EFFECT OF AN EXPLOSIVE ELECTRON EMISSION ON MAGNETIZED SHEATH BETWEEN PLASMA AND ISOLATED WALL

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It is carried the two-dimensional computer simulation of evolution of the magnetized sheath that arises between plasma and isolated wall under the influence of an explosive emission of electrons from the microspot of the surface using the PIC/MCC method. Calculations are performed for different electron current densities, values of the magnetic induction and gas pressures. One of the obtained effects is the direction changing of the electric field under the influence of explosive emission near the center of the electrons emission. Due to this effect the unipolar arc ignition is shown. It is studied the influence of magnetic field on the development of unipolar arc.

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1. INTRODUCTION

Plasma is separated from the plasma reactor's walls by a space charge sheath because of the mobility difference between ions and electrons. The phenomena in sheath play a considerable role in the various plasma technologies of solid surfaces processing and controlled thermonuclear power production.

One of the most interesting phenomena bound up with the sheath is formation of an unipolar arc. According to modern representations unipolar arcs cause the reactor's walls corruption. Particularly, the unipolar arc is the emission source of heavy ions which are sources of the increased Bremsstrahlung radiation losses of energy. Essential for this kind of discharges is that single electrode serves as both the cathode and the anode. The cathode is the region of the explosive electron emission; the anode is ring-like area surrounding the cathode. Explosive electron emission can appear on some cathode surface defects and is caused by the increased electric fields near them, followed by the thermal and secondary electron emission. In some conditions, that should be determined, the return flow of electrons appears around the emitting spot. This return flow closes the current loop of the unipolar arc.

Most of qualitative theoretical unipolar arc models are based on the Bohm sheath theory [1]. According to this theory, if the metal plate placed into the plasma doesn't let out any charged particles (there are no emission centers on its surface), the balance of electronic and ionic currents from plasma is set. The plate accepts floating potential which shields the plate from all electrons except the high-energy ones in Maxwell distribution

A circulating current that appears between plasma and plate is called an unipolar arc: "hot" electrons from plasma overcome detaining potential V_f^*, transfer current on a plate, and from a plate "cold" emitted electrons transfer a current to plasma.

Numerical experiments of the explosive emission influence on the sheath were carried by the Gielen G., Shram D. [2] and Roshansky V., et al [3]. Both scientists' groups carried out the calculations within the hydrodynamic plasma description in the presence of a magnetic field, but a electron friction with neutral atoms were neglected. Hydrodynamic models assume Maxwellian velocity distribution, but its justice needs to be proven under the conditions of the explosive emission. But mentioned and other [4] theoretical and numerical models are just qualitative, and there are no detailed theory based on self-consistent model. In this article we study the evolution of the sheath in partially ionized plasma in the presence of inclined to the wall magnetic field by the method PIC/MCC.

2. MODEL

A two-dimensional model of sheath is considered. One boundary of modeling area is a wall at a floating potential. The ion flow with directed Bohm velocity and the thermal electron flow are defined at the opposite boundary. The area between boundaries is filled with the argon plasma. It is supposed that electrons and ions recombine on the wall. The secondary electron emission with coefficient $\gamma = 0.3$ is taken into account. We assume that the magnetic field B is constant in space and is inclined to the wall at the angle $\theta = 8^{\circ}$.

The high-density electron flow is defined from central small area of wall ($0.0049\ \text{m} \le y \le 0.0051\ \text{m}$) to take into consideration the explosive electron emission.

Simulations were made by means of Particle-in-Cell and Monte-Carlo methods [6] to take into an account in our code the following reactions caused by electron and ion impacts: elastic electron-neutral collisions, elastic ion-neutral collisions, ionization, neutral excitation by electron heat, charge exchange between ions and atoms.

