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Compact x-ray spectrometer based on thermoluminescent detectors

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Abstract. A small-sized pulsed x-ray spectrometer was designed and developed. The spectrometer is designed to study pulsed x-rays in the energy range of quanta 1-30 keV. The spectrometer is an assembly of thermoluminescent LiF detectors arranged one after another. Thermoluminescent detectors record x-ray radiation and are used as filters for selection of x-ray radiation in the spectrum. Thermoluminescent LiF detectors are immune to electromagnetic interference, and their response is linear in a wide dynamic range of the absorbed radiation dose (from 20 mSv to 10 Sv). Calibration measurements and test tests have shown good performance and reliability of the small-sized spectrometer.

The study of high-intensity pulsed x-ray radiation provides information about the physical processes occurring in the sources of this radiation.

One such source of intense pulsed x-ray radiation is the plasma of high-current pulsed electric discharge devices. X-ray radiation of such sources is characterized by high intensity (more than 10^{16}) and short duration ($\sim 10^{-8}$ s) [1,2,3]. Powerful electromagnetic interference, arising at the time of formation of x-rays, can distort the operating signal at the stage of its formation and transmission.

Under such experimental conditions, separate detection of particles and, hence, their separate spectrometry becomes impossible. As a rule, to obtain information on the radiation spectrum, one should apply different nuclear-physical methods for measuring pulse x-ray radiation spectra (2;3).

One of the most widespread measurement methods of the pulse x-ray radiation spectrum is the absorption filter method [1-6]. The method is based on the spectral selection of primary x-ray radiation using absorption filters with different thicknesses. This method implies measurement of the attenuation curve, which is the dependence of x-ray energy J fully absorbed in the detector after its passing through the filter, on the thickness of this filter x :

$$J(x) = \int S(E)\varphi(E)\exp(-\mu(E)x)dE \quad (1)$$

where $S(E)$ is the spectral characteristic of the detector; $\varphi(E)$ is the sought spectrum; and $\mu(E)$ is the attenuation coefficient of radiation in the filter. Expression (1) is the first order Fredholm's equation relative to the function $\varphi(E)$. It belongs to the class of ill-posed problems.

As a rule, various multichannel spectrometric systems with a preliminary separation of x-ray photons by their energy using x-ray filters are used to measure the attenuation curve. Spectrometer channels are built according to the classical scheme: filter and detector. Multichannel spectrometers



have large overall dimensions (a diameter of 50 mm and linear dimensions of 150–30 mm) and are difficult to operate [3-5].

To carry out investigations of the spectral composition of x-ray pulses from a plasma in the range of x-ray energies of 1.0–25 keV, we developed and successfully tested a compact noise-immune single-channel spectrometer (the overall dimensions of the device are $\text{Ø} 5 \times 10 \text{ mm}$) based on an array of thermoluminescent detectors.

The operating principle of thermoluminescence detectors is well known. The charge carriers produced by ionizing radiation are localized in trapping centers and retained there for a long period of time. As a result, the absorbed energy is accumulated and can be released thereafter when the irradiated detectors are heated. Upon heating to 240–300°C (depending on the detector material), emission of optical photons (thermoluminescence) is observed, whose level is proportional to the absorbed dose of ionizing radiation.

Physically, thermoluminescent detectors are manufactured in the form of disks with a diameter of 5 mm and a height of 0.9 mm. Thermoluminescent LiF detectors ($Z = 8.2$) are immune to electromagnetic interference, practically insensitive to ultraviolet radiation, and do not have a dead surface layer; at the same time, their response is linear in a wide dynamic range of the absorbed radiation dose (from 20 mSv to 10 Sv) [6,7]. It should be noted that when using industrially manufactured thermoluminescent LiF detectors for x-ray diagnostics detectors with identical parameters must first be selected.

A small noise-immune single-channel spectrometer was made on the basis of an array of eleven LiF detectors located one after the other. In this case, thermoluminescent detectors act as filters that perform x-ray spectrum selection.

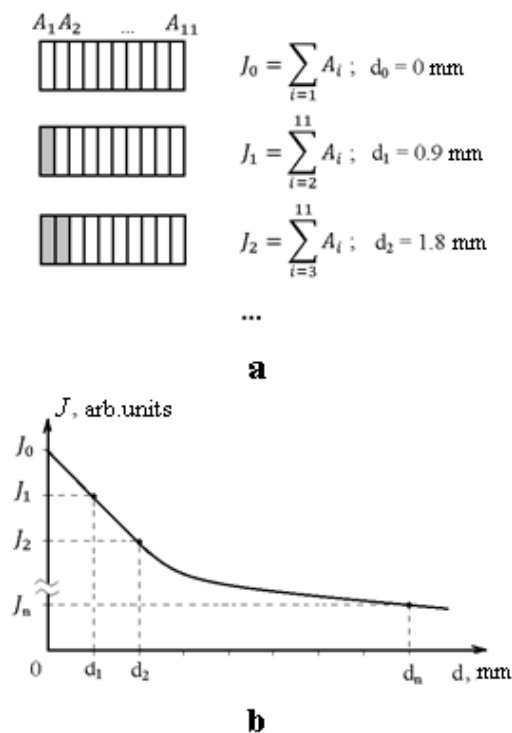


Figure 1. (a) The algorithm for measuring the attenuation curve: (J_i) absorbed energy, (d_i) filter thickness, and (A_i) detector signal from; and (b) the attenuation curve plotted on the basis of this algorithm.

