Plasma Accelerator Magnetic Field Configuration Effect on Dielectric Target Potential

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Abstract – In the recent years the use of highly efficient plasma technologies of processing the new materials and coatings attracts essentially growing interest. Single-stage plasma accelerators with closed electron drift and narrow acceleration zone excel the other types of plasma sources by the simplicity of their design and perfect scaling. Such devices can be efficiently used for ion treatment of metal and non-metal targets. In cases of ion treatment of dielectric targets the problems can occur due to uncompensation of the ion flow by electrons which results in appearance of positive charge at the target and reduces the efficiency of ion treatment.

In the present work the results of measurement of the source magnetic field configuration effect on the floating potential of dielectric target irradiated by the ion-plasma flow from the accelerator are presented in dependence on working gas pressure and discharge parameters in the source for different regimes of its operation.

It is shown that manipulation by diffuse source magnetic field in the source-target space allows to decrease the target potential in the wide pressure region. The role of different magnetic field area in formation of floating target potential is also shown.

1. Introduction

In the recent years the use of highly efficient plasma technologies of processing the new materials and coatings attracts essentially growing interest [1–3]. Most commonly, plasma accelerators with closed electron drift with different modifications, magnetrons, vacuum arcs are used as the plasma sources. Of those, single-stage plasma accelerators with closed electron drift and narrow acceleration zone (accelerator with anode layer, AAL) excel by the simplicity of their design. These sources are capable of generating formed ion-plasma flows with different configurations, shaped as rings and ellipses, convergent/divergent with respect to the axis. Such devices can be efficiently used for ion treatment of metal and non-metal targets, cleaning, etching and activation of the surface. AAL can effectively process any materials even without the additional electron emitter [4]. In this case, at processing of non-conductive, dielectric targets the problems occur due to uncompensation of the ion flow by electrons which results in appearance of positive charge at the target and reduces the efficiency of ion treatment.

In the present work the results of measurement of the source magnetic field configuration effect on the floating potential of dielectric target irradiated by the ion-plasma flow from AAL are presented in dependence on working gas pressure and discharge parameters in the accelerator for different regimes of its operation.

2. Experimental setup

The experiments are carried out with single-stage plasma accelerators with closed electron drift and narrow acceleration zone of coaxial geometry. Accelerator has the ring discharge channel with width 10 mm width. The principle scheme of the experiments is shown in the Fig. 1. The multilayer current coil is coaxial with the accelerator main axis and allows to vary a 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 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 unit of a hollow cathode type is used by us as a source of additional electrons. The floating potential is measured with capacitive voltmeter.

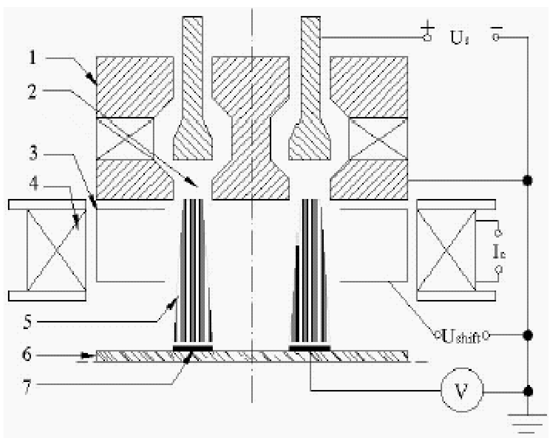

Fig. 1. Functional scheme of the experiments. 1 – source, 2 – discharge channel, 3 – hollow cathode, 4 – current coil, 5 – plasma flow, 6 – target, 7 – metal collector

In the experiments we use the hollow cathode placed around the beam. The design of our hollow cathode has been made in form of tore with rectangular section without an internal lateral surface. The unit have 144 mm external diameter, 80 mm internal diameter and 50 mm height and is placed between a front of source and the target. It is coaxial with plasma beam. We also use ion-electron emission from wall of short pipe as the other source of additional electrons. Pipe is placed coaxially with the beam as well. The internal diameter of the pipe is about 84 mm.

