ABOUT INFLUENCE OF EFFECTS NONEQUILIBRITY AND NONLOCALITY ON THE PARAMETERS OF THE DISCHARGE SUSTAINED BY SURFACE WAVES

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The kinetic equation for plasma in two-dimensional non-uniform field of a surface wave was obtained. At the approximation of predetermined field there were found the distribution functions in dependence on the value of a coefficient of spatial attenuation. With using such distribution functions such plasma characteristics as density, frequency of elementary processes, diffusion coefficients, number of particles falling down to the wall, were calculated. There was shown that in high frequency electric field transport may also have anisotropic character. Taking this into account the "correct" hydrodynamic equations were obtained. Comparison with earlier known results was carried out. As result of this work it is possible to state – taking into account the non-equilibrium and nonlocal properties is important for description of discharges sustained with surface waves.
PACS: 52.80.-s

It is well known, that a field of a surface wave is two-dimensionally non-uniform [1], for example in the cylinder it penetrated on radius and attenuates along a direction of propagation. Usually kinetic theory of the discharge sustained surface waves (SW), for example, axial – symmetric is built in approach of axial uniform of a field [2,3]. This assumption simplified the problem. It is valid only in approach of a "thin" waveguide, when it is possible really to neglect by attenuation of a wave stipulated by Coulomb collisions. However, if resonant attenuation SW to take into account stipulated by transformation SW in body waves [1,4-5] the situation sharply varies.

In the kinetic equation it is necessary to take into account addends which are proportional to lapse rates of a distribution function. The factors facing to these addends are proportional to coefficient of spatial attenuation α. Generally they contain the additive contribution from three mechanisms: Coulomb collisions, Landau's mechanism and transformation of waves in a point of a plasma resonance [1].

The kind of the solution of the kinetic equation depends on value of coefficient of spatial attenuation. At rather small coefficients of spatial attenuation (without the account of resonant attenuation contribution from addends proportional to lapse rates is possible to take into account on a perturbation theory to lapseless to the local solution [6]. If attenuation is not a little (all three mechanisms of attenuation), for the degree laws of dependence of a field from coordinate both collision and ionization frequencies from energy are taken into account

$$\nu_{en}(\varepsilon) = \nu_0 \varepsilon^p, \nu_{ion}(\varepsilon) = \theta \varepsilon^q, E_r(r) = E_1 r^{l_1}, E_z(r) = E_2 r^{l_2}$$

$$\varepsilon = u - e\varphi_A(r,z) = \frac{mv^2}{2} \qquad (1)$$

where: ν_{en} frequency of quasi-elastic collisions, ν_{ion} frequency of ionization, $E_{1,2}$ amplitudes of radial and axial components of a field of a wave accordingly, ε a kinetic energy of electrons, φ_A ambipolar potential, u a total energy of electrons, e, m a charge and mass of particles accordingly, ν_0, θ - constants independing from energy, p, q, l_1, l_2 numbers; than it is possible to find the automodel solution of the kinetic equation:

$$f_0(u,r) = \frac{f(\xi)}{r^\beta}, \xi = \frac{r}{u^\beta} \qquad (2)$$

where β and β_1 are numbers.

At rather small coefficients of spatial attenuation EDF represents local distribution with distortion in the field of major energies (in a tail part EDF), since

$$\varepsilon_1^* = T_e\left(\frac{e\varphi_A}{T_e}\right)\left(\frac{e\varphi_A}{T_0 + \frac{e^2E^2}{3m\delta\omega^2}}\right)\alpha^{1/3} > T_e, \qquad (3)$$

where: T_e - "temperature" of electrons, T_0 temperature of neutral gas, δ - part of energy, transmitted at one collision, ω frequency of a field SW.

If attenuation is not a little, then "body" EDF is subject also to distortion, and the distortion in the field of a tail begins at smaller values of energy $T_e < \varepsilon_2^* < \varepsilon_1^*$. The depletion EDF is characteristic for both cases in the field of a tail, i.e. the waning EDF goes faster, than exponential curve. Hence, EDF becomes nonmaxwellian and nonlocal, since depends on a field in across section.

