Observation of modulational instability of plasma waves

Yu. Ya. Brodskiĭ, A. G. Litvak, S. I. Nechuev, and Ya. Z. Slutsker
Institute of Applied Physics, Academy of Sciences of the USSR

(Submitted 14 December 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 4, 176–178 (25 February 1987)

A modulational instability of plasma waves excited by an electron beam in an isotropic plasma has been studied experimentally.

Strong Langmuir turbulence is one of the interesting entities in nonlinear plasma physics. The incontestible progress which has been achieved in the theoretical study of this problem is stimulating special model experiments designed for studying the basic elementary processes which determine the nature of the dynamics of intense plasma waves (or Langmuir waves). In some recent experiments, Wong and Cheung[1] detected a Langmuir collapse (a self-contraction of multidimensional bursts of waves). In the present letter we report the first results of a direct observation of a modulational instability of plasma waves excited by an electron beam in a homogeneous and isotropic plasma.

The experimental apparatus is described in detail in Ref. 3. The plasma is produced in a low-pressure discharge [$P = (1\text{–}1.5) \times 10^5$ torr; the working gas is xenon] with a hot cathode in a chamber 40 cm in diameter and 35 cm long with multipole magnetic insulation of the walls. The cathode is a square frame 11 cm on a side, on which tungsten filaments are strung in parallel. The cathode is positioned near one end of the chamber, at its axis. The anode is the chamber wall. A static voltage $U_a = 50\text{–}160$ V is applied to the cathode, with respect to the wall of the chamber, to sustain the discharge. The cathodes operate under conditions of a thermal limitation of the emission current J_{em}, so that it is possible to independently vary the plasma density n_e, from 10^8 to 10^9 cm^{-3}, and the voltage U_a. The density n_e, which is proportional to J_{em}, depends only weakly on U_a in the selected range. An electron beam with an energy $\sim eU_a$ excited plasma waves in the steady-state isotropic plasma. Inside the chamber, near the other end, is an auxiliary anode 11 cm in diameter, which is connected in the dc sense to the chamber wall. A short ($\tau_p = 2\text{–}10\ \mu$s) pulse of a high voltage $U_p = 1.5$ kV of positive polarity is applied to this anode. The plasma waves in

0021-3640/87/040217-03$01.00 © 1987 American Institute of Physics

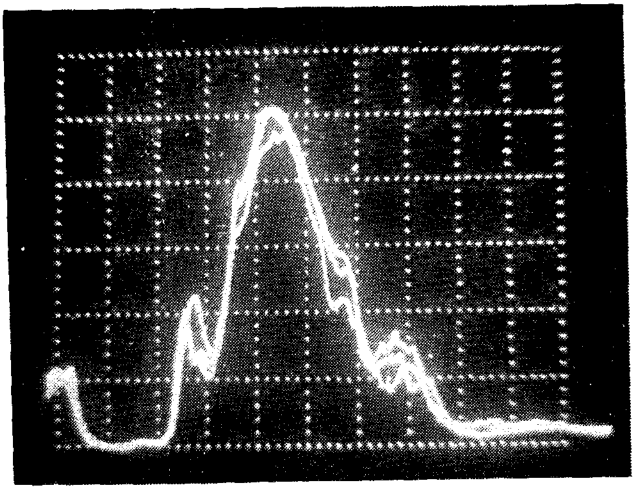

FIG. 1.

the plasma are detected by a moveable dipole antenna. This antenna can also be used as a double probe to monitor the plasma properties. Unfortunately, it was difficult to detect the waves during the pump pulse, because of the intense electron beam. It was established, however, that this pulse does not cause an additional ionization, because of its brevity (the time between ionizing collisions is $\sim 100\ \mu$s).

