Localization of x rays produced by interaction of a relativistic beam with a dense plasma

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It is shown that when a relativistic electron beam (current 1 A) interacts with a dense plasma ($n_p \sim 10^{16}$–5×10^{16} cm^{-3}), a localization of x rays of energy ~15 keV is produced in the plasma formation region. The geometric dimensions of the localization do not exceed the geometric dimensions of the plasma formation and decrease with increasing plasma density. The intensity of the x rays is found to depend on the width of the energy spectrum of the beam electrons, on the beam current, and on the plasma density.

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Our experimental investigations[1] of the interaction of a relativistic electron beam with a dense plasma ($n_p \sim 10^{15}$–5×10^{16} cm^{-3}) have shown that the effectiveness of the collective interactions of a monoenergetic beam does not decrease with increasing plasma density. These interactions, which lead to a strong decrease of the beam relaxation length in the plasma, are accompanied by excitation of millimeter waves and by the production of x rays. We report here the results of experiments that have revealed the onset of localization of the x rays. Relations are established between the observed phenomenon, the degree to which the beam is monoenergetic, and the energy distribution function of the relativistic-beam electrons. These relations play a decisive role in collective interactions of a beam with a plasma.

The apparatus used for the investigation was described in[1,2]. The electron-beam parameters were $W=2$ MeV, current $I=1$ A, $\tau=2$ μsec, and beam diameter 1 cm. The plasma was produced by a coaxial plasma gun operating in the plasma-focus regime.[3] The plasma was 10–15 cm long and ~3 cm in diameter. The plasma density at the instant of beam passage ranged from 10^{16} cm^{-3} to 5×10^{16} cm^{-3}.

The x rays were recorded with a plastic scintillator with a photomultiplier, with a semiconductor x-ray pickup having an angle aperture $\alpha=0.15°$, and a pinpoint camera. The semiconductor pickup was moved both along the system axis and along the interaction-chamber diameter. The x-ray energy was determined from the absorption in filters made of aluminum foil or lead plates.

The measurements have shown that in addition to the high-energy (~2 MeV) sharply directional x rays which are obviously due to the bremsstrahlung of the beam electrons, there are also two zones of softer x rays, which appear only when the relativistic electron beam passes through a plasma of density higher than 10^{16} cm^{-3} (Fig. 1), and has an isotropic character.

The first zone is located 6–10 cm from the end face of the plasma gun, i.e., in the region of the plasma formation. From the x-ray photographs (Fig. 2) of this zone, obtained with a pinpoint camera whose optical axis was perpendicular to the axis of the interaction chamber, it is seen that the geometric dimensions of the first x-ray zone are ~3 cm in diameter and 4–5 cm in length, i.e., the x rays come from the plasma-formation region. The longitudinal and transverse measurements with the semiconductor pickup confirm this result. The x-ray energy in this zone is of the order of 15 keV. By varying the delay time between the start of the plasma formation and the passage of the electron beam through the plasma it is possible to move this zone along the system axis and to change its geometric dimensions.

The x-ray intensity depends strongly on the width of the energy spectrum of the relativistic-beam electrons. When the spectrum width is increased from 10 to 80% (Fig. 3) the x-ray intensity decreases by more than one order of magnitude (Fig. 4). In addition, the x-ray intensity decreases with decreasing electron-beam current (there is no radiation at all at a beam current I

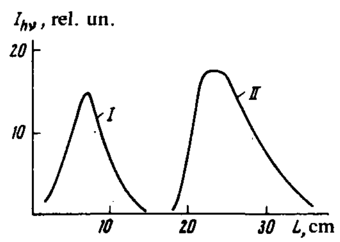

FIG. 1. Distribution of x rays along the interaction chamber: *I*—first zone, *II*—second zone.

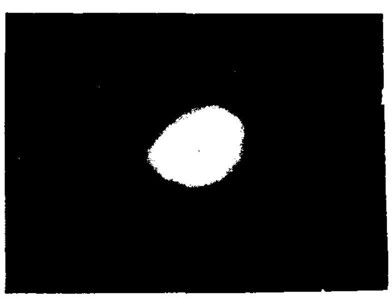

FIG. 2. Pinpoint of the first x-ray zone.

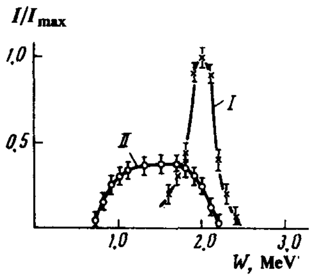

FIG. 3. Energy spectra of relativistic beam electron: I)—$\Delta W/W = 10\%$; II)—$\Delta W/W = 80\%$.

= 10 mA) and with decreasing plasma density. It should be noted that the energy lost by the beam also decreases under all these conditions.

The second x-ray zone is located 25–40 cm away from the end face of the gun (Fig. 1). The measurements have shown that the energy of this radiation is ~100 keV and the diameter of the radiation region is equal to the diameter of the interaction chamber. This gives grounds for assuming that these x rays are due to electrons that lose their energy by collective interaction with the dense plasma and fall on the interaction-chamber walls. Electrons having this energy were registered with a magnetic analyzer.[1] With increasing width of the electron energy spectrum, the second x-ray zone broadens greatly and the radiation energy increases.

In the preceding experiments on plasma-beam interaction (see, e.g.,[4]), a time correlation was established between the excitation of the high-frequency oscillation and the appearance of the x rays. It can therefore be assumed that in our experiments there is also localization of the microwave radiation, in the electric field of which the electrons acquire energy. To prove this, however, special experiments are necessary. The very interesting experiments on the interaction of nonrelativistic beams with a tenuous plasma ($\sim 10^9$ cm^{-3})[5] and on the excitation of waves in

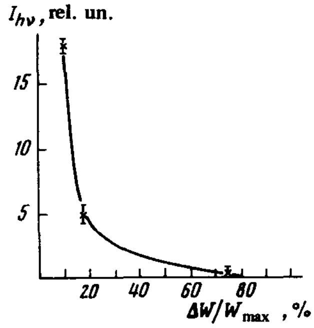

FIG. 4. Dependence of intensity of the first x-ray zone on the width of the electron energy spectrum.

an inhomogeneous plasma[6] have demonstrated convincingly the feasibility of spatial localization of plasma microwave oscillations. The extent to which the x-ray localization observed by us in the interaction of relativistic electron beams with a dense plasma is connected with the processes investigated in[5,6] will be demonstrated by further experiments.

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