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PENETRATION OF MICROWAVE WITH A STOCHASTIC JUMPING PHASE (MSJP) INTO OVERDENSE PLASMAS AND ELECTRON COLLISIONLESS HEATING BY IT

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The results from a theoretical study as well as from numerical simulation of either direct or inclined incident to boundary vacuum-overcritical density plasma of the linearly polarized electromagnetic waves are discussed. The chief results of our studies are the following: (i) at considered parameters the penetration coefficient (PC) of the MSJP is about one order of magnitude higher than a PC of the wide-band regular electromagnetic wave (WREW); (ii) in particular, at inclined incident of the MSJP a electron heating is most essential and besides the electron distribution function has high energy "tail". This anomalous behavior of a penetration coefficient as well as the electron heating are connected with a jumping phase of MSJP.

Litvak and Tokman [1] have been demonstrated the useful possibility to transport waves through the region of their absorption owing use of a classical analog of quantum electromagnetic induced transparency. Fainberg et al [2] shown that the stochastic electric fields with a finite time of a phase correlation can effective heat the particles of the collisionless plasma because the inverse correlation time at interaction particle-wave in fact have a physical sense of some effective collision frequency.

In present paper the results from a theoretical study as well as from numerical simulation of either direct or inclined incident to boundary vacuum-overcritical density plasma of the linearly polarized electromagnetic waves are discussed. The dynamics of plasma electrons is described by the relativistic Vlasov equation for the distribution function and by Maxwell's equations for the self-consistent electric and magnetic fields. Ions are immobile. Our method [3] allows a fully nonlinear kinetic treatment of electron dynamics for arbitrary densities and wave intensities provided that the time step is small compared to the electron plasma period. We considered a penetration into overdense plasmas of the MSJP as well as the wide-band regular electromagnetic wave (WREW), which has the identical spectral density of signal.

The plausible mechanisms of a wave passage through a wave barrier are following:

- linear and nonlinear transformation of different waves;
- linear and nonlinear echo with help of van Kampen waves;
- linear "enlighterment" of a wave barrier ("beam antennes");
- collisional penetration of a wave into a wave barrier;
- penetration of a wave is due to the jumps of a wave phase because a penetration coefficient is proportional a phase derivative that result from a electric field derivative.

It is well to bear in mind the following mechanisms of a particle heating by waves:

- resonant absorption that is effective as result of synchronism between a wave and a particle, i.e. a temporal shift of a phase difference is equal to zero;
- collision absorption is conditioned by losing of particle-wave synchronism (therefore, efficiency is proportional to ratio of a collision frequency to a wave frequency);
- linear and nonlinear absorption into a inhomogeneous wave;
- wave absorption is due to jumps of a wave phase as result of losing of a wave-particle synchronism.

PHYSICAL MODEL

Consider the case where the electron plasma is initially homogeneity and ions are immobile. The electron distribution function is Maxwellian one with a thermal velocity V_T. Plasma density is $n(x) = n_0\theta(x)$ (where $\theta(x)$ is Heviside function; ($\omega_p > \omega_0$); ω_p and ω_0 are the electron plasma frequency and the wave frequency, respectively. Electromagnetic wave have: $\vec{k} = (k_x, k_y, 0)$, $\vec{E} = (E_x, E_y, 0)$, $\vec{B} = (0, 0, B_z)$, at

$$x = x_L,\ E_y^{sf}(t) = B_z^{sf}(t) = F_0\cos(\omega_0 t + \tilde{\varphi}(t)), \quad (1)$$

where $\tilde{\varphi}(t)$ is steady state Poisson`s stochastic process with a frequency $1/\tau_0$ and into a interval $[-\pi, \pi]$. Correlation coefficient of such stochastic process is:

$$R(t) = \exp\left(-\frac{|t|}{\tau}\right)\cos\omega_0 t,$$

Spectrum density of this signal is [3]:

$$G(\omega) = \frac{1}{(1/\tau)^2 + (\omega - \omega_o)^2}.$$

The wide-band signal that has a such spectral density corresponds set of a regular modes with slow changing in time a phase φ^{nf} as well as an amplitude F^{nf} for each mode [3] a namely:

$$E_y^{nf}(t) = B_z^{nf}(t) = F^{nf}\cos\left(\omega_{nf}t + \varphi^{nf}(t)\right). \qquad (2)$$