Following parameters of the unperturbed plasma were used: electron and ion densities $n_{e,i} = 10^{15}\ \text{m}^{-3}$, electron temperature $T_e = 2.5\ \text{eV}$, ion temperature $T_i = 0.03\ \text{eV}$. The explosive emission current density varies within $j_e = 10^3 - 10^5\ \text{A/m}^2$, the argon pressure varies within $0.05\,torr < p < 0.5\,Torr$. In our case, the value of wall potential has been set $V_{fl} = 5\ \text{B}$ approximately corresponding to the floating wall potential for plasma, thus electronic and ionic streams on a wall are approximately equal.

3. NUMERICAL RESULTS

The spatial potential distribution is shown on Fig. 1, a for the case $j_e = 10^5\ \text{A/m}^2$, $B = 0$. We can see that the electron emission essentially influences the potential of the electric self-consistent field in the sheath. The potential minimum is formed in front of the emission spot and the sheath width is greatly increased. The potential profiles along a perpendicular direction to the wall for different emission current densities and are presented on the Fig.1,b. The solid line corresponds to the case without emission. Dotted, dashed and stroke dashed lines correspond to emission current densities $j_e = 10^3$ A/m^2, $j_e = 10^4$ A/m^2 and $j_e = 10^5$ A/m^2 respectively.

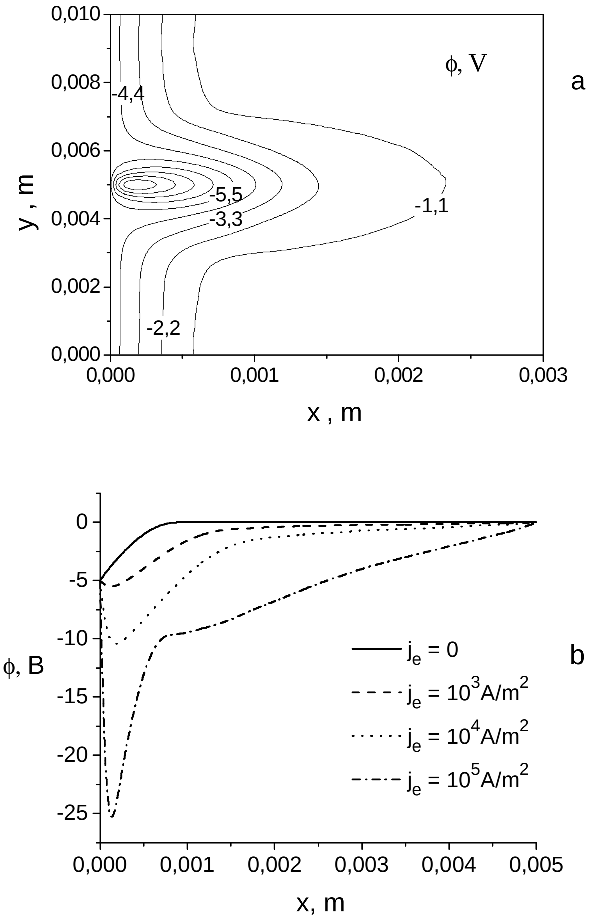

Fig. 1. The potential distribution over the emitting spot near the wall at $j_e = 10^5$ A/m^2, $B = 0$ *(a) and potential distributions along the perpendicular direction to wall under emission center without explosive emission (solid line) and with explosive emission (b)*

Fig. 2 shows spatial distributions of macroelectrons at $p = 0.5\,Torr$, $j_e = 10^5\ A/m^2$, $B = 0.2\,T$ (a) and at $p = 0.5\,Torr$, $j_e = 10^5\ A/m^2$, $B = 0.01\,T$ (b). It is seen that the high electron density regions are formed over the emission center. This is due to gas ionization by electrons which are emitted from the wall. This region is narrow in the case $B = 0.2\,T$ and wider in the case $B = 0.01\,T$ due to magnetized of electrons in the first case. In the last case we see the return current on the wall at some distance from the center of emission, that can be characterized as the formation of unipolar arc. At the contrary, we see the low electron density in the sheath and hence low current to the wall at $B = 0.2\,T$.

