INTERACTION OF THE MODULATED ELECTRON BEAM WITH INHOMOGENEOUS PLASMA: PLASMA DENSITY PROFILE DEFORMATION AND LANGMUIR WAVES EXCITATION

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Nonlinear deformation of the initially linear plasma density profile due to the modulated electron beam is studied via computer simulation. In the initial time period the field slaves to the instantaneous profile of the plasma density. Langmuir waves excitation is suppressed by the density profile deformation. The character of the plasma density profile deformation for the late time period depends significantly on the plasma properties. Particularly, for plasma with hot electrons quasi-periodic generation of ion-acoustic pulses takes place in the vicinity of the initial point of plasma resonance.
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1. INTRODUCTION

Propagation of the modulated electron beam through inhomogeneous plasma is typical for plasma electronics. Strong longitudinal electric field is excited in the local plasma resonance region (LPRR) at the modulation frequency [1] in this case. This field excites Langmuir waves [2] and ion-acoustic waves [3] in plasma. The study of such effects is important particularly in the frames of construction of beam-plasma devices with direct radioemission, using of electron beams for radio waves' emission in the space, etc.

2. SIMULATION METHOD AND PARAMETERS

Simulation of the modulated electron beam interaction with inhomogeneous plasma was carried out via particle-in-cell method using the modified package PDP1 [4]. In this package plasma layer is located between two conductive electrodes. The plasma treated was fully ionized. Initial plasma density profile was linear. Density modulated electron beam (modulation depth is 100%) moved from left electrode to right one. The beam current and velocity v_0 as well as the characteristic inhomogeneity length L were selected so that the charge density profile in LPRR did not differ strongly from the sinusoidal shape [5]. For all the cases treated electron density in the beam was small relatively to the background plasma.

Simulation was carried out for such parameters. Plasma density was $(1\text{-}3)\cdot10^{14}$m^{-3} ($f_{pe}=(0.74\text{-}2.20)\cdot10^8$Hz). Length of the simulation region was 2m (characteristic length of inhomogeneity was L=1.5m). Plasma electrons' temperature was 22eV; plasma ions' temperature was 0.1eV (hydrogen), 0.03eV (xenon). Beam velocity was $7\cdot10^7$m/s ($v_0/v_{Te}=35$, $v_0/c=0.23$). Beam modulation frequency was $f=1.1\cdot10^8$Hz (critical density was $n_c=1.5\cdot10^{14}$m^{-3}).

3. INITIAL PERIOD OF TIME

In the initial time period ($f{\cdot}t\leq5$) space-time distributions of field replicated corresponding distributions of the beam current density. Consequently only stimulated oscillations excited by the beam existed in plasma in that period.

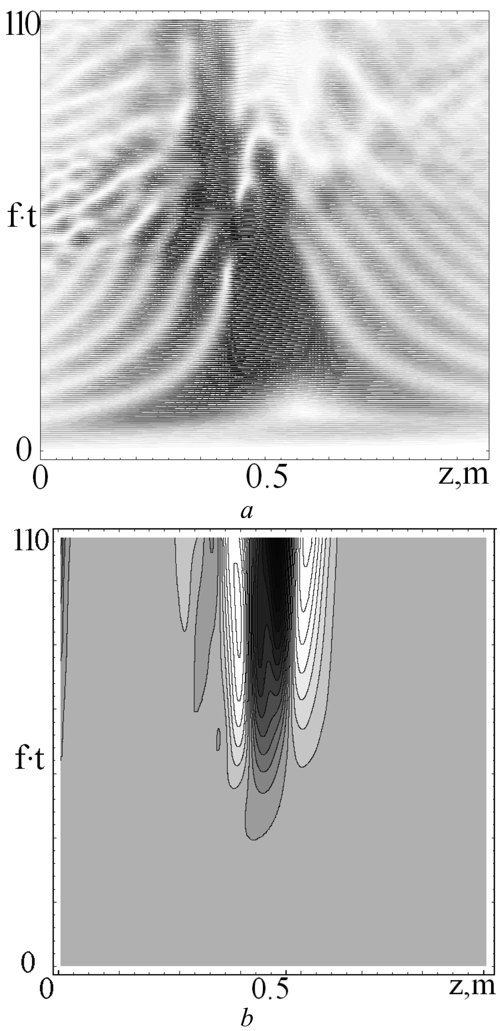

Fig.1. Space-time distribution of the absolute value of electric field (a) and distribution of the ion density (b) for hydrogen ions, j_m=3A/m^2

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In the interval $f{\cdot}t$=(5-40) the space-time distributions typical for linear oscillations were gradually formed (see Fig.2a,b). Maximum of electric field appeared and gradually moved from the subcritical plasma to LPRR. The phase velocity of electric field in this region changed its sign [5]. These effects are caused by interaction of the field of modulated electron beam, Langmuir wave and wake waves [1]. The beam field has the spatial and temporal periodicity of the beam modulation. Langmuir wave is excited by the beam at the modulation frequency and propagates from LPRR to the subcritical plasma. The wake waves are excited at the local plasma frequencies by the forefront of electron beam.

