NEW METHODS OF CHARGED PARTICLE ACCELERATION

DYNAMICAL ACCELERATING STRUCTURES OF THERMOIONIC PLASMA

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The conditions of dynamical accelerating structures of double layer type forming on the edge of thermo-ionic plasma are investigated. Plasma was created by the way of material thermo-evaporation with further ionization under the influence of intensive electron beam. It has been shown that since thermo-ionic plasma forming the double electrical layer of volume charge (DL) creates where the ions of evaporated material (thermo-ions) are accelerate with further possible deposition on substrate. The conditions of intensive thermo-ion flows formation were determined.

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INTRODUCTION

The interest devoted to intensive ion beams forming is caused first of all by a number of advantages in their technological application. Not so high ion energy in that beams helps to reduce inner tensions in got cover, improve adhesion to substrate and pass chemical reactions on the surface as well. Commonly the vapor of working substance in vacuum made by its heating with electron beam with further ionization of evaporated atoms. However the traditional scheme of electron beam evaporation with external injection of energetic electron beam is limited by low efficiency of working environment ionization and problems of beam transportation to a target as well. In this connection it is offered the alternative way when the electron beam is forming by the surface of evaporated material from gas-discharge plasma. Electrons accelerate in electrical field of surface layer, which appears due to voltage applying between gas-discharge plasma and a target. Plasma emitter using excludes the problems of electron beam transportation that gives an opportunity to electron energy decreasing to hundreds of electronvolts and allows to create the counter ion flow of the same energy.

It is experimentally and theoretically shown [1, 2] that around the target (since surface plasma creating due to vapor ionization by electron beam) the double electrical layer of volume charge (DL) is forming, which provides thermo-ions acceleration to the side of a substrate. Since the DL is dynamical accelerating structure it makes sense to study this new method of thermo-ion flow forming for technological application.

1. EXPERIMENTAL SETUP

The experiments of generating intensive thermo-ionic flow were carried out with help of plasma source based on the reflective discharge with the filament cathode (Fig. 1). The source was made from water-cooling discharge tube (1) from stainless steel 40 mm in diameter and 270 mm in length. In the butt end of the tube the tungsten filament cathode (2) was set. The opposite side of the tube was connected to a vacuum chamber. As a cathode-reflector the water-cooled substrate holder (4) was used. All the system was set in nonuniform longitudinal magnetic field. The magnitude of magnetic field was chosen in such a way that the electron beam formed close to filament cathode has a diameter of 20 mm and expands up to diameter of 200 mm in the treatment area that allows to create the divergent beam for sample treatment of high area of surface.

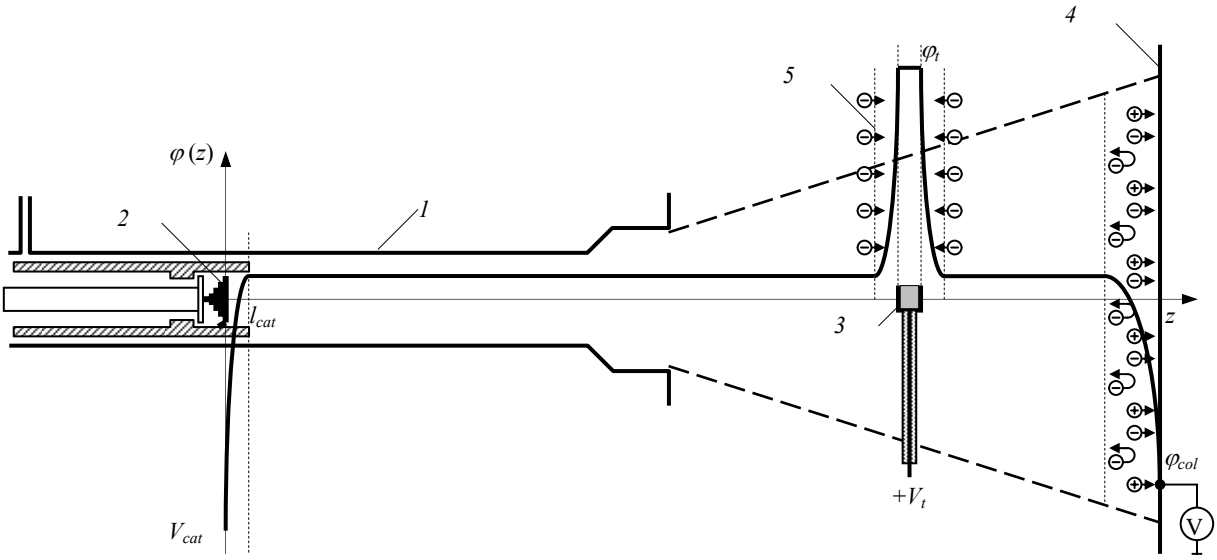

Fig. 1. The scheme of thermo-ionic plasma creation.
1 – discharge tube; 2 – filament cathode; 3 – crucible with metal;
4 – cathode-reflector (treatment surface); 5 – volume charge layer

