. 4) show that the obtained Schottky barriers have a good thermal stability, at least, in the +25 to +50°C temperature range. Only a slight increase in photocurrent with temperature

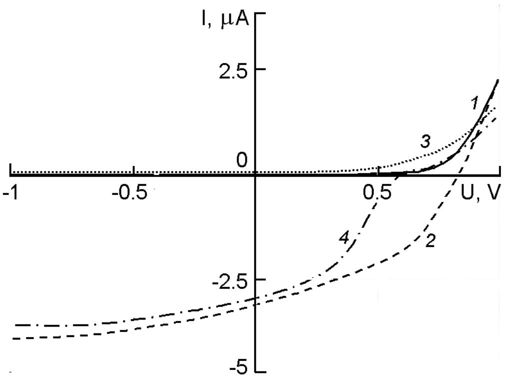

Fig. 3. Current-voltage characteristics of *n*ZnSe(O,Te)/Ni Schottky barriers: Type I without (*1*) and with (*2*) illumination; Type II without (*3*) and with (*4*) illumination.

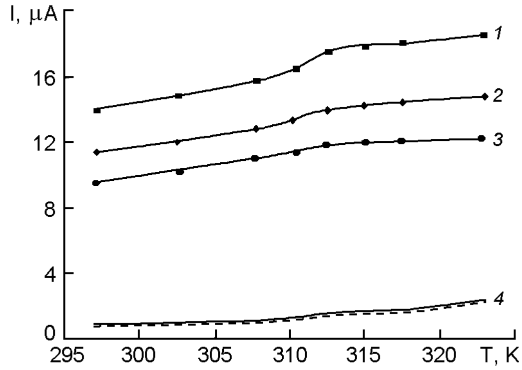

Fig. 4. Photocurrent as a function of temperature in *n*ZnSe(O,Te)/Ni structures at different bias voltages: for $U = -0.5$ V at various illumination levels (*1*–*3*); for $U = 0.5$ V (*4*).

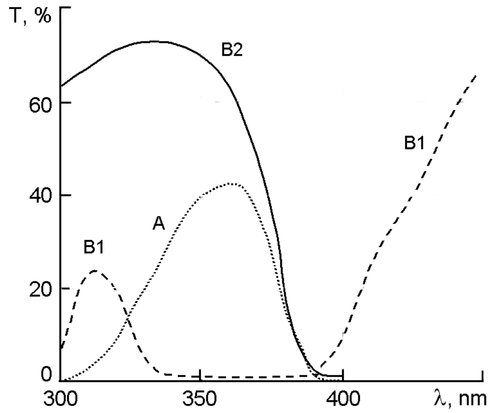

Fig. 5. Transmission spectra of glass filters: A — UFS-8 (d = 5 mm); B1 — ZhS-3 (d = 2.5 mm); B2 — UFS-2 (d = 2.5 mm).

was observed. Such behavior can be explained by fluctuations of the lower level of the conductivity band and the upper level of the valence band, which are related to imperfect structure layer close to the semiconductor surface. As a result, such fluctuations give rise to potential wells for photocarriers (traps). Without electric field, such fluctuations result in localization of one type carriers only, while the presence of electric fields may simultaneously create potential wells both for electrons and holes. The electrons and holes trapped in this manner are thus localized in space and can recombine with time due to the tunneling effect. At higher temperatures, the release probability of the trapped carriers increases due to thermal dissociation, thus increasing the photoconversion efficiency.

The photosensitive structures with Schottky barrier of *n*ZnSe(O,Te)/Ni type had current sensitivity S_λ = 0.1–0.15 A/W at λ = 420–440 nm; at 250–270 nm, it was about 0.02 A/W. Moreover, the results of previous studies [4] have evidenced a threshold sensitivity of about 10^{-12} W·cm^{-1}·Hz$^{-1/2}$ and dynamic range of the current-voltage characteristic not less than 40 dB. The photosensitivity spectrum of Schottky diodes based on zinc selenide covers all the biologically relevant UV ranges UV-A, UV-B, UV-C, remaining "blind" at $\lambda > 480$ nm, which simplifies considerably the development problem of UV filters. The absence of sensitivity in the long-wavelength spectral region offers the following advantages:

— selection of light filters is simplified substantially, because most filters, alongside with transmission in the UV range, are also transparent in the red spectral region, to which this photoreceiver is insensitive;

— it is possible to use interference light filters, because the second harmonics is out of the detector sensitivity range.

To develop UV detectors for various ranges on the basis of the above-described structures, light filters of two types have been developed: glass filters for UV-B and UV-A ranges, and interference filters for UV-C and UV-B ones. For the glass filters, we obtained spectral distribution of transmission corresponding to the UV-B range by using a combination of industrially produced color glasses of appropriate thickness: UFS-2 (2.5 mm) and ZhS-3 (2.5 mm). For preparation of UV-A filters, UFS-8 glass (5 mm thickness) was used (Fig. 5).

