

Impulse X-ray spectrometer based on the thermoluminescent detectors

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Abstract

We have developed the compact spectrometer for hot plasma impulse X-ray diagnostics, based on the analysis of thermoluminescent detectors main characteristics. The main results of X-ray emission research on various plasma devices are represented.

Keywords: Thermoluminescent Detectors, Diagnosing Plasma, X-ray spectrometer, High current electric discharge devices (Z-pinches), X-ray radiation

X-ray diagnostics of plasma objects is one of the basic methods for obtaining information on the parameters of radiating plasma and processes occurring in it [8, 13, 11, 1, 5, 10].

The X-ray radiation of plasmas of highcurrent electricdischarge devices (Zpinches) is characterized by a high intensity (more than 10¹⁶ quanta per burst) and small duration (10⁻⁸ s) and has a complex spectrum with a maximum at about 1 keV. Highpower electromagnetic noise arising at the plasma formation instant, can distort the working signal at the stage of its formation and transmission. This requires that special protection measures should be taken.

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 nuclearphysical methods for measuring pulse X-ray radiation spectra [8].

One of the most widespread measurement methods of the pulse X-ray radiation spectrum is the gray absorption filter method [3]. 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 . It belongs to the class of ill posed problems.

As a rule, different multichannel spectrometric systems with the preliminary separation of quanta by their energies using X-ray absorption filters are usually used to measure attenuation curve $J(x)$. Based on the experimentally measured data of the attenuation curve, the X-ray spectra are reconstructed by mathematical methods [8, 3].

The thermoluminescent detectors (TLDs) are most attractive for use in plasma diagnostics [6, 12].

Their principle of operation consists in the fact that the charge carriers produced in them under exposure to ionizing radiation are localized in trapping centers and held in them for a long time. When an irradiated TLD is heated up to a temperature of 240-300°C (depending on the material), light quanta are emitted (thermoluminescence), the quantity of which is proportional to the absorbed dose of the ionizing radiation. As a material for the TLD, lithium and calcium fluorides, activated by different elements, and alumophosphate glasses are used. Constructively, the TLDs are made as a disk with a diameter of 5 mm and height of 0.9 mm. At present, TLDs based on alumophosphate glass and LiF ($Z = 8.2$) are the most frequently used [8, 6, 12, 3].

The selection of these detectors is explained by the stability of their composition and characteristics, since they are manufactured in industrial lots for dosimetry purpose.

It is important to note that the TLDs are not subjected to the action of electromagnetic noise pickup and are characterized by the linearity of the response in a wide range of absorbed doses (from 20 mSv to 10 Sv). One of the basic TLD characteristics is the dependence of the light yield of thermoluminescence on the X-ray quantum energy in a range of 130 keV. The studies performed according to the procedure described in [2] showed that the deviations of the detector response from the linear dependence do not exceed 8% (this allows us to perform measurements of the pulse X-ray radiation spectrum). The linear dependence is broken at high absorbed doses (>10 Sv). This phenomenon can be explained using the thermoluminescence formation mechanism with allowance for the overlapping effect of charged particle tracks and the degree of their ionization ability in the detector [3]. When soft X-ray radiation (2 keV) of a plasma object is recorded, one must know how the detector reacts to the ultraviolet plasma radiation. By performing experimental investigations of the thermoluminescence curve for the TLD made of lithium fluoride, irradiated by the X-ray and ultraviolet radiation, it is possible to determine the influence of the ultraviolet radiation on the thermoluminescence intensity. A mercury lamp was used as a UV radiation source. It was shown that the LiF sensitivity in the ultraviolet spectrum region is 10^{-2} of the detector sensitivity to X-rays.

The obtained results showed that it is possible: (i) to use the TLD for diagnosing UV radiation of plasma; (ii) to use the LiF detectors without protective filters for diagnosing very soft X-rays.

One should note that certain requirements are specified for industrially manufactured TLDs when they are used in experiments on plasma diagnostics; i.e., detectors with identical (within the measurement error) readings are selected after X-ray irradiation of a TLD lot under the same conditions. The LiF thermoluminescent detectors are insensitive to electromagnetic pickups, do not require the on line signal reading system, weakly react to the UV radiation as compared to X-ray irradiation, and have a high diagnostic absorbed dose range. All these properties allow one to create on their base a small-sized seven-channel spectrometer (the diameter is 20 mm and the length is 20 mm) for diagnosing X-ray radiation in a range of 125 keV (taking into account the possibility of using detectors without protective filters).