Thermo-ionic plasma was created by the way of evaporation with further metal ionization put in tungsten crucible (3). With this aim the positive potential $+V_t$ on the crucible was applied.

The discharge tube had a galvanic connection with grounded vacuum chamber and was an anode. It should be pointed out that in our case the crucible played a role of second anode with potential on hundreds volts higher than potential of the main anode of gas-discharge unit.

As a plasma-forming gas argon was used at pressure about 10^{-4} Torr.

2. RESULTS AND DISCUSSION

When the crucible heats by electron beam the neutral atom flow from the metal surface is formed, the part of them is ionized by electron impact. Generated ions are accelerating by the electric field of layer toward the electrons, the bipolar current appears. The maximum of current density through the layer in linear geometry is determined by Langmuir relation [3].

$$\frac{j_i}{j_e} = \sqrt{\frac{m_e}{M}}. \qquad (1)$$

Where j_i – the ion current density; j_e – the electron current density; m_e and M – masses of electron and ion correspondently.

Whereas the electron current density is determined by the parameters of gas-discharge plasma depended on the work regime of the plasma source, then the ion current density is determined magnitude as well.

As soon as the ion generation velocity by the surface reaches such a value when generated particle quantity will exceed the particle one outflew through the layer, then between volume charge layer and the anode surface plasma bulk appears. This we called thermo-ionic plasma and initial layer of negative volume charge transforms into double electrical layer [4] on the edge of anode plasma (Fig. 2).

The velocity of particle generation in surface plasma is determined mainly by neutral atoms concentration of evaporated substance in surface layer, which in its turn depends on the crucible temperature.

With the evolution of the evaporation and ionization processes since not all generated ions can go trough the layer due to current conductive limiting, DL will expand from the crucible surface owing to gas-kinetic pressure.

In case of constant voltage supplied on the crucible the DL expansion is accompanied with increasing of outer layer surface, electron beam power and the crucible temperature.

The crucible temperature increasing causes rising of substance evaporation velocity, enhancing neutral atoms concentration by the surface and increasing of charged particles generation velocity. It leads to volume of surface plasma bulk raising and as a consequence to further DL expansion from the crucible, area increasing and current on the crucible raising.

This process will continue as long as there is no violation of the relation (1), which will lead to a break the conditions of DL existence. It limits the heating of the crucible, the temperature decreases, neutral atoms concentration drops rapidly and the generation of surface plasma stops. Only when restoring the original conditions the process is repeating. In this case there is a pulse mode, which is not always suitable for industrial purposes.

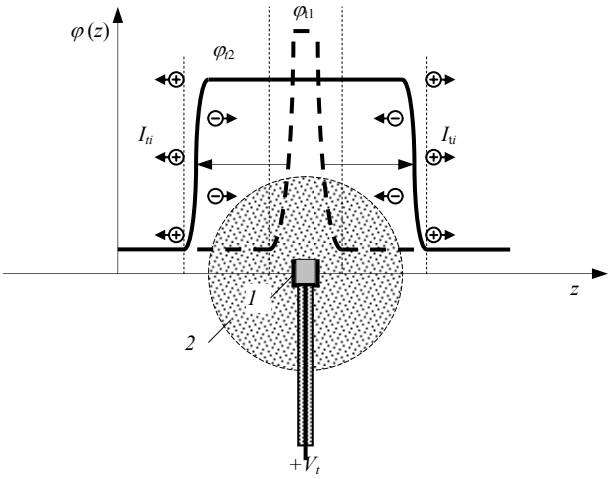

Fig. 2. The scheme of double layer formation on the edge of thermo-ionic plasma. 1 – crucible; 2 – thermo-ionic plasma

The results of ion flow dynamics investigation from the crucible and dynamics of the active power spent on its heating are shown in Fig. 3 as the oscillograms of crucible voltage and current, the collector current and the full ion current of the sample surface. The collector with area about 1 cm^2 was set on the treated surface.

