# FLOATING POTENTIAL OF DIELECTRIC TARGET IN PLASMA-BEAM DISCHARGE WITH MAGNET FIELD

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We present the results of investigations of the floating potential compensation of dielectric target in selfsustained plasma beam discharge in the magnetic field. We use gridless single-stage plasma accelerators with closed electron drift and narrow acceleration zone without of additional electron emitter as plasma beam source. When the source of such type works in collimated beam mode, lack of electrons in the ion flow leads to occurrence of positive charge on the target and reduces the efficiency of ion treatment. Existence of additional glow discharge in beam drift space can influence on target potential. We discuss experimental results of measurement of dielectric target potential for different conditions and proposal to solve the problem.

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## 1. INTRODUCTION

Modern plasma technologies allow obtaining the modification of surface and volume properties of materials in a very wide range [1]. In some cases these technologies operate with plasma-beam discharges and dielectric targets. The production of ion-plasma beam is possible by different types of ion or plasma sources. Usually, the design of such type of the source includes additional electrons source. Mainly the simple hot filament or complicated hollow cathode is used as additional electrons source. However, there exist situations when this is unusable. And sources of additional electrons of the other types either are complex in operation, or have high prices (or are subjected to both of those issues).

Of those, single-stage plasma accelerators with closed electron drift and narrow acceleration zone (accelerator with anode layer, AAL) excel from other plasma sources by the simplicity of their design. Additionally, use of accelerator with anode layer as a plasma flow source solves the problem of low conductivity of the target material. Efficient treatment by the plasma flow is possible even for dielectric materials in vacuum mode of AAL without electrons source [2].

In case of treatment of dielectric target by AAL without electron emitter in vacuum mode the target will have certain potential. The problem occurs due to lack of electrons in the ion flow, and it leads to occurrence of positive charge on the target and reduces the efficiency of ion treatment. Use of additional glow discharges in space between a source and a target allows essential reducing of the potential of processed dielectric target [3]. For obtaining the best conditions of target processing, the careful optimization of conditions of existence of such plasma-beam discharge is necessary.

## 2. EXPERIMENTAL SETUP

The experiments are carried out with single-stage plasma accelerators with closed electron drift and narrow acceleration zone of coaxial geometry without additional electron emitter. Accelerator has the ring discharge channel with width 10 mm, as it was described in [3]. The principle scheme of the experiments is shown in the Fig.1. The multilayer current coil (3) is coaxial with the accelerator main axis and allows variation of magnetic field distribution in the source-target space. The power supply of the coil allows change of the direction of magnetic induction vector to opposite one. The plasma source power supply allows use of the anode voltage of up to 2,5 kV. The usual discharge current is less then 500 mA. Distance from the source front to dielectric target is about 160 mm. The floating potential was measured in the different points of the vacuum volume with the use of a mobile plane Langmuir probe (4) and thin metal collector (5) by capacitive voltmeter.

## 3. RESULTS

The gridless plasma source of AAL type can work either in collimated or diffuse beam mode [4]. In diffuse beam mode glow discharge with current equivalent to current of main discharge exists around the source [5]. The ion flow propagates from this discharge region to the source cathode and sputters the cathode material. The particles from the cathode can contaminate the substrate surface and break the technological process [4]. So we investigate the dielectric target potential for collimated beam mode of source work.

