THE INFLUENCE OF ANOMALOUS SKIN-EFFECT ON THE DISCHARGE SUSTAINED BY SURFACE WAVE

N.A.Azarenkov, Vladimir V.Gushchin, Valery V.Gushchin

Depart. of Physics & Technology, V.N. Karazin Kharkov National University, Ukraine

In the present work the non self-consistent theory of the discharge sustained by SW. In the approximation of the set field analytical ratio for EEDF are found. The approached distributions of discharge parameters, such as plasma density, spatial diffusion coefficient, frequencies of elementary processes (excitation, ionization, etc.), and quantities of inelastic processes are received. It is shown, that under certain conditions the contribution to them from bounce electrons can become determining.

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1.INTRODUCTION

In the theory of the discharge sustained by surface waves (SW), effects of spatial nonlocality and nonequlibrity are essential. The full system of the equations is self-coordinated, (it is resulted in [1]) and can be strictly solved only numerically. However in the given report we want to reveal influence of anomalous skin-effect on the discharge characteristics. Therefore we shall construct the phenomenological kinetic theory - electron energy distribution function (EEDF) we shall find in approximation of the set field. For this purpose we shall present fields distributions in a modelling kind. We choose distributions of potential of a spatial charge field as, close to observed on experiment:

$$\Phi_s(x)=\Phi_{wall}\{1-\frac{4x^2}{d^2}\} \qquad (1)$$

where: Φ_{wall} - a wall potential of the discharge chamber; d - thickness of a plasma layer;

At the description of nonequilibrium and nonlocal plasma the most convenient method simplifying research of the kinetic equation (KE) is nonlocal approach [2,3]. Within the framework of this method all particles are separated on the flying and trapped. The last make oscillations inside the potential hole created by a field of a spatial charge. By virtue of that basically collision between themselves (without the change of energy), it is possible to count their movement collisionless. Therefore EEDF of trapped electrons depends only on full energy $\varepsilon=w+e\Phi_s(x)$ (here $w=\frac{mv^2}{2}$ - electron kinetic energy), that has experimental confirmation [4]. This fact allows transferring the KE - the six-dimensional equation in patrician derivatives - in the one-dimensional ordinary differential equation (ODE). Such simplification is achieved by averaging the equation on the cross-section accessible to particles with energy ε :

$$\sum \overline{v}_k^{¿}(\varepsilon+\varepsilon_k^{¿})\times ¿$$

$$\frac{d}{d\varepsilon}\{\overline{D_\varepsilon}\frac{\partial f_0^0(\varepsilon)}{\partial\varepsilon}+\overline{V_\varepsilon}f_0^0(\varepsilon)\}=¿$$

$$¿$$

$$¿\frac{\sqrt{\varepsilon_k^{¿}+\varepsilon}}{\sqrt{\varepsilon}}f_0^0(\varepsilon+\varepsilon_k^{¿})-\overline{v}_k^{¿}(w)f_0^0(\varepsilon)$$

$$f_0^0(\varepsilon)\times ¿$$

$$¿-¿$$

$$¿\overline{v_{ion}}(\varepsilon)-\sqrt{\frac{\varepsilon+2I}{\varepsilon}}f_0^0(\varepsilon+2I)\overline{v_{ion}}(\varepsilon+2I) \qquad (2)$$

$$¿¿$$

where such designations are entered: $\varepsilon_k^{¿}, I$ - excitation potentials on k power level and shock ionization of neutral atom from the basic condition accordingly; $\overline{v_k^{¿}}, \overline{v^{ion}}$ - frequencies of excitation on k power level and the shock ionization, average on cross-section section, accordingly; the badge $\overline{A}$ means procedure of averaging on the cross-section section accessible to particles with energy ε .

The power diffusion coefficients are determined as the sum of three composes: $D_\varepsilon=D_x+D_z+D_{ql}$, where first two composed describe the diffusion due to anomalous skin-effect on the bounce electrons which obvious kind is resulted in [1], and the third composed corresponds to the quasylinear diffusion arising in a vicinity of a point of a plasma resonance, determined according to [5].

2. BASIC ASSUMPTIONS

However to find analytical solutions of the equation (2) without simplifying assumptions is not probably. Therefore we break space of energy into ranges, in each of which the kind of the collision integral becomes simpler. So the second composed in the left part (2) describes change of the EEDF due to elastic collisions, and the right part of this equation - due to inelastic collisions. Thus the first and the third composed in the right part take into account return of electrons in low-energy area as a result of inelastic collisions (excitation and shock ionization accordingly).