Maximum of the electric field amplitude took place at $f{\cdot}t$=45, later this amplitude gradually decreased (Fig.3a). Oscillations of maximal amplitude became inharmonic. Particularly the constant component of electric field appeared. It pulls the electrons out from the region of maximal field amplitude. Later the oscillations became harmonic again.

The main peak of the field oscillations disappeared approximately at $f{\cdot}t$=65. The new peak was formed on the left side of it (in the subcritical plasma, see Fig.1c).

The peak of electric field amplitude in LPRR results to the plasma density profile deformation. For the parameters selected the transient time of electric field excited by the beam is small relatively to the characteristic time of the plasma density profile perturbation. Simulation demonstrated that the field slaved to the instantaneous profile of the plasma density. The initial shape of the density cavity was determined by the spatial distribution of electric field for the linear stage of the process [6].

4. LANGMUIR WAVES' EXCITATION

It is clear from Fig.2a that after the field establishing in the LPRR Langmuir waves (LW) start propagation from this region to the subcritical plasma (for $ft\geq 55$). Later their amplitude remained approximately constant. For *ft~65-80* the stationary spatial distribution of the amplitudes is formed [1, 5]. It is caused by the interference of the LW and electrons' oscillations excited by the beam field.

The LW phase velocity is decreased far from LPRR (Fig.2b). The magnitudes of phase velocity v_{ph}, (along the line AA', Fig.2b) and group velocity v_g (along the line AA', Fig.2a) found from the simulation results are in good agreement with the estimations for the parameters selected ($6.4{\cdot}10^6$m/s and $8.5{\cdot}10^6$m/s for v_{ph}, $1.35{\cdot}10^6$m/s and $1.41{\cdot}10^6$m/s for v_g).

Nonlinear deformation of the plasma density profile results to significant decrease of the LW excitation effectiveness (see Fig.3).

5. ION-ACOUSTIC WAVES EXCITATION

The character of the plasma density profile deformation depends significantly on the plasma properties. For isothermal plasma the density step is formed on the initial LPRR position [7].

For plasma with hot electrons formation of the density cavity in LPRR results to excitation of the ion-acoustic