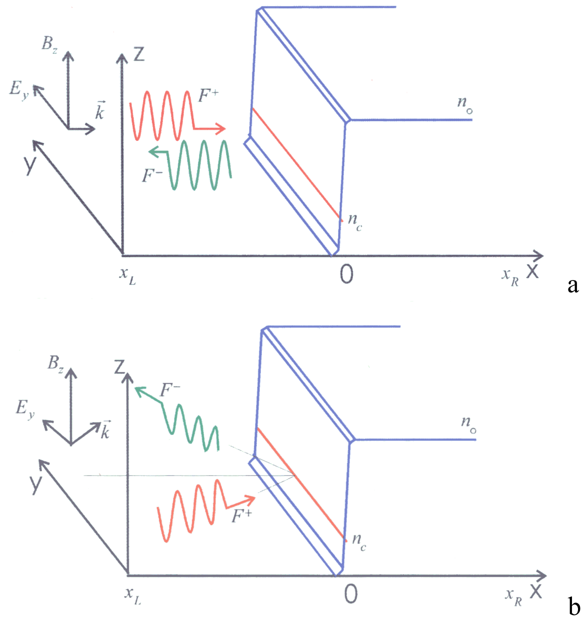

Fig. 1. Scheme of a model region:
a) - direct wave incident upon the surface;
b) - inclined wave incident upon the surface

Besides we considered a penetration in plasma a monochromatic electromagnetic wave:

$$E_y^{mf}(t) = B_z^{mf}(t) = F_0\cos(\omega_0 t). \qquad (3)$$

BASIC EQUATIONS AND NUMERICAL METHODS

The electron dynamics is described by the Vlasov equations for a distribution function $f(t, x, p_x, p_y)$:

$$\frac{\partial f}{\partial t} + V_x\frac{\partial f}{\partial x} + e\left(E_x + \frac{V_y}{c}B_z\right)\frac{\partial f}{\partial p_x} + e\times.$$

$$\times\left(E_y - \frac{V_x}{c}B_z\right)\frac{\partial f}{\partial p_y} = 0 \qquad (4)$$

The longitudinal electric field for one dimensional case may be obtain in agree to Gauss formula:

$$E_x = E_x|_{x=x_L} + 4\pi\int_{x_L}^{x}\rho(\xi)\,d\xi. \qquad (5)$$

In the plane case Maxwell equations for self-consistent electromagnetic fields have a form:

$$\frac{1}{c}\frac{\partial E_y}{\partial t} + \frac{\partial B_z}{\partial x} = -\frac{4\pi}{c}j_y,$$

$$\frac{1}{c}\frac{\partial B_z}{\partial t} + \frac{\partial E_y}{\partial x} = 0,$$

and, if we enter the auxiliary fields $F^{\pm} = E_y \pm B_z$, are split in two of the such equations

$$\left(\frac{1}{c}\frac{\partial}{\partial t} \pm \frac{\partial}{\partial x}\right)F^{\pm} = -\frac{4\pi}{c}j_y, \qquad (6)$$

where the charge density ρ and the transversal current density j_y are defined as:

$$\rho = e\left(n_0 - \int f(x,\vec{p})\,d\vec{p}\right), \qquad (7)$$

$$j_y = e\int\left(V_y(x) f(x,\vec{p})\,d\vec{p}\right). \qquad (8)$$

The boundary conditions to transversal and longitudinal E_x fields have a form:

$$E_x|_{x=x_L} = 0, \quad F^+|_{x=x_L} = F(t), \quad -F^-|_{x=x_R} = 0, \qquad (9)$$

where $F(t)$ is a relation from (1), (2) or (3). To a numerical simulation we used our code SUR [4, 5] at following parameters: $V_y^{osc} = 3V_T$, $\omega_0 = 0.5\omega_p$, $\tau = 40/\omega_p$, $x_L = -1000\lambda_D$, $x_R = 1000\lambda_D$, fall length of a ion profile $\Delta L = 50\lambda_D$, $L = 5000$, λ_D Debay length.

RESULTS OF NUMERICAL SIMULATION

The results of numerical simulation exhibited in Figs.2 – 4 (see also the preliminary results in [6]. The penetration coefficient defined as ratio of a penetration-wave energy flow (at $x = x_R$) to incident-wave energy flow (at $x = x_L$) with a corresponding time shift.

To numerical simulation of inclined incident of electromagnetic radiation to boundary vacuum-plasma the such parameters were used as to direct incident with the exception only of plasma size that was $L = 2500$. In this case an incident electromagnetic radiation render a strong influence to plasma electrons (in particular at big incident angles. The longitudinal fields are close to transversal one`s. The longitudinal electron energy (and their temperatures) grows more than once. The electron distribution function is non-Maxwellian function because the accelerated electron “tail”. The incident transversal electromagnetic waves is transformed partially in a longitudinal wave as well as electron energy.