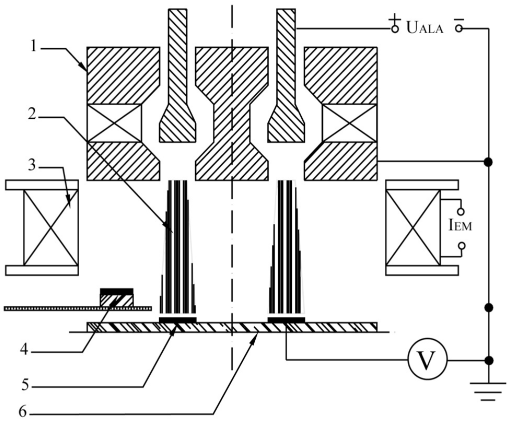
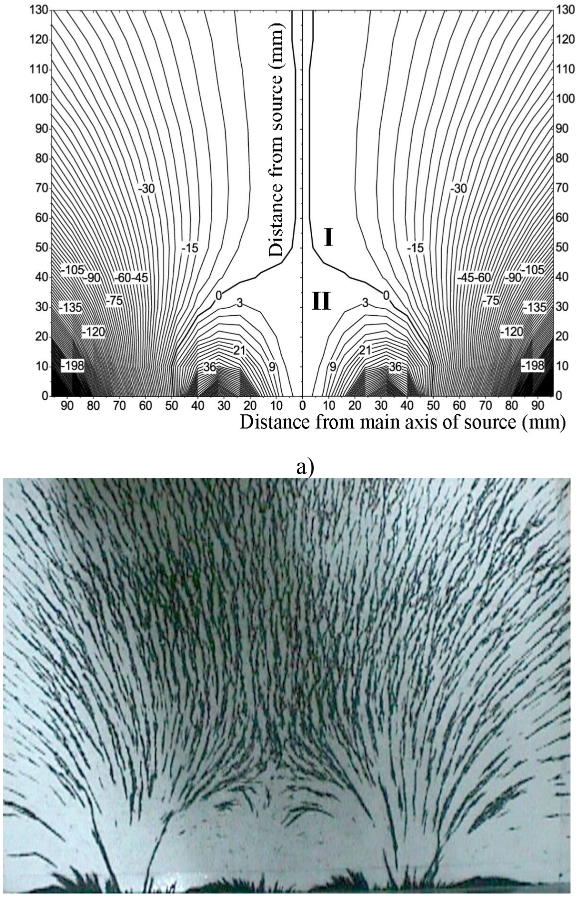


*Fig.1. Functional scheme of the experiments. 1 – source, 2 – plasma flow, 3 – current coil, 4 – mobile probe, 5 – metal collector, 6 – target*

The magnetic field is the inseparable component of devices with the closed electrons drift. Usually, magnetic systems of technological ALA are built on permanent magnets, and the necessary configuration of a field in a discharge gap is set by a choice of the form of pole tips. Thus the part of magnetic field falls outside of pole tips volume and the diffuse magnetic field exists around of the source with a complex enough configuration. On a basis of such magnetic system it is possible to obtain two configurations of magnetic lines above an obverse surface of the source. The first one corresponds to a case of field of balanced magnetron and the second one – to unbalanced magnetron. In the first case, passing of electrons from a zone of existence of the discharge to a target is essentially limited by the field configuration, and in the second case there are magnetic lines connecting the cathode of the accelerator with a target. In the second case it is possible to expect more complete compensation of the potential of dielectric target, and consequently the magnetic system of source is constructed so that a configuration close to the case of unbalanced magnetron is reached in the space of drift.



a)

b)

*Fig.2. The magnetic field map of plasma source obtained experimentally. a) - from measurement with Hall unit (μWb); b) – field is mapped using an iron powder technique*

Fig.2 shows the magnetic field maps obtained with iron powder technique (b) and from measurement of magnetic field above the accelerator with Hall unit and the subsequent construction of corresponding magnetic field map (a). One can see from the figure that the field above a source can be divided in two areas. In the first one, lines of a magnetic field go from a source to a target, so that they will not block a compensation of potential by free electrons. In the second case, the lines look like arcs closed on cathodes, so that electrons will have to overcome a confined magnetic field in addition to a weak electric one which is set by the anode potential. Earlier we already wrote about existence of additional discharges in these diffuse fields [5]. It is obviously important to check up the contribution of each of the components of formed plasma-beam system to the process of target potential compensation.

