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A.V.Antipov, G.I.Britvich, V.G.Vasil'chenko,
A.A.Chumakov

**PRECISE DENSITOMETER
FOR THIN-FILM DOSIMETERS**

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Abstract

Antipov A.V. et al. Precise Densitometer for Thin-Film Dosimeters: IHEP Preprint 93-65. – Protvino, 1993. – p. 7, figs. 4, refs.: 8.

A precise densitometer for thin-film dosimeters has been developed in order to measure the radiation loading on the accelerator equipment in the dose range from 10^3 to $5 \cdot 10^5$ Gy. With help of this densitometer, the optical density $S = \ln(I_0/I)$ of thin-film based on $CO PD(F)-5/150$ was measured in the region of S from about 10^{-3} to 1.6. The accuracy was about 0.2% for $S = 1.6$. $CsI(Tl)$ scintillator was excited by alpha-particles from a ^{238}Pu radioactive source and used as the probing pulsed light-source. The apparatus and software used and the data processing were industry supplied equipment and quite identical to gamma spectrometry ones.

Аннотация

Антипов А.В. и др. Прецизионный денситометр для пленочных дозиметров: Препринт ИФВЭ 93-65. – Протвино, 1993. – 7 с., 4 рис., библиогр.: 8.

Для оценки радиационных нагрузок (от 10^3 до $5 \cdot 10^5$ Гр) на оборудование ускорителя с помощью пленочных (толщиной 70 микрон) дозиметров СО ПД(Ф)-5/150, разработан денситометр, измеряющий оптическую плотность $S = \lg(I_0/I)$ в диапазоне от $\sim 10^{-3}$ до 1.6, причем точность при $S = 1.6$ составляла около 0,2%. В качестве импульсного источника света использовался сцинтиллятор $CsI(Tl)$, возбуждаемый альфа-частицами от источника ^{238}Pu . Аппаратные и программные средства измерения и обработки идентичны применяемым в гамма-спектрометрии с использованием промышленных приборов.

The interest in the radiation hardness of the used materials has increased since modern accelerator beam intensities in high energy physics experimental setups became quite high and the radiation loads these materials enhanced [1,2]. We have chosen the CO PD(F)-5/150 trade mark thin-films for the radiation monitoring and dose release control in irradiated samples of materials. These samples were irradiated in gamma-quanta and product hadrons from the IHEP accelerator fields. The wide-band absorption of these coloured plastic films allowed us to use no spectrometric measurements and to work without the light source monochromatization during the densitometric measurements [5]. The measurement accuracy of the optical density $S = \lg(I_0/I)$ was totally determined by the light source, the photoreceiver and the measuring devices instabilities. The light emitting diodes (LEDs) are usually used as a light-source of modern densitometers. These LEDs require stabilized power supply and have temperature light yield instability of about -1%/K. This paper is devoted to a densitometer with alpha-particles excited luminescence of $CsI(Tl)$ scintillator as a light-source. The light yield instability of the scintillator depends only on the temperature of the environment (about +0.4%/K). The scintillator with the same light yield is a reference light-source to compensate for the whole measuring channel temperature instability.

The transmission spectra of the films before and after low energy gamma quanta irradiation from ^{137}Cs radioactive sources is shown in Fig.1. It is clear that the light-source should emit in the wave length region from ~ 480 to ~ 640 nm in order to get the best signal-to-noise ratio. The monocrystal of $CsI(Tl)$ scintillator under alpha-particle excitation has the maximum emission at about 560 nm (see Fig.1) [6]. It is quite suitable. Besides that there is the highest light yield of scintillation per one particle for the alpha excitation of the scintillator e.g., the energy release of a single 5481 KeV alpha-particle from ^{238}Pu radioactive source is equivalent to a 3759 KeV gamma-quanta [1]. The photopeak-to-total ratio for these high energy gamma-quanta detected by 1 cm^3

of $CsI(Tl)$ crystal is about $4 \cdot 10^{-2}$ only. The temperature dependence of the light yield for this material is about $+0.36\%/K$ at around $300^\circ K$ [8].

Figure 1. The transmission spectra of the thin film dosimeter. Curve 1 - before irradiation, curves 2-4 - after receiving the doses of 1.9, 6.2 and 12 Mrad, respectively, curve $CsJ(Tl)$ - the luminescent spectrum of the scintillator excited by α -particles [6].

Figure 2. The densitometer principle scheme: 1 - α -particle source (^{238}Pu); 2 - $CsI(Tl)$ scintillator; 3 - a thin-film under investigation having the size of $30 \times 12 \text{ mm}^2$ and thickness of about 70μ ; 4 - the optical lock system with the diameter of about 9 mm; 5-6 - the miniature reference of light-sources; 7 - FEU-85 photomultiplier.

The principle scheme of the densitometer is shown in Fig.2. The $CsI(Tl)$ cylinder scintillator 10 mm high and with the same diameter was bombarded by

alpha-particles from a ^{238}Pu reference spectrometric radioactive source through a 2 mm diameter collimator. A diaphragm of 9 mm diameter and optical locking system were placed between the film under investigation and photoreceiver (FEU-85 photomultiplier). Such construction allowed one to change films in the presence of external light without switching off the photomultiplier power supply. The two $\text{YAlO}_3 : \text{Ge}$ crystals ($3 \times 3 \text{ mm}^2$ area and 90 mcm thickness) with embedded alpha sources ^{238}Pu and with reflection covers [8] were used as the reference light-sources. Two different reflection covers supplied us with two different light yields of two reference sources. It is essential that the light yield temperature dependence for $\text{YAlO}_3 : \text{Ge}$ is similar to the CsI(Tl) one at around 300° K and equals about $+0.39\%/K$ [8]. The anode photomultiplier signals were fed to a pulse-height analyzer via an amplifier. With the help of the analyzer software we determined the centres of gravity, FWHM, the number of events for the amplitude spectrum peaks. The amplitude spectra of one unirradiated film and of three films irradiated by different doses are shown in Fig.3, as an illustration. There is one reference light-source peak in this figure too. This peak consists of four coincidence reference light-source peaks from four above mentioned films. The counting rates from the reference peaks were about 160 S^{-1} and those from CsI(Tl) excited by alpha-particles were about 370 s^{-1} . So, comparatively low counting rates allowed one to register the events by the analyzer without counting rate losses.