We enter a threshold of inelastic processes - potential of excitation on the lowest allowed power level ε_1 . In the energy range $\varepsilon<\varepsilon_1$ inelastic processes are insignificant, therefore it is possible to put the right part of the KE (2) equal to zero. The solution of the received equation is determined by the following ratio:

$$f_0(\varepsilon)=C_1\int_{\varepsilon}^{\varepsilon_0}\exp[\int_{\varepsilon}^{\varepsilon'} d\varepsilon'' \frac{\bar{V}_\varepsilon(\varepsilon'')}{\bar{D}_\varepsilon(\varepsilon'')}]\frac{d\varepsilon'}{\bar{D}_\varepsilon(\varepsilon')} \quad (3)$$

where constants of integration are defined at the solutions sew together.

But here it is necessary to insert one more energy range $0<\varepsilon<(kT_I)$, where (kT_I) is a small power scale of wane EEDF. This scale of wane is numerically equal to the energy which remaining at the electron after inelastic impact. Therefore it is necessary to take into account the first and the third composed in the right part (2). The solution of the received equation:

$$f_0(\varepsilon)=\int_{\varepsilon}^{\varepsilon_0}\frac{d\varepsilon'}{D_\varepsilon(\varepsilon')}\int_0^{\varepsilon'} d\varepsilon''\sqrt{\frac{\varepsilon''+\varepsilon_1}{\varepsilon''}}\nu¿(\varepsilon''+\varepsilon_1)\times¿$$
$$¿$$
$$¿ f_0(\varepsilon''+\varepsilon_1) \quad (4)$$

With the account of (4) the EEDF (3) it is valid in the energy range $(kT_I)<\varepsilon<\varepsilon_1$. The following power range- $\varepsilon_1<\varepsilon<\varepsilon_2$, where $\varepsilon_2=-e\Phi_{wall}$ -is a wall potential of the chamber. In this energy range it is neglected by elastic collisions (the second composed in the left part (2)) and the electrons returning in the area of small energy after inelastic processes (the first and the third composed in the right part (2)). But also in this case we receive the equation with variable coefficients. For possibility of its solution we shall simulate dependence of frequency of inelastic processes on energy as degree function: $\nu^{inel}(\varepsilon)=\nu_0[\frac{\varepsilon-e\Phi_s(x)}{\varepsilon}-1]^{p-1}$. Then with the account of (1) the solution of KE in this energy range is determined by the following ratio:

$$f_0(\varepsilon)=\{B_1K_\mu(\sigma^{2/\mu})+B_2I_\mu(\sigma^{2/\mu})\}\sqrt{\frac{\varepsilon}{\varepsilon_1}-1} \quad (5)$$

where $K_\mu(x), I_\mu(x)$ - McDonald's and Bessel cylindrical functions of the second kind about μ accordingly; $\mu=\frac{1}{p+2}$; $\sigma=\frac{\varepsilon-\varepsilon_1}{(kT_I)}$; the power scale of wane of the EEDF in inelastic area is defined by the following ratio: $(kT_I)=[\frac{4}{\mu\nu_I}\varepsilon_1^p\bar{D}_\varepsilon(\varepsilon_1)]^\mu$. It is necessary to notice, that the EEDF as (5) coincides with subintegral distribution function in (4).

At the energies $\varepsilon>\varepsilon_2$ nonlocal approach is not applicable, since it is limited on the field value by the condition $eE\lambda<\varepsilon_1$. In this energy range it is necessary to solve not KE (2), and to solve the kinetic equation in view of spatial gradients. But the electrons energy should exceed potential of a wall on small size for an opportunity sew together received solutions with received by means of nonlocal approach. For the same reason it is possible to neglect dependence of the coefficients in KE from energy and to take their values at $\varepsilon=\varepsilon_2$. The solution for EEDF in the energy range $\varepsilon>\varepsilon_2$ has the following kind:

$$f_0(\varepsilon,x)=C_n\exp\{-n\pi\frac{\varepsilon-\varepsilon_2}{kT_2}\}\cos(n\pi\frac{x}{d}) \quad (6)$$

where: $(kT_2)=d\sqrt{\frac{D_\varepsilon(\varepsilon_2)}{D_x(\varepsilon_2)}}$ (the coefficient of spatial diffusion is determined by the following ratio- $D_x=\frac{2e}{3m}\frac{(\varepsilon-e\Phi_s(x))^{3/2}}{\nu_{en}(\varepsilon-e\Phi_s(x))}$) - small power scale of the wane EEDF in tail area. Carrying out the sew together of the solutions (4) - (7) in the points $\varepsilon=\varepsilon_1$ also $\varepsilon=\varepsilon_2$ we find values of the constants of integration:

$$B_2=-B_1\frac{\pi}{2}\exp\{-2\sigma^{2/\mu}\};$$

$$C_n=B_1\frac{2}{\mu}\frac{(kT_2)}{(kT_I)}\sqrt[4]{\frac{1}{\sigma}}\sqrt{\frac{\pi}{2}\frac{kT_I}{\varepsilon_1}}\exp\{-\sigma^{2/\mu}\};$$

$$B_1=C_1\frac{\varepsilon_1}{X_1}\frac{\bar{V}_\varepsilon(\varepsilon_1)}{\bar{D}_\varepsilon(\varepsilon_1)}\exp\{-\int_0^{\varepsilon_1}\frac{\bar{V}_\varepsilon(\varepsilon)}{\bar{D}_\varepsilon(\varepsilon)}d\varepsilon\},$$