The basic difficulty of the theory of non-uniform gas-discharge plasma is stipulated by the following factors: the spatial distribution of a field beforehand, as a rule, is not known. It is determined by a lateral view of concentration and source distribution of ionization, i.e. shape of electrons distribution function. And the electrons distribution function (EDF), in turn, is shaped by a field [6]. This complexity bypass as follows. The kinetic equation is solved in approach of a given field. In our case it is equivalent to the task of a lateral view of ambipolar potential (field of a surface wave obeys to Maxwell equations, therefore it is considered as given). Its lateral view is selected as degree function [7]. At local distribution EDF is possible to present as:

$$f_0(u,r) = n(r) f_0(u) \qquad (4)$$

where the function f_0 is normalized on unity:

$$4\pi\sqrt{\frac{2}{m^3}}\int_0^\infty \sqrt{u} f_0(u) du = 1 \qquad (5)$$

In a nonlocal case factorized EDF is impossible, therefore it is normalized on density:

$$n(r,z) = 4\pi\sqrt{\frac{2}{m^3}}\int_0^\infty \sqrt{u}\, f_0(u,r,z)du \qquad (6)$$

Now, knowing EDF and setting ambipolar potential distribution as degree function [7]:

$$\varphi_A = \varphi_{wall}\{(1-[\frac{2z}{L}-1]^{p_1})(1-(\frac{r}{R})^{p_2})\} - \varphi_{wall} \quad (7)$$

where: R-radius of a wave guide, L- length of the discharge (distance on which density of plasma decreases from the peak value n_0 up to underload n_{cr}), φ_{wall} - potential of a wall (thus ambipolar potential can not exceed potential of a wall). From this requirement we determine spatial distributions of density (both radial, and axial):

$$n(r,z) \propto \left(1-\left[\frac{2z}{L}-1\right]^{p_1}\right)\left(1-\left(\frac{r}{R}\right)^{p_2}\right) \qquad (8)$$

Their analysis shows difference of radial density distribution from the Bessel function of an order zero, and the axial distribution has nonlinear character.

If we know EDF, the ambipolar field distribution and transport coefficients, then we can find the kinetic coefficients, such as frequency of ionization and excitation frequency, complete number of inelastic collisions and quantity of particles hitting on walls. In other words, it is possible to obtain many parameters of the discharge within the framework of the simplified theory and qualitatively to estimate a role of effects of a non-equilibrium and nonlocality.

Many theories of the discharge are grounded on the hydrodynamic approach [8,9]. It’s much easier and consequently so attractively. On their basis the model operation explicates also in view of two-dimensional inhomogeneity and nonlinearity [10]. But an overwhelming majority of these operations guess, background EDF is nonmaxwellian. As the minimum three reasons exist in real laboratory plasma on which EDF is declined from equilibrium: spatial boundedness, presence of an external field and inelastic processes. What will be with these results if to take into account nonequilibrity? As a minimum the kinetic coefficients the included in hydrodynamic equations can vary.

On the other hand, it is known [11], if nonequilibrity is stipulated by a field, the hydrodynamical equations become simpler and are reduced to one equation of a continuity (diffusion) in which coefficients are determined equilibrium EDF in view of a series development on lapse rates of all quantities giving in change EDF. If nonequilibrity is stipulated by a combined effect of inelastic processes and field, the hydrodynamic equations in which inelastic processes renormalized kinetic coefficients [12] is gained.

Having EDF it is easy to receive the hydrodynamic equations for numbered kinds of nonequilibrity. Supplementing these equations, equation for a field, we shall receive combined equations featuring the discharge within the framework of hydrodynamics are based on nonequilibrity EDF. Further, already by known expedient [9] easy to receive: axial and radial plasma density distributions, condition of an ignition, diffusion constants and drift velocity, expression for effective length of the discharge:

$$L_{eff} = 4R\frac{\omega}{\nu_{en}}\ln^{-1}(\frac{n_0}{n_{cr}}-1) \qquad (9)$$

within the framework of a field non-equilibrium and in case of a non-equilibrium stipulated by a combined effect of a field and inelastic processes

$$L_{eff} = 4R\frac{\omega}{\nu_{en}}\ln^{-1}(\frac{\frac{n_0}{n_{cr}}}{1+\langle Q_{inel}\rangle}-1) \qquad (10)$$

where Q_{inel} is the addend corresponding for inelastic processes.

