PbS nanodots for electron radiation thin - film sensor

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Introduction. Damage of biological structures caused by ionizing radiation results from interaction of ionizing particles with DNA molecules. These molecules are scaled to nanodimensions, therefore, it is necessary to have a radiation detector of corresponding nano volume. This experimental work offers to use a thin-film dosimeter that consists of nanodots embedded in a solid thin-film matrix. The nanodots are supposed to be radiation-sensitive substance. The signal from the dosimeter can be read by measuring emission of low energy photo excited electrons (~ 1 eV) that have the mean free path of the order of several nanometers.

The target of the research was to examine changes in photoemission properties of the samples with lead sulphide (PbS) nanodots embedded in zirconia (ZrO_2) thin-film matrix under influence of electron radiation. PbS nanodots were chosen for their possible application as a radiation dosimeter because it has been reported that they have interesting optical absorption and emission properties [1]. Moreover, the research [2] done with ultraviolet radiation showed that PbS nanodots can provide useful dosimetric signal.

Samples. ZrO_2:PbS films were fabricated using sol-gel technique [3]. Samples with 10% and 20% concentration of PbS in ZrO_2 matrix were studied. All films were deposited on a glass substrate. Thickness of the films was in a range of 0.1-1 μm. Typical size of PbS nanodots was 2-4 nm. To verify the size of the nanodots, the atomic force microscope Solver P-47 PRO was employed.

Methods. The films were irradiated with 6 MeV electron beam generated by the electron accelerator CLINAC 2100CD. Dose rate was 3 Gy/min. Photoemission (PE) current of irradiated and nonirradiated films were recorded using homemade spectrometer. PE was excited by 4-6 eV photons provided by the deuterium lamp source (LOT-Oriel Europe). Inaccuracy of photon energy for photostimulation was ±0.015 eV in wavelength range 200 – 300 nm. This was estimated using linear dispersion of the factory made and calibrated monochromator that was known from the manufacturor data sheet. Emitted electrons were detected using secondary electron multiplier (VEU-6, Russia) in vacuum condition 10^5 torr. Electron scattering distance in the films was estimated by measuring surface electrical potential of the films using Kelvin mode of atomic force microscopy (AFM). The atomic force microscope Solver P-47 PRO was used.

Results and discussion. The derivatives of PE current at different doses of electron radiation for ZrO_2:PbS films with 10% and 20% concentration of PbS nanodots are shown in Fig. 1.

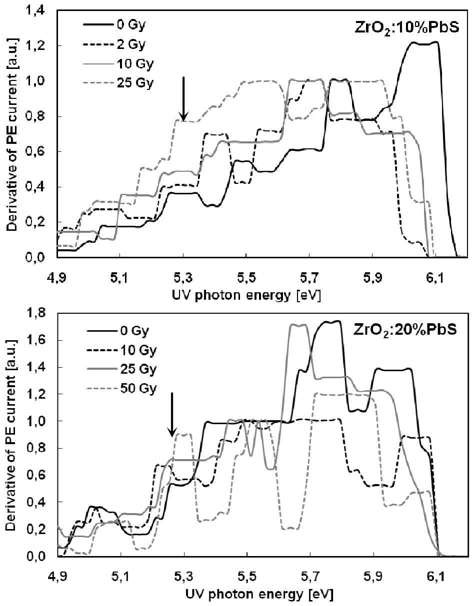

Fig. 1. Photoemission current derivatives for ZrO_2:10%PbS, ZrO_2:20%PbS films at different doses of electron radiation

The derivatives of PE current have peaks at 5.3 eV in case of both types of the films. Amplitude of the peaks increases with increase in radiation dose. Dependence of the amplitude on the dose of electron radiation is shown in Fig. 2. Linear correlation between the amplitude and the dose is observed for both concentrations of PbS nanodots, both cases having high R-squared (R^2) value (0.986 for ZrO_2:10%PbS and 0.968 for ZrO_2:20%PbS). The films with 20% concentration of PbS nanodots have slightly lower R^2 value.

Response of ZrO_2 matrix to electron radiation was studied as well. The peaks at 5.3 eV are not observed for the ZrO_2 matrix (not shown in the Figures).

The idea of the nano/micro dosimetry is that the signal measured has to be provided from a small area exposed to radiation. To estimate the smallest radiation sensitive area of the ZrO_2:PbS films, i.e., spatial resolution, electron scattering distance in the films was measured. One half of each film was covered with 2.3 mm thick aluminium plate. This resulted in additional electron scattering right and left to the border line between covered and exposed parts of the films. Electron scattering distance was estimated by scanning surface electrical potential of the films in the direction from the covered to the exposed parts perpendicularly to the border line. The film surface right and left to the border line had increased electrical potential in comparison to the rest surface of the films. Electron scattering distance was measured starting from the border line to the point in the exposed part of films where surface electrical potential dropped abruptly to its lower value. Scattering of electrons in the ZrO_2 matrix was studied as well. The results are presented in Fig. 3.

