Collective interaction of relativistic electron beam with a dense plasma

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Results are presented of an experimental investigation of the collective interaction of a relativistic electron beam with a plasma of density from 10^{15} to 10^{17} cm^{-3}. The beam loses from 15 to 90% of the energy, depending on the plasma density. Emission in the wavelength region ~1 mm, as well as soft x radiation, was observed from the plasma following interaction of the plasma with a relativistic electron beam.

1. One of the most important problems in the interaction of relativistic electron beams with a plasma is the effectiveness of the interaction of these bands with a dense plasma. This question is very important, in particular, in the study of beam heating of a dense plasma. In addition, the interaction of electron beams with a dense plasma is of interest for the development of a beam-plasma generator in the millimeter and submillimeter bands.

We have investigated the collective interaction of a relativistic electron beam with a plasma of density from 10^{15} to 10^{17} cm^{-3}. We found that the energy loss of the electron beam can range from 15 to 90% in such an interaction with the plasma.

The setup used for the experiments is described in detail in[1,2]. The electron beam, obtained from a standard linear accelerator, had the following parameters: $W=2$ MeV, $I\sim 1$ A, $\tau=2$ μsec, beam diameter ~1 cm. The plasma was produced with a coaxial plasma gun operating in the plasma "focus" regime.[3,4] The gun was fed through a vacuum discharge gap from a capacitor bank rated 40 μF at a voltage up to 20 kV. The discharge current was 160–300 kA. The discharge produced at the gun output a plasma-focus formation of ~2–3 cm diameter and 15–20 cm length.

The electron density of the plasma at the focus was measured with the aid of a laser interferometer at the wavelength $\lambda = 6300$ Å, and was determined also from the Stark broadening of the H_β and H_γ hydrogen lines.[5,6] The time dependence of the density was determined

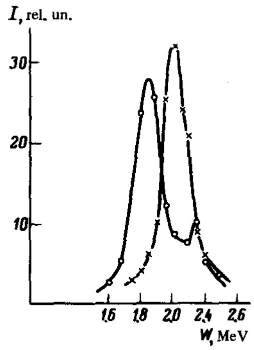

FIG. 2. Energy spectra of electron beam: ×—without plasma, ○—after passing through the plasma ($n_p \lesssim 10^{16}$ cm^{-3}).

from the change in the intensities of the H_β and H_γ lines, measured with the aid of an ISP-51 spectrometer coupled to an SFR-2M high-speed camera. The current of the relativistic electron beam was registered with a Faraday cup. Magnetic analyzers located ahead of the plasma gun and at the exit from the system were used to plot the energy spectra of the electrons before and after passage through the plasma.

Figure 1 shows oscillograms of the beam current without the plasma (a) and after passage through a plasma (b) of density $n_p \lesssim 10^{16}$ cm^{-3}, while Fig. 2 shows the energy spectra of the beam electrons before and after passage through the plasma focus. From the second figure it is seen that the energy lost by the beam reaches in this case 15% of the initial energy.

When the plasma density is increased to $(6-7)\times 10^{16}$ cm^{-3}, the beam current decreases strongly (Fig. 3b), and electrons of energy $\lesssim 100$ keV appear in the energy

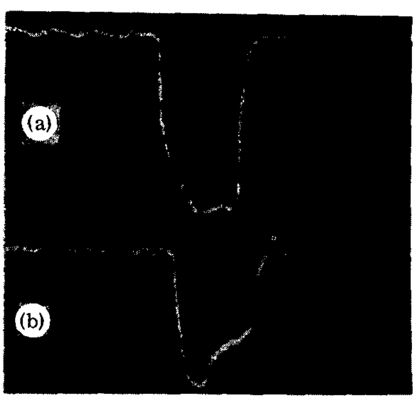

FIG. 1. Relativistic electron beam current: a—without plasma, b—after passing through a plasma ($n_p \lesssim 10^{16}$ cm^{-3}).

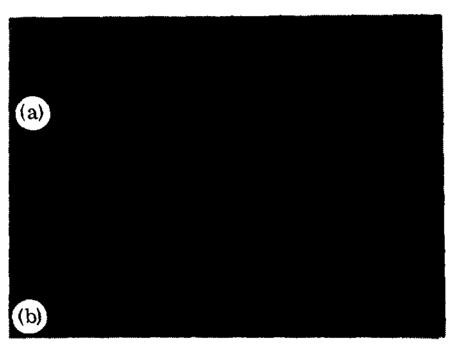

FIG. 3. Relativistic electron beam current: a—without plasma, b—after passing through a plasma ($n_p \sim 6\times 10^{16}$ cm^{-3}).

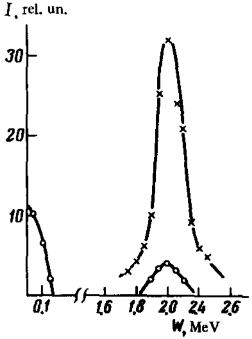

FIG. 4. Energy spectra of the beam electrons: ×— without plasma, ○—after passing through the plasma ($n_p \sim 6\times10^{16}$ cm^{-3}).

spectrum (Fig. 4), i.e., the energy lost by the electron beam reaches 90%.

At a plasma density $n_p \gtrsim 10^{16}$ cm^{-3}, the observed electromagnetic radiation from the plasma in the wavelength range ~1 mm. The radiation was observed with the aid of pyroelectric pickups with waveguides operating beyond cutoff at the input and crystal detectors with horn antennas. When the plasma density increased above 10^{16} cm^{-3}, the amplitude of the radiated signal decreased. This may be attributed to the loss of the sensitivity of the detector with decreasing radiation wavelength.

At a plasma density $n_p \sim 6\times10^{16}$ cm^{-3}, we observed an increase in the amplitude of the diamagnetic-probe signal upon passage of the relativistic electron beam through the plasma, in comparison with the signal amplitude without the beam. At the same time, soft x-rays not registered without the beam were observed to be emitted from the region of the plasma focus.

Thus, the results of our experiments indicate the presence of a collective interaction of a relativistic electron beam with a dense plasma.

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