The experiments show that the nature of the plasma waves which exist in the steady-state plasma changes substantially when the high-voltage pulse is applied; these waves become fundamentally time-varying. Immediately after the high-voltage pump pulse, bursts of intense plasma waves are observed in the plasma, lasting $\sim$20–30 μs and separated by a time interval of 10–15 μs. The number of bursts is two or, more rarely, three (see Fig. 1; the sweep rate is 10 μs/div). The most intense bursts are observed at $n_e \simeq 7\times 10^8$ cm^{-3}, $U_a = 120$–160 V, and $U_p = 1.5$ kV. There are well-

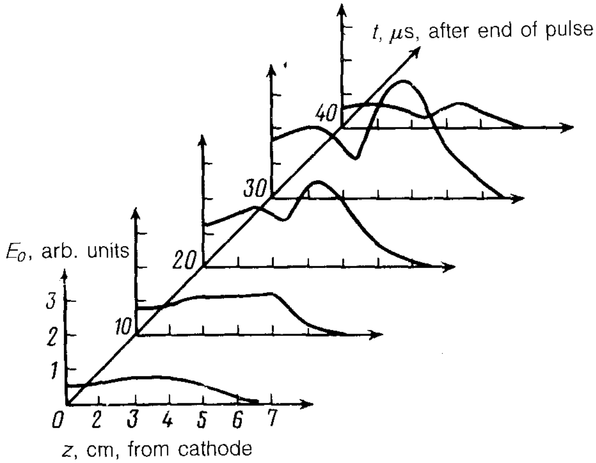

FIG. 2.

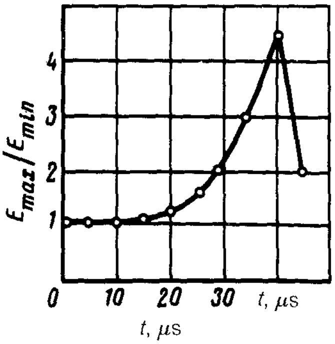

FIG. 3.

defined thresholds for the appearance of the bursts, both along the τ_p scale, at $\approx$2–3 μs (at $U_p = 1.5$ kV), and along the U_p scale, at $\approx$200–300 V (at $\tau_p = 10$ μs). Figure 2 shows profiles of the wave intensity along the chamber axis (the z axis) at various times. It can be seen from this figure that at the beginning of a burst the scale length of the field region is $\sim$6 cm, but as time elapses the increase in the field is accompanied by a breakup of the initial distribution into two bursts, with scale lengths $\sim$3 cm. The modulation depth (the ratio of the maximum field amplitude $E_{\max}$ to the amplitude at the neck, $E_{\min}$) increases as time elapses and reaches a maximum value in 35–40 μs (Fig. 3), although by this time $E_{\max}$ has already begun to decrease. The transverse dimensions of the field region are also $\sim$6 cm. So far, no detailed measurements have been made of the temporal dynamics of the transverse distribution.

In the experiments we measure the decrease in the frequency of the plasma waves during a burst, which is evidence of a decrease in the plasma density in the field region. Since the transit time for ion sound crossing the region of nonuniform field ($\sim$10 μs) is slightly shorter than the length of a burst, we can assume that the plasma nonlinearity is local, $\delta n_e = E^2_{\max}/16\pi T_e$, to find some estimates. The change in the density corresponding to the measured frequency shift $\sim$15 MHz is $\delta n_e = 0.15 n_e$. A corresponding estimate of the maximum field E_0 at $T_e = 10$ eV yields $E_{\max} \approx 100$ V/cm, which is in satisfactory agreement with the value found from an estimate of the effective length of the antenna used,[4] $E_{\max} \approx 200$ V/cm.

In summary, these results show that this experiment has resulted in a direct observation of the onset of a modulational instability of plasma waves in an isotropic plasma. Estimates show that the scale of the growing perturbations ($\sim$2–3 cm) is at the threshold at which Landau damping "comes into play" ($r_d \approx 0.1$ cm). This circumstance seems to be responsible for both the limitation on the field increase and the absence of a self-contraction (collapse) of the wave bursts which result from the instability.

[1] A. Y. Wong and P. Y. Cheung, Phys. Rev. Lett. **52**, 1222 (1984); Phys. Rev. Lett. **55**, 1880 (1985).
[2] V. E. Zakharov, Zh. Eksp. Teor. Fiz. **62**, 1745 (1972) [Sov. Phys. JETP **35**, 908 (1972)].
[3] Yu. Ya. Brodskiĭ, V. L. Gol'tsman, S. I. Hechuev, and Ya. Z. Slutsker, Zh. Tekh. Fiz. **55**, 83 (1985) [Sov. Phys. Tech. Phys. **30**, 46 (1985)].
[4] A. A. Andronov and Yu. V. Chugunov, Usp. Fiz. Nauk **116**, 79 (1975) [Sov. Phys. Usp. **18**, 343 (1975)].

Translated by Dave Parsons