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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

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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 (108 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].

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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 240300C (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 wasconstructed 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) Rosss 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