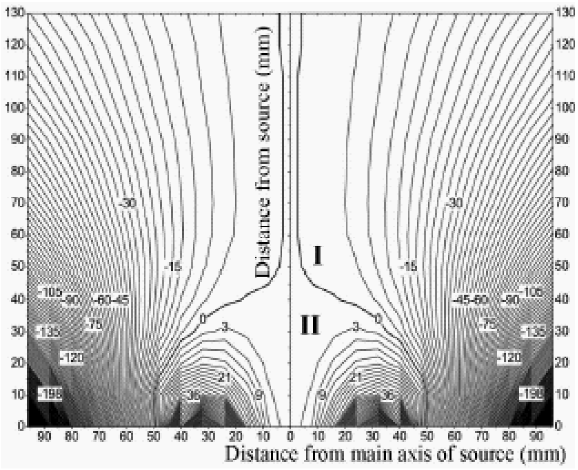

Fig. 2. The magnetic field map of plasma sources obtained experimentally. (μWb)

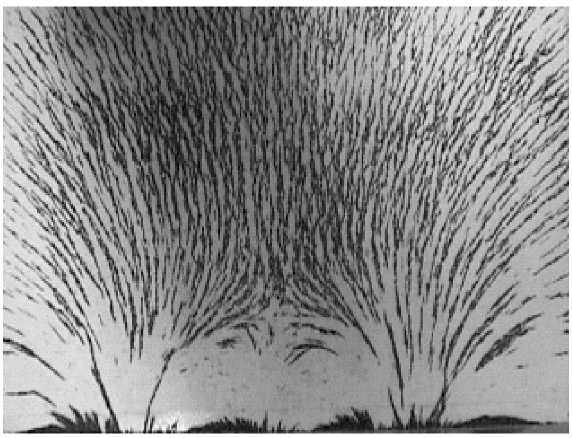

Fig. 3. The magnetic field is mapped using an iron powder technique

The floating potential in the different points of the vacuum volume was measured with use a Langmuir probe and a capacitive voltmeter.

3. Results

The discharge in the source exists in crossed magnetic and electric fields. We create the necessary configuration of a magnetic field with the use of permanent magnets and poles. Usually diffuse magnetic field exists around the poles. This field and potenti-