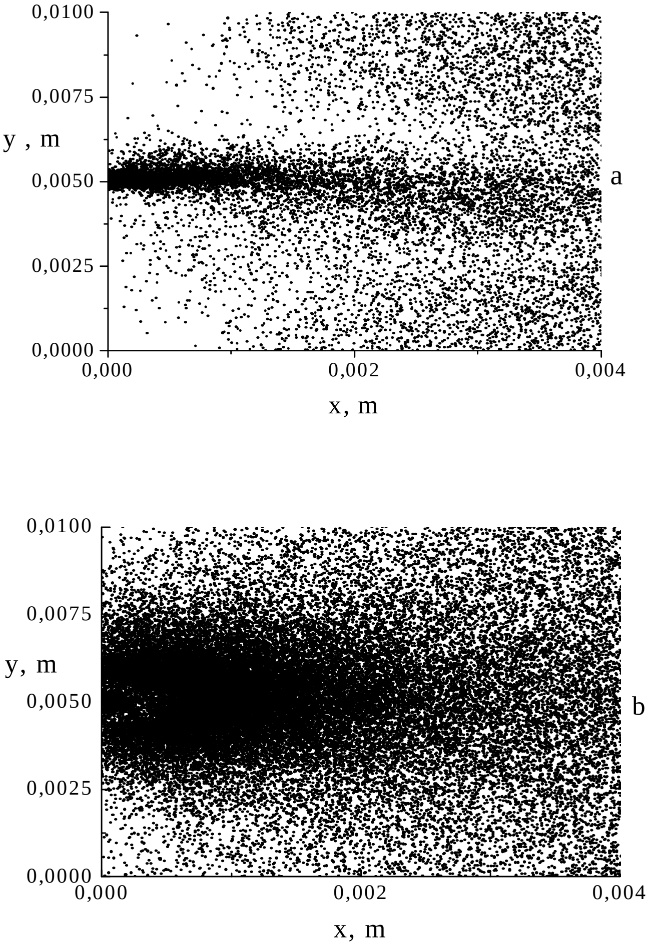

Fig.2. Spatial distributions of macro electrons at $p = 0.5\,Torr$, $j_e = 10^5\ A/m^2$, $B = 0.2\,T$ *(a) and* $B = 0.01\,T$ *(b)*

The potential profiles as well as ion and electron density profiles along a perpendicular direction to the wall under emission center are shown in Fig. 3 for case $B = 0.2\,T$ (a) and $B = 0.01\,T$ (b). It is seen that densities of electrons and ions are reduced in the sheath monotonically with distance from the wall at $B = 0.2\,T$. At that a significant deviation from quasi-neutrality of the plasma takes place only at $x < 0.0025\,m$. In the case $B = 0.01\,T$ a maximum density of electrons and ions is formed at some distance from the wall and the deviation from quasi-neutrality of the plasma takes place in wider region near the wall. It is seen that at $x < 0.004\,m$ electron density the electron density significantly exceeds the density of ions, but in the region $0.0004\,m < x < 0.001\,m$ the ion density exceeds the density of electrons. These features of spatial distribution of electrons and ions lead to a drawing of the potential distributions of the electric field. We note that the increase in the magnetic field leads to a reduction of the negative peak potential near the center of the emission and to increase its width in a direction perpendicular to the wall. At $B = 0.01\,T$ except for a large negative peak near the building wall is formed by a positive maximum, which indicates the formation of positively charged region in the plasma.

