Suppression of parametric plasma instability by increasing the damping of a Landau pump wave

V. I. Arkhipenko, V. N. Budnikov, E. Z. Gusakov, I. A. Romanchuk, and L. V. Simonchik
Institute of Physics, Academy of Sciences of the Belorussian SSR, Minsk; A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR

(Submitted 1 November 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 2, 71–73 (25 January 1986)

The possibility of suppressing the absolute and convective parametric instabilities as a result of an increase in the damping of the Landau pump wave has been demonstrated experimentally for the first time.

Anomalous reflection and absorption of electromagnetic radiation by a plasma as a result of the onset of parametric instabilities is a serious obstacle in the achievement of laser-driven controlled thermonuclear fusion and rf heating of plasma in magnetic-confinement devices. Experiments aimed at searching for methods of controlling the development of parametric processes are therefore of crucial importance. Since the wave participating in a parametric interaction are generally strongly retarded, and since their phase velocity is approximately equal to the thermal velocities of plasma particles, the parametric turbulence level depends essentially on the damping of waves according to the Landau mechanism. Using as an example the parametric instability of the decay of an oblique Langmuir wave into an oblique Langmuir wave and an ion-acoustic wave, $l \to l' + s$, we show experimentally that a directed increase in the damping of the Landau pump wave can suppress the parametric instability and virtually entirely eliminate the anomalous reflection of a wave from the parametric interaction region.

The experiment was carried out using the "Granit" apparatus.[1] By introducing a wave guide into the plasma an oblique Langmuir wave was excited in the plasma at a frequency $f_0 = 2350$ MHz. Near the transformation point $\omega_{pe}(0,0) = \omega_0$, where $\omega_{pe}^2/\omega_0^2 = 1 - (z/a) - (r^2/b^2)$ $(a = 5\text{ cm}, b = 0.4\text{ cm})$, the oblique Langmuir wave is reflected parametrically at a frequency $f_0 - f$ and the ion-acoustic wave is pumped at a frequency[2] $f_s = 3$ MHz. At a pump-wave power $P_0 = 5$–20 mW, the spectral power density of the scattered wave, $p_s(P_0)$, is an exponential function which corresponds to a convective instability of the inhomogeneous plasma[3] and at $P_0 \sim 20$ mW the conditions cause an absolute parametric instability[4] which sharply increases (by a factor of 10^4) the reflection. At $P_0 \sim 27$ mW, the reflection is nearly total. Under these conditions, by allowing another wave of power P_1 and frequency $f_1 = 2900$ MHz, markedly different from f_0, to strike the plasma we were able to lower the level of the reflected signal by more than three orders of magnitude (Fig. 1). Using a multigrid analyzer which was positioned along the magnetic-field direction 5 cm beyond the transformation region, we detected at the same time an appreciable increase in the number of accelerated electrons, in particular, at energies $E \approx 35$ eV corresponding to the phase velocity of the pump wave near the parametric interaction. This circumstance led us to assume that the absolute instability is suppressed because of the increase in the damping of the Landau pump wave. The link between the suppression of the instability and the Landau damping was confirmed quantitatively in an experiment in the convective-enhancement region, where the spectrum of the scattered signal can be calculated with

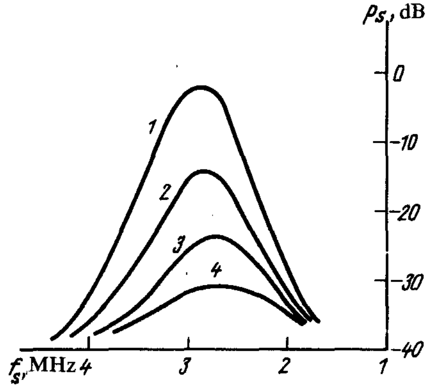

FIG. 1. Spectra of a signal scattered at a frequency $f_0 = 2350$ MHz at different power levels delivered at $f_1 = 2900$ MHz: 1—$P_1 = 0$; 2—4 mW; 3—7 mW; 4—25 mW.

allowance for the Landau damping:

$$P_s = \kappa \frac{\omega_0}{2\omega_s} \frac{k''_{se} T_e + k''_{si} T_i}{k''_{se} + k''_{si}} \exp\left\{2\pi \tilde{Z} - \frac{\omega_s}{\omega_0}\frac{\nu_{ea}}{c_s} a - 2\pi a \omega_0 f_e\left(\frac{2\omega_0}{\omega_s} c_s\right)\right\}, \qquad (1)$$

where

$$\tilde{Z} = \frac{\kappa P_0 a}{128\pi n_c T_e \omega_0}\left(\frac{\omega_s}{c_s}\right)^4 \frac{\exp\left\{-\frac{\omega_s}{\omega_0}\frac{\nu_{ea}}{c_s} a - 2\pi a\omega_0 f_e\left(\frac{2\omega_0}{\omega_s}c_s\right)\right\}}{1+\frac{3}{8} r_d^2\, b \frac{\omega_s^3}{c_s^3}};$$