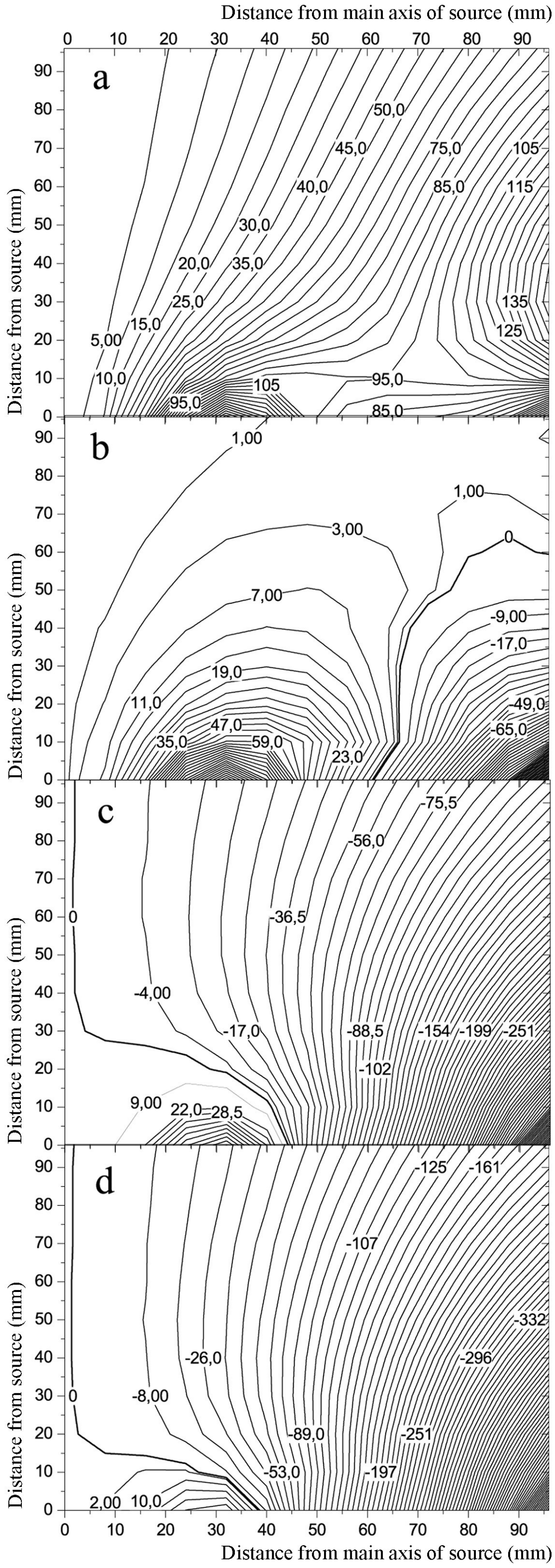
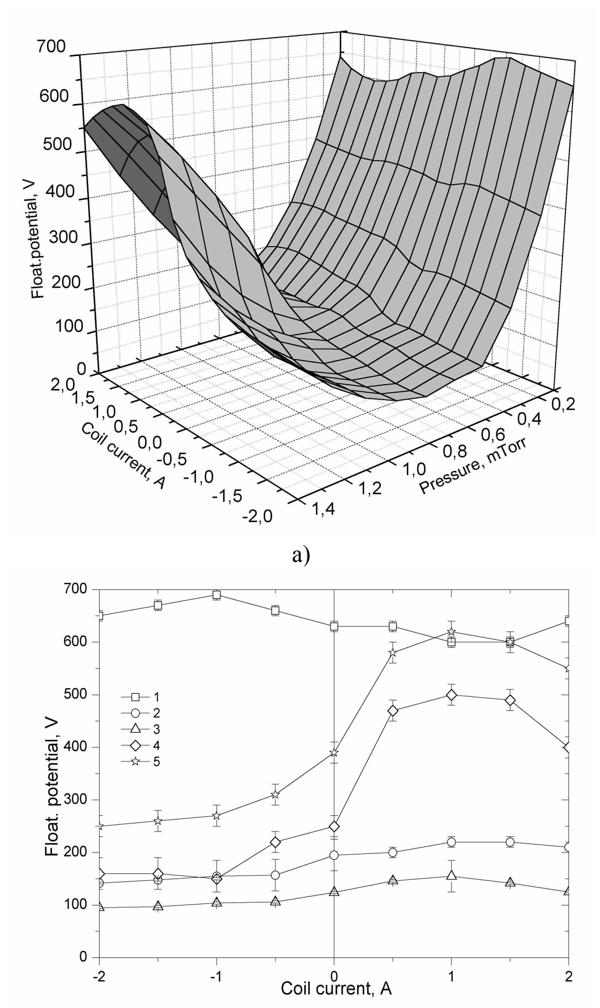


*Fig.3. The changes of magnetic field map of plasma sources with changes of coil current (μWb). a – additional magnetic field in coil is additive to source field, current – 2,5 A; b -- additional field is also additive, current – 1 A; c -- additional field is opposite*