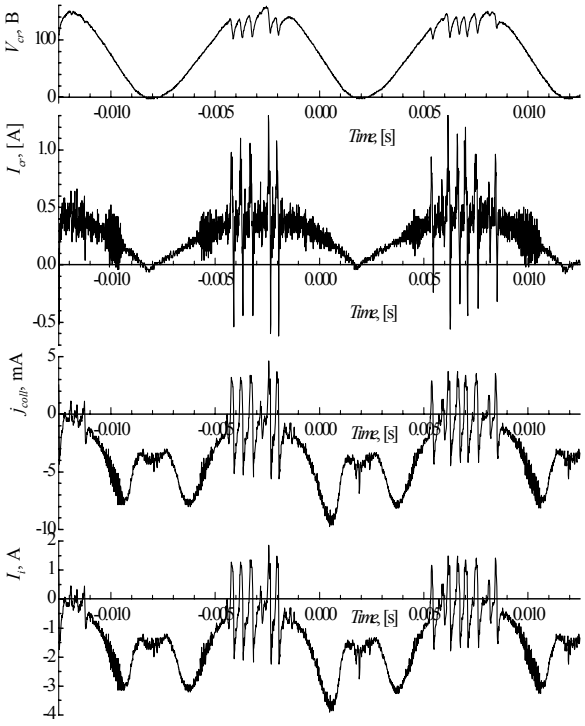

Fig. 3.The oscillograms of voltage on the crucible V_{cr} crucible current I_{cr}, current density on collector $j_{кол}$ and whole ion current I_i at average crucible current of 1,5 A

One can see that since dense thermo-ionic plasma expanding the crucible current I_{cr} and voltage V_{cr} are increase. In this regime dotted in Fig. 2 monolayer exists. The forming of double layer takes priority over the development of intense HF-oscillations concerned with beam-plasma instability. In the moment of the DL form-

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ing (see solid line in Fig. 2) the crucible current I_{cr} sharply raises (the crucible voltage is reduced), becomes more than the discharge current I_d and the DL is destroyed.

The rapid change of the crucible current sign I_{cr} indicates on the starting of crucible reheating processes for the dense surface plasma forming. Then the process is repeated cyclically.

On the treatment surface mainly electron current goes, and only at the moment of double layer creating the electron current changes on the ion one. Thus, the regime of thermo-ionic-deposition in this system is carried out in a pulse mode at the time of double layer forming on the edge of thermo-ionic plasma.

It should be pointed out the following. Accordingly (1) the electron current through the layer must be sufficiently higher than ion one. However in our experiments (see Fig. 3) the electron current on collector $j_{кол}$ has the same order of magnitude with ion one. The authors have obstructed to make the explanation to observed phenomena yet.

CONCLUSIONS

Thus, forming and acceleration of charged particles beams occurs due to dynamical DL forming on the edge of thermo-ionic plasma. Plasma is created owing to material thermo-evaporation with further ionization under intensive electron beam influence formed by the surface of evaporated material in the volume charge layer. It has been shown, that forming and accelerating of ion flow in the system are in pulse mode at the moment of DL forming on the edge of thermo-ionic plasma when electron current on a target changes on ion one.

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ДИНАМИЧЕСКИЕ УСКОРЯЮЩИЕ СТРУКТУРЫ ТЕРМОИОННОЙ ПЛАЗМЫ

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Исследуются условия формирования динамических ускоряющих структур типа двойной слой на фронте термоионной плазмы. Плазма создавалась путем термического испарения с последующей ионизацией материала под воздействием интенсивного электронного пучка. Показано, что по мере образования термоионной плазмы, формируется двойной электрический слой объемного заряда (ДС), в котором происходит ускорение ионов испаряемого материала (термоионов) с последующим возможным осаждением на подложке. Определены условия формирования интенсивных термоионных потоков.

ДИНАМІЧНІ ПРИСКОРЮЮЧІ СТРУКТУРИ ТЕРМОІОННОЇ ПЛАЗМИ

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Досліджуються умови формування динамічних структур, що прискорюють, типу подвійний шар на фронті термоіонної плазми. Плазма створювалася шляхом термічного випаровування з подальшою іонізацією матеріалу під впливом інтенсивного електронного пучка. Показано, що в міру утворення термоіонної плазми, формується подвійний електричний шар об'ємного заряду (ПШ), в якому відбувається прискорення іонів (термоіонів) матеріалу, який випаровується з подальшим можливим осадженням на підкладці. Визначені умови формування інтенсивних термоіонних потоків.