is so large that the current after the switching turns out to be insufficient to maintain the highly-conducting state, the latter is violated. After a definite time, which depends on the electric parameters of the semiconductor, and also on V_n and R_b, the conducting state arises again and the cycle of the reversible switching thus repeats periodically. The oscillations considered here differ from purely relaxation oscillations [3] due to the presence of two discrete values of the sample resistance and to the switching voltages between them, in that their time parameters are determined by the kinetics of the electronic processes in the sample, and not by the reactive parameters of the passive circuit elements.

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SELF-TRAPPING OF POWERFUL ELECTROMAGNETIC WAVES IN A DENSE PLASMA

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It is well known from linear wave theory that an isotropic plasma is opaque to electromagnetic waves at a frequency below the plasma frequency, $\omega < \omega_p$. However, if the intensity of the electromagnetic wave is sufficiently large, it produces a redistribution of the density of the charged particles and formation of a waveguide channel in a "transcritical" plasma is possible [1 - 4]. In the present article we describe direct observations of the passage of intense electromagnetic waves through a dense plasma. We show that the results are in agreement with the theoretical estimates.

1. The experimental setup consisted of an evacuated cylinder (80 cm diameter and 220 cm long), evacuated to a pressure 0.1 Torr. With the aid of a coaxial plasma source located on the end wall of the cylinder, this volume was filled with a plasma with low degree of ionization. The maximum electron density was $N_e \approx 10^{13}$ cm^{-3} and was attained within ∿0.5 msec after the start of the discharge in the injector, after which a plasma decay set in with a characteristic time ∿10 msec. The microwave generator was a pulsed magnetron for the 10-cm band, delivering up to 300 mW. The radiator was a horn antenna and the receiver the open end of a waveguide; the distance between the antenna and the waveguide ranged from 40 to 60 cm. The internal surface of the vacuum chamber, on the side of the receiving waveguide, was covered with an absorber to decrease the reflection of the waves from the walls. The magnetron was triggered with different delays relative to the start of the discharge, making it possible to investigate the interaction in a wide range of concentrations. The plasma concentration was determined from the cutoff of two weak probing signals with wavelengths $\lambda = 3$ cm and $\lambda = 12$ cm, under the assumption that the plasma decay is exponential. A system of resonant filters was used to decouple the weak signal from the powerful pulse.

2. The extensive experimental material accumulated as a result of the measurement[1)] makes it possible to regard as established the penetration of

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[1)] At each value of the pulse delay (electron concentration) and of the incident power, some 30 - 40 measurements were made. Although the effect of bleaching of the plasma was registered in each experiment, the measurement results were averaged to obtain the quantitative characteristics.

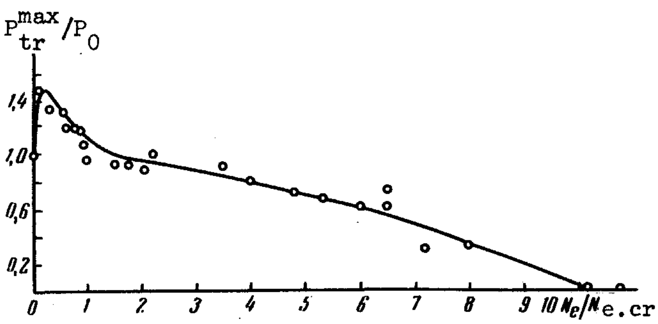

Fig. 1. Maximum signal power passing through a plasma layer 40 cm thick, against the plasma concentration at an incident-pulse power $P_i = 50$ kW, P_0 - signal power in vacuum, $N_{e.cr} = 10^{11}$ cm^{-3}, z = 40 cm.

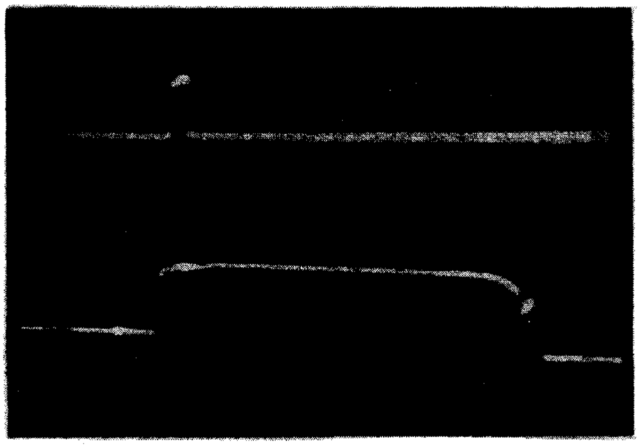

Fig. 2. Oscillograms of transmitted (upper trace) and incident (lower trace) pulses. The duration of the incident pulse is $\tau_i = 20$ μsec.