*to source field, current – 1 A, d -- additional field is also opposite to source field, current – 2 A*



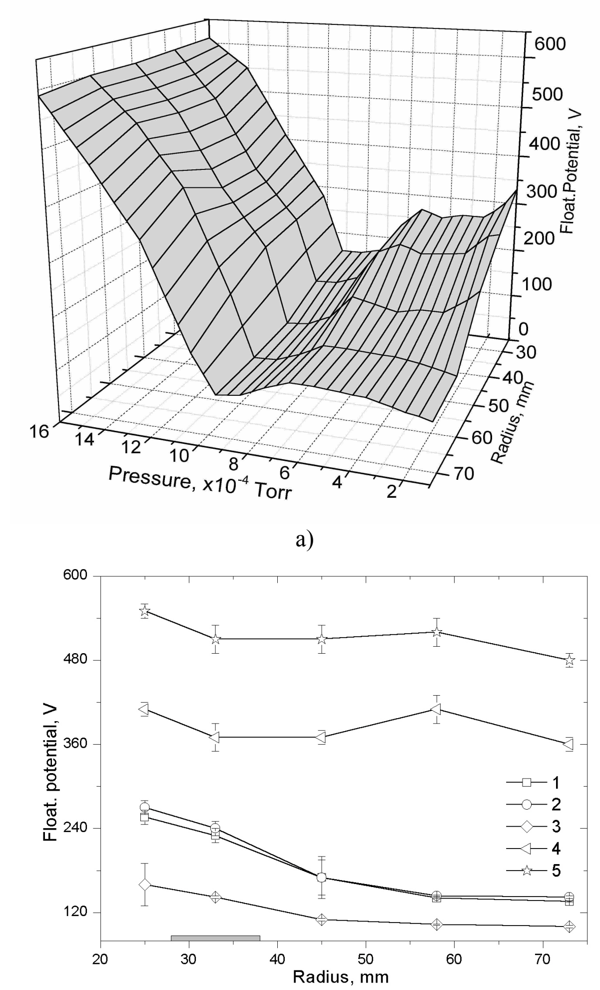
a)

b)

*Fig.4. The dependencies of floating potential of dielectric target on different magnetic field distribution for different pressure. a) diagram of float potential value at coil current and pressure plane; b) Target potential vs coil current, 1 – 0.1 mTorr; 2 – 0.5 mTorr; 3 – 0.9 mTorr; 4 – 1.2 mTorr; 5 – 1.4 mTorr*

Current coil located coaxially with a source in space of beam drift allows conducting of respective experiments. Field of the coil allows change of the geometry of mixed magnetic field in wide enough range. As one can see from Fig.3, it allows stretching the second zone to area of placement of the target and it to move it significantly from the target to a plane of the source. For convenience, we`ll designate the situation of addition of fields of the coil and the source as "direct" insertion, and a situation of subtraction of the fields as "opposite" one. In case of direct insertion, we shall consider a current in coil $I_{cl}$ as a positive, and the opposite one as a negative. It is shown that value of diffuse field is small enough, and in case of formation of discharge plasma in this area it should provide small influence on the results. Results of measurement of the floating potential of target $U_{fl}$ in case of direct and opposite insertion of the coil are shown in Fig.4.

In Fig.4 the three-dimensional diagram (a) showing dependence of a potential of the target on a pressure in the chamber and a current in the coil and some its cross sections by plane $U_{fl}(I_{cl})$ (b) is presented. It is shown that in case of low enough pressure (curves with numbers 1 to 3) change of geometry of magnetic field results in a small change of the target potential. But in case of absence of the glow discharge in space of the drift, the situation improves with distribution of a zone of arc type to the target region. And with the advent of the additional discharge in space of the drift, the situation becomes an opposite (curves with numbers 3-5). It can be easily explained considering fact that at low pressure the electrons are generated mainly in the area of anode layer, and with the advent of additional discharge their significant quantity appears in the first area of magnetic field. Simplification of their coming onto the target considerably lowers its potential.



a)

b)

*Fig.5.The dependencies of floating potential of dielectric target for different pressure in vacuum chamber on radial spacing from the main axis of system. a) diagram of floating potential value on radius and pressure plane; b) Target potential vs radius, 1 –0.3 mTorr; 2 – 0.5 mTorr; 3 – 0.9 mTorr; 4 – 1.2 mTorr; 5 – 1.4 mTorr*

At the same time, one can see that with the further growth of pressure the potential of a target becomes rather significant again. Simultaneously, the additional discharge fills the whole vacuum chamber, and a plasma source switches to the diffuse beam mode. In this situation the target potential becomes almost equal to the anode one, and efficiency of cleaning of the target decreases dramatically.