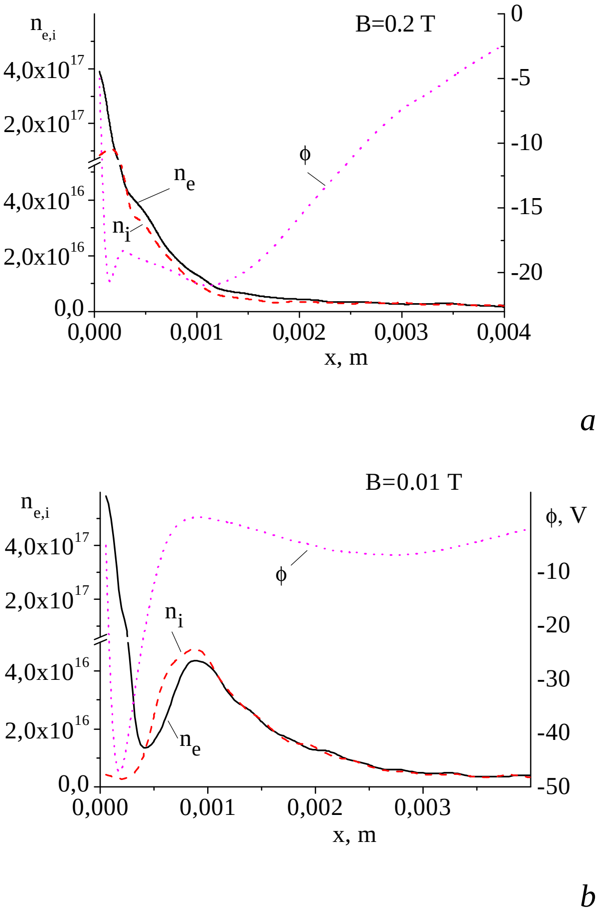

Fig. 3. Spatial distributions of ion and electron densities, an electric field potential at $p = 0.5\,Torr$, $j_e = 10^5\ A/m^2$, *(a)* $B = 0.2\,T$ *and (b)* $B = 0.01\,T$

CONCLUSIONS

This article presents computer simulations of unipolar arc phenomena in the frame of a self-consistent physical model. The potential distribution near the surface emitting was calculated. It is shown that due to emission of electrons in the potential distribution is formed a minimum, which can lead to reverse current of electrons on the wall in the vicinity of the emission spot. The magnetic field significantly alters the structure of the potential in the sheath. In particular, its increase leads to a narrowing of the dense electron cloud in front of the emission center and to the electron density decreasing in the sheath on the periphery of the spot emission, which can be an obstacle to the development of unipolar arcs.

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ВЛИЯНИЕ ЭЛЕКТРОННОЙ ЭМИССИИ НА ЗАМАГНИЧЕННЫЙ ПРИЭЛЕКТРОДНЫЙ СЛОЙ МЕЖДУ ПЛАЗМОЙ И ИЗОЛИРОВАННОЙ СТЕНКОЙ

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Методом PIC/MCC выполняется двухмерное компьютерное моделирование эволюции замагниченного приэлектродного слоя, возникающего между плазмой и изолированной стенкой, под влиянием взрывной эмиссии электронов из микропятна на поверхности. Вычисления выполняются для различных плотностей электронного тока, значений магнитной индукции и давлений газа. Одним из полученных эффектов является изменение направления электрического поля под влиянием взрывной эмиссии вблизи пятна эмиссии. Благодаря этому эффекту показано зажигание униполярной дуги, а также изучено влияние магнитного поля на ее развитие.

ВПЛИВ ЕЛЕКТРОННОЇ ЕМІСІЇ НА ЗАМАГНІЧЕНИЙ ПРИЕЛЕКТРОДНИЙ ШАР МІЖ ПЛАЗМОЮ ТА ІЗОЛЬОВАНОЮ СТІНКОЮ

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Методом PIC/MCC виконується двохвимірне комп'ютерне моделювання еволюції замагніченого приелектродного шару, що виникає між плазмою та ізольованою стінкою, під впливом вибухової емісії електронів з мікроплями на поверхні. Обчислення виконуються для різних густин електронного струму, значень магнітної індукції і тисків газу. Одним з одержаних ефектів є зміна напрямку електричного поля під впливом вибухової емісії поблизу плями емісії. Завдяки цьому ефекту показано запалення уніполярної дуги, а також вивчено вплив магнітного поля на її розвиток.