power electromagnetic waves into a dense ($N_e > 10^{11}$ cm^{-3}) plasma to a depth greatly exceeding the thickness of the skin layer (see Fig. 1). With increasing power P_i, the microwave signal penetrates into an ever denser plasma, and the magnitude of the transmitted signal at P_i = const decreases with increasing electron density. In a number of cases, the amplitude of the signal passing through the dense plasma exceeds the amplitude of the signal in the absence of a plasma but not by more than 1.3 - 1.6 times. The value of N_e at which cutoff occurs (the transmitted signal vanishes) increases with increasing incident pulse up to $P_i \approx 50$ kW, and then flatens out[2]. From an analysis of the waveform of the pulse passing through the plasma it follows that, regardless of the excess of concentration above the critical value (for $\lambda = 10$ cm) and regardless of the power of the incident pulse, starting with $P_i = 15$ kW (no measurements were made at lower powers), the characteristic time of plasma "bleaching" does not exceed the duration of the leading front of the pulse ($\sim 2 \times 10^{-7}$ sec), as is clearly seen from the oscillograms in Fig. 2[3].

To determine the magnitude of the perturbations produced by a powerful microwave pulse, a weak continuous signal ($P_s \sim 10^{-3}$W) with $\lambda = 7$ cm, for which $n_{e.cr} = 3 \times 10^{11}$ cm^{-3}, was additionally applied to the plasma. It was observed that if the sounding signal has the same electric-field polarization as the main signal, then the plasma becomes transparent also to the sounding signal in the presence of 10-cm radiation, and the duration of the sounding signal is larger by 2 - 3 times than for the transmitted powerful pulse. For a weak wave with orthogonal polarization of the electric field, the plasma remains opaque as before.

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[2] This saturation is due to effects of high-frequency breakdown in the weakly ionized plasma; these effects are observed already on the leading front of the pulse. The time of breakdown development depends on the pulse power and on the electron concentration.

[3] The appreciable decrease of the duration of the transmitted pulse compared with the incident pulse is also connected with the occurrence of microwave breakdown.

3. The obtained experimental data are in good agreement with the hypothesis that a waveguide channel is produced in the "transcritical" plasma. The simplest model of this channel, when an H_{01} wave from a rectangular waveguide is incident on the plasma, is a flat transparent ($\omega_p < \omega$) layer with dimensions a and b, satisfying the inequality $b > \lambda/2 \gg a$. Under the conditions of the experiment, the principal nonlinear mechanism was ohmic heating of the plasma, since during the time of the channel formation ($\sim 2 \times 10^{-7}$ sec) the electrons have time to experience many collisions and to increase their energy greatly. In a plasma with $N_{e0} \simeq 5 \times 10^{11}$ cm^{-3} and $T_e = 3 \times 10^3$°K, the effective collision frequencies are $\nu_{ei} = 2 \times 10^7$ sec^{-1} and $\nu_{em} = 5 \times 10^7$ sec^{-1}. Since $\nu_{ei} \sim T_e^{-3/2}$ and $\nu_{em} \sim T_e^{1/2}$, we can neglect in the estimates the collisions of the electrons with the ions and represent the time dependence of the electron temperature in the initial section in the form

$$T_e = T_0 \left[1 + \left(\frac{e^2 E^2 \nu_{em}^2}{4 m \omega^2 T_0} t\right)^2\right],$$

where T_0 is the initial electron temperature. At $P_i = 30$ kW, T_e decreases by more than one order of magnitude in a time $t \simeq 10^{-7}$ sec, but still does not reach the stationary level. Of course, in this case the electron density in the field region decreases strongly, $N_e \simeq (T_0/T_e)N_0 \ll N_{e0}$. Since the time of formation of the channel is small compared with the time of ion-molecule collisions ν_{im}^{-1}, the redistribution of the concentration proceeds with the speed of ionic sound. Consequently, for a channel with a smaller transverse dimension the relation $a \leq \sqrt{(T_e/M)\tau} \simeq 2$ cm should be satisfied. It is possible that not one but several thin "slit" channels are produced in the plasma. Such a model makes it possible to explain, in particular, the experimentally observed matching of the incident radiation with the plasma.

An investigation of wave self-trapping effects is of interest for a large group of problems connected with the propagation of intense electromagnetic radiation in a plasma. In particular, to determine the efficiency of high-frequency plasma-heating methods it is necessary to carry out similar experiments in a collisionless strongly ionized plasma, where the lifetime is not limited by breakdown and a transition to higher levels is possible; at such levels an important role should be played by effects of anomalous dissipation of the field energy in extended regions (along the channel) of plasma resonance ($\omega_p \simeq \omega$). One can also expect the occurrence of waveguide channels in a dense plasma produced under the influence of electromagnetic radiation (for example in a laser plasma).

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