Comparing these characteristics with results obtained on the basis of the usual hydrodynamic equations [9] it is possible to see a series of differences: the radial distribution of density by more flater (it is especially strong expressed at automodel distribution), the axial distribution becomes nonlinear (that is according to [5]); effective length of the discharge diminishes in relation to results of the local theory (at automodel distribution the discharge most shorter), the condition ignition became approximate and nonlocal. And it means that the non-equilibrium and nonlocality is significantly changed all discharge characteristics.

Only in approach of a “thin” waveguide, when the role lapse rate of the terms in the kinetic equation diminishes and, hence, EDF is close to local and the results of both hydrodynamics are close. It means, that the existing hydrodynamic theories are restricted to approach of a “thin” waveguide. For wide waveguide these theories give wrong results.

The appearance of an anisotropy of transport coefficients is characteristic for the discharges in stationary electric fields, but this anisotropy disappears in high-frequency (HF) field [11]. If HF field amplitude depends on time, than it is equivalent to the account of a time increment (decrement). This situation is realized, for example, when the surface wave is excited by a beam of charged particles or exterior electromagnetic wave [13].

Picking a field in appropriate way, we shall receive the kinetic equation extending all known and having the relevant passages to the limit. Already at a level of the equation the occurrence of an anisotropy of transport coefficients is visible, since there are corresponding for a drift stream and operation of a field above a diffusion stream. Naturally this anisotropy will enter and the solutions for EDF and in discharge characteristics on the basis of a kinetics.

The hydrodynamical equations become anisotropic, the transport coefficients along a field and across are different, that is stipulated by distinction of a field components of a surface wave and renormalization of drift velocity.

On the basis of the evaluations done and obtained results it is possible to state: that the account of a non-equilibrium and nonlocality EDF renders essential influence to parameters of the discharge sustained by a surface wave; the hydrodynamic equations, and consequently, all discharge characteristics vary. Anisotropy of transport coefficients in high-frequency (HF) field occurs if it (field) amplitude depends on time.

The work is carried out within the framework of the project № 1112 STCU.

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ПРО ВПЛИВ ЕФЕКТІВ НЕРІВНОВАЖНОСТІ ТА НЕЛОКАЛЬНОСТІ НА ПАРАМЕТРИ РОЗРЯДУ, ЩО ПІДТРИМУЄТЬСЯ ПОВЕРХНЕВИМИ ХВИЛЯМИ

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Отримано кінетичне рівняння для плазми у двомірнонеоднорідному полі поверхневої хвилі. У наближенні сталого поля знайдено вирази для функцій розподілу у залежності від величини коефіцієнту просторового послаблення. За допомогою цих функцій розподілу підраховано такі характеристики плазми, як густина плазми, частоти елементарних процесів, коефіцієнти дифузії, кількість частинок, що потрапляють на стінки. Наведено, що у високочастотному електричному полі перенос також може носити анізотропний характер. З урахуванням цього отримано „вірні” гідродинамічні рівняння. Проведено порівняльний характер з раніше відомими результатами. Як підсумок роботи можливо стверджувати, що урахування нерівноважності та не локальності важливо, якщо описувати розряди, що підтримуються поверхневими хвилями.

О ВЛИЯНИИ ЭФФЕКТОВ НЕРАВНОВЕСНОСТИ И НЕЛОКАЛЬНОСТИ НА ПАРАМЕТРЫ РАЗРЯДА, ПОДДЕРЖИВАЕМОГО ПОВЕРХНОСТНЫМИ ВОЛНАМИ

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Получено кинетическое уравнение для плазмы в двумернонеоднородном поле поверхностной волны. В приближении заданного поля найдены выражения для функций распределения в зависимости от величины коэффициента пространственного ослабления. С помощью этих функций распределения посчитаны такие характеристики плазмы как плотность, частоты элементарных процессов, коэффициенты диффузии, количество частиц, попадающих на стенки. Показано, что в высокочастотном электрическом поле перенос тоже может носить анизотропный характер. С учетом этого получены «правильные» гидродинамические уравнения. Проведен сравнительный анализ с ранее известными результатами. Как итог работы можно утверждать – учет неравновесности и нелокальности важен при описании разрядов, поддерживаемых поверхностными волнами.