LAST RESULTS OF NOVEL PLASMAOPTICAL DEVICES INVESTIGATION

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The combined system composed of the vacuum arc evaporator and plasmaoptical system with plasma lens (PL) geometry are presented and studied. The plasmadynamical characteristics of high density low energy plasma flow propagating through the PL are investigated. The application of the plasma lens to the transport of low energy high-current ion beam can improve the delivery of plasma flow to substrate, as well as provide microdroplet removal by means of the fast electrons within the lens region.

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INTRODUCTION

The vacuum arc plasma sources, like MEVVA, for production high-current (ampere scale), moderate energy (1…100 keV) heavy metal ion beams with different species [1] are known and well explored. The axi-symmetric cylindrical electrostatic PL, based on the fundamental plasma optical principles, is well-explored tool for focusing and manipulating kind ion beams, where the concern of beam space charged compensation is critical [2]. The combination of these tools in one device looks a very attractive. The attachment of PL in a volume of MEVVA source creates new possibility for manipulating a low energy ion plasma flow propagating towards to substrate (deposition option) or to emission grid (plasma source option).

In [3 - 6] it has been noted that changing potential relief in the PL volume allows to control the properties of high density low energy plasma in wide range. In part, a new approach was proposed to the elimination of microdroplets from the dense metal plasma flow based on the use of an electrostatic PL to generate an energetic electron beam formed self-consistently by ion-electron secondary emission in the near-wall plasma layer from the internal surface of the lens central electrode. It can provide evaporation and thus elimination of microdroplets from the plasma flow. Some preliminary theoretical and experimental studies were carried out providing confidence and optimism that proposed idea for micro-droplet elimination has good potential for success.

1. EXPERIMENTAL CONDITIONS

The experiment was carried out at the setup is shown in Fig. 1. The gas inlet was in vacuum chamber (1) directly. The working gas is Ar required for stable arc discharge only, so that it does not influence on the plasma flow dynamics. The pulsed cathodic arc plasma gun include: 2 – metal cathode, 3 – ring-shaped insulator around the cathode, 4 – igniter electrode. The PL include electrodes (5, 7) and magnet circuit based on permanent magnets. Also we have diagnostic tools, langmuir probe (10) and moved collectors (9). A repetitively pulsed cathodic arc plasma gun (i.e., a MEVVA ion source without the ion optic extraction system) was used to produce energetically streaming copper plasma. The PL is of 140 mm length and 80 mm aperture. It includes three cylindrical electrodes with different lengths in a magnetic field.

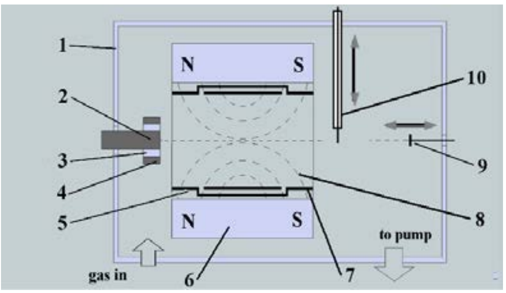

Fig. 1. The experimental setup.
1 – vacuum chamber; 2 – cathode; 3 – insulator;
4 – igniter; 5 – electrode; 6 – magnets; 7 – electrode;
8 – magnetic field line; 9 – collector; 10 – Langmuir probe

The lens outer electrodes are grounded and one of them is anode of discharge of MEVVA source. The central electrode was biased under different positive and negative potentials. The vacuum chamber possessed sealed window which enabled different experimental studies (plasmadynamical measurements by sectioned collector, emission spectra analysis by CCD spectrometer, charge state distribution (CSD) by magnetic sector analyzer, substrate for coating deposition). For measurement pulse currents and electric potentials traditional electrophysical methods are used.

In the our experiments we use copper cathode. The arc form the dense low temperature metal plasma from the cathode material. The arc current was from 50 to 200 A. The pulse duration was 100…600 μs and repetitively pulsed at 0.5…5 pulses per second. The base vacuum chamber pressure was 1.5×10^{-6} Torr.

2. RESULTS AND DISCUSSION

Let us discuss some results of studies of the plasmadynamical characteristics of the plasma flow in the our system.

Propagation of the plasma beam in the free space after PL is illustrated in Fig. 2. The transmission of the transportation space increases in all cases. The flow focusing exists in case the floating potential (b) at the central lens electrode, it is higher in the case of the positive potential (a) and is also present in case of the negative potential (c). The data shown are the averages over six plasma pulses. The z-axis zero is the plasma lens exit plane. We believe that in case of floating potential (Fig. 2,b) this effect is due to self-consistent mode formed in the lens volume.