$\kappa \approx 0.2$ is the fraction of the pump power expended on the excitation of an oblique Langmuir wave, ν_{ea} is the electron-atom collision frequency; c_s is the velocity of ion sound; r_d is the electron Debye length; k''_{se} and k''_{si} are the constants of the damping of an acoustic wave by electrons and ions, respectively; and $f_e(w)$ is the longitudinal-velocity electron distribution function at the transformation point. Assuming that $f_e(w)$ varies only slightly at low energies, we can represent it as a sum of the distribution functions $f_0(w)$ of the original plasma and the high-energy part of $f_1(w)$. By assuming that all epithermal electrons detected by the analyzer are generated at the transformation point, we can determine the function $f_1(w)$ from the I-V characteristic of the analyzer:

$$f_1(w) = \frac{4\pi}{\omega_{pe}^2 S_* \beta}\frac{dI}{dU}\bigg|_{U = \frac{m w^2}{2e}}, \qquad (2)$$

where $S_* = \pi r_0^2 \tau$ is the efficiently operating area of the analyzer's diaphragm; $r_0 = 0.08$ cm is the transverse dimension of the fast-electron beam, which is determined from the emission of plasma at the analyzer; $\tau = 0.08$ is the geometric transmission coefficient of all the grids of the analyzer; and β is a parameter which takes into account the relaxation of the electron distribution due to inelastic collisions and also

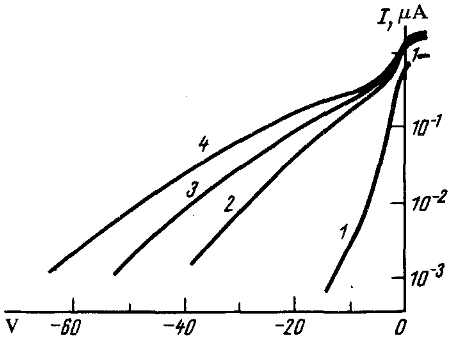

FIG. 2. Probe characteristics of a multigrid probe. 1—Original plasma; 2—$P_0 = 15$ mW; 3—$P_0 = 15$ mW, $P_1 = 7$ mW; 4—$P_0 = 15$ mW, $P_1 = 18$ mW.

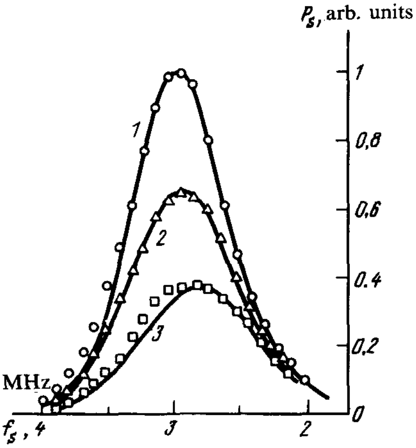

FIG. 3. Spectra of a signal scattered at a frequency $f_0 = 2350$ MHz under convective-enhancement conditions. Solid curves—calculation; discrete values—experiment.

the error in the determination of r_0. Since the I-V characteristics (Fig. 2) in the energy region $E > 10$ eV are approximately exponential, the distribution function $f_e(w)$ can be represented as a double Maxwell's function with a temperature of the original plasma, T_e, and of the epithermal tail, T_h:

$$f_e(w) = \left(\frac{m}{2\pi T_e}\right)^{1/2} \exp\left(-\frac{mw^2}{2T_e}\right) + \delta\left(\frac{m}{2\pi T_h}\right)^{1/2} \exp\left(-\frac{mw^2}{2T_h}\right), \qquad (3)$$

where $\delta = \delta'/\beta$, and δ' is determined from the experimental curves in Fig. 2, with the help of (2); for $P_0 = 15$ mW and $P_1 = 0$ δ' is 0.00072. The parameter β was adjusted only once in the comparison of the calculation on the basis of Eq. (1) with the spectrum of the convective part: in our experiment, $\beta = 0.12$. Power was then supplied to the plasma at a frequency f_1, gradually increasing its level. As a result, the number of fast electrons increased: at $P_1 = 7$ mW $\delta' = 0.00064$ and $T_h = 10$ eV and at $P_1 = 18$ mW $\delta' = 0.00064$ and $T_h = 12.5$ eV. At the same time, the level of the scattered parametric signal dropped, beginning with the rf part of the spectrum, as a result of an increase in the damping of the Landau pump wave principally in the short-wave region. The maximum of the scattered signal shifted toward the small frequency shifts. The spectra calculated theoretically on the basis of Eq. (1), without the use of additional adjustable parameters, are in very good agreement with the experimental spectra (Fig. 3). This agreement serves as proof that the suppression of parametric instability found experimentally is caused by an increase in the damping of the Landau pump waves as a result of additional electron heating.

[1]V. I. Arkhipenko *et al.*, Fiz. Plazmy **7**, 396 (1981) [Sov. J. Plasma Phys. **7**, 21 (1981)].
[2]V. I. Arkhipenko *et al.*, Zh. Tekh. Fiz. **55**, 298 (1985) [Sov. Phys. Tech. Phys. **30**, 174 (1985)].
[3]Q. D. Pilija, Proc. of the Tenth Conf. on Phenomena in Ionized Gases, 1971, p. 320.
[4]V. I. Arkhipenko *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **39**, 453 (1984) [JETP Lett. **39**, 549 (1984)].

Translated by S. J. Amoretty