In Fig.5 the three-dimensional diagram showing distribution of the floating potential in volume of the chamber in dependence on pressure in the chamber and distances from an axis of the system (a) and some its sections by plane $U_{fl}(r)$ is presented (b). One can see that with the pressure increase a stage comes when the potential is leveled on the chamber volume. The dielectric target appears immersed in plasma of a positive column of the glow discharge and gets the corresponding floating potential, which can be below the anode one only by a value of about $kT_e$. Due to fact that for this discharge the anode is that of the source, the target potential appears comparable with the anode one.

## CONCLUSIONS

One can see from the presented results that presence of magnetic field in a volume of the discharge influences value of the floating potential of a dielectric target contacting with such plasma-beam discharge. Both size and geometry of a magnetic field provide the influences. In conditions of low pressure (below 1 mTorr) the target placement in the second area linked to the anode layer and magnet field lines of arc type closed on cathodes is preferable. In the pressure range of about 1 mTorr and above, the target placement in a zone, which is isolated from the anode layer by magnetic field and does not limit pass of free electrons onto the target, is preferable. For obtaining as low as possible potential on a dielectric target in the range of low vacuum it is important to provide its isolation from plasma of the additional glow discharge arising in space of a beam drift. Otherwise, the target appears immersed in plasma of the high-voltage glow discharge and gets the corresponding floating potential.

Thus, providing compensation of a dielectric target potential in the pressure range of 1…10 mTorr with the use of plasma-beam discharge is possible only if one will not allow contact between the glow discharge plasma and the target.

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## ПЛАВАЮЩИЙ ПОТЕНЦИАЛ ДИЭЛЕКТРИЧЕСКОЙ МИШЕНИ В ПУЧКОВО-ПЛАЗМЕННОМ РАЗРЯДЕ С МАГНИТНЫМ ПОЛЕМ

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Мы представляем результаты исследований компенсации плавающего потенциала диэлектрической мишени в самосогласованном пучково-плазменном разряде в магнитном поле. Мы используем бессеточный одноступенчатый плазменный ускоритель с замкнутым дрейфом электронов и узкой зоной ускорения без дополнительного эмиттера электронов в качестве источника пучка плазмы. Когда источник такого типа работает в режиме коллимированного пучка, недостаток электронов в ионном потоке ведет к возникновению положительного заряда на мишени и уменьшает эффективность ионной обработки. Существование дополнительного тлеющего разряда в пространстве дрейфа пучка может влиять на потенциал мишени. Мы обсуждаем экспериментальные результаты измерения потенциала диэлектрической мишени для различных условий и предлагаем решение проблемы.

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## ПЛАВАЮЧИЙ ПОТЕНЦІАЛ ДІЕЛЕКТРИЧНОЇ МІШЕНІ У ПУЧКОВО-ПЛАЗМОВОМУ РОЗРЯДІ З МАГНІТНИМ ПОЛЕМ

***А.М. Добровольський, А.Н. Євсюков, О.А. Гончаров, І.М. Проценко***

Ми представляємо результати досліджень компенсації плаваючого потенціалу діелектричної мішені у самоузгодженому пучково-плазмовому розряді у магнітному полі. Ми використовуємо безсітковий одно ступеневий плазмовий прискорювач з замкнутим дрейфом електронів та вузькою зоною прискорення без додаткового емітера електронів як джерело пучка плазми. Коли джерело такого типу працює в режимі колимованого пучка, недолік електронів у іонному потоці веде до виникнення позитивного заряду на мішені та зменшує ефективність іонної обробки. Існування додаткового жевріючого розряду у просторі дрейфу пучка може впливати на потенціал мішені. Ми обговорюємо експериментальні результати вимірювань потенціалу діелектричної мішені для різних умов та пропонуємо розв’язок проблеми.