The spectrometer is assembled on the flange. The flange has seven grooves, and the assemblies of ten detectors were placed one after another in each groove. The assemblies were placed in the flange grooves behind the attenuation filters made of different materials (Mylar, Be, Al, and Cu) with different thicknesses. In the course of measurements of the X-ray spectrum, the following detection methods were used: (i) the gray filter method (the attenuation curve was constructed from readings of the spectrometer channels behind the filters with different thicknesses), (ii) absorbed energy method (analysis of the TLD signals of one assembly), and (iii) Ross filter method (analysis of signals from assemblies located behind the filters made of different materials).

The readings from the TLD were taken using the 02 device (it heated the detector and

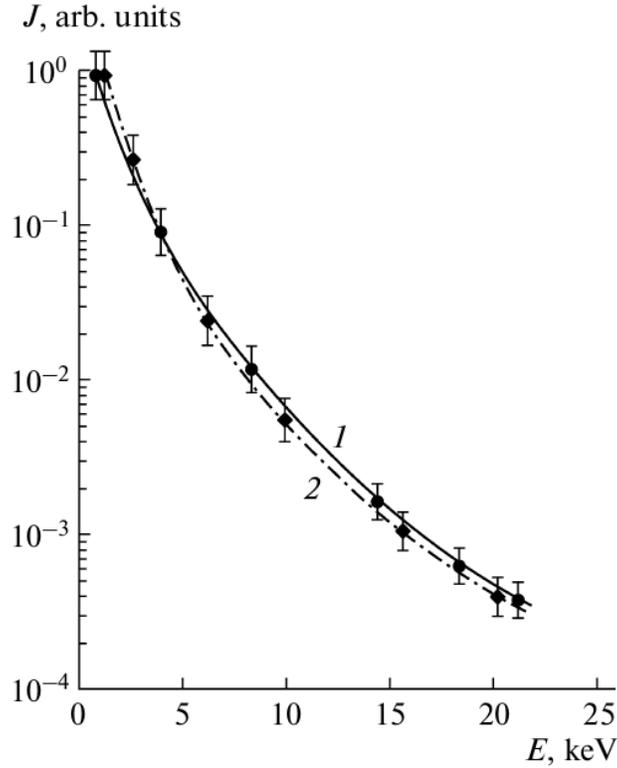


Figure 1: X-ray radiation spectra, measured by the (1) TLD-based and (2) SSD-based spectrometers

detected the thermoluminescent signal). The spectrometer was calibrated on the setup containing the pulse X-ray tube with a set of fluorescent emitters and set of radioisotope X-ray generators [11]. The X-ray radiation spectra were reconstructed from the attenuation curve data measured in the experiment by the effective energy method [4, 9].

The advantage of using the TLD-based X-ray spectrometer was demonstrated in the experiments on studying X-ray radiation of plasma. Both TLD-based spectrometers and spectrometers based on silicon semiconductor detectors (SSDs) were used in the experiment.

Figure (Fig. 1) shows the X-ray spectra measured by the spectrometers based on the TLD and an SSD (pin technology, a 400 m thick sensitive layer is, and 0.1 m thick aluminum coating) [2]. Apart from the fact that the TLD-based spectrometer is noise immune and allows one to measure the X-ray radiation in a wide absorbed dose range without recourse to protective filters, the X-ray spectrum measured by it is more informative (the soft X-ray radiation region) and reliable (noise immune).

The calibration measurements and tests demonstrated a good serviceability and reliability of the TLD-based spectrometer.

Using the designed small-sized noise immune TLD based spectrometer, the spectral composition of the pulse X-ray radiation of plasmas was experimentally studied. They allowed us to obtain the following results: (i) on the plasma focus plasma-generating facility, to distinguish three sections in the X-ray spectrum, within which the spectrum is characterized by

the quasithermal behavior with the corresponding effective temperature and establish optimal combinations of the gas pressure and discharge current, at which the spectrum intensity is at optimum [11]; (ii) on the lowinductive vacuum spark facility, to determine the dependences of the X-ray yield on the configuration of the electrodes of the discharge chamber and discharge current and determine the optimal construction of discharge electrodes, at which the maximal intensity of the X-ray radiation is obtained [14]; (iii) to study highenergy electrons of the microwave discharge plasma in the configuration of the Magnetor bidipole magnetic trap from the data of the X-ray radiation analysis [7].

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