Polarization of continuous x-radiation of a picosecond laser plasma

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A polarization of continuous x-radiation ($h\nu \geqslant 10$ keV) was observed in a plasma produced by a ruby laser with a pulse duration of ~ 20 psec and flux density of $\sim 10^{14}$ W/cm^2. This indicates that there is a flux of epithermal electrons in the plasma in the direction of its density gradient.

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When a strong laser radiation with a flux density $I \geqslant 10^{13}$ W/cm^2 (at $\lambda \sim 1$ μm) interacts with matter, anomalous mechanisms of energy absorption in a laser plasma are revealed—collective plasma processes with velocity distribution of plasma electrons that deviate from the Maxwellian distribution. In particular, this produces epithermal x-radiation in the energy range $h\nu \geqslant 10$ keV.[1–4]

One of the more effective methods of studying the mechanisms of production of epithermal electrons (resonance absorption[5] and development of parametric instabilities[6]) is the measurement of polarization of the x-ray bremsstrahlung, since this gives direct information on the presence and direction of ordered electron fluxes in the plasma.[7,8] Thus, for example, a measurement of the polarization of x-radiation of the solar corona[9] showed that it has directed electron fluxes.

In this paper we investigate the polarization of the epithermal x-radiation ($h\nu \geqslant 10$ keV) of plasma produced by a ruby laser at a low temperature in the self-synchronization mode.[10] The main parameters of the laser are: energy 0.2–0.5 J, pulse duration 10–30 psec, and flux density in the target 10^{13}–10^{14} W/cm^2.

To measure the polarization, we used a Thompson polarimeter comprised of a LiD scatterer and two pairs of scintillation spectrometers placed perpendicularly to each other with ϕ 30×30-mm^2 NaI(Tl) crystals and photomultipliers FÉU-85 (Fig. 1). Moreover, an additional scintillation spectrometer, which was placed behind the scatterer, was used to control the energy of x rays passing through it. The spectrometers installed on the target vacuum chamber were used to measure the effective temperature of the epithermal electrons T_E from the spectrum of their bremsstrahlung by the absorber method.[4] The exit window of the vacuum chamber was sealed by a 50-μm-thick aluminum foil. The spectrometric channels were calibrated by using Fe^{55} (5.9

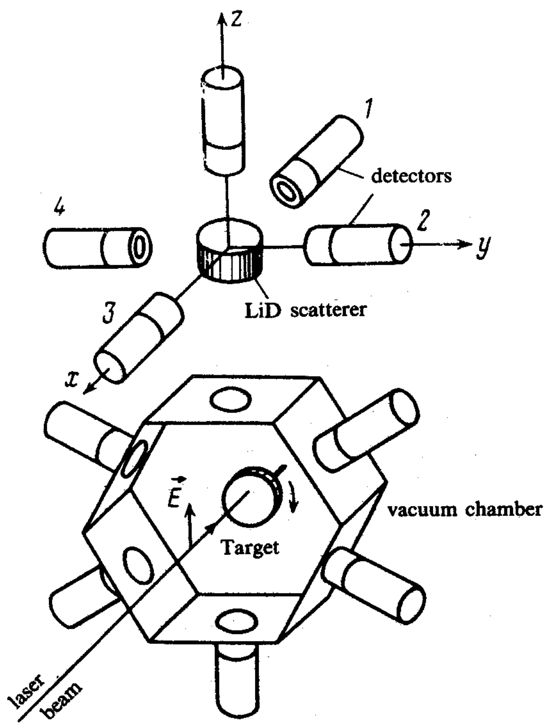

FIG. 1. Setup for measuring the polarization of x-radiation (position 1).

keV) and Cd^{109} (22.5 keV and 88 keV) γ-emitting isotopes. The drift of the photo-peak during one series of measurements ≈ 1.5 h was $\leqslant \pm 1\%$. The collection and processing of information as well as calibration were carried out by an automatic collection and data processing system based on the electronics of the KAMAK system and the PDP-11/05 minicomputer.[11]

The polarimeter was placed in such a way that the collimated beam of x-radiation from the target would hit the scatterer in the parallel direction to the electric vector **E** of the laser radiation (see Fig. 1) in the one series of measurements (position 1). In the other series of measurements (position 2) the vacuum chamber and the polarimeter were rotated 90° around the optical axis of the system.

In position 1, the polarimeter could record the presence in the plasma of the electron flux directed along the axis of the laser beam. In position 2, the fluxes directed along the laser beam and along the **E** vector could be recorded.

The results of measurements obtained by using a massive, plane, tungsten target are given in Table I. The angle of incidence of the laser beam ϕ (p polarization) was 0°, 15°, and 35°. The 15° angle corresponds to the optimum angle for resonance absorption for pulses $\approx$20 psec in duration.[12] The spectrometers 1 and 3 (see Fig. 1) were rotated to an appropriate angle for oblique incidence. The value of P (degree of polarization of x-radiation) in Table I is given by

$$P = \frac{(E_2 + E_4) - (E_1 + E_3)}{(E_2 + E_4) + (E_1 + E_3)},$$

where E_i are the readings of the ith spectrometer.

As seen in Table I, in position 1 polarization of the x ray bremsstrahlung can be observed for all the angles of incidence. The direction of the polarization vector indicates that there is in the plasma an electron flux along the normal to the target. i.e., along the density gradient of the plasma. The flux of epithermal electrons in this direction is attributable to the resonance absorption.

TABLE I. Dependence of the degree of polarization of the continuous x-radiation on the angle of incidence for the tungsten target and on the direction of observation.

Location of the Polarimeter	Angle of Incidence ϕ, deg	Degree of Polarization P
1	0	12 ± 4%
	15	13 ± 4%
	35	8.5 ± 5%
2	0	12 ± 4%

The measurements of polarization for targets made of other materials (C, Al, Cu, and Mo) at angles of incidence 0° and 15° showed that the value of *P*, which was independent of the target's material within the limits of measurement accuracy ($\pm 4\%$), was $11.5 \pm 2\%$ on the average.

For the *W* target the measurements were also performed in position 2 of the polarimeter. In this case the degree of polarization *P*, within the limits of measurement accuracy, was the same in absolute value as that in position 1 and had the same sign. We can conclude from this that in this case there is no noticeable electron flux along the **E** vector. The effective temperature of the epithermal electrons T_E in our experiments was 3–8 keV.

In estimating the measurement error we took into account the errors due to the statistics and drift of the electronic system. To eliminate the systematic errors, we switched the positions of the detector pairs after each series of measurements. Calculation of the multiple scattering in LiD (ϕ $16 \times 12\text{-mm}^2$ scatterer) showed that it does not exceed 10%.

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