TRANSITION RADIATION OF THE MODULATED ELECTRON STREAM IN THE STRONGLY INHOMOGENEOUS MAGNETIZED PLASMA

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Transition radiation of the modulated electron stream moving along the concentration gradient of the cold planarly stratified strongly inhomogeneous plasma is calculated for the case of strong external magnetic field parallel to the concentration gradient

PACS: 52.40.Mj

1. INTRODUCTION

Transition radiation of the modulated electron beams in the inhomogeneous plasma is particularly interesting due to the possible construction of the beam-plasma devices of direct radiation [1]. In the laboratory experiments beam-plasma systems are usually placed into the external magnetic field, that prevents the swelling of the beam. Therefore plasma is anisotropic. The simplest model of the anisotropic plasma corresponds to the infinitely strong magnetic field. Transition radiation of the modulated electron stream in the magnetized plasma is studied, e.g., in [2-5]. It is shown that this process is most effective in the local plasma resonance region (LPRR), where the modulation frequency coincides with the electron plasma frequency, and in the local Cherenkov resonance region (LChRR), where the electron beam velocity coincides with the phase velocity of electromagnetic waves. In the LChRR predominantly the wave co-directional with the beam is excited. In the weakly inhomogeneous plasma the contribution from the LPRR and LChRR can be calculated separately. In the general case, when the distance between the LPRR and the LChRR is arbitrary, it is impossible to make analytical calculations. Therefore numerical methods are used. This report contains the results of numerical computations for the case when the characteristic length of the inhomogeneity is less or of the order of the radiated wave.

2. MODEL DESCRIPTION AND BASIC EQUATIONS

Cold planarly stratified plasma is considered. Strong magnetic field is directed parallel to the concentration gradient (Fig.1). Monoenergetic electron stream moves along the magnetic field forming the current density wave.

$$\vec{j}(\vec{r},t) = \vec{e}_z j_m \exp\left[i(\omega t - \vec{\kappa}\vec{r})\right], \vec{\kappa} = \left\{0; \kappa_\perp; \kappa_{//}\right\}, \quad \kappa_{//} = \omega / v_0 \qquad (1)$$

The direction of the wave vector of current density wave makes the angle to the magnetic field direction. The plasma concentration first linearly increases from *0* to $2n_c(\omega)$, where $n_c(\omega)$ is the critical concentration at the modulation frequency ω, and then remains constant (2).

$$n_p(z) = \begin{cases} 0, \ z \le -L; \\ \dfrac{m\omega^2}{4\pi e^2}\left(1 + \dfrac{z}{L}\right), \ -L < z < L; \\ \dfrac{m\omega^2}{2\pi e^2}, \ z \ge L, \end{cases} \qquad (2)$$

Transition radiation for such model was calculated in the approximation of the given current.

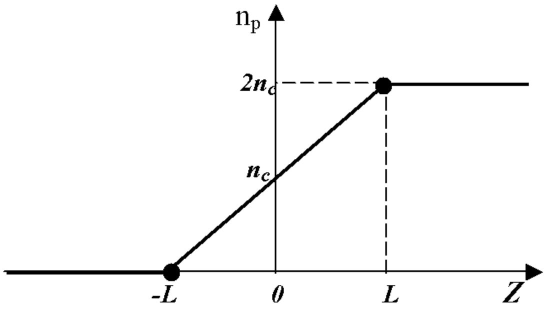


Fig.1. Plasma concentration profile

The equation that describes the electromagnetic wave excitation by the current wave has a form:

$$\frac{d^2 H_x}{dz^2} + \left(k_0^2 - \frac{\kappa_\perp^2}{\varepsilon_{//}}\right)H_x = i\frac{4\pi\kappa_\perp}{c\varepsilon_{//}} j_m \exp(i(\omega t - \kappa_{//} z)) \qquad (3)$$

The method of Green's function was used for calculating the values of the amplitudes of electromagnetic waves.

$$H(z) = Y_1(z)\int_{-\infty}^{z} \frac{Y_2(z) f(z)}{W} dz + Y_2(z)\int_{z}^{\infty} \frac{Y_1(z) f(z)}{W} dz \qquad (4)$$

