# Photoelectron Emission as a Tool to Assess Dose of Electron Radiation Received by $ZrO_2$:PbS films

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***Abstract* — PbS nanodots embedded in $ZrO_2$ thin film matrix ($ZrO_2$:PbS films) were studied for application in nanodosimetry of electron radiation used in radiation therapy. $ZrO_2$:PbS films were irradiated with 9 MeV electron radiation with doses 3, 7 and 10 Gy using medical linear accelerator. Detection of the dosimetric signal was made by measuring and comparing photoelectron emission current from $ZrO_2$:PbS films before and after irradiation. It was found that electron radiation decreased intensity of photoemission current from the films. Derivatives of the photoemission spectra were calculated and maximums at photon energies 5.65 and 5.75 eV were observed. Amplitude of these maximums decreased after irradiation with electrons. Good linear correlation was found between the relative decrease of the intensity of these maximums and dose of electron radiation. Observed changes in photoemission spectra from $ZrO_2$:PbS films under influence of electron radiation suggested that the films may be considered to be effective material for electron radiation dosimetry. Photoelectron emission is a tool that allows to read the signal from such dosimeter.**

***Index Terms* — PbS nanodots, photoelectron emission, dosimetry, radiation therapy, thin films.**

## I. INTRODUCTION

Aim of radiation therapy is to deliver dose of ionizing radiation to the target tissue and to destroy cancer cells. Nanodosimetry is a cutting-edge technology which aim is to measure absorbed dose in nano volume of the irradiated substance. There are several reasons why the field of nanodosimetry is gaining more and more attention: (i) biological effects caused by radiation depend on dose absorbed by nanosized DNA units; (ii) there is a trend in radiation therapy to apply high dose gradients (Gy/(μm…nm)); it was found that survival of the cells depends on the gradient value [1]; (iii) nanoparticles as radiation scattering centers are expected to provide local micro-/nano- treatment that minimally influences risk organs/cells. However, there are still no detectors that measure radiation in nanovolumes [2]. To solve the problem, a nanosized detector is required; nanoobjects such as nanodots or nano thick films can be great candidates for implementation of such dosimeter [3-5]. However, in order to get reliable readout from the dosimeter, it must not be influenced by measurement process. Therefore, contactless technologies are preferable.

One of possible contactless technologies is emission of low energy electrons that escape from 10-100 nm deep solid surface layer [2]. One type of the emission of low energy electrons is prethreshold photoelectron emission (PE) stimulated by ~ 5 eV photons. Typically, PE current ($I$) depends on difference between photon energy ($h\nu$) and electron work function ($\varphi$) of the emitter in accordance with the parabolic law [6]:

$$I = A(h\nu - \varphi)^m \qquad (1)$$

where $A$ and $m$ are constants which describe density of electron states and electron transitions between states.

If work function $\varphi$ is altered by ionizing radiation, high response in change in emission current $I$ is provided.

The research demonstrates novel results on application of photoelectron emission for detection of dose of electron radiation used in radiation therapy.

## II. METHODS

$ZrO_2$:PbS films consisting of PbS nanoparticles embedded in $ZrO_2$ matrix were explored for purposes of nanodosimetry of electron radiation. PbS nanodots were supposed to be radiation-sensitive and electron emission active centers because they have emission and absorption lines in large spectral region [7–9]. Moreover, the research [10] on application of $ZrO_2$:PbS films for dosimetry of ultraviolet radiation demonstrated that it was PbS nanodots, not $ZrO_2$ matrix, that are sensitive to exposure with ultraviolet light.

$ZrO_2$:PbS films were fabricated by research group of R. Reisfeld using sol-gel technique with 20% concentration of PbS nanoparticles [9]. The films were deposited on a glass substrate. Thickness of the films was 0.1-1 μm. TEM measurements show that typical size of PbS nanodots in $ZrO_2$ matrix is 2-4 nm [9].

$ZrO_2$:PbS films were irradiated with 9 MeV electrons that supplied doses 3, 7 and 10 Gy using medical linear accelerator. PE current was recorded before ($I_0$) and after ($I_{Gy}$) irradiation. Photoemission was excited by 4-6 eV photons provided by deuterium lamp (LOT-Oriel Europe). Emitted electrons were detected using the secondary electron multiplier (VEU-6, Russia) in vacuum $10^{-5}$ Pa, a handmade spectrometer was used (inaccuracy of quantum energy measurement ±0.03 eV in wavelength

range 200 – 300 nm). Detection was made at room temperature.

## III. RESULTS AND DISCUSSION

Radiation decreased intensity of PE current from $ZrO_2$:PbS films ($I_0 > I_{Gy}$). Fig. 1 demonstrates relative increment ($\delta I$) of the current:

$$\delta I = (I_{Gy} - I_0)/I_0 \cdot 100\% \qquad (2)$$

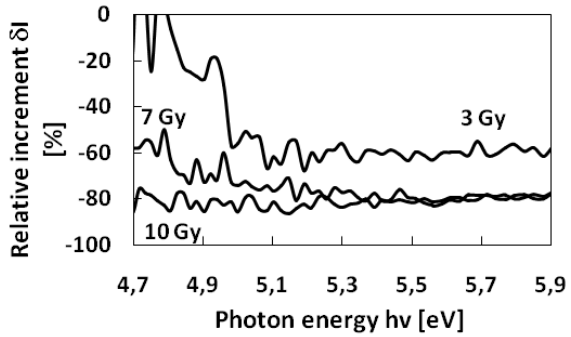
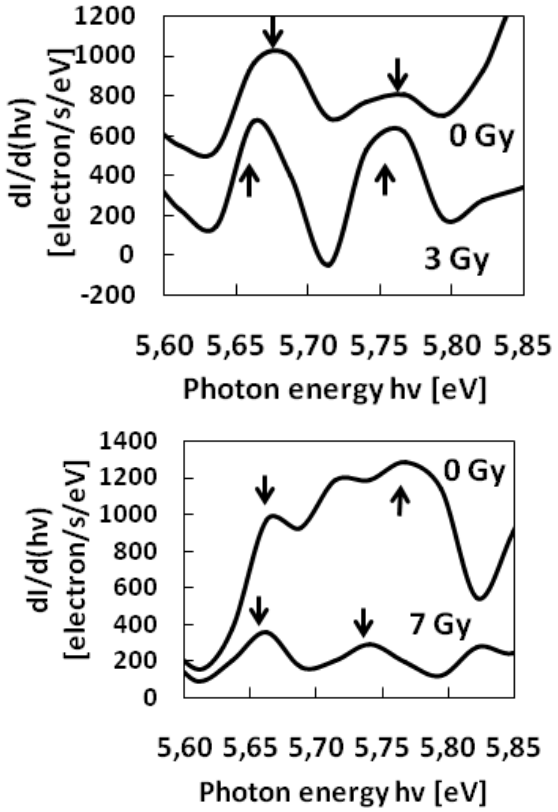



Fig. 1. Relative increment δI of PE current of $ZrO_2$:PbS films for different doses of electron radiation.

Fig. 1 indicates that radiation influences PE from $ZrO_2$:PbS films.



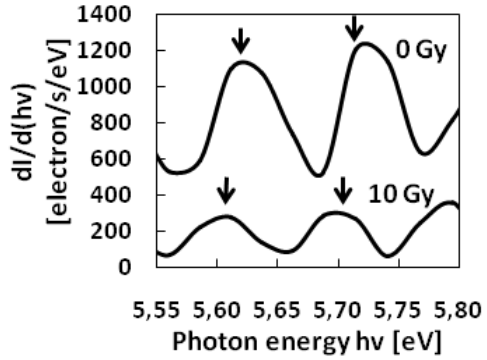




**Fig. 2**. Derivatives d$I$/d($h\nu$) of PE spectra of $ZrO_2$:PbS films for different doses of electron radiation.

To investigate dose-dependent peculiarities of the PE spectra, derivatives d$I$/d($h\nu$) of the PE current were calculated from the $I(h\nu)$ spectra (Fig. 2). Maximums of d$I$/d($h\nu$) were found at 5.65±0.03 eV and 5.75±0.03 eV (Fig. 2). Radiation decreased amplitudes of the maximums. This decrease could be due to loss of emission active centers under influence of radiation.

To verify contribution of PbS nanodots to PE, emission was measured from $ZrO_2$ film without PbS nanoparticles. In this case, the maximums observed above were not detected. This gave evidence that the analyzed maximums were provided by electron emission from PbS dots.

To estimate possibility to use $ZrO_2$:PbS films for dosimetry, relative increments $\Delta$(d$I$/d($h\nu$)) of the maximums at 5.65 and 5.75 eV were correlated to the dose:

$$\Delta\left(\frac{dI}{dh\nu}\right) = \frac{\left(\frac{dI}{dh\nu}\right)_{Gy} - \left(\frac{dI}{dh\nu}\right)_0}{\left(\frac{dI}{dh\nu}\right)_0} \cdot 100\% \qquad (3)$$

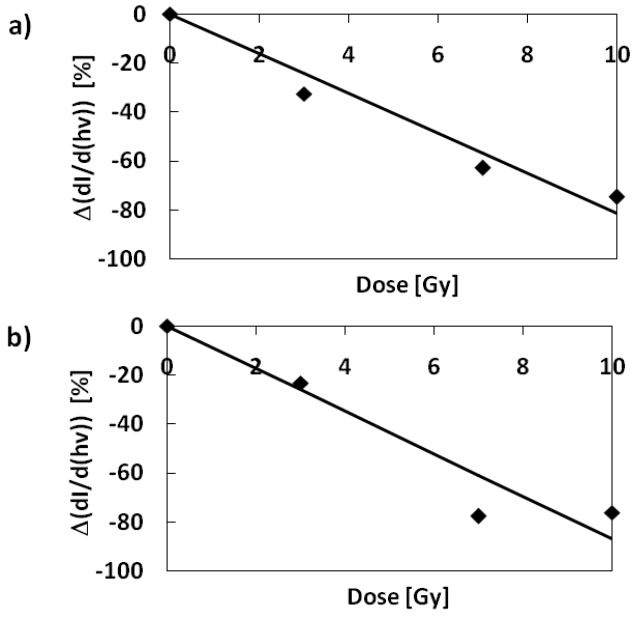



**Fig. 3**. Linear correlation between $\Delta$(d$I$/d($h\nu$)) and dose of electron radiation: (a) for the maximum at 5.65 eV; (b) for the maximum at 5.75 eV.

Fig. 3 demonstrates good linear correlation between the relative increments $\Delta(dI/d(h\nu))$ and dose of electron radiation.

## IV. CONCLUSIONS

The method of photoelectron emission has potential to detect the signal from $ZrO_2$:PbS nanodotted film for measuring dose of electron radiation employed in radiation therapy.

Intensity of photoemission current from $ZrO_2$:PbS films decreases after irradiation of the films with 9 MeV electrons. The maximums at 5.65 and 5.75 eV of PE spectra derivatives dI/d(hν) of $ZrO_2$:PbS films could be the tool for estimation of the dose. Good linear correlation was observed between the relative increments of the amplitude of these maximums and dose of electron radiation.

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