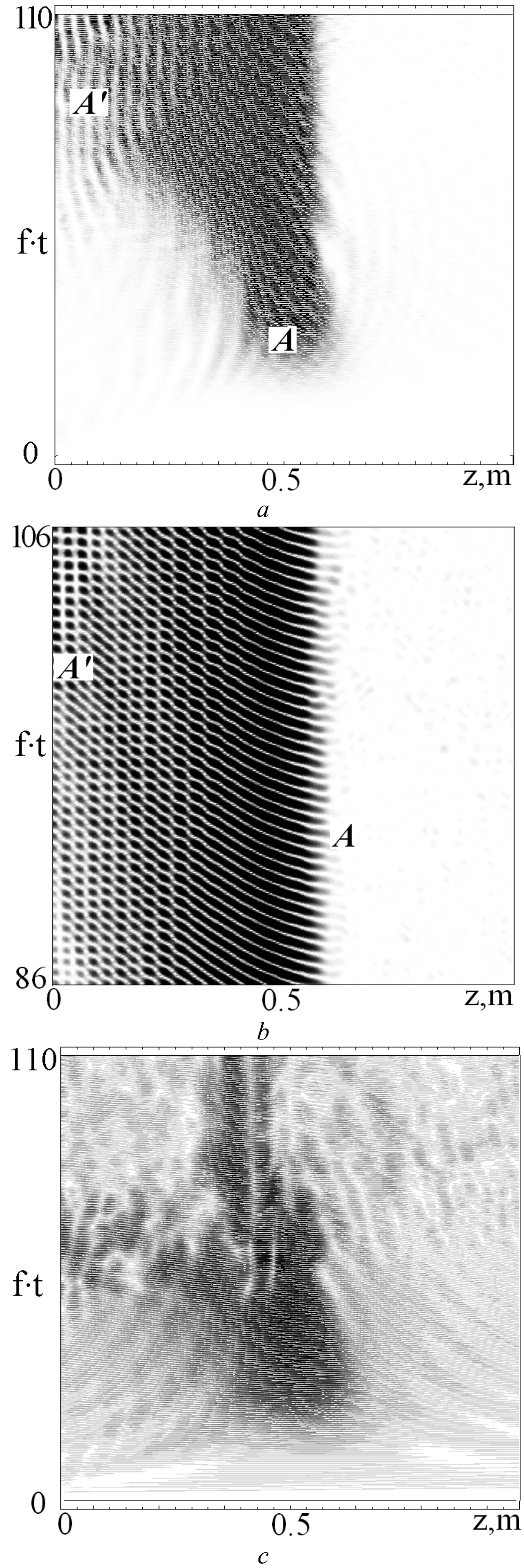

Fig.2. Space-time distribution of absolute value of the difference of electron and ion densities for linear profile of plasma density. Simulation parameters: xenon ions, j_m=0.3A/m^2 (a, b); hydrogen ions, j_m=3A/m^2 (c)

pulses. These pulses propagate forward and backward from the cavity (Fig.3). New peaks of electric field are excited at the local density maximums formed by these

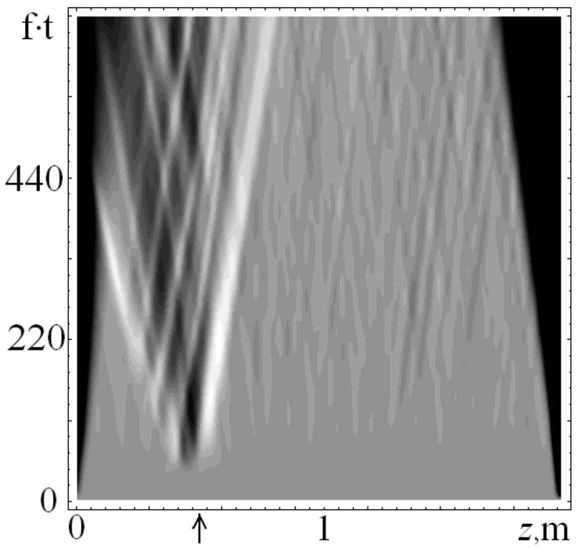

Fig.3. Space-time distribution of the ions' density perturbation. The arrow shows the local plasma resonance point

pulses in subcritical plasma. These peaks form in turn the new couples of ion-acoustic pulses.

These pulses propagate in plasma with hot electrons without damping. Consequently in the late time points the region of irregular ion-acoustic oscillations is formed in the vicinity of initial LPRR [7]. Ion-acoustic character of the oscillations referred is indicated by their velocity and by coincidence of electron and ion density profiles.

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ВЗАИМОДЕЙСТВИЕ МОДУЛИРОВАННОГО ЕЛЕКТРОННОГО ПУЧКА С НЕОДНОРОДНОЙ ПЛАЗМОЙ: ДЕФОРМАЦИЯ ПРОФИЛЯ КОНЦЕНТРАЦИИ ПЛАЗМЫ И ВОЗБУЖДЕНИЕ ЛЕНГМЮРОВСКИХ ВОЛН

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С помощью компьютерного моделирования исследуется нелинейная деформация первоначально линейного профиля концентрации плазмы модулированным электронным пучком. В начальные моменты времени поле подстраивается под мгновенное распределение концентрации плазмы. Возбуждение ленгмюровских волн ограничивается деформацией профиля концентрации. Характер деформации профиля концентрации плазмы существенно зависит от параметров плазмы. В частности, для плазмы с горячими электронами в окрестности первоначальной точки плазменного резонанса имеет место квазипериодическая генерация ионно-акустических импульсов.

ВЗАЄМОДІЯ МОДУЛЬОВАНОГО ЕЛЕКТРОННОГО ПУЧКА З НЕОДНОРІДНОЮ ПЛАЗМОЮ: ДЕФОРМАЦІЯ ПРОФІЛЮ КОНЦЕНТРАЦІЇ ПЛАЗМИ ТА ЗБУДЖЕННЯ ЛЕНГМЮРІВСЬКИХ ХВИЛЬ

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За допомогою комп'ютерного моделювання досліджується нелінійна деформація первісно лінійного профілю концентрації плазми модульованим електронним пучком. В початкові моменти часу поле підлаштовується під миттєві розподіли густини плазми. Збудження ленгмюрівських хвиль обмежується деформацією профілю концентрації. Характер деформації профілю концентрації плазми істотно залежить від параметрів плазми. Зокрема, для плазми з гарячими електронами поблизу первісної точки плазмового резонансу має місце квазіперіодична генерація іонно-акустичних імпульсів.