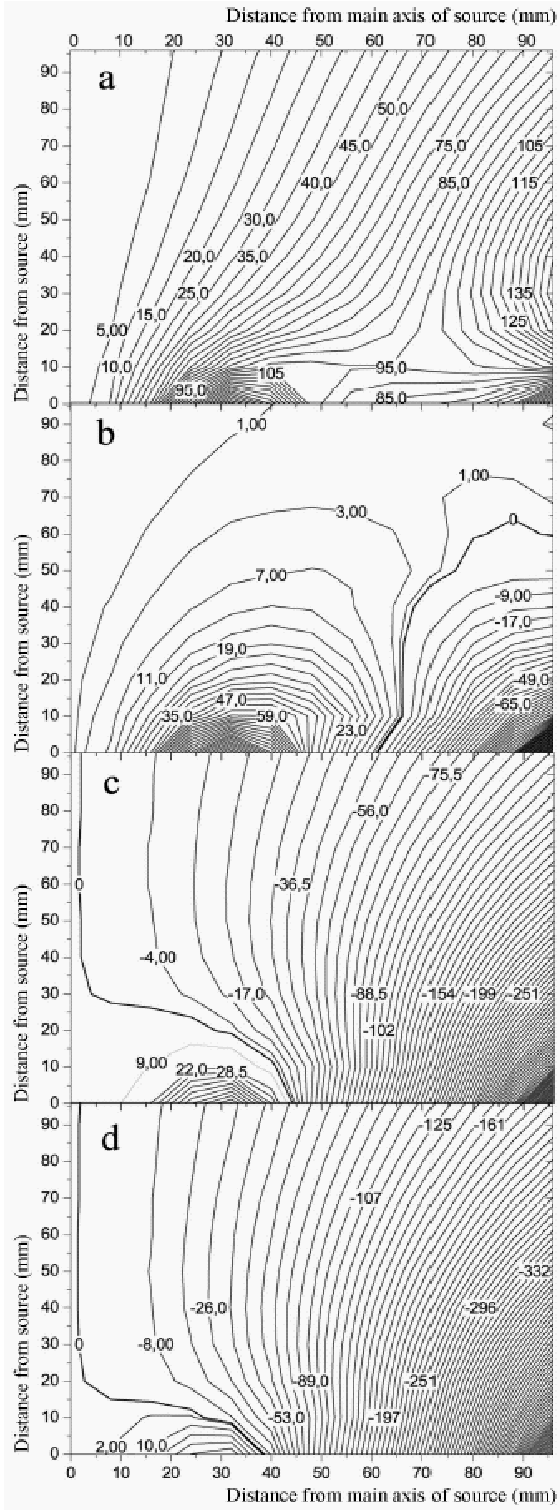

Fig. 4. The changes of magnetic field map of plasma sources with changes of coil current (Wb). a – additional magnet field in coil is additive to source field, current – 2,5 A; b – additional field also is additive, current – 1 A; c – additional field is opposite to source field, current – 1 A, d – additional field is also opposite to source field, current – 2 A

als of the anode and the target influence processes in this volume. Thus we have to know magnetic field distribution. The results of the measurements are shown in Fig. 2. It is in very good agreement with the shape of the magnetic field mapped using an iron powder technique, Fig. 3. It is possible to divide the map into two regions. I — outer region with the unclosed magnetic field lines in printed frame, II — inner region with magnetic field lines of arc type. The presence of two different regions should influence a compensation of target floating potential. For coil. The change of magnet field distribution un der changes of coil current is shown in Fig. 4, *a–d.* One can see that variations of coil current can essentially change the geometry of magnetic field lines in a region of the target placement. In case of acceleration of intrinsic magnetic field of the source by that of the coil it is possible to place the target into the second region, whereas in case of opposite magnetic field adding the target can be significantly moved away from that region. By this way we can define the influence of the magnetic field distribution on compensation ability of these discharges. Fig. 5 shows the dependencies of floating potential of dielectric target in case of different magnetic field distribution without separate source of electrons. One can see from these dependencies that by variation of field geometry we can manipulate the floating potential. However, we cannot obtain zero value of floating potential in such way. As we wrote earlier [5], the additional discharges are present in a gap between the source and the target. And in case of absence of separately installed source of electrons, these discharges supply part of electrons for compensation of floating target potential.

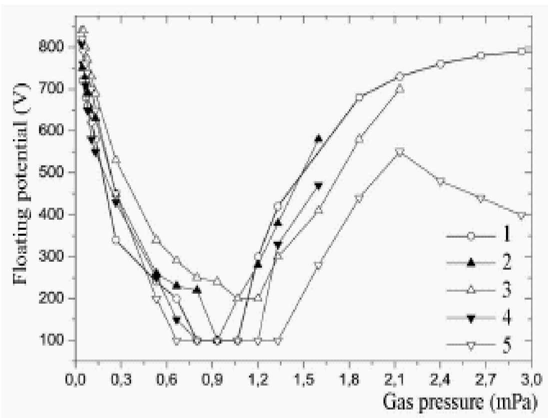

Fig. 5. The dependencies of floating potential of dielectric target on different magnetic field distribution without separate source of electrons. 1 – I_C=0 A; 2 – I_C=1 A; 3 – I_C=2.5 A; 4 – I_C=–1 A; 5 – I_C=–2.5 A

At the same time, one can see that this mechanism of compensation works in narrow enough pressure range and does not allow to obtain zero potential of the target even in this range. In case of amplification of these discharges we obtain intense sputtering of the surfaces surrounding the region of existence of the discharges and contamination of surface of processed samples rather than improvement of the compensation. Besides, the region of plasma glow surrounds the target, and the last attains the potential of an isolated body placed into the plasma.

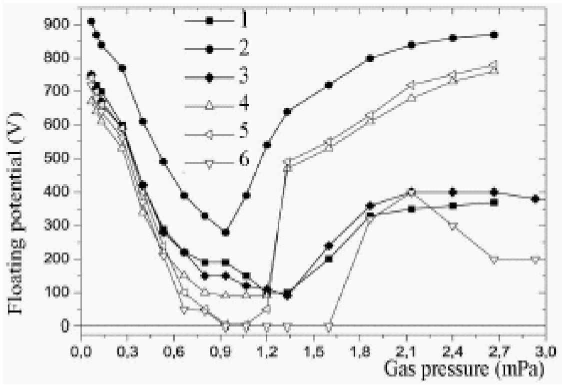

Fig. 6. The dependencies of floating potential of dielectric target on the hollow cathode potential. 1 — hollow cathode is grounded; 2 — under floating potential; 3 — under self-sustained shift; 4 — under –100 V; 5 — under –200 V; 6 — under –400 V