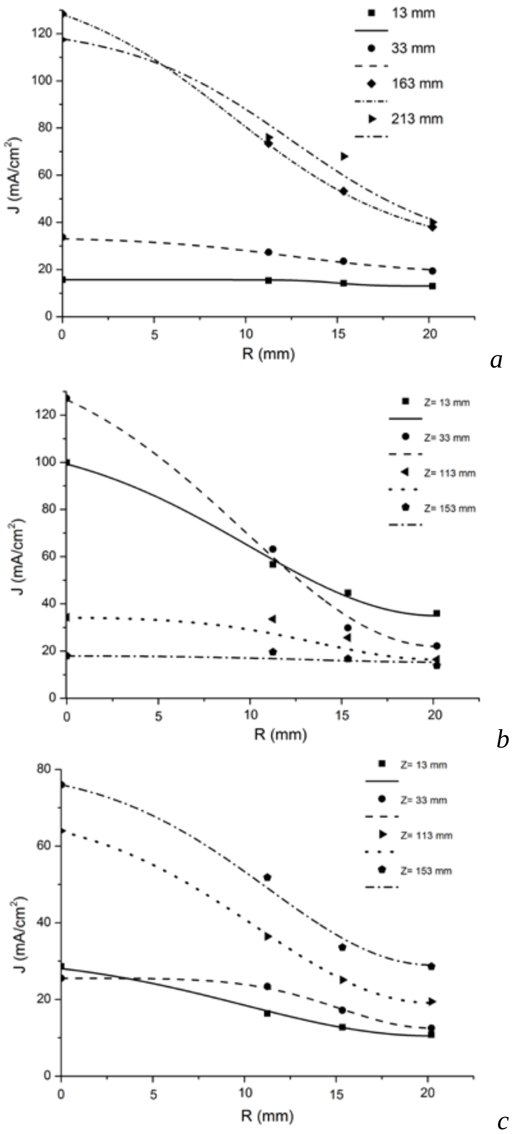

Fig. 2. Radial current density distribution, I_d = 100 A, P= $1.5{\cdot}10^{-6}$ Torr, B = 0.03 T throughout the plasma pulse: a) +50 V on central collector; b) floating potential; c) -400 V

Note the measurements show the formation of a positive self-sustained potential of about 10 V at the central electrode upon transport of the plasma stream. Also we can see focusing of the streaming plasma at the exit of the lens for negative applied potential (-500 V, actual potential is -400V) at the central lens electrode. This could be due to generation of fast electrons from secondary emission by ion impact on the inner surface of the central lens electrode. These electrons together with slow plasma electrons can accumulate at the axis and provide ion focusing due to a polarization effect. In pure plasmaoptical regime with applied positive potential, actual potential being just about +50 V, the central electrode serves as the second anode of vacuum-arc discharge and plasmaoptical focusing effect appearance in this case is not so clear. The obtained results have good agreement with general theoretical approaches.

The Fig. 3 shows the radial profile of plasma beam in free space after PL. Fig. 3,a shows the profile after the PL with and without the negative potential on central electrode, approximately -400 V. The curves exhibit the ion saturation current density at bias potential -100 V. One can see an increase of the ion current density by a factor about 5.

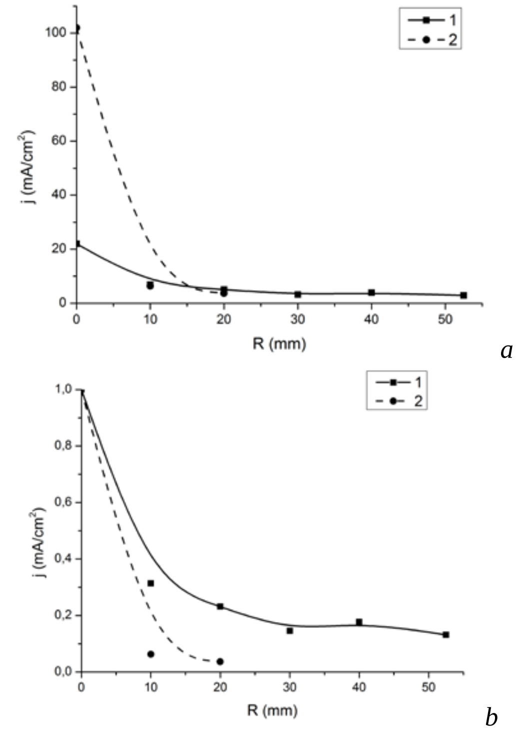

Fig. 3. The ion saturation current density profile. a) radial distribution: 1 – U_{PL}=0; 2 – U_{PL}=-400 V; b) normalized radial distribution: 1 – U_{PL}=0; 2 – U_{PL}=-400 V; I_d=100 A; B=0.03 T

The Fig. 3,b shows the normalized profile of the beam for the case Fig. 3,a. The half-width of the profile decreases with increasing of a negative potential on PL. It shows not only increasing transmission of transportation space but also focusing of low energy plasma flow. The distance for the plane of Fig. 3. from the PL exit is more than 70 mm. There is no focus plane for -400 V on central PL electrode. The ion saturation current density profile along radius for the position of 50 mm from PL exit is shown in Fig. 4. Here we have the current density rising by a factor of approximately 15.

