Resonant absorption of intense electromagnetic radiation in an inhomogeneous plasma

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It is shown that a p-polarized electromagnetic wave can be totally polarized in two nonlinear regimes corresponding to different values of the angles of incidence and different radiation intensities. The physical nature responsible for the formation of the regions of strong absorption of the electromagnetic wave in an inhomogeneous plasma is explained.

A stepwise distribution of the dielectric constant ϵ near the plasma resonance, which is caused by the ponderomotive force,[1] can facilitate the resonance absorption of a p-polarized radiation.[2] The numerical calculations carried out by Gil'denburg *et al.*[3] showed that a regime of nearly total absorption is achieved at a maximum angle of incidence (corresponding to maximum linear absorption), $\theta = \theta_0$, of a plane wave incident on a slightly inhomogeneous plasma if the incident power level is relatively low. The self-consistency can be explained in this case by the mode-locked excitation of a decaying quasi-static mode to a plasma-density plateau, with a sufficiently small value of the dielectric constant ϵ.(1) In this letter we show that there is another region of large absorption which is attributable to a mode-locked excitation of a quasi-surface mode and which corresponds to a stronger deformation of the density profile. According to Zharov *et al.*[2] and Gil'denburg *et al.*,[3] this absorption region is attributable to a rather large amplitude of the incident wave.

We assume that an intense monochromatic ($e^{i\omega t}$) p-polarization plane wave (B_y, E_x, E_z) is incident from a vacuum ($z < -l$) on the plasma with a linear density profile $n_0 = n_c(1 + z/l)$. We can write the equations for a field in a plasma, with allowance for the strictional nonlinearity, as follows:

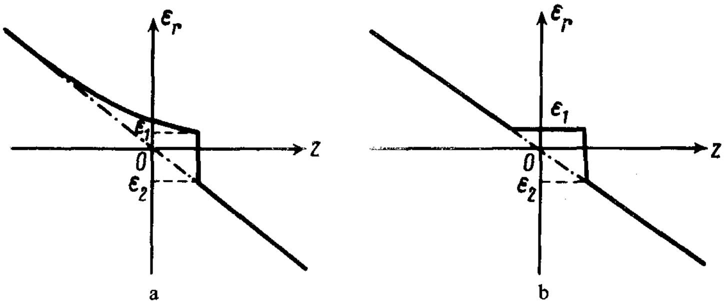

FIG. 1

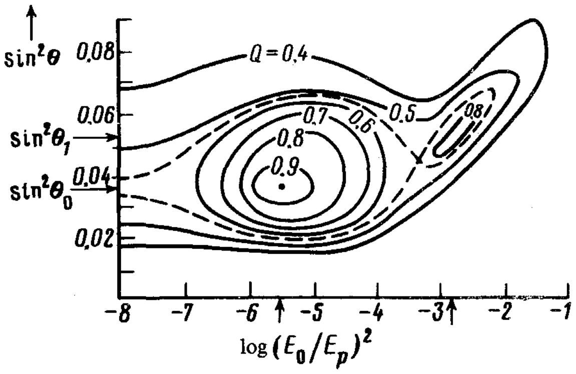

FIG. 2.

$$\frac{d^2B_y}{dz^2}+\frac{1}{\epsilon}\frac{d\epsilon}{dz}\frac{dB_y}{dz}+k_0^2(\epsilon-\gamma^2)B_y=0,$$

$$E_x=\frac{i}{k_0\epsilon}\frac{dB_y}{dz},\quad E_z=\frac{\gamma}{\epsilon}B_y,\quad \gamma=\sin\theta,\qquad k_0=\omega/c \tag{1}$$

$$\epsilon=1-\frac{n}{n_c}-i\nu\frac{n}{n_c};\ n=n_0\left(1-\frac{|E_x|^2+|E_z|^2}{E_p^2}\right);\ E_p^2=\frac{4m\omega^2T_e}{e^2};\ \nu=\frac{\nu_{eff}}{\omega}$$

[here the common factor $\exp(-ik_0\gamma x)$ is dropped]. The system of equations in (1) was solved numerically according to a procedure similar to that used in Ref. 3. The calculation results are shown in Figs. 2 and 3.

Figure 2 shows the lines of the absorption constant Q (in power) on the plane of the parameters $\sin^2\theta, \log(E_0/E_p)^2$ for a plasma of typical inhomogeneity scale $l=50k_0^{-1}$, $\nu=10^{-3}$. The dashed line, which separates the region of closed curves ["separatrix"], corresponds to an absorption coefficient that falls just short of the maximum value $Q_0=0.5$ in the linear case. The two groups of curves inside the

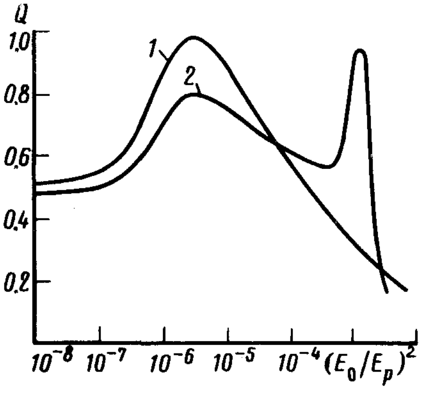

FIG. 3.

separatrix correspond to two fundamentally different resonance absorption regimes which are associated with the excitation of the quasi-static mode on the plateau[4] (relatively low power levels) and with the excitation of the quasi-surface mode at the density discontinuity (relatively large densities). The central points of each group of curves determine the ideally matched (reflectionless) absorption regimes ($Q = 1$). We should point out immediately that these points are scattered in power by almost three orders of magnitude. The position of the second point, the point of interest to us, which is linked with the new matching region, can be analytically evaluated in terms of the WKB approximation which holds at sufficiently large density jumps. For a model (Fig. 1b) distribution of the dielectric constant, we can write the conditions for the total absorption of the incident wave due to a mode-locked excitation of the quasi-surface mode as follows[2,6]:

$$\begin{gathered} \gamma^2 \equiv \sin^2\theta = \frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2} \simeq 2\epsilon_1 , \\ \nu \equiv \nu_{eff}/\omega = 4\epsilon_1 \exp\left\{ -\frac{4}{3} k_0 l (\gamma^2 - \epsilon_1)^{3/2} \right\}. \end{gathered} \tag{2}$$

In (2) we took into account that $\epsilon_2 \simeq -2\epsilon_1$ (Refs. 1 and 4), $\nu \ll 1$. The longitudinal component of the electric-field induction D on the density discontinuity is given by

$$D^2 = \frac{4E_0^2 \epsilon_1^2}{\nu} \gamma^2 (1 - \gamma^2)(\gamma^2 - \epsilon_1)^{-1/2}. \tag{3}$$

In terms of the quasi-static approximation

$$\epsilon_1 = 2^{-3/2} (D^2/E_p^2)^{1/3} \tag{4}$$

For comparison, the absorption coefficient is plotted in Fig. 3 as a function of the amplitude of the incident wave for the maximum angle of incidence $\theta_0 \simeq 0.19$ (curve 1) and for the angle $\theta_1 \simeq 0.23$ which is larger than the maximum angle (curve 2). As we can see, in the second case the absorption coefficient can reach a large value (larger than 50%) in the region of appreciable incident-radiation power level.

The results obtained by us thus suggest that a strong absorption of radiation occurs when its power level is raised. It is clearly of interest to use this effect in the search for the conditions under which a maximum amount of energy of a strong electromagnetic field can be transferred to a plasma.

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1) The explanation used by Vucoviĉ *et al.*[5] to account for this effect is not correct.

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