Estimated electron scattering distance is 0.6 mm in ZrO_2:10%PbS, 1.5 mm in ZrO_2:20%PbS, 0.4 mm in the ZrO_2 matrix. It was hypothesized that PbS nanodots result in stronger scattering of electrons.

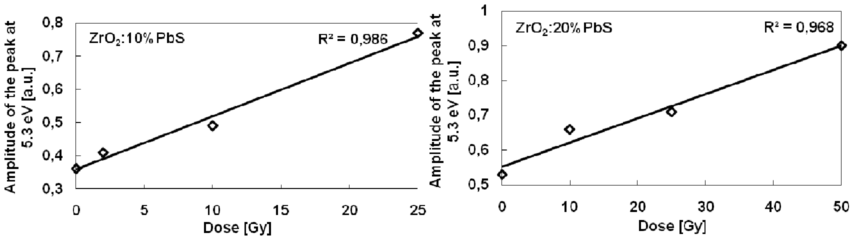

Fig. 2. Dependence of the amplitude of the peak at 5.3 eV on the dose of electron radiation for ZrO_2:10%PbS and ZrO_2:20%PbS films

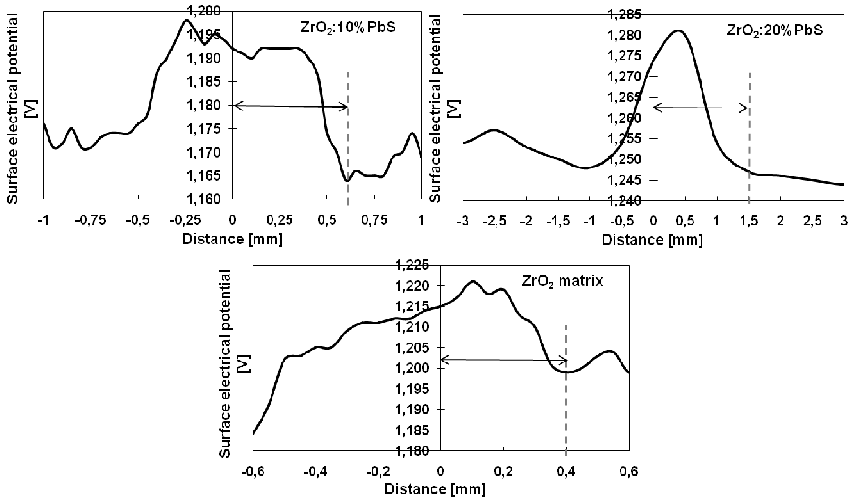

Fig. 3. Electron scattering distance on the border between exposed and non-exposed parts of ZrO_2:10%PbS, ZrO_2:20%PbS films, and ZrO_2 matrix. Zero X-coordinate shows the position of the border line. Negative distance corresponds to the non-exposed part of the films; positive distance corresponds to the exposed part of the films.

Conclusions. Electron radiation changes PE spectra of ZrO_2:PbS films resulting in peaks in derivatives of PE current. Amplitude of the peaks at 5.3 eV depends linearly on the dose of electron radiation.

Based on the estimation of electron scattering distance in ZrO_2: PbS films, the conclusion is made that increase in PbS concentration results in stronger electron scattering. This decreases the spatial resolution of the films, meaning that useful dosimetric signal comes from the bigger area of the film. This is undesirable for nano/micro dosimetric applications.

References

1. Reisfeld R. Nanosized semiconductor particles in glasses prepared by the sol-gel method: their optical properties and potential uses // Journal of Alloys and Compounds, Vol. 341, 2002. – P. 56–61.

2. Dekhtyar Yu., Romanova M., Anischenko A. et al. PbS nanodots for ultraviolet radiation dosimetry // IFMBE Proceedings. 15th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics (NBC 2011), Vol. 34, 2011. – P. 133–136.

3. Sashchiuk A, Lifshitz E, Reisfeld R et al. Optical and conductivity properties of PbS nanocrystals in amorphous zirconia sol-gel films // Journal of Sol-Gel Science and Technology, Vol. 24, 2002. – P. 31–38.

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The research studies influence of electron radiation on photoemission current of zirconia (ZrO_2) thin-films with embedded lead sulphide (PbS) nanodots. PbS nanodots are supposed to be radiation sensitive substance of the films. Linear dependence of amplitude of certain peaks in the derivatives of photoemission current on the dose of electron radiation was observed. Electron scattering distance in the films was measured in order to estimate spatial resolution of the films, i.e., the smallest surface area from which a plausible signal can be detected. It was observed that increase in concentration of PbS nanodots results in stronger scattering of electrons by the surface of the films. This is undesirable because spatial resolution of the thin-film sensor decreases.