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SELF-ACTION OF AN ELECTROMAGNETIC WAVE IN A DENSE COLLISIONLESS PLASMA

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The self-action of an electromagnetic wave in a plasma [1 - 3] is usually connected either with the action of striction forces or with inhomogeneous heating of charged particles in pair collisions. There is a recent report [4] of experimental observation of thermal self-channeling of an electromagnetic wave under conditions when the electron mean free path λ is smaller than the dimension L of the field inhomogeneity. At the same time, interest attaches to the case when the opposite condition $\lambda >> L$ is satisfied. We note that in the collisionless case there exists a possibility of energy transfer from the wave to the electrons by at least two mechanisms. There are the linear transformation of a transverse wave into a longitudinal one, with subsequent absorption of the latter, and anomalous increase of the high-frequency conductivity as a result of the parametric instability of the high-frequency and low-frequency potential waves [5, 6].

In our experiment we investigated the penetration of a powerful electromagnetic wave through a layer of dense plasma situated in high vacuum ($\sim 10^{-6}$ mm Hg), with the maximum ratio $\omega_{Le}^2/\omega_0^2 = 5$, where ω_0 is the angular frequency of the field. The plasma layer was produced by four spark sources located on the periphery of a cylindrical vacuum chamber [7] with approximate inside diameter 60 cm. The distribution of the density along the chamber axis had a bell-shaped form, and the thickness of the layer at the level of the critical density was 30 cm. The plasma electron temperature was approximately 10 eV. The electromagnetic wave was generated by a magnetron operating in the 10-cm band, with power up to 1 MW, and was guided to the plasma layer with the aid of a horn-lens radiator which produced along the chamber axis a weakly diverging radiation beam with transverse dimension 20 cm. The field in the chamber was registered with a segment of a rectangular waveguide, which was moved along the chamber axis, and with a symmetrical antenna having four electric microwave probes[1] located at different distances from the chamber axis.

Owing to the thermal expansion of the plasma, a gradual increase of the transmission of the plasma layer is observed even at low powers of the incident wave (1 of Fig. 1). However, the time required for this process (the time interval from the instant when the generator is turned on to the instant when the field reaches a level 1/3 of its value in vacuum), at power levels below 5 - 7 kW, does not depend on the intensity of the incident wave. Further increase of the power leads to a noticeable decrease of the time required to increase the transmission (2 and 3 of Fig. 1), and at the center of the layer the field intensity increases more rapidly than on the periphery (4 and 5 of Fig. 1), pointing to the formation in the plasma of a channel with inhomogeneous distribution of the charged-particle concentration. The change of the plasma density in the channel was registered relative to the instant of unblocking of the antenna, for a 1-MW diagnostic microwave signal having a frequency lower by a factor 1.5 than the main signal, and also with the aid of

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[1] We present below the values of the detected antenna current. To convert them into the values of the field in the plasma it is necessary to know the coupling coefficient between the antenna and the radiation, with allowance for the dielectric constant of the plasma.

