DEVELOPMENT OF ADDITIONAL MAGNETRON DISCHARGE IN THE DRIFT REGION OF AN ION SOURCE WITH CLOSED ELECTRON DRIFT

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A gas discharge of the magnetron type which is formed in the beam drift region of an ion source with closed electron drift was investigated. The electric field due to the target bias potential results in the development of an additional gas discharge of the magnetron type in the drift region. Trajectories of electron beams emitted by the ion source were visualized using light emission from the working gas excited by the electrons.

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1. INTRODUCTION

The target bias potential in ion beam etching systems strongly influences the effectiveness of surface cleaning. Ion beams impinging on the target surface can charge the surface positively and cause ion beam deceleration. Ion beam charge neutralization is usually achieved by means of additional devices injecting electrons or negative ions into the positively charged beam [1] or by providing a longitudinal (with respect to the ion beam direction) electric field, produced by an additional source, that leads to the development of a non-self-maintained discharge generating extra electrons [2]. The stray magnetic field from the ion source emission slit does not affect the heavy ions, which readily reach the target along ballistic trajectories. But on the other hand the value of stray magnetic field is strong for electrons; their motion in the drift space is diffusive, and consequently depends on the magnetic field line configuration. The aim of the work described here was to determine localization of additional discharges of the magnetron type arising in the drift space due to the influence of the bias potential electric field and to visualize the trajectories of electrons emitted from the Hall ion thruster. This investigation is a development from prior research [3].

The basic processes in Hall thrusters have been well investigated [4,5]. Crossed $\boldsymbol{E} \times \boldsymbol{B}$ fields induce electron drift across the electric and magnetic field directions. The suppressed transverse mobility of the electrons allows maintaining a strong transverse electric field. At the same time ions in the plasma are accelerated to the emission slit in the cathode, through which most of them readily leave the acceleration region. The electron trajectories are more complex, and the electron emission current density is small compared to the ion emission current density. Subsequent electron motion is dependent on the topology of the magnetic field within the beam drift region.

2. EXPERIMENT

The Hall thruster used in our work has the following characteristics: length of the racetrack emission slit - 250 mm in the straight part, racetrack bending radius - 40 mm, emission slit width (discharge gap) - 2 mm. Magnet pole pieces were made of soft iron. The water-cooled anode of 23×10 mm^2 rectangular cross-section was made of stainless steel. A thin stainless steel plate (400×150 mm^2) was used as the target. A retarding potential method was used to determine the relative contributions of the electron and ion components to the total current passing through the target. The retarding potential was applied between the target and a special grid placed in front of the target at 10 mm distance. At the same time, the back and side target parts were electrically shielded. The working gas (argon) pressure was in the range $1 \times 10^{-3} \ldots\ 4 \times 10^{-4}$ Torr, and the vacuum chamber base pressure was about 5×10^{-6} Torr. The power supply voltage was up to 2.5 kV, and the discharge current up to 0.3 A. The magnetic field distribution within the drift region is shown in Fig. 1. Arrows indicate the magnetic field direction at that location (but not magnitude). The axial variation of the radial magnetic field has a bell-shaped distribution and corresponds to the magnetron trap configuration. In the center of the slit the magnetic induction was 2 kG. Three segments of separatrices can be seen within the field region (Fig. 1).

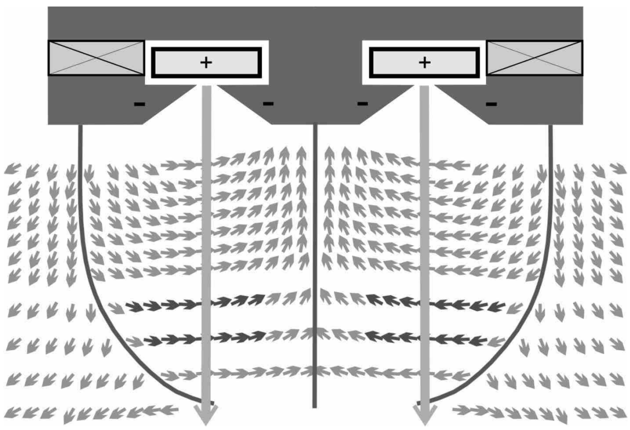

Fig.1. Magnetic field direction (small arrows) in the ion source drift region is shown in the plane perpendicular to the plane of the emission slit. The separatrices are shown as thin lines, and the ion beams as thick lines

3. RESULTS AND DISCUSSION

Photographs of the plasma discharge region are shown in Fig. 2 and Fig. 3. These images were taken along the racetrack emission slit at a small angle to its plane. The electron and ion beam trajectories were visualized using

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light emission from the working gas excited by charged particles. The photograph in Fig. 2 is for the case when the ion collector is electrically connected to the grounded vacuum chamber. Consequently, there is no electric field in the drift space due to collector bias potential, and the light emission induced by the ion beams is seen in the photos as two bright vertical strips. Comparison of Fig. 1 and Fig. 2 allows us to conclude that the spatial location of the three somewhat less bright emission strips as well as the electron beams coincides with the location of the

