Anisotropy of x rays from a laser plasma

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We observed experimentally an anisotropy in the continuous x radiation from a dense laser plasma produced when plane-polarized radiation from a neodymium laser ($\lambda = 1.06\ \mu$) is focused on the surface of an aluminum target at a flux density $q \sim 10^{14}$ W/cm^2. The results are discussed.

An important role in the problem of plasma heating to thermonuclear temperature by laser radiation[1] is played by the determination of the mechanisms whereby laser radiation of high power is observed in the plasma corona and by the study of the influence of each of the mechanisms on the plasma parameters. Experiments[2] have revealed a number of effects, such as a decrease of the reflection coefficient R with increasing flux density q, generation of heating radiation harmonics by the plasma ($m\omega_0/2$, where m is an integer), oscillation of the reflected-radiation intensity with frequency $\sim 10^9$ Hz, etc., effects that cannot be explained within the framework of the bremsstrahlung absorption mechanism. In earlier studies (e.g. [3]) of x-radiation from a laser plasma, no anisotropy of the x-rays was observed. In[4], however, polarization of the x-rays was observed, indicating an anomalous character of the interaction between the laser radiation and the plasma. We report here careful investigations of the angular distribution of the x-radiation aimed at observing the anisotropy expected

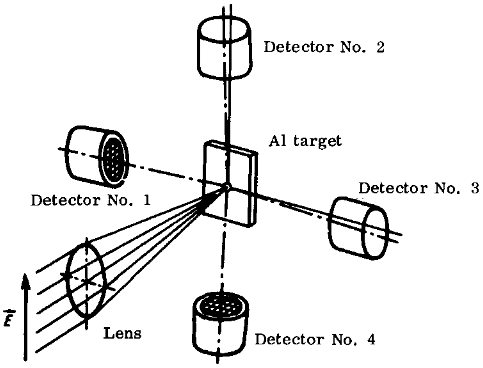

FIG. 1. Arrangement of multichannel x-ray detectors relative to the target.

as a result of the development of parametric instabilities.[5]

Plane-polarized radiation from a neodymium laser (degree of polarization ~90%) with energy up to 30 J, duration ~3.5 nsec at the half-power level, contrast not worse than 5×10^5, and divergence $\sim5\times10^{-4}$ rad was focused by a lens of focal length 10 cm on the surface of flat bulky aluminum targets. The radiation flux density reached $q\sim10^{14}$ W/cm^2. We investigated the angular distributions of the numbers of 1.3—12 keV x-ray quanta passing through filters with different transmission curves. The detector was x-ray film (type UF—R or UF—VR), with sensitivity up to 1 Å, placed in a special cassette, at the entrance to which there were mounted up to 14 beryllium filters with thicknesses from 100 to 2600 μ. The cassettes were oriented at different angles to the investigated plasma and to the polarization vector **E** of the heating light wave (see Fig. 1).

At flux densities $q\geqslant3\times10^{13}$ W/cm^2 the x-radiation has revealed a noticeable anisotropy manifest in the fact that a larger number of quanta is emitted in a unit solid angle in the direction perpendicular to **E** than in the direction parallel to **E**. Figure 2 shows the results of measurements of the degree of anisotropy ζ, defined as the ratio of the numbers of x-ray quanta per unit solid angle across and along **E**, on the limiting transmission energy $E_{1\text{lim}}$ of the beryllium filter. The electronic plasma "temperature" T measured in flashes with x-ray anisotropy by the method of filters assuming a Maxwellian distribution of the electrons by velocities, turned out to depend on the direction in which the radiation was registered. For example, in the flash corresponding to Fig. 2, the electron "temperature" determined for the direction perpendicular to E was $T\sim350$ eV, as against $T_\parallel\sim700$ eV for the parallel direction. This result shows that the presence of anisotropy affects significantly the value of the temperature measured by the filter method.

The anisotropy of the angular distribution of the number of x-ray quanta emitted by a laser plasma can be naturally interpreted within the framework of the recently established notions of the theory of parametric resonance.[5] According to[2,5], the threshold flux for the development of periodic and aperiodic potential instabilities in an aluminum plasma with density close to critical range from 10^{12} to 10^{13} W/cm^2, depending on

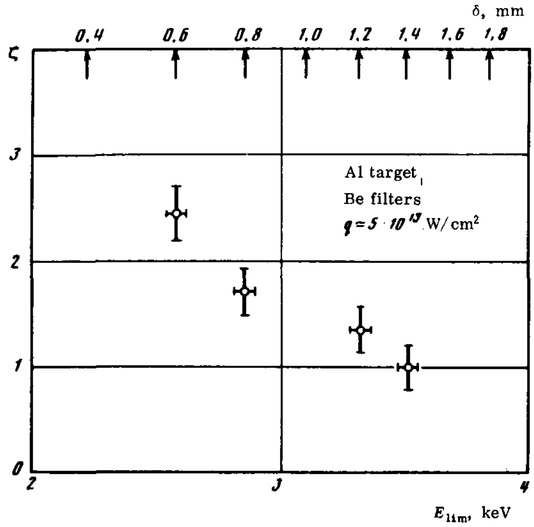

FIG. 2. Degree of anisotropy ζ of x-radiation vs the limiting transmission energy of the beryllium filter $E_{1\text{lim}}$ (corresponds to a hundred-fold attenuation of the radiation intensity by a filter of thickness δ).

the type of instability and on the relative contribution of the effects of dissipation and inhomogeneity of the laser plasma. Under the conditions of our experiment, the fastest to increase is the amplitude of the plasma oscillations propagating in a direction parallel to **E**. This increase, in conjunction with one of the mechanisms of the linear, quasilinear, or nonlinear saturation of the instability,[5] brings the plasma to a turbulent state with sufficiently high level of plasma oscillations, ensuring in accordance with the Cerenkov effect a quasilinear deformation of the electron distribution function in the region of epithermal velocities $v\gg v_T$ of the same order as the phase velocity of the high-frequency plasma oscillations. As a result, the electron distribution function in this velocity range becomes non-Maxwellian and close to the distribution function of electron beams propagating along **E**.[6] The relative number of such fast electrons increases in proportion to the laser-radiation flux and amounts, under the conditions of our experiment, to fractions of 1%[6] of the total number of electrons in the region of the critical plasma density. For an instability of the type of decay of the light wave into electron Langmuir and ion-acoustic oscillations, the distribution function takes a power-law form $\delta f\sim v^{-n}$. Integration of the cross section of the bremsstrahlung radiation of the fast electrons with such a distribution function, as the electrons are slowed down by the aluminum ions, yields many more 1.3—12 keV x-ray quanta than the number of recombination-radiation quanta, which is larger by approximately two orders of magnitude than the number of bremsstrahlung quanta when the electrons have a Maxwellian distribution. This circumstance is decisive for the manifestation of the anisotropy of the x-ray angular distribution typical of a nonrelativistic electron beam. The calculated value of the degree of anisotropy ζ agrees with the experimental results (at $n=4$ and in the interval of fast-electron velocities v from $7.5v_T$ to $25v_T$). Thus, the observed anisotropy of the x-radiation in conjunction with the results of[2], which can be reconciled with the theory of parametric resonance in a laser plasma, points clearly to an anomalous character of the interaction of powerful light beams with a plasma.

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