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AMPLIFICATION OF PHOTOCONDUCTIVITY OF ZnSe/ZnO:O NANOHETEROSTRUCTURES AFTER REACTOR IRRADIATION

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Abstract. The possibility of radiation enhancing the photoconductivity of ZnSe/ZnO:O nanoheterostructures up to $10^{-6}$ Ohm$^{-1}$ with the formation of a photoconductor structure, concentration of photoelectrons up to $N_e=2.7 \times 10^{17}$ cm$^{-3}$ associated with the formation of resonance levels: $\Gamma_{6v}^{-5.76}$ eV, $L_{1,3v}^{-4.85}$ eV, $Zn_i^{-3.34}$ eV, $O_{Se}^{-3.13}$ eV and $X^{-2.72}$ eV, which is of interest for the manufacture of semiconductor scintillation and photo-detectors.

Keywords: nanoheterostructure, photovolt-ampere characteristic, photoconductivity, resonance level.

A photosensitive structure based on ZnSe single crystals, ZnO/ZnSe hetero-nanocoils, n-ZnO/p-ZnSe type II heterostructures have high photocatalytic activity and are used as photodetectors from 355 to 638 nm [1-3]. The previously performed X-ray diffraction analysis showed that the ZnSe/ZnO: O nanoheterostructure (NHS) has ZnO nanocrystalites up to 27 nm in size, and the photoconductivity $\sigma_{PC}=+0.71 \times 10^{-10}$ and $-0.56 \times 10^{-10}$ [2]. However, the effect of reactor radiation on the photoelectric and optical properties of NHS has not been studied.

The aim of the study is to study the photoelectric characteristics, determine the energy and population of the levels of the electronic structure from the optical absorption of ZnSe/ZnO:O NHS before and after reactor irradiation.

The object of the research is scintillator crystals heat-treated in an oxidizing environment ZnSe: O grown by the Bridgman method at the Research Institute of Monocrystals (Kharkov, Ukraine).

Research methods

Optical density spectra were measured on an SF-56A (LOMO) spectral instrument at $\lambda=190-1100$ nm. Table 1 shows the optical densities (D) at the maxima of absorption bands and transition energies. The concentration of optical centers N (cm$^{-3}$) responsible for the absorption band was calculated using the Smakula formula:

$$N = 1.28 \times 10^{17} \frac{n}{(n^2 + 2)^{1.5}} \cdot \frac{K_m H}{f};$$

(1)

where $n$ is the refractive index for the wavelength corresponding to the maximum of the absorption band, in the case of $E_g$ - the band for the ZnSe crystal $n = 2.6645$; $f$ is the oscillator strength for transitions involving the zone is equal to 1; $H$ is the half-width of the band, (eV); $K_m$ is
the absorption coefficient at the maximum of the band (cm$^{-1}$); $N_{e_g}$ is the concentration of electrons at the $E_g$ level.

Photo-volt-ampere characteristics - were measured by two contact method on standard devices. We studied the dependences of the dark and photocurrent (when illuminated by an incandescent lamp) on the applied external voltage, of both polarities at 300 K.

Table 2 shows the electro-optical characteristics of the NHS before and after irradiation. Photoconductivity was determined from the ratio, where $R_l$ and $R_d$ are resistance to light and dark (Ohm).

$$\sigma_{PC} = (R_d - R_l)/R_d R_l$$ (2)

NGS were irradiated in the core of the WWR-SM nuclear reactor (10 MV): by the flux of $\gamma$-radiation from the isotope $^{17}$O with energies up to 7 MeV in the thermal column with fluences $3.3 \times 10^{15}$, $6.6 \times 10^{16}$ and $3.3 \times 10^{17}$ cm$^{-2}$ and fast neutrons with the integral flux (fluences) $1.3 \times 10^{15}$ cm$^{-2}$ to $5 \times 10^{16}$ cm$^{-2}$. At these doses, the formation of electron-positron pairs, Compton electrons, and Frenkel pairs was expected, as well as the ordering of radiation defects from excited nuclei of uranium and O fission fragments with high energies up to 7 MeV and from fast neutron fluxes.