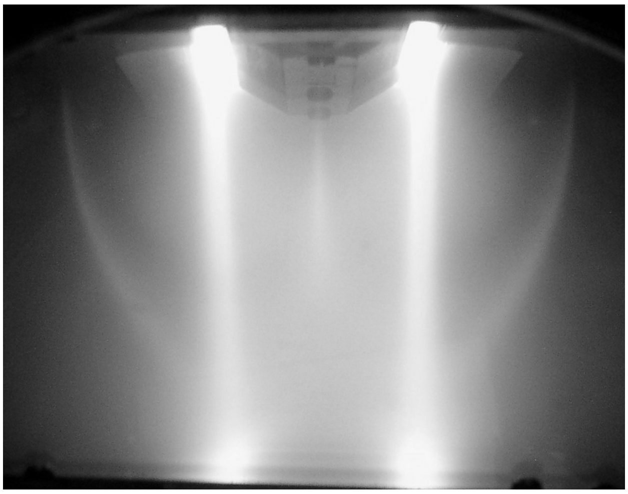

Fig.2. Photograph of light emission in the drift space for the case of grounded target. The discharge voltage is 1500 V, argon pressure 4 × 10^{-4} Torr, and the bias potential is about zero

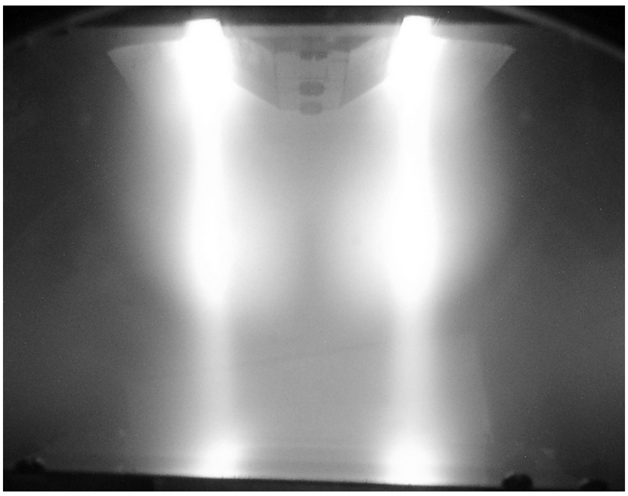

Fig.3. Photograph of light emission in the drift space for the case of isolated target. The discharge voltage is 1500 V, argon pressure - 4 × 10^{-4} Torr, and the bias potential is about 240 V

separatrices. The diffuse light emission between the curved "electron" strips corresponds to the magnetic field configuration in the trap and indicates that the electron motion is mostly normal to the magnetic field lines. The weak light emission out of the lighted region is evidence that the separatrices play a role as electron collectors at any point along the beam trajectories. Measurements carried out by the retarding potential technique reveal that in this case the contribution of the electron component to the total target current does not exceed 20 - 25 %.

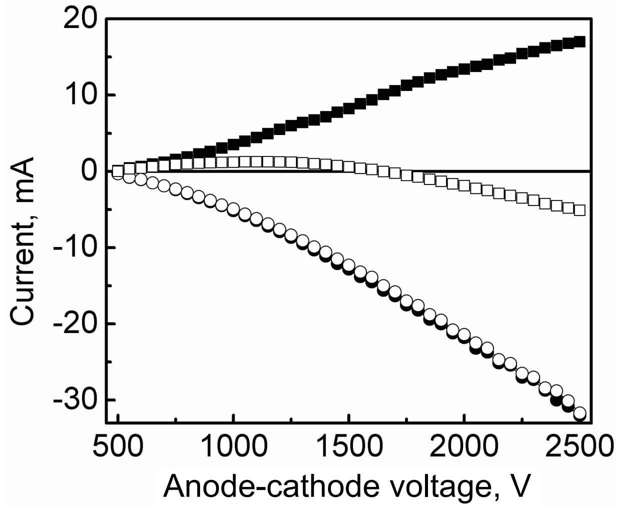

Fig.4. Voltage-current characteristics of the source discharge (circles) and corresponding variation of cathode current (squares). White symbols – the target is grounded; black symbols – the target is electrically isolated. Curves for current passing through the target and vacuum chamber walls are not shown

