Detection of absolute instability of parametric decay

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A spatially localized instability $t \rightarrow l + s$, whose properties are in agreement with the predictions of the linear and nonlinear theories, was detected in the inhomogeneous plasma in the region of the field peak in front of the reflection point of the pump wave.

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In this communication we report the results of observation of the absolute instability of parametric decay near the peaks of the pump field. The experiment was performed in a cylindrical nonmagnetized plasma 2 meters in diameter and 3 meters in length. The density gradient along the axis of the apparatus was measured by varying the ionizing dc current which passed through the individual groups of filaments, so that $L = (d \ln n/dx)^{-1}$ varied from 100 to 1000 cm. The shf radiation was supplied by an antenna whose angle of half divergence of the beam was 12°. The frequency $\nu_0 = 2.45$ GHz corresponded to the critical density of the plasma $n_c = 7.58 \times 10^{10}$ cm^{-3}. The temperature ratio T_e/T was ≈ 10. Because of the earth's magnetic field the density gradient formed a 10° angle with the chamber axis. The shf radiation was mostly p polarized but also had a small s component. According to the established theory, a standing wave is generated in front of the reflecting layer, where $n = n_c \times \cos^2\theta$, which, upon further penetration into the plasma, first dampens and then increases sharply near the critical layer ($n = n_c$) (see Fig. 1). We obtained this picture by measuring the electric field with the help of a neon lamp. This measurement technique is based on the fact that the shf field increases the charge conductivity. The required accuracy was established in the measurements of Kopeika and coauthors.[1]

The data given in Fig. 1 crudely correspond to the condition described by the Airy function in front of the reflection point. There are enough data in Fig. 1, however, to differentiate between the critical and the reflecting layers of the plasma. We use the Airy functions below only to obtain crude estimates.

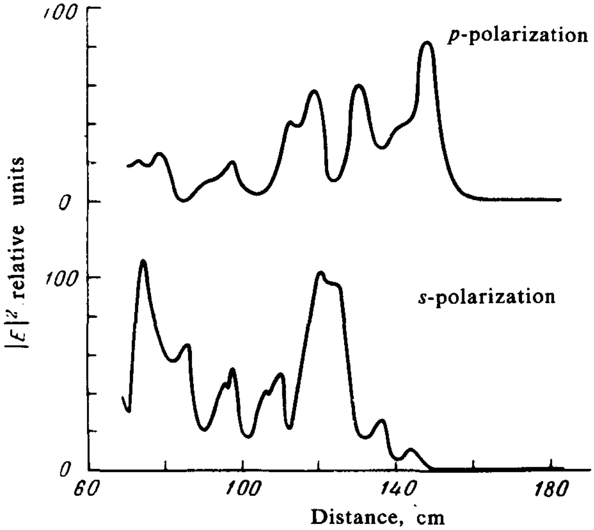

FIG. 1.

Figure 2 shows a typical variation of the ion-acoustic fluctuations (IAF) as a result of varying the shf radiation power. In this case the argon plasma is characterized by the following parameters: $r_{De} = 4\times 10^{-3}$ cm, $L = 300$ cm, the ratio of the decrement to the frequency of the ion-acoustic wave $\gamma_s/\omega_s = 0.035$, $\nu_{ei}/\omega_0 = 6.5\times 10^{-5}$, $\omega_{Li}/\omega_{Le} = 3.7\times 10^{-3}$, and $E^2_{\text{vac}}/4\pi n_e \kappa T_e = 10^{-5}$ for a power $P_0 = 20$ W. The fluctuations in the frequency range of 10 kHz to 10 MHz were measured by a Langmuir probe which collected the electrons. The ion plasma frequency in the critical layer is equal to 9 MHz.

