Fast-electron current oscillations in the case of parametric instability in a plasma layer

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We investigate experimentally the oscillations of the current of fast electrons produced when a microwave is incident on a plasma layer. The increased excess above threshold changes the oscillation frequency from 22 to 4 MHz. The phenomenon is explained on the basis of the premises of the nonstationary theory of Langmuir turbulence.

In experiments on nonlinear interaction between microwave radiation and an inhomogeneous plasma layer, we have observed an anomalous transparency of the plasma layer, the production of accelerated electrons, and the appearance of Raman lines in the scattered radiation.[1] These facts have enabled us to conclude that parametric instability sets in under these experimental conditions. As the work developed further, we undertook a more detailed study of the instability, namely, we increased the time resolution of the apparatus used to measure the electron currents. This has revealed a new phenomenon, namely nonstationary electron turbulence produced in a collisionless plasma.

The electron currents were measured with a multigrid probe screened against the action of the microwave field and placed inside the plasma layer. The load of the probe collector was a 50 Ω resistor, so that the electric circuit of the probe, and also the amplifier and the recording apparatus, ensured a temporal resolution up to 25 MHz. Just as in the already mentioned experiments, a powerful electromagnetic wave in the 10-cm band was turned on at the instant when the electron concentration at the center of the plasma layer reached its maximum. We then registered the appearance of a current of fast electrons that are produced if the maximum electron concentration in the layer is equal to or larger than a critical value for the incident radiation. This phenomenon is characterized by an incident-radiation power threshold of 100 kW, corresponding to a field intensity 360 V/cm in the incident wave at the probe location, or to a ratio $v_E/v_{Te} = 0.3$ (v_{Te} is the initial thermal velocity of the electrons, $V_{Te} = 10^8$ cm/sec and $v_E = eE_0/m\omega_0$).

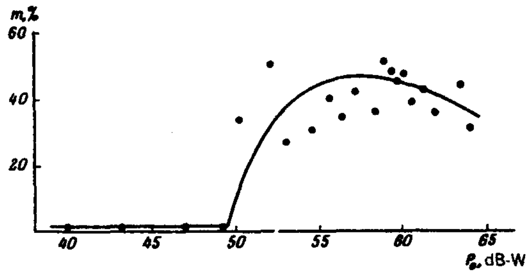

FIG. 2. Depth of modulation of the electron current vs. frequency of incident wave: the abscissa scale is logarithmic; the threshold of the oscillations is 360 V/cm. The curve corresponds to the time interval 1.0–1.5 μsec from the instant of turning on the incident wave.

We have observed that the electron current in the probe has an oscillating component (see Fig. 1). This component has an appreciable time duration, practically comparable with the total lifetime of the electron current, i.e., with the time of plasma-layer decay due to the action of the high-power microwave field. The time of appearance of the electron current is approximately 0.1 μsec, which coincides with the duration of the leading front of the microwave pulse; this time remains practically unchanged in the range of incident-wave powers corresponding to electric fields from 360 to 1750 V/cm.

The depth of modulation (m,%) of the electron current as a function of the incident-wave power is characterized

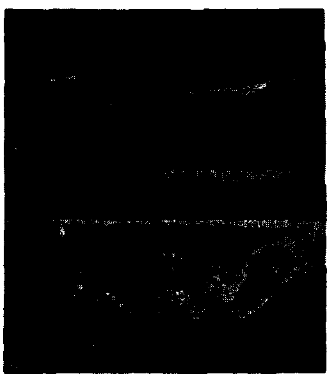

FIG. 1. Oscillograms of the current of accelerated electrons: 1—electric field or incident wave 1 kV/cm [excess above pressure $a^2 = (1/2)\,(1 - E_{thr}/E_0) = 0.32$], 2—incident wave 1.5 kV/cm ($a^2 = 0.38$); oscilloscope sweep 1 μsec/div.

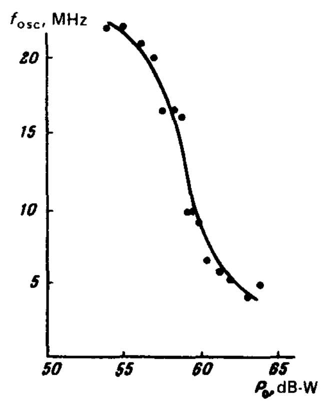

FIG. 3. Dependence of the oscillation frequency on the incident-wave power: the curve is plotted for the time interval 1.0–1.5 μsec.

by an abrupt threshold, also equal to 100 kW, and then stays at an approximate level of 40% (see Fig. 2). At higher powers, the depth of modulation has a weakly pronounced tendency to decrease. An interesting feature of the observed process is the variation of the oscillation frequency with changing power level of the incident wave. It follows from Fig. 1 that at a slight excess of the power above the instability threshold the oscillation frequency is much higher than 20 MHz, and cannot even be measured by the employed apparatus (SI-15/1 amplifier with S8-9A oscilloscope). With increasing excess over threshold, the oscillation frequency decreases, as illustrated in Fig. 3, and varies approximately like $f_{osc} \sim \ln(E_{thr}^2/E_0^2)$. In all our measurements we registered frequencies from 22 down to 4 MHz, i.e., this region may include the 5-MHz oscillations mentioned in[2], where a similar plasma placed in a waveguide operating in the 10-cm band was investigated. This may signify that the processes occurring in plasma in these experiments are similar.

An attempt can be made to attribute the observed oscillations to an intense acoustic wave and the associated modulation of the local plasma potential. However, such an explanation is not confirmed by experiment, since turning off the incident wave at the middle of the electron-current pulse leads to a rapid (approximately 0.1 μsec) vanishing of both the electron current and its modulation, whereas the damping decrement of the acoustic wave should be at least smaller than its frequency. In addition, the acoustic waves produced in the case of a potential periodic instability have wave numbers $k_s \gg k_0$ and a probe measuring approximately 1 cm cannot respond to small-scale density changes. It can consequently be concluded that the observed oscillations are connected with the turbulent state of the electrons. Oscillations of such a state were theoretically predicted in[3,4]. A qualitative comparison with the theory[4] shows that under our experimental conditions the time of turbulence development is $t_T = 2\times10^{-8}$ sec, the time necessary for the turbulence to assume a stationary value is $t_\infty \approx 10^5$ sec, and the oscillation frequency is $f_{osc} = 6\times10^6$ Hz. The experimentally observed decrease of the oscillation frequency with increasing excess over threshold can be attributed to a decrease in the collisionless damping of the plasma waves ($\tilde{\gamma}$) with increase of their amplitude; nevertheless, the comparison can only be qualitative, since the employed theory has been developed for the case when $\beta \gg 1$, and in the experiment we have $\beta \sim 1$ (β^{-1} is the scale of the kernel in the angular distribution of the noise energy). In addition, the cited paper[4] deals with decay of a pumping wave into two plasmons, whereas under our conditions the lower threshold is unstable against the formation of a plasma and an ion-acoustic wave.

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