The photograph in Fig. 3 is for the case when the target is isolated (electrically insulated) from the vacuum chamber. If the discharge voltage is 1500 V and argon pressure is 4 × 10^{-4} Torr, the bias potential is about 240 V. Increasing the target bias potential from 0 to 240 V results in not merely a qualitative modification of discharge mode in the drift space (Figs. 1,2), but a change in some of the quantitative discharge characteristics (Fig. 4). Evidently the discharge voltage-current characteristics (dependencies of anode current versus anode-cathode voltage) are approximately not influenced by the target bias potential. However, the dependencies of current passing through the cathode versus anode-cathode voltage are quite different depending on whether the target is grounded or electrically isolated (Fig. 4). Then the longitudinal electric field of the isolated target and the trap magnetic field form a system of crossed $\boldsymbol{E} \times \boldsymbol{B}$ fields. This occurs in a relatively narrow region of the drift space where the orthogonal (with respect to the electric field $\boldsymbol{E}$) component $\boldsymbol{B}$ of the magnetic field have maximum value; (most probably this is the region indicated by dark gray arrows in Fig. 1). We can conclude from comparison of Fig. 1 with Fig. 3 that the plasma lighting is in fact visible within this drift space. This can be considered as the development of a magnetron type discharge. Because the longitudinal electric field due to the bias potential and the electric field in the discharge region are in opposite directions, one can conclude that the directions of the Hall drift in these discharges are opposite. The discharge is a source of additional electrons that partially neutralize the target positive charge and consequently reduce the total target current, and of additional ions that move to the cathode. The scenario of the additional magnetron discharge was confirmed by one more experiment. The target bias potential was simulated by a voltage applied between the target and the grounded vacuum chamber, generated by an independent external power supply with low internal resistance (Fig. 5). The curves shown in Fig. 5 are almost reflection symmetric. This implies that the additional electron current and additional ion current generated by the additional magnetron discharge are nearly equal.

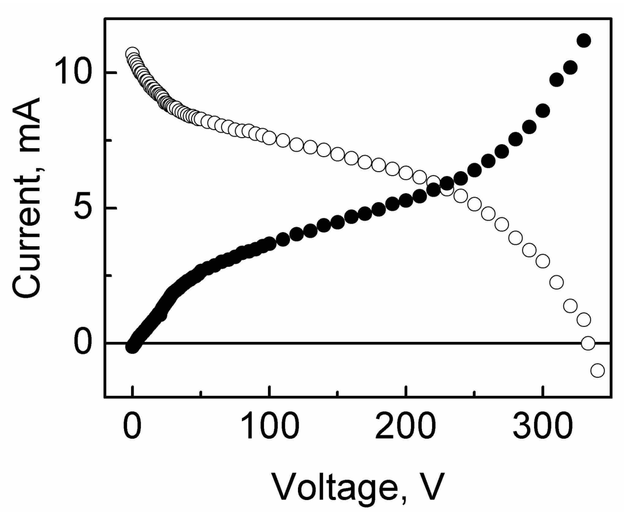

Fig.5 Variation of target current (white circles) and cathode current (black circles) versus external voltage applied between target and the grounded vacuum chamber. The discharge voltage is 1500 V and argon pressure 4×10^{-4} Torr

The discharge occurs at a certain target potential. Apparently it develops at a target potential of about 70 V, corresponding to the inflection on both curves in Fig. 5. Paradoxically, this additional electron source is not able to provide complete target neutralization because the origin of this discharge is the bias potential

4. CONCLUSIONS

Summarizing, the magnetic field separatrices play the role of electron collectors along the region from the gas discharge to the target. Electrons can be attracted along with the electron beams at any point along the beam trajectories. The electric field due to the target bias potential can result in the development of an additional gas discharge of the magnetron type in the drift region.

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РАЗВИТИЕ ДОПОЛНИТЕЛЬНОГО МАГНЕТРОННОГО РАЗРЯДА В ПРОСТРАНСТВЕ ДРЕЙФА ИОННОГО ИСТОЧНИКА С ЗАМКНУТЫМ ДРЕЙФОМ ЭЛЕКТРОНОВ

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Исследован газовый разряд магнетронного типа, возникающий в пространстве дрейфа пучков ионного источника с замкнутым электронным дрейфом. Электрическое поле, вызванное плавающим потенциалом мишени, приводит к развитию в дрейфовом пространстве дополнительного газового разряда магнетронного типа. По свечению возбужденного электронами рабочего газа визуализированы траектории электронных пучков, эмитированных ионным источником.

РОЗВИТОК ДОДАТКОВОГО МАГНЕТРОННОГО РОЗРЯДУ В ПРОСТОРІ ДРЕЙФУ ІОННОГО ДЖЕРЕЛА З ЗАМКНЕНИМ ДРЕЙФОМ ЕЛЕКТРОНІВ

І.В. Борденюк, О.А. Панченко, С.В. Сологуб, Я.Г. Браун

Досліджений газовий розряд магнетронного типу, який виникає в просторі дрейфу пучків іонного джерела з замкненим дрейфом електронів. Електричне поле, викликане плаваючим потенціалом мішені, може призводити до розвитку в дрейфовому просторі додаткового газового розряду магнетронного типу. За світінням збудженого електронами робочого газу візуалізовані траєкторії електронних пучків, емітованих іонним джерелом.