Lowering of the parametric-instability threshold by injection of an electron beam in a plasma

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It is shown experimentally that injection into a plasma of an electron beam of low density makes it possible to lower appreciably the threshold of the parametric instability and to increase the energy drawn from the external high-frequency (RF) pump field.

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Parametric instabilities are an effective mechanism of transferring the energy of an external RF field to a plasma.[1] One frequency region offering promise of RF heating is the region of the lower hybrid resonance.[2] In real thermonuclear devices, however, when a plasma is exposed to an external RF field, one should expect parametric instabilities to develop in this frequency range in peripheral regions,[4] where the main absorption of the RF power is in fact absorbed. This causes a decrease of the RF energy density in the center of the plasma volume near the energy threshold of the parametric-instability excitation, and this leads ultimately to a lowering of the efficiency of the RF heating.

The experimental results described below show that the combined effect exerted on a plasma by an RF field and of a low-density electron beam ($n_b/n_e < 0.1$, where n_b and n_e are the beam and plasma densities, respectively), by lowering the parametric-instability threshold, increases the efficiency of the RF heating, and helps eliminate the aforementioned difficulties.

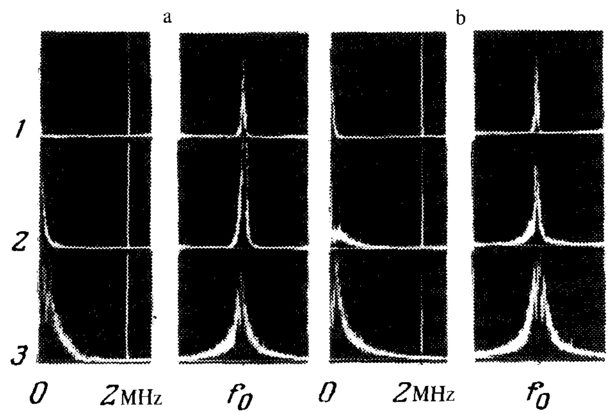

FIG. 1. Spectra of oscillations in plasma: a—in the absence of a beam, for various voltages U_0 (volts): 1) 30, 2) 60, 3) 125; b—at various beam current at subthreshold conditions, I_b (mA): 1) 0.1, 2) 0.8, 3) 10. Beam energy 200 eV.

The plasma was produced in an alundum tube 60 cm long and 6 cm in diameter by a spatially periodic RF field. [4] The entire system was placed in a homogeneous longitudinal magnetic field $H = 1000$ Oe. The pump frequency $f_0 \approx 21$ MHz was in the region of the lower-hybrid resonance. An electron beam of ~ 1 cm diameter was produced with the aid of a thermionic emitter placed on the axis of the system in the region of the homogeneous plasma. The measurements were made with RF probes and a movable electrostatic multigrid electron-energy analyzer. The wroking gas was helium at ~ 10^{-3} mm Hg. The electron density n_e ranged from 5×10^8 to 3×10^{10} cm^{-3}.

In the absence of an electron beam, when the pump field determined by the exciting-system voltage U_0 exceeds a certain threshold, there is observed (Fig. 1a) the development of an aperiodic parametric instability with excitation of a slow sound wave. [5] On the other hand, if the excitation threshold is not reached, then only an RF signal at the pump frequency f_0 is registered in the plasma (frame 1).

When the electron beam is turned on, an analogous excitation of low frequency (LF) oscillations and a broadening, symmetrical relative to the frequency, takes place in the spectrum in the high-frequency region but now under subthreshold conditions. Onset of oscillations is observed starting with certain values of the beam current ($I_b \approx 0.3$ mA). Further increase of the beam current leads to an increase of the LF oscillations and to broadening of the spectra in the LF and RF regions. Variation of the beam energy in the 100—300 eV range exerted no influence on the form of the spectra on the observed oscillations, and on their intensity.

At pump field intensities above threshold, the beam also leads to a growth of the oscillation intensity, although magnitude of the beam current, which influences the parametric instability, increased with increasing pump field intensity. Thus, the level of development of the parametric instability can be additionally controlled by injecting an electron beam into the plasma.

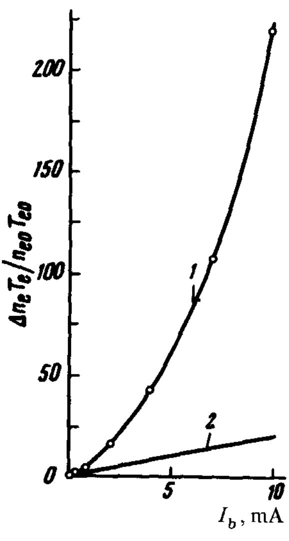

FIG. 2. Experimental (1) and calculated (2) relative energy contents of the plasma as functions of the beam current. n_{e0} and T_{e0} is the energy content of the plasma in the absence of a beam at $U_0 = 30$ V.

Beam injection under subthreshold conditions effected simultaneously with excitation of oscillations was accompanied by an appreciable increase of the energy content of the plasma, namely, an increase took place in both its concentration and in the electron temperature T_e (from 7 to 20 eV) as measured on the plasma periphery outside the beam. To reach the same values of T_e in the absence of a beam it was necessary that the pump field threshold value be exceeded fourfold. The observed increase of the energy content of the plasma greatly exceeds the value obtainable by 100% absorption of the beam energy (Fig. 2). In the calculation we took into account only the main form of the losses, a form connected with the longitudinal escape of particles from the system, i.e., curve 2 of Fig. 2 is even somewhat exaggerated.

Consequently, the observed increase of the energy content of the plasma can be attained only by drawing more energy from the external RF field. This fact, and also the similarity of the oscillation spectra, make it possible to regard the electron beam as a certain startup mechanism of the given parametric instability, which lowers its excitation threshold and improves the conditions for the absorption of the energy of the external RF field by the plasma.

The reason why injection of an electron beam lowers the threshold of the parametric buildup still remains unclear, but it is possible that this lowering is connected with a decrease of the decrement of the high-frequency waves in such a system.

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