**Optical density:**

![Fig. 1. Spectra of OP NHS ZnSe / ZnO: O before (1) and after (2, 3, 4) reactor irradiation at the indicated fluences](image)

**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>before and after irradiation of $\gamma$-rays of the reactor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>3.3-10$^{15}$ cm$^{-2}$ 6.6-10$^{16}$ cm$^{-2}$ 3.3-10$^{17}$ cm$^{-2}$</td>
</tr>
<tr>
<td>$\Gamma_{6\nu}$</td>
<td>6.04 $\Theta V_{3,8 \nu} = 16 \times 10^{16}$ cm$^{-3}$</td>
</tr>
<tr>
<td>$M_{1\nu}$</td>
<td>5.16 $\Theta V_{3,8}$ $N_{M_{1\nu}}=9.6 \times 10^{16}$ cm$^{-3}$</td>
</tr>
<tr>
<td>$L_{1,3\nu}$</td>
<td>4.85 $\Theta V_{3,6}$ $N_{L_{1,3\nu}}=1.6 \times 10^{16}$ cm$^{-3}$</td>
</tr>
<tr>
<td>$Z_{2\nu}$</td>
<td>3.39 $\Theta V_{3,53}$ $N_{Z_{2\nu}}=0.79 \times 10^{16}$ cm$^{-3}$</td>
</tr>
<tr>
<td>$Z_{2\nu}$</td>
<td>3.39 $\Theta V_{3,53}$ $N_{Z_{2\nu}}=0.7 \times 10^{16}$ cm$^{-3}$</td>
</tr>
</tbody>
</table>
**Photoelectric properties:** In fig. 2 (A) and table 2 shows the electrophysical characteristics of the ZnSe/ZnO:O NHS in the dark and under illumination, where before the irradiation the NHS was linear, i.e. ohmic I - V characteristic with low $\sigma_{PC}$=+0.71·$10^{-10}$ Ohm$^{-1}$ and -0.56·$10^{-10}$ Ohm$^{-1}$. Irradiation in the thermal column of a nuclear reactor at fluences $3.3\cdot10^{15}$ cm$^{-2}$ (3, 4); $6.6\cdot10^{16}$ cm$^{-2}$ (5, 6); $3.3\cdot10^{17}$ cm$^{-2}$ (7, 8); (C) fast neutrons $1.3\cdot10^{15}$ cm$^{-2}$ (3, 4); $10^{16}$ cm$^{-2}$ (5, 6); $5.4\cdot10^{16}$ cm$^{-2}$ (7, 8) led to an increase in $\sigma_{PC}$ to $10^{-8}$ Ohm$^{-1}$ with the formation of the photosensitive of surface state density, which is associated with the formation of radiation defects.
Table 2

Dark ($\rho_T$) and light ($\rho_C$) resistivity, polarization (+ R/-R) and photoconductivity ($\sigma_{PC}$) NHS.

<table>
<thead>
<tr>
<th>Samples and types of exposures</th>
<th>$\rho_T$, $10^9$ Ohm·cm</th>
<th>$+R/$ $R$</th>
<th>$\rho_C$, $10^9$ Ohm·cm</th>
<th>$+R/$ $R$</th>
<th>$\sigma_{PC}$, $10^{10}$ Ohm$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unirradiated</td>
<td>+4.8; -5.5</td>
<td>0.87</td>
<td>+1.1; -1.35</td>
<td>0.81</td>
<td>+0.71; -0.56</td>
</tr>
<tr>
<td>$\gamma$-reactor flux</td>
<td>3.3·$10^{15}$ cm$^{-2}$</td>
<td>+4.5; -9.5</td>
<td>0.47</td>
<td>+0.63; -0.76</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>6.6·$10^{16}$ cm$^{-2}$</td>
<td>+13; -13</td>
<td>1</td>
<td>+0.2; -0.3</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>3.3·$10^{17}$ cm$^{-2}$</td>
<td>+1.1; -4.8</td>
<td>0.23</td>
<td>+0.037; -0.04</td>
<td>0.92</td>
</tr>
<tr>
<td>Fast neutrons</td>
<td>1.3·$10^{15}$</td>
<td>+0.32;</td>
<td>0.26</td>
<td>+0.0009;</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-1.2</td>
<td></td>
<td>-0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10$^{16}$</td>
<td>+15; -37</td>
<td>0.41</td>
<td>+0.12; 0.3</td>
<td>0.43</td>
</tr>
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<tr>
<td></td>
<td>5.4·$10^{16}$</td>
<td>+37; -38</td>
<td>0.98</td>
<td>+3.5; -4.3</td>
<td>0.81</td>
</tr>
</tbody>
</table>