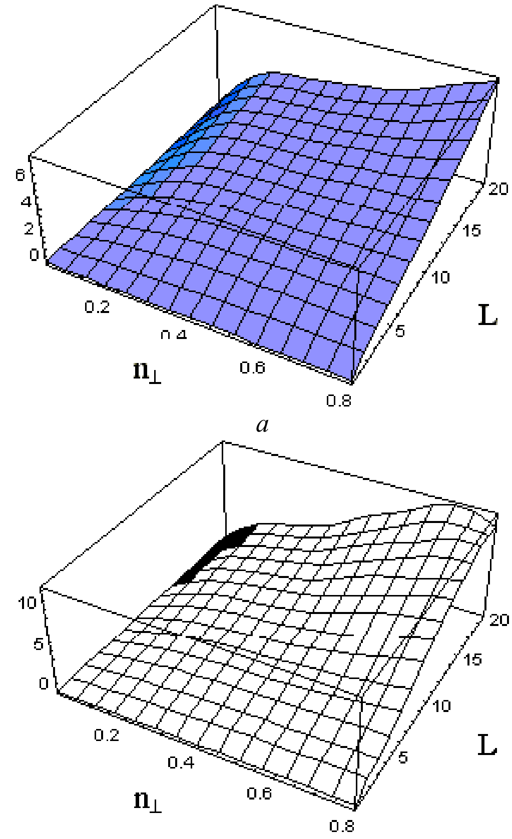
$Y_{1,2}$ - the solutions of the homogeneous wave equation (3).

Contributions from the integrals (4) into the radioemission magnitudes are given by the interval $-L<z<L$ with a non-zero concentration gradient and by the points $z=-L$ and $z=L$ where concentration gradient jump takes place. For large *L* the main contribution from the interval $-L<z<L$ is made by the vicinity of the resonant points, i.e. LPRR and LChRR. Contribution from the concentration gradient jumps forms the non-resonant component of the radioemission. With increasing of the

characteristic length of the inhomogeneity the contribution from the resonance points grows and the non-resonant component decreases.

3. RESULTS AND DISCUSSION

For the modulated electron beams moving into the plasma, emission both into plasma (Fig. 2a, 2b, 3a) and into vacuum (Fig. 3b) monotonically increases with the increasing of the characteristic length of the inhomogeneity *L* and the beam velocity. For the case of large *L* the radiated power dependence on the transversal component of the wave vector $\kappa_\perp$ of the current density wave becomes non-monotonic. Emission into the vacuum is considerably less. Depending on $\kappa_\perp$ it has maximum, which moves to smaller $\kappa_\perp$ with the increasing of *L*.



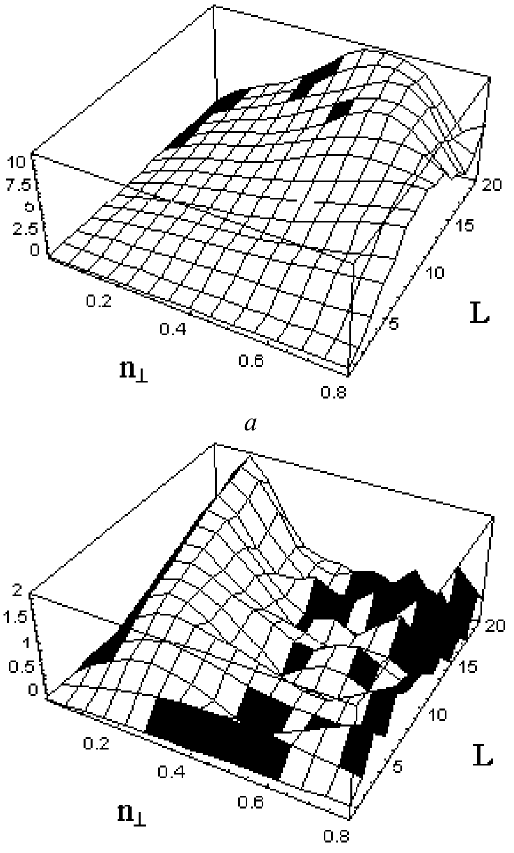
a

b

Fig. 2. Emission into the dense plasma for the stream moving into the plasma for β =0.1 (a) and for β =0.3 (b)

For the beams moving from plasma, emission into the plasma (Fig. 4a) considerably decreases and becomes approximately equal to the emission into the vacuum (Fig. 4b). It should be noted that analytical calculation for the weakly inhomogeneous plasma doesn't give any radiation into the plasma for this case. The dependence of the emission power in both directions on the parameters of model is approximately the same as for the beam moving into plasma.