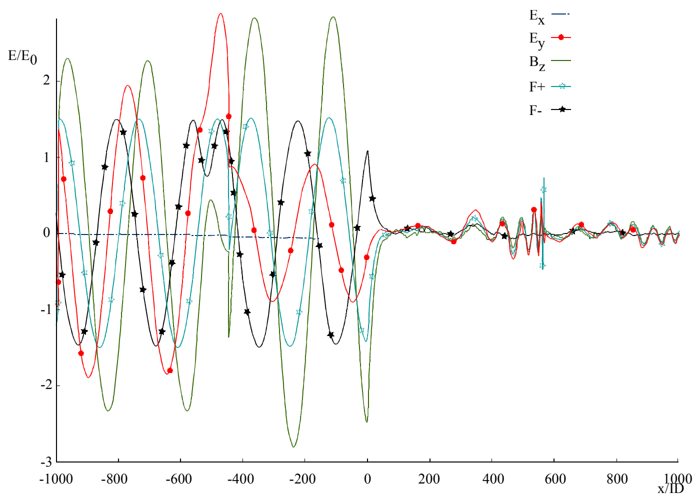

Fig. 2. Spatial distribution of the incident (F+), the reflected (F-) and the penetrated into plasma (Ex, Ey, Bz) waves. Plasma boundary is at $x/lD = 0$

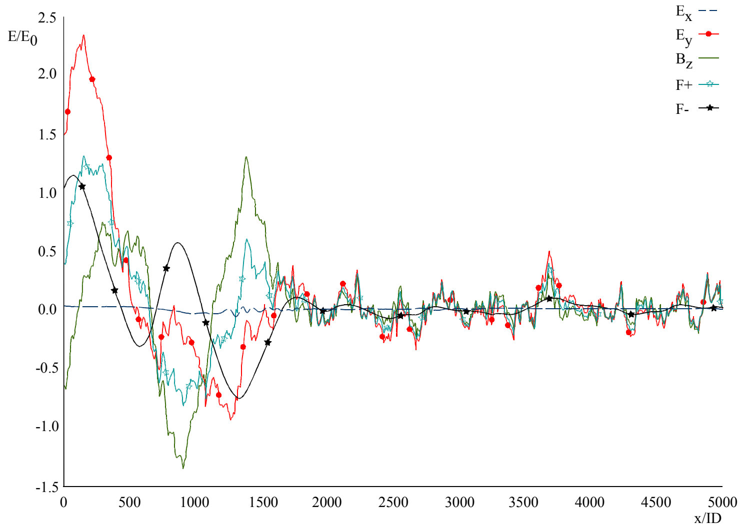

Fig. 3. Spatial distribution of incident, reflected and penetrated into the plasmas (Ex, Ey, Bz) waves for a signal with the regular phase jumping. The plasma boundary is located at . $x/D = 1500$. Period of regular phase jumping is τ=40/ω_p.

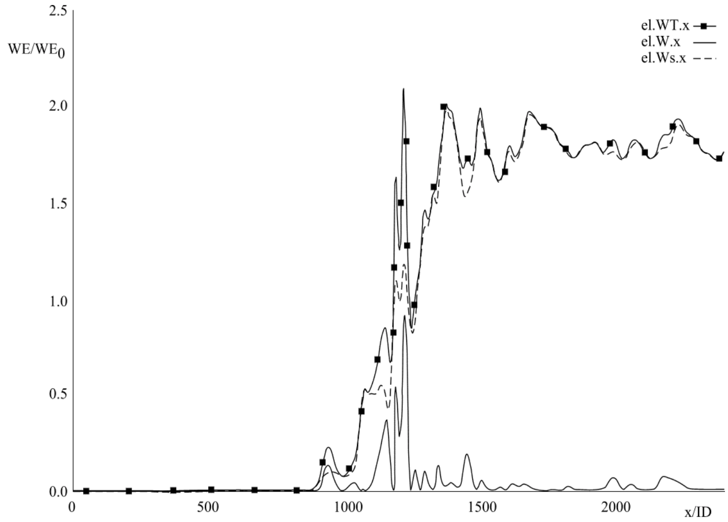

Fig.4. Spatial energy distribution of longitudinal field at inclined incident for regular (W.x) and stochastic (Ws.x) radiation and radiation with regular phase jumping within the time interval τ - (WT.x). The plasma boundary is located at $x/D = 1000$

To illustration we depicted a character experimental oscilloscope of the stochastic signal realization

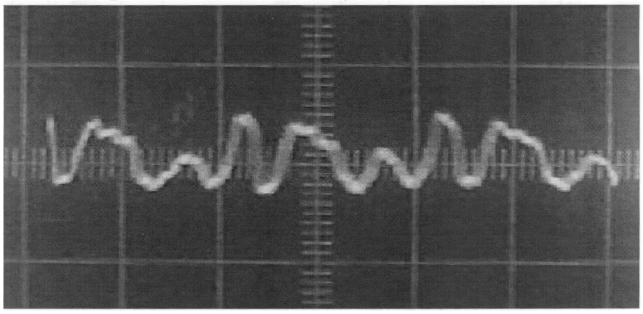

Fig.5. Some experimental realizations of microwave with a stochastic-jumping phase

CONCLUSION

The chief results of our studies are the following:(i) at considered parameters the penetration coefficient (PC) of the MSJP is about one order of magnitude higher than a PC of the WREW; (ii) in particular, at inclined incident of the MSJP a electron heating is most essential and besides the electron distribution function has high energy “tail”. This anomalous behavior of a penetration coefficient as well as the electron heating are connected with a jumping phase of MSJP.

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