The characteristic features of the fluctuations in the neighborhood of the peak field are different from those in the critical layer. Thus, according to Fig. 3a, the fluctuation spectrum at $n = n_c$ does not have a structure and is very broad. Conversely, as seen in Fig. 3b, near the reflecting layer the first peak of the lines in the frequency spectrum occurs at the frequency of 1.5 MHz.[2]

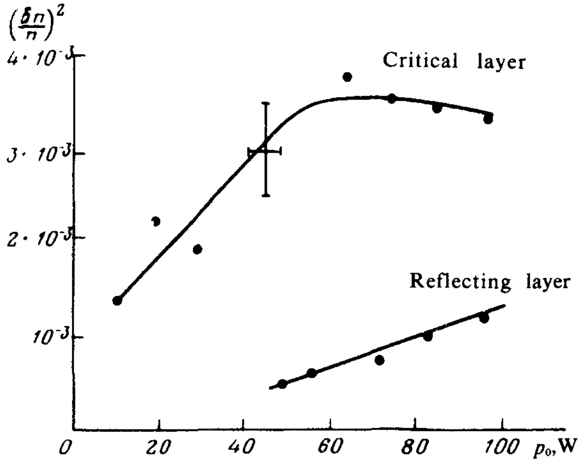

FIG. 2.

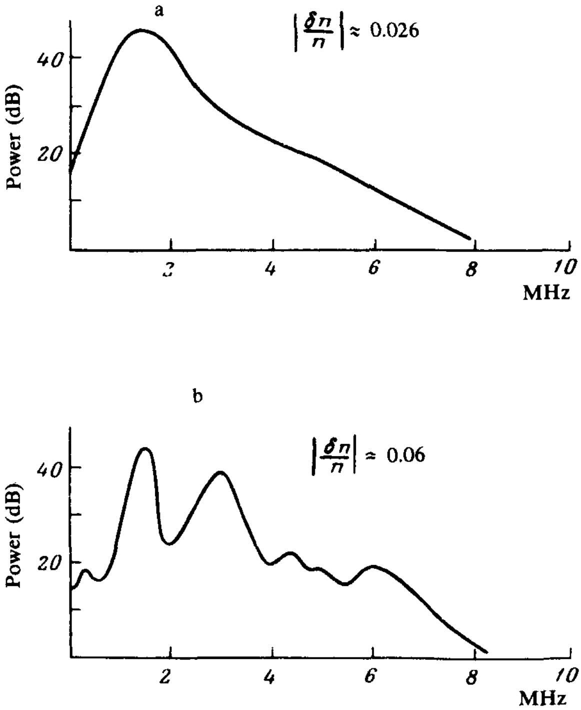

FIG. 3.

The spectral properties of the parametrically excited low-frequency oscillations can be easily accounted for by the following equation:

$$(\omega/\omega_{Ii})^2 = (kr_{De})^2 = (x/3L) = (1/3)[\sin^2\theta + |\xi_m|(c/\omega_0 L)^{2/3}],$$

where x is the distance between the critical and the reflecting layers, ξ_m is the coordinate for the peak of the Airy function $Ai(-\xi)$, and θ is the angle of incidence of the pump wave. This equation correctly describes the location of the peak frequency in Fig. 3d, since it gives 1.3 MHz for the experimental values $x = 20$ cm and $L = 300$ cm.

This equation also accounts for the qualitative difference between the spectra in Figs. 3a and 3b, since the resonance detuning in the critical layer does not depend on the angle of incidence and in the reflecting layer it is a function of the angle θ. Therefore, the spectrum in Fig. 3b matches the angular characteristic of the antenna which radiates the pump wave.

The ion-acoustic fluctuations were also recorded in the E^2 peak, which preceded the peak near the reflecting layer. The main peak of the IAF spectrum turned out to be equal to 5 MHz, whereas under these conditions the peak of the spectrum near the reflecting layer was 3 MHz. The probe was placed near the chamber axis. This confirms the theoretical prediction that the IAF frequency depends both on the location of the layer and on the angle θ. The threshold of the absolute instability $t \to l + s(\Lambda_{th} = 12\gamma_s^2/\omega_{Li}^2)$ almost coincides with the threshold $t \to l + \alpha(\Lambda_{th} = 4\nu_{ei}/\omega_0)$ and with the IAF threshold: $\Lambda_{th} = (E_0^2/4\pi n_e \kappa T_e)_{th} = 4 \times 10^{-4}$, if we assume that the pump field increases in accordance with the theory of the linear layer $E_0^2 = E_{\text{vac}}^2 \times 3.7\,(L\omega_0/c)^{1/3}$. The last equation may give slightly lower values because of strong plasma fluctuations and because the real threshold must be above the theoretical.

The $\sim$5-cm spatial localization Δx of IAF, which is approximately equal to the width of the peak of the pump field, is independent of the power. Consequently, the width of the region of the wave numbers of the parametrically excited waves is equal to $(\delta k/k) \sim (\Delta x/2x) \lesssim 0.1$. A decrease of the plasma density in this region (Fig. 4) is directly attributable to the level of the Langmuir turbulence $\Delta n/n = E_l^2/4\pi n_e \kappa T_e$. This indicates that the square of the intensity of the longitudinal field, which exceeds the pump field, can be measured. According to the theoretical predictions,[2] this is possible at the given parameters under turbulent conditions resulting from the $t \to l + s$ decay. Taking into account the qualitative description of the turbulence and using the increment $\gamma = (1/4)\,[\omega_0\omega_s E_0^2/4\pi n_e \kappa T_e]^{1/2}$, according to Bychenkov *et al.*,[2] we ob-

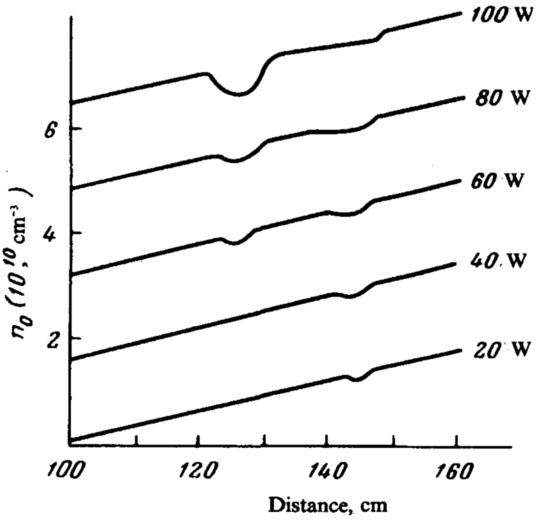

FIG. 4.

TABLE I.

Power, WATTS	$\frac{E_{\text{vac}}^2 \, 10^5}{4\pi n_e \kappa T_e}$	$\frac{(\Delta n)_{max}}{n}$	$\frac{<\Delta n>}{n}$	$\frac{E_o^2 \, 10^4}{4\pi n_e \kappa T_e}$	$a = \frac{<\Delta n>}{n} : \Lambda^{3/2}$
50	2,5	0,012	0,006	5	5.5×10^2
60	3	0,019	0.009	6	6.5×10^2
80	4	0,038	0,022	8	10×10^2
100	5	0.046	0,025	10	7.9×10^2

$E_l^2/4\pi n_e \kappa T_e = \alpha \Lambda^{3/2}$, where $\alpha = (16/3\pi)\ (\omega_0\omega_s)^{1/2}/\nu_{ei} \approx 800$. The data in Table I demonstrate that α is nearly constant. The theory of weak turbulence gives $(\delta n/n)^2 \sim \Lambda^{1/2}(\Delta n/n)$, which is close to that observed near the reflecting layer (Fig. 2).

Finally, the spectrum in Fig. 3b indicates that the instability of $t \to l + s$ can be realized, since an IAF line is directly generated in this case and after formation of the turbulent spectrum a broadened line of the double frequency is formed. Since γ/ν_{ei} does not exceed several units, the broadening of the turbulent spectrum is small and these two lines do not overlap. The turbulent spectrum for unstable $t \to l + \alpha$ has only one broadened line. Note that near $n = n_c$ the IAF of the main peak correspond to small k's, which indicates a strong turbulence with practically continuous spectrum.

Thus, we have demonstrated that the transparent plasma is completely unstable in the region of the maximum pump field and obtained a qualitative agreement with the predictions of the linear and nonlinear theory of the parametric decay $t \to l + s$.

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2) To eliminate the electron cyclotron frequencies in the earth's field, we used external coils to excite a weak magnetic field. The observed frequencies proved to be independent of the magnetic field.

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[2] V. Yu. Bychenkov, V.P. Silin, and V.T. Tikhonchuk, Pis'ma Zh. Eksp. Teor. Fiz. **26**, 309 (1977) [JETP Lett. **26**, 197 (1977)].