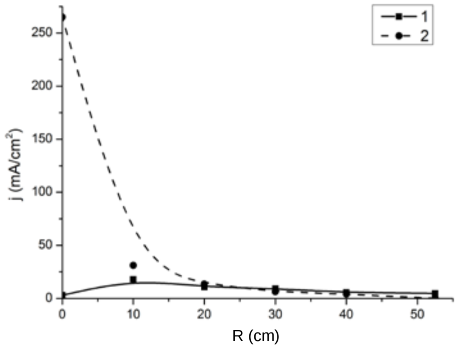

Fig. 4. The ion saturation current density profile. 1 – U_{PL}=0; 2 – U_{PL}=-400 V; I_d=100 A; B=0.03 T

As one can see, the ion current density at longer distance from the lens (see Fig. 3) with negative potential on PL is much higher than that at closer distance (see Fig. 4) when there is no potential.

The optical emission spectroscopy measurements were carried out to obtain additional information about the processes in the plasma volume. The results for the case of negative applied potential at the central electrode are shown in Fig. 5. The results shown are the average over 20 plasma pulses. One can see the significantly increased relative intensity of the lines both of copper atoms and single charged copper ions within the plasma with the increasingly negative central electrode. The last can indicate the presence of fast electrons in the plasma lens volume. The presence of fast electrons in the PL volume can also explain the results presented in Fig. 6.

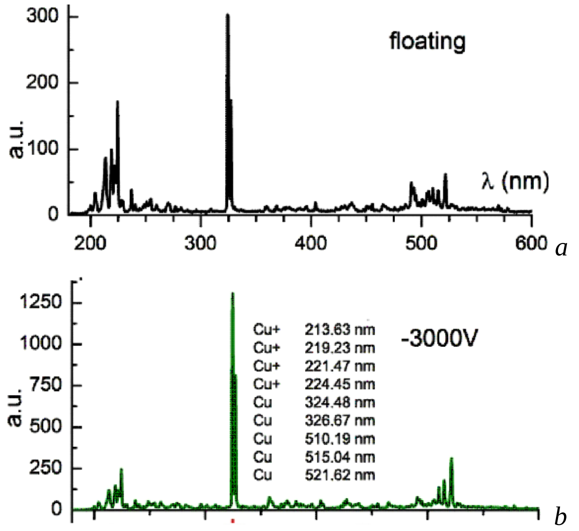

Fig. 5. Optical emission spectra of the discharge plasma for different central lens electrode potentials: a) floating; b) -3 kV. B = 0.03 T; pressure 1.5·10^{-6} Torr

The Fig. 6 shows CSD in a copper low energy plasma flow with and without the PL. It is noticeable that changing the lens parameters we can influence on state charge distribution in the flow. It is also noticeable that the presence of a magnetic field and a potential on the central electrode of the lens leads to a significant increase in the current of all charge states in the flow. The latter is due to the overall improvement of flow through the cathode to the target.

In order to make CSD measurements, our combined system was transformed into ion source with an emission grid and accel-decel ion optical system to provide formation ion beam with extraction voltage 15 kV suitable for testing in the magnetic sector analyzer. The obtained results show the peculiarities of CSD changing plainly in case of applied negative potential to the central lens electrode and magnetic field presence (see Fig. 6).

Behavior of the spectrum lines can be also easily explained by the presence of fast electrons in the volume. In essence, these electrons evaporate microdroplets and add neutral copper atoms into the volume that lead to essential increasing a rate of resonant charge exchange process. Note, the emission current of the extracted ion beam, currents of Cu ions with charges from 1+ till 4+ drastically increase with application of negative potential and magnetic field on the contrary to the case without magnetic field and negative lens potential. Particularly, emission current increases approximately from 0.25 to 0.5 A, Cu^{3+} from 0.45 to 1.8 mA, Cu^{1+} from 0.05 to 0.75 mA. These data indicate on focusing low energy plasma flow towards emission grid and exhibit existence fast electrons in the flow propagation area.