Another way to high quality filters for biologically relevant ranges of UV radiation is to make use of Fabry-Perot metal-dielectric-metal filters (MDM). This technology

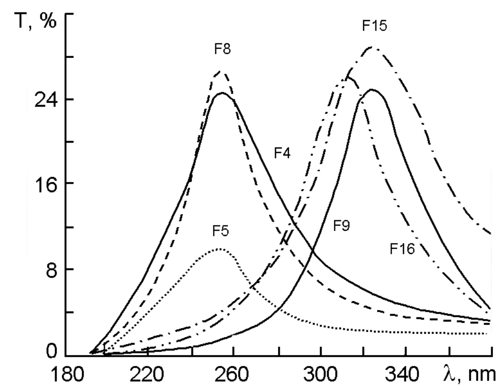

Fig. 6. Transmission spectra of experimental samples of interference filters for UV-B and UV-C ranges.

provides formation of filters for the UV-C range, which is impossible using conventional colored glass filters. A preliminary theoretical calculation of layer thickness and composition and appropriate choice of application procedures for metal and dielectric layers allowed us to create filters of various spectral compositions, including those corresponding to UV-B and UV-C spectral ranges (Fig. 6). The filters comprise: (a) quartz substrate; (b) first semitransparent reflecting layer; (c) non-absorbing dielectric layer; (d) second semi-transparent reflecting layer; and (e) second dielectric layer acting as both anti-reflecting and protecting one. The actually obtained parameters of such filters in the 220–350 nm range are: maximum transmission T_λ = 15–35 % at the corresponding width δ_λ before 50 nm.

To account for the "cosine factor", we have studied the output signal as a function of the angle between the incident beam and normal to the detector surface (Fig. 7). A substantial deviation from the output signal maximum value is observed when the incidence angle is increased, which should be accounted for in the development of instruments on the basis of these detectors. The

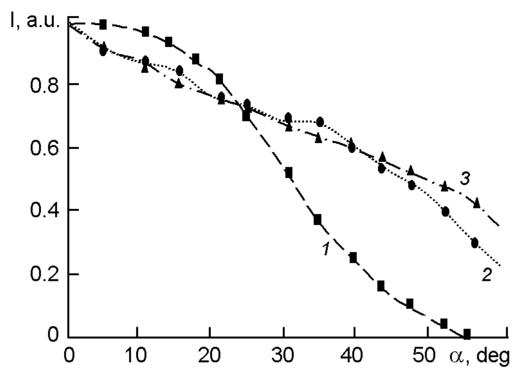

Fig. 7. Sensitivity of UV detector based on *n*ZnSe(O,Te)/Ni structure as function of α (the angle between the incident light beam and normal to the detector surface): without transparent Teflon film (*1*); with 1 mm thick Teflon film (*2*); with 0.4 mm thick Teflon film (*3*).

use of diffusely transmitting Teflon films weakens this dependence substantially. Selective photodetectors for UV-A, UV-B and UV-C ranges on the basis of *n*ZnSe(O,Te)/Ni structures can be used in various instruments for recording UV radiation intensity and power in the biologically relevant spectral ranges, as well as for reconstruction of solar radiation spectrum.

Acknowledgments. Authors are thankful to Prof.V.Ryzhikov who provided the samples as well as to Dr.W.G.Lee for help in measurements.

References

1. T.V.Blank, Yu.A.Goldberg, *Fiz. Tekhn. Poluprov.*, **37**, 1025 (2003).
2. V.P.Makhniy, V.V.Melnik, *Fiz. Tekhn. Poluprov.*, **29**, 1468 (1995).
3. B.Grynyov, V.Ryzhikov, Jong Kyung Kim, Moosung Jae, Scintillator Crystals, Radiation Detectors and Instruments on Their Base, Institute for Single Crystals, Kharkov (2004).
4. V.D.Ryzhikov, L.P.Gal'chinetskii, N.G.Starzhinskiy et al., *Telecommunications and Radio Engineering*, **55**, 84 (2001).

Структури Шотткі nZnSe(O,Te)/Ni та перспективи їх використання у якості селективних ультрафіолетових детекторів

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Представлено дані про оптичні та електрофізичні властивості фоточутливих шарів з бар'єрами Шотткі nZnSe(O,Te)/Ni і показано перспективи їх використання як УФ фотоприймачів. Фотоприймачі такого типу мають струмову чутливість S_λ = 0.1–0.15 А/Вт для λ = 420–440 нм, для λ = 250–270 нм S_λ = 0.02 А/Вт, а також порогову чутливість ~10^{-12} Вт·см$^{-1}$·Гц$^{-1/2}$. Розроблено світлофільтри для виділення різних фотобіологічно активних областей УФ випромінювання для використання їх у детектуючих пристроях.