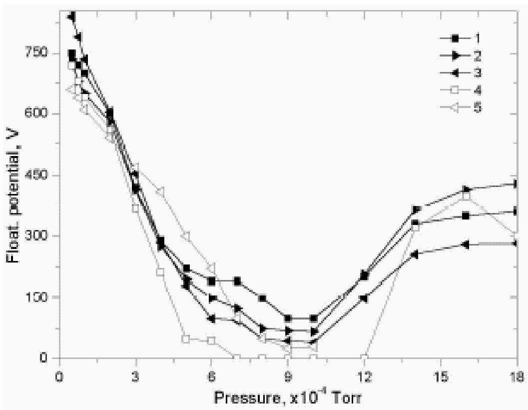

Fig. 7. The floating target potential vs pressure under conditions of presence of a hollow cathode and a different distributions of magnetic field. 1 — only source magnetic field and hollow cathode is grounded; 2 — additional magnetic field as for fig. 3 (a); 3 — additional magnetic field as for fig. 3 (d); 4 — hollow cathode potential is — 400 V and only source magnetic field; 5 — hollow cathode potential is — 400 V and additional magnetic field as for fig. 3(d)

It is known that one can reach total compensation of the plasma flow in such sources by the use of thermoemitter. Here is only one problem consisting in not long lifetime of such emitter and the sensitivity to the nature of working gas. We can avoid this problem by the use of any localized discharge with cold cathode. Working pressure range is too low for self-sustained discharge with hollow cathode. However, the fact of existence of ion-plasma flow can be utilized, and the hollow cathode can be constructed around it. In such case presence of primary electrons will be provided by the beam itself, and the region of the discharge existence will be limited by the hollow cathode volume. Results of measurements of the target potential with the first version of hollow cathode are presented in fig. 6. One can see that the worst case takes place when the hollow cathode is under the floating potential, and the best one is realized at supply of – 400 V bias to it with respect to the source cathode. It is clear that in the first case the electrode itself has positive potential with respect to the source cathode and takes the electrons off the volume, whereas in the second case the electrode possesses minimum potential in the system thus forming electrostatic open trap for the electrons. In such system non-self-sustained discharge with hollow cathode can already exist, and accumulation of additional electrons is possible.

One can see that at pressure higher than $1{,}6\cdot10^{-1}$ Pa compensation of the target potential is absent again. In this pressure range localization of auxiliary discharge also disappears, and the target appears to be placed in the plasma. This can explain disappearance of the compensation effect.

Fig. 7 shows the results of measurements of target potential under conditions of presence of a hollow cathode and the different distributions of magnetic field. The target potential appears to be sensitive to magnetic field distribution in the hollow cathode space. However, for improvement of the situation with respect to one with simply strongly negatively biased hollow cathode, thorough match of the field geometry with that of the cathode electrode may be required.

4. Conclusions

The experiments show that in case of AAL work in the vacuum mode, the deficit of electrons in a zone of the ion flow transport results in the growth of potential of irradiated target up to the value of anode potential of the accelerator. The manipulation by diffuse source magnetic field in the source-target space allows to decrease the target potential in wide pressure region. Increasing of the target potential in pressure range of more than $1{,}6\cdot10^{-1}$ Pa is defined by filling the volume with the glow discharge plasma. In this case the isolated plate should have the floating plasma potential which is close to plasma potential. The different magnetic field areas bring the different contributions to formation of floating target potential. From the first area, the electrons easily travel along a magnetic field line to the target, whereas from the second one, movement of the electrons in direction of the target is possible only across magnetic field lines or by a jump to the first area nearby the line of their division.

The electrons from peripheral discharges can compensate the target potential, however not to full extent. It is possible to have total compensation of the target floating potential by the use of additional localized discharge with cold cathode. For the most efficient utilization of the hollow cathode discharge, one should match value and geometry of the magnetic field with the cathode electrode design in place of its location to a maximum possible extent.

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