The algorithm used to construct the attenuation curve is shown in figure 1. The total signal from all the thermoluminescent detectors corresponded to the absorbed energy of x-ray emission of the entire investigated spectrum in the energy range in which x-rays were detected in the spectrometer. The signals from each detector determined the degree of attenuation of x-rays upon their passage.

The attenuation curve was constructed by indications of the thermoluminescent detectors, taking their thicknesses into account. The first point on the attenuation curve corresponds to the total signal from all thermoluminescent detectors with an absorption thickness equal to zero. The second point on the attenuation curve corresponds to the total signal from all thermoluminescent detectors minus the signal from the first detector, whose thickness is the attenuation thickness in this case. The third point on the attenuation curve corresponds to the total signal from all thermoluminescent detectors minus the signals of the first two detectors. The attenuation curve shown in figure 1(b) was constructed in this manner.

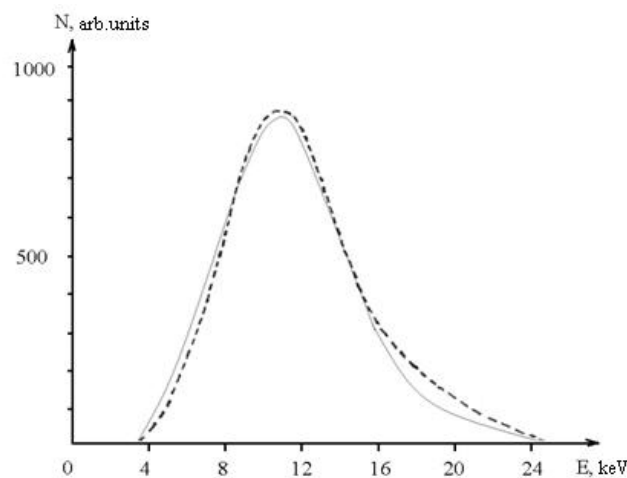


Figure 2. The radiation spectra of the x-ray tube measured by the amplitude analysis method (the dashed line) and reconstructed from the attenuation curve measured by the described compact spectrometer based on the thermoluminescent detectors (the solid line)

The x-ray spectra were reconstructed by the method of effective energies [2,3]. To increase the measurement accuracy, it is possible to use the first thermoluminescent detectors with a smaller thickness. To expand the energy range in the investigations of the spectral composition of x-ray pulses from the plasma, it is necessary to increase the number of thermoluminescent detectors in the spectrometer or use thermoluminescent detectors with a higher effective atomic charge.

Readings were read out of the thermoluminescent detectors using a DVG-02TM instrument [7]. Using this instrument, the detector was heated and a thermoluminescent signal was recorded. The spectrometer was calibrated on a special test bench, which included a pulsed x-ray tube with a set of fluorescent emitters and a set of γ -ray radionuclide sources [7].

To test the performance of the spectrometers, we measured the attenuation curves for the radiation intensity of a pulsed x-ray tube, whose emission spectrum was preliminarily studied by the amplitude analysis method. The spectra of the pulsed x-ray tube were reconstructed by the attenuation curves obtained thereby. As follows from figure 2, the x-ray spectrum reconstructed (by linear programming method) from the attenuation curve and the spectrum of the pulsed x-ray tube measured by the amplitude analysis method coincide with an accuracy of 5% or better.

The x-ray emission spectra of plasma of high-current pulsed electric discharges were studied on "low-inductive vacuum spark" [3,6] facility using both a spectrometer developed by us on the basis of thermoluminescent detectors and a multichannel spectrometer based on semiconductor detectors.

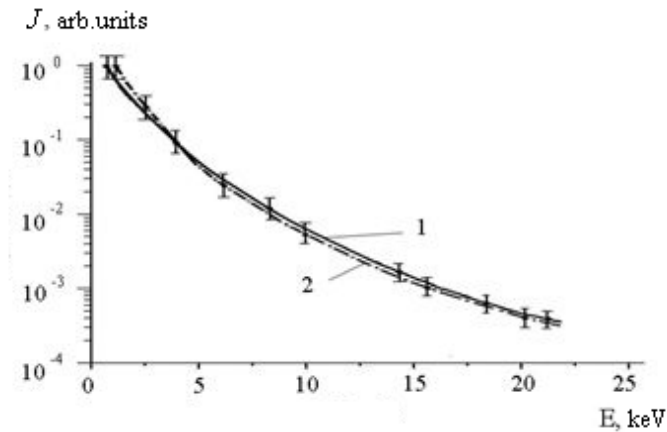


Figure 3. The x-ray spectra measured (1) by the spectrometer based on the thermoluminescent detectors and (2) the spectrometer with the semiconductor detectors.

Figure 3 shows the x-ray spectra measured by a spectrometer based on thermoluminescent detectors (curve 1) and a 7-channel spectrometer based on semiconductor detectors (*p-i-n* technology, a 400- μm thick silicon sensitive layer, and a 0.1- μm thick aluminum coating layer). The channels of the semiconductor spectrometer were constructed according to the classical scheme: a filter (a beryllium foil) and a semiconductor detector [2].

The calibration measurements and test tests demonstrated the good operability and reliability of the compact spectrometer based on the array of thermoluminescent LiF detectors.

With the help of this spectrometer, a number of experimental studies of the spectral composition of x-ray radiation of plasma generated at various facilities have been carried out. The results of the research are given in the works [4-7].

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