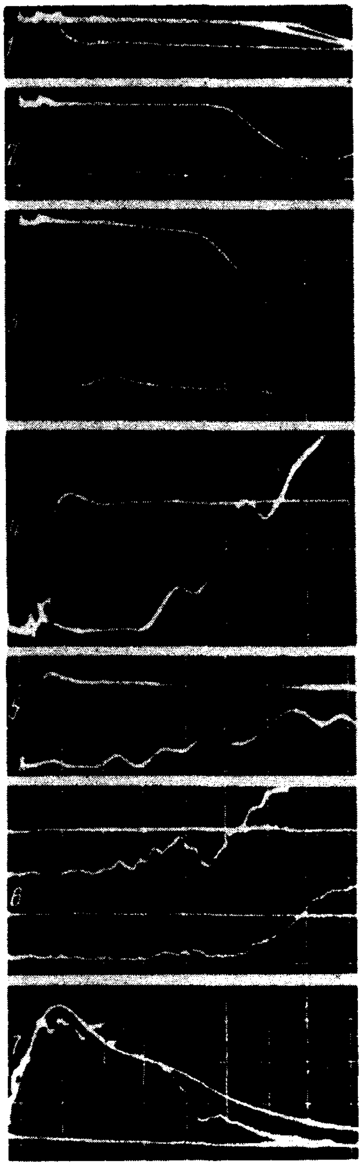

Fig. 1. Oscillograms: 1, 2, 3 - the microwave envelope is registered with a waveguide located behind the layer; the oscillograms of the signals with and without the plasma are superimposed. Powers: 1 - 10 kW, 2 - 140 kW, 3 - 480 kW. Time scale 1 μsec/cm; 4, 5 - signal from antenna located at the center of the layer, 4 - on the chamber axis, 5 - 10 cm from the axis (the signals are obtained in one pulse. Time scale 1 μsec/cm; 6 - penetration of diagnostic signal into the plasma layer, registration with the aid of the antenna; below - without a powerful microwave signal, above - power 100 kW (2 μsec/cm); 7 - ion current of Langmuir probe, probe voltage 100 V, the signals for the incident-wave powers 0 and 500 kW are superimposed.

cylindrical Langmuir probes. As seen from oscillograms 6 and 7 of Fig. 1, the density of the charged particles decreases when a powerful wave is applied. This is accompanied by oscillations of both the ion current of the Langmuir probe and of the antenna signal. The frequency of these oscillations is 1 - 2 MHz.

Increasing the power of the radiation incident on the layer to 300 - 500 kW leads to a sharp change in the character of penetration of the radiation through the plasma: the layer turns out to be transparent in the entire depth even on the leading front of the microwave signal, i.e., within 0.2 μsec. The change of the character of penetration of the radiation through the layer is demonstrated in Fig. 2, which shows the distribution of the antenna signals along the chamber axis at different incident-wave powers.

Simultaneously with increased penetration of the radiation through the layer, we registered a decrease in the reflection of the incident waves from

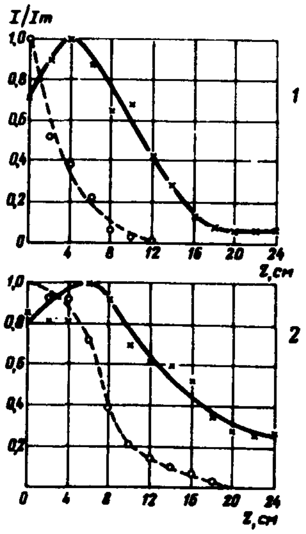

Fig. 2. Field distribution along the axis of the vacuum chamber: 1 - at 0.2 μsec after turning on the microwave field; 2 - at 5 μsec after turning on the microwave field; dashed lines - power 2 kW, solid lines - 500 mW.

the layer back into the horn-lens antenna. However, whereas the penetration of the wave is observed some time after the generator is turned on, the reflected signal is lower than its level at powers up to 5 - 7 kW immediately after the generator is turned on. This observation apparently indicates a strong absorption of the incident radiation in the plasma.

Thus, we have registered penetration of microwave radiation of relatively low power, with $E_0^2/8\pi \ll nT_e$, through a layer of dense collisionless plasma. Thus, a power 5 - 7 mW corresponds to $E_0/E_T = 0.03$ ($E_T = [3T_e m\omega_0^2 e^{-2}]^{1/2}$). The power range 300 - 500 kW, at which the layer becomes rapidly transparent, corresponds to $E_0/E_T = 0.2 - 0.3$.

The observed effect can apparently be attributed to parametric buildup of potential waves in the plasma [6]. Indeed, according to [8] we have for the threshold of the aperiodic instability $E_0/E_T = 0.02$, whereas experimentally the influence of the wave field on its penetration through the layer is observed at $E_0/E_T = 0.03$. Favoring the development of instability of the plasma are also the observed oscillations of the density in the sound-frequency range, and also the dependence of the reflection of the wave by the layer on the power of the incident radiation.