In fig. 1. (A and B) and table. 1. shows the optical density spectra D of ZnSe/ZnO: O NHS before (curve 1) and after reactor irradiation (curves 2, 3, 4). All curves obtained are reproducible. It is seen that the maximum D at $E_g$=2.58 eV (480 nm) is D ($E_g$)=1.62. The calculation of the population per $E_g$ (or the concentration of photoconductivity electrons) by the Smakula formula (1) gives the value $N_{se}=1.26·10^{16}$ cm$^{-3}$. The gamma radiation of the reactor with a flow of $3.3·10^{15}$ cm$^{-2}$ led to the formation of radiation level $L_{1.3v}$ (255 nm) and $O_{Se}$ (395 nm), while $E_g$ decreased by 0.06 eV (curve 2 in Fig. 1. (A)), which corresponds to the binding energy of the ZnO exciton [1], where an increase in the flux to $6.6·10^{16}$ cm$^{-2}$ led to the destruction of the $O_{Se}$ reactor but formed the Zn$\text{ii}$ reactor (365 nm) (curve 3), a further increase in the flux to $3.3·10^{17}$ cm$^{-2}$ formed split $\Gamma_{6v}$-6.04 eV, $M_{4v}$-5.16 eV and narrow radiation level $-Zn_i$, while $O_{Se}$ was restored, $E_g$ increased by 0.02 eV and $N_e$ to $2.75·10^{17}$ cm$^{-3}$. Irradiation with fast neutrons of NHS ZnSe/ZnO: O at a fluence of $10^{15}$ cm$^{-2}$ (Fig. 1. B and Table 1) led to the formation of radiation level $L_{1.3v}$ and X-2.72 eV, an increase in $N_e=2.6·10^{16}$ cm$^{-3}$, where a decrease in $E_g$ by 0.06 eV (curve 2) was observed, and an increase in the fluence up to $10^{16}$ cm$^{-2}$ formed radiation level $\Gamma_{6v}$, and at a fluence of up to $5·10^{16}$ cm$^{-2}$ radiation level $L_{1.3v}$. Irradiation with fast neutrons with a fluence of $1.3·10^{15}$ cm$^{-2}$ led to the formation of RU $L_{1.3v}$ and X, a decrease in $E_g$ by 0.06 eV, an increase in $\sigma_{PC}$ to $10^6$ Ohm$^{-1}$, and a crooked photo-I–V characteristic of the photosemiconductor structure. An increase in the fluence to $10^{16}$ cm$^{-2}$ also led to an increase in $\sigma_{PC}$, but an increase in the blocking photo-semiconductor barrier of the photo-I-V characteristics was observed, where an increase in the fluence to $5.4·10^{16}$ cm$^{-2}$ led to the destruction of such properties.

Thus, it has been shown that reactor gamma irradiation of ZnSe/ZnO:O NHS led to the formation of radiation levels associated with the formation of photo-surface state density and an increase in $\sigma_{PC}$ to $10^6$ Ohm$^{-1}$; The observed decrease in light scattering by delocalized carriers in the region of 500-1100 nm is consistent with a significant increase in photoresistance, which is of practical interest for the manufacture of photodetectors and photodiodes.

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References