And value of a constant C_1 is defined by the value of the plasma density on the axis of a layer. Having defined ratio for EEDF, we can [6] define in the standard image distributions of the discharge characteristics. So with the help of a ratio:

$$n(x)=\frac{4\sqrt{2}\pi}{m^{3/2}}\int_{-e\Phi_s(x)}^{\infty}(\varepsilon-e\Phi_s(x))^{3/2}f_0(\varepsilon)d\varepsilon \quad (7)$$

it is possible to find spatial distribution of the plasma density. By means of a ratio:

$$D_x(x)=\frac{8\pi}{3m^2}\int_{=e\Phi_s(x)}^{\infty}(\varepsilon-e\Phi_s(x))^2\frac{f_0(\varepsilon)}{\nu_{en}(\varepsilon)}d\varepsilon \quad (8)$$

coefficient of spatial diffusion. By means of a ratio:

$$\nu^{inel}(x)=\frac{8\pi N_a}{m^2}\int_{-e\Phi_s(x)}^{\infty}(\varepsilon-e\Phi_s(x))\times¿$$
$$¿$$
$$¿\sigma_{inel}(\varepsilon)f_0(\varepsilon)d\varepsilon \quad (9)$$

distributions of the frequency of inelastic processes. And a ratio:

$$W=\{4\pi V^2D_\varepsilon(\varepsilon)\frac{\partial f_0(\varepsilon)}{\partial V}\}|_{V=V^{inel}} \quad (10)$$

Where N_a - concentration of neutral atoms; σ^{inel} - sections of inelastic processes (excitation, shock ionization, etc.). And included in the ratio (8) - (11) EEDF are defined according to (4) - (7). EEDF is determined through the coefficient of power diffusion, and in plasma of the low pressure there is a contribution from anomalous skin-effect on the bounce electrons. As shown in [1] in the collisionless limit the contribution from the bounce electrons at least is not less, than the contribution from the quasylinear diffusion. It means that in the field of low pressure vary EEDF. And it conducts to change of all discharge characteristics.

3. CONCLUSIONS

The non self-consistent theory of the discharge sustained by SW is constructed. Solutions for EEDF in approximation of the set field various power ranges of energy are received. With the help of this ratio discharge characteristics are found. From them the contribution given by the bounce electrons follows, that under certain conditions can become dominating.

REFERENCES

1. N.A.Azarenkov et al, submitted to Quest. of Atom. Sci. and Tech. 2004.
2. V.I.Kolobov, V.A.Godyak // *IEEE Trans. Plasma Sci.(23)*. 1995, p.503-531.
3. U.Kortshagen, C.Busch et al.// *Plasma Sources Sci. Techn. (5)*. 1996,p.1-17.
4. U.Kortshagen //*Phys.Rew.E (49)*. 1994, p.4369-4379.
5. Yu.M.Aliev, A.V.Maximov et al. // *Phys.Rew.E (51)*. 1995, p.6091-6103.
6. L.D.Tsendin, Y.B.Golubovskii // *Sov. J. Tech. Phys. (22)*, 1977, p.1066-1075.

ВЛИЯНИЕ АНОМАЛЬНОГО СКИН-ЭФФЕКТА НА РАЗРЯД ПОДДЕРЖИВАЕМЫЙ ПОВЕРХНОСТНЫМИ ВОЛНАМИ

Н.А.Азаренков, Владимир В. Гущин, Валерий В.Гущин

В данной работе построена несамосогласованная теория разряда, поддерживаемого ПВ. В приближении заданного поля найдены аналитические решения для ФРЭЭ. Получены приближенные распределения разрядных характеристик, таких как плотность плазмы, коэффициент пространственной диффузии, частоты элементарных процессов (возбуждения, ионизации и т.п.) и количество неупругих процессов. Показано, что при определенных условиях вклад от bounce электронов может стать определяющим.

ВПЛИВ АНОМАЛЬНОГО СКІН-ЕФЕКТУ НА РОЗРЯД, ЩО ПІДТРИМУЄТЬСЯ ПОВЕРХНЕВИМИ ХВИЛЯМИ

М.О.Азарєнков, Володимир В. Гущин, Валерій В. Гущин

В даній роботі побудовано самоузгоджену теорію розряду, що підтримується ПХ. У наближенні заданого поля знайдено аналітичні рішення для ФРЕЕ. Отримано наближені розподіли характеристик розряду, таких як густина плазми, коефіцієнт просторової дифузії, частоти елементарних процесів (збудження, іонізації та ін.) та кількості процесів. Показано, що за певних умов bounce електрони можуть відігравати визначну роль.