The development of parametric instability should lead to an increase in the effective collision frequencies, and in such a case the usual thermal mechanism of self-action of the radiation is possible. We can also propose that as a result of the development of the acoustic oscillations, there occurs during parametric resonance a strong modulation of the plasma density ($\Delta n/n \simeq 1$) by the sound wave along the electric field of the incident wave. In this case the layer is also transparent to the radiation. This process is more favored energywise than the formation of a broad channel in the plasma layer.

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POPULATION INVERSION IN SOLIDS BY IMPACT EXCITATION OF IMPURITIES

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There are two known methods of producing inverted population in semiconductors by direct electric excitation. The first is based on injection of non-equilibrium carriers through a p-n junction in degenerate semiconductors [1]; it is realized in injection lasers. The second method consists of producing inverted population in the conduction (or valence) band of a homogeneous semiconductor by electric-field pulses that cause ionization of the ions of host lattice or of the impurity [2 - 6]. There is still no unequivocal proof that the latter method can produce inverted population.

We propose in this paper a new method of producing inverted population in solids at the excited levels of deep impurity centers, by impact excitation with majority carriers accelerated by an external electric field. A similar method is used successfully in gas lasers.

The proposed method of producing inverted population was realized by us in zinc sulfide doped with manganese. This substance is a broad-band ($\varepsilon_g = 3.7$ eV) high-resistivity semiconductor of n-type ($\rho \sim 10^8 - 10^{10}$ ohm^{-1}cm^{-1}). The manganese enters the ZnS lattice in the form of Mn^{2+}, replacing the zinc. The presence of an unfilled 3b shell in Mn^{2+} leads to the appearance of a number of local energy levels connected with electronic transitions in this shell. The ground state (^6S) of the Mn^{2+} ion corresponds to an electron configuration $3d^5$ with parallel spins, and the excited state (^4G) corresponds to spin flip of one of the $3d^5$ electrons. The crystal field of the lattice leads to a splitting of the excited level into several sublevels and to a partial lifting of the hindrance from the transitions under consideration. The luminescence in ZnS:Mn is due to a transition from the lowest excited level $^4T_1(^4G)$ to

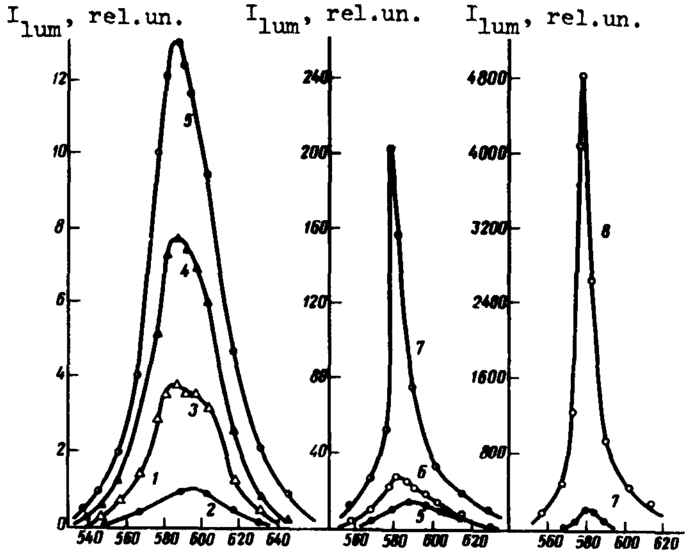

Fig. 1. Emission spectra of ZnS:Mn at different intensities of the exciting electric field: 1 - 0.8 × 10^6, 2 - 1 × 10^6, 3 - 1.1 × 10^6, 4 - 1.2 × 10^6, 5 - 1.3 × 10^6, 6 - 1.46 × 10^6, 7 - 1.62 × 10^6 V/cm.