GENERATION OF LOW FREQUENCY WAVES IN A MAGNETOPLASMA BY A PLASMA-WAVE MODULATED BEAM CREATING RF DISCHARGE

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Ionization self-interaction of fields of the electromagnetic sources in the whistler band $\Omega_H < \omega < \omega_H$ (ω_H and Ω_H are the gyrofrequencies of electrons and ions, respectively) allows a mutual localization of the ionizing radiation and the creating plasma. As a result of such a self-interaction, formation is observed of narrow plasma-wave channels which localize radiation as well as power transfer to a plasma within a narrow magnetic-force tube [1]. The channel is sustained by means of ionization of a gas by the field of short-wavelength whistlers (plasma waves) trapped in the channel due to the total internal reflection.

In this paper, we present the results of an experimental study on dynamics of the ionization self-ducting of plasma-wave beams formed in a magnetic field by a rf dipole source, whose signal was amplitude-modulated. It is shown that the formation of the plasma channel is accompanied by injection of the high-energy electron beams from the discharge in the external magnetic-field direction. Ionization of a neutral gas by the electrons of these beams provides an additional stretching of the channel. The channel growth rate is determined by the dispersion properties of the waves that create and sustain this channel. The current of the beam excites the azimuthal magnetic field and the radial and longitudinal polarization fields in the channel. In the case of an amplitude modulation of the rf source the changes at the modulation frequency are observed in the plasma parameters and the channel dimensions. There are also appear traveling current structures and electromagnetic fields associated with the current. Relaxation times of low frequency oscillations were sufficient to observe an “echo” after switching off modulation of the rf source.

Figure 1 shows dynamics of low frequency oscillations in the azimuthal magnetic-field component $H_\varphi(t)$ and the radial, $E_r(t)$, and longitudinal, $E_z(t)$, electric-field components generated by a plasma-wave discharge when the fed rf power, $W(t)$, is modulated. The curves plotted in Figure 1 corresponde to the following values of parameters: $W_{max} \approx 25$ W, $\omega/2\pi \approx 240$ MHz, modulation frequency $f_{mod} \approx 60$ kHz, pressure $p \sim 10^{-3}$ Torr, and external magnetic field $B_0 \approx 300$ Gs.

An essential characteristic feature of the phenomenon observed consists in change of a sign of oscillations in all the components of excited electromagnetic fields that proves the excitation of longitudinal electric currents with alternating signs in the channel. It is to be noted that a shape of oscillations in all the component of the excited field depends on the external magnetic field B_0 and the gas pressure p.

Plasma density oscillations, normalized to the background level N_b, which were measured with negative probes located at distance 4 cm from the center of the channel and at distance 85 cm from each other along the channel, are given in Figure 2 for the parameters $p \sim 10^{-3}$ Torr, $f_{mod} \sim 60$ kHz, and $B_0 \approx 300$ Gs.

Curves plotted in Figure 2 demonstrate a small delay in increasing and in disappearing the plasma nonuniformity at a point distant from the rf source (dashed line) and at a near-source point (solid line). These lines cross each other and this indicate a change of sign in a longitudinal gradient of the plasma density. This gradient is directed outwards the source during the first half of a pulse, and towards the source during the second half.

"Echo" signals are well seen in Figure 3 where oscillograms $W(t)$ and $H_\varphi(t)$ are given for $f_{mod} = 6$ kHz, in which case there is no a rapid modulation of the fed power.

Generation of the rf oscillations observed in the experiment takes place as follows. With increasing a fed rf power, the plasma density in the duct increases and a positively charged column forms, which grows in its length. The electrons are heated by plasma-wave fields trapped in the duct due to the total internal reflection, and are injected along the external magnetic field. As a result, a positive potential of the plasma column grows and ion diffusion through its lateral areas becomes more efficient. The stretching of the column then proceeds by means of spending energy of the trapped radiation even if the fed power begins to decrease. In this case the potential and the plasma density in the column accordingly decrease.

The electron beam injected from the column excites the azimuthal magnetic field, whereas the extending charged plasma column generates the radial and longitudinal electric fields traveling together with this column. The observed picture of oscillations in excited LF fields are readily explaned if one supposes that modulated wave beams generate nonuniformities in the plasma-wave channel. These have the form of a sequence of positively charged plasma crests. These crests are strongly stretched along the external magnetic-field $\mathbf{B}_0$ and travel along $\mathbf{B}_0$ from the source together with waves trapped in these crests.

Electron fluxes injected from crests create the negatively charged regions between the crests, which are short-circuted by the currents of the background plasma and the currents due to ion fluxes from the lateral areas of the crests. As a result, at comparatively fast amplitude modulation of radiation, the formation of a forced wave of perturbations in the plasma-channel parameters becomes possible, the velocity of this wave coinciding with that of stretching the channel in the background plasma ($v_c \sim v_e$). The characteristic longitudinal scale of this wave of perturbations is given by $\lambda_c \sim (v_e/f_{mod})$ and the wave frequency is equal to the modulation frequency.

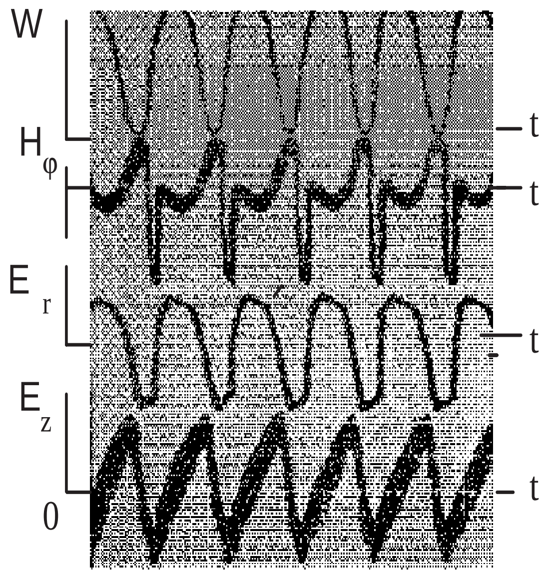

Figure 1.

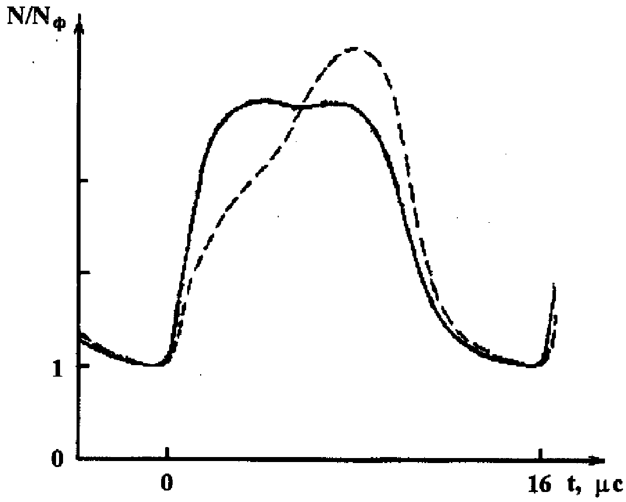

Figure 2.

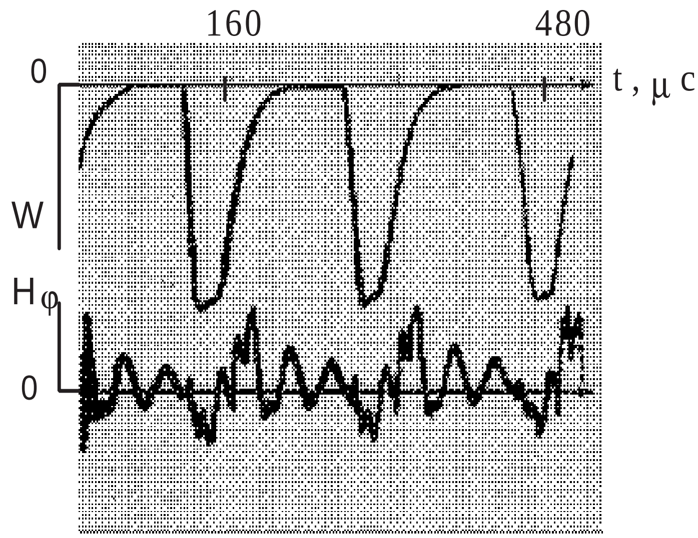

Figure 3.

Thus, oscillations of parameters in the plasma waveguide excite in the positive channel the eigenoscillations and eigenwaves with frequencies close to f_{mod}. For instance, the observed "echo" signals $H_\varphi(t)$ in pauses between rf pumping pulses ($W \sim 0$) are explaned by excitation of the MHD waves of H-type, whose dispersion curves transform in to those of whistler waves with increasing the wave frequency. Beating in the total field of plasma waves with different longitudinal scales enable us to explain an excitation of oscillations at frequency ~ 70 kHz (see the curve of $H_\varphi(t)$ in Figure 3) that is observed during a long enough rf pulse.

Acknowledgments

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References

[1] G. A. Markov, V. A. Mironov, and A. M. Sergeev, JETP Lett. 29, 617 (1979)