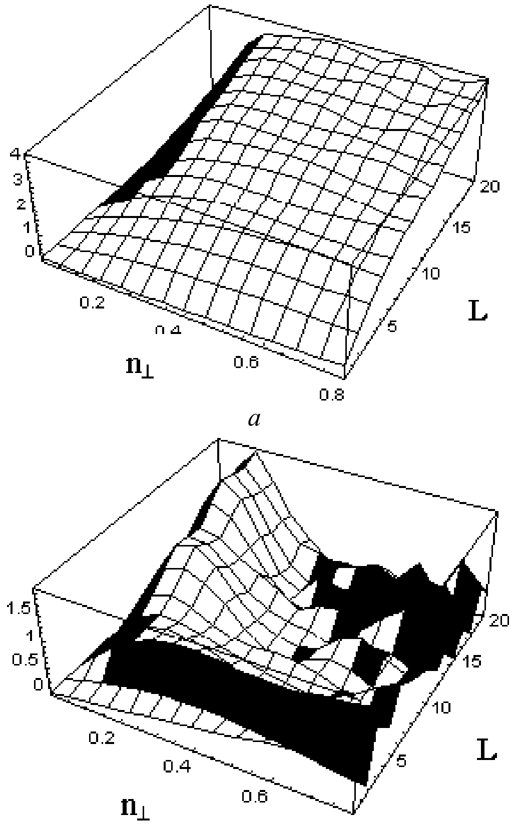
Thus, for the small *L* the dependence of emission on the direction of the electron stream is less noticeable. This is explained by appearing of the significant nonresonant component, caused by the growth of the concentration gradient of the plasma.



a

b

Fig.3. Emission into the dense plasma (a) and into the vacuum (b) for the stream moving into the plasma (β =0.5)



a

b

Fig.4. Emission into the dense plasma (a) and into the

vacuum (b) for the stream moving into the vacuum(β =0.5)

The value of emission both into the vacuum and into the plasma considerably depends on the velocity of the modulated electronic stream (Fig. 2a, 2b) and increases for the higher-energy beams in general.

The dependence of the amplitude of emission on the parameter κ ($\kappa=\omega/v_0$) is shown on the Fig. 5. The sign of k determines the direction of the electron stream ($\kappa>0$ – into the plasma, $\kappa<0$ – into the vacuum). This dependence is approximately the same as in the case of isotropic plasma.

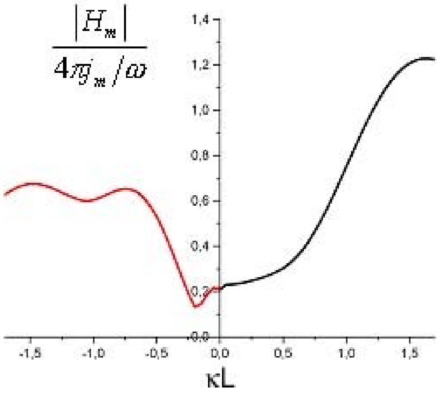


Fig. 5. The normalized amplitude of emission versus κL

For the modulated electron beams moving into the plasma the radiated power (the right side of the Fig.5) increases with the growth of the parameter κ. This result can be explained by increasing of the characteristic dimension of the resonance region (Lv/ω), where interaction of the modulated electron beam with the electric field of the excited wave is most substantial (with increasing of L) or by increasing of the holding time of electrons in this region (with increasing of κ, i.e. with decreasing of the stream velocity).

For the modulated electron beams moving from the plasma the radiated power (the left side of the Fig.5) is non-monotonic. This can be explained by the fact that, when the direction of electron stream changes, the phase correlation of the emission field, concerned with the jump of the refraction index, and the radiation from the LPRR and LChRR change to the opposite. For the modulated electron stream moving into the plasma these fields are co-phased, and for the stream moving from plasma they are anti-phased, so they can compensate each other under some conditions.

4. CONCLUSION

1. The most intensive transformation of the current wave of the modulated electron stream into the electromagnetic waves occurs in LChRR and LPRR and in the vicinity of the reflection point.
2. For the modulated electron beams moving into the plasma, electromagnetic waves are emitted predominantly into the dense plasma. Emission into the vacuum penetrates through the opacity barrier.
3. For the modulated electron beams moving into the vacuum, electromagnetic waves are emitted both into the dense plasma and into the vacuum. Emission into the plasma approximately equal to the emission into the vacuum.

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