The value of optical density S is determined by the following expression

$$S = \lg(I_o/I), \quad (1)$$

where I_o and I denote the centres of gravity of peaks from an unirradiated phon film and from irradiated film, respectively. The results of 9 testings of S with reference optical densities from 0.06 to 1.01 were in agreement with the nominal density values. The accuracy of S value can be estimated as follows:

$$\Delta S = \lg(e) * (\varepsilon_o + \varepsilon), \quad (2)$$

where

$$\varepsilon_o = \Delta I_o/I_o, \quad \varepsilon = \Delta I/I.$$

Here ε was determined by the position determination accuracy of the peak center of gravity from the film under investigation. The measurements with the films of different optical densities have shown that this peak can be presented by means of Gaussian with RMS

$$\sigma = (5.08 + 7.20 * S^{1.45}) * 10^{-2}. \quad (3)$$

The ε_o was determined by the reconstruction accuracy of the phon peak position by means of the reference one during the measurement with the film under investigation. This reconstruction procedure can be written as follows:

$$I_o = a * R + b, \quad (4)$$

where R denotes the reference peak position, a and b denote the fitting parameters determined by the method of least squares. The a and b determination was based on multiple phon film measurements (33 tests during 4 days). The value of ε_o was chosen as

$$\varepsilon_o = \max(\Delta I_{o,i}/I_{o,i}) * m, \quad i = 1, \dots, 33.$$

$\Delta I_{o,i}$ was the experimental accuracy of determining the position of the peak center of gravity $I_{o,i}$ from one of 33 phon films. The coefficient m value was chosen so that the I_o versus R hypothesis (4) was true with the probability of $P=99\%$ for χ^2 criterion. The obtained value of ε_o was 0.71% when the reference peak position determination accuracy was 0.5%. So equation (2) can be written as follows:

$$\Delta S = 0.4343 * (7.10 * 10^{-3} + K_p \frac{5.08 + 7.20 S^{1.45}}{\sqrt{Q}} * 10^{-2}), \quad (5)$$

where Q denotes the number of events for the film under investigation peak, K_p denotes Student coefficient for the coincidence probability value P and sample size value Q . For the real measurements during 500 s Q was equal to about $1.85 * 10^5$ and $K_p = 2.576$ ($P=99\%$). That is why (5) was reduced to

$$\Delta S = 3.21 * 10^{-3} + 1.87 * 10^{-4} * S^{1.45}. \quad (6)$$

The graduation of the thin-film dosimeters on dose D was carried out in low energy gamma-quanta fields from ^{137}Cs and ^{60}Co radioactive sources. The results are presented in Fig.4 with the fitting function:

$$\lg D = 3.592 \sum_{i=1}^5 (A_i * Z^{i-1}) + 4.107, \quad (7)$$

$$A_1 = 3.480 * 10^{-3}, \quad A_2 = 6.070 * 10^{-1}, \quad A_3 = 1.682, \quad A_4 = -3.762, \quad A_5 = 2.452,$$

$$Z = (4.050 * 10^{-1} * \lg S + 9.221 * 10^{-1}),$$

$$S = \lg(I_o/I).$$

Figure 3. The pulse height spectra from the PM's anode: 1-2 – signals from the reference of the light-sources; 3 – $Cs(Tl)$'s peak of light after coming through an unirradiated film; 4-6 – peaks of light after coming through a film irradiated with the doses of 1.3 and 10 Mrad, respectively.

Figure 4. The optical density of irradiated films versus the γ -quanta doses from ^{137}Cs and ^{60}Co radioactive sources. The solid curve is the fit presented by eq.(7) in the text.

The error value obtained with equation (2) exceeded the more accurate one derived with the equation:

$$\Delta S = 0.4343 + \sqrt{\varepsilon_0^2 + \varepsilon^2}.$$

However, equation (2) is more convenient for the analysis. The lower bound of S measurement dynamic range for our densitometer construction was determined by the reconstruction accuracy of the phon peak position by means of the reference one during the measurement with the film under investigation. An extension of this lower bound may be reached through the investigation of a more accurate dependence of I_0 versus R . The usage of two reference peaks instead of only one of them will allow one to extend this lower bound too. The upper S value limitation was due to the fact that both the reference peak and the film under investigation peak should be presented in the analyzed pulse high region of the analyzer. It is clear that this limitation is not serious and can easily be overcome by changing the apparatus configuration. The peak area analysis will allow one to extend the upper bound of S dynamic range when the peak position does not change obviously with the S increasing.

CONCLUSION

The densitometer for the optical density S from 10^{-3} to 1.6 measurements was created. The main peculiarity of the densitometer construction was the usage of the $CsI(Tl)$ scintillator excited by alpha-particles from the ^{238}Pu radioactive source as the probing pulsed light-source. This construction peculiarity allowed one to reach the accuracy of the optical density measurements of 0.2% for the $S=1.6$. This value is not the limit of the accuracy. The accuracy about 0.04% can be reached using the $CsI(Tl)$ as the reference light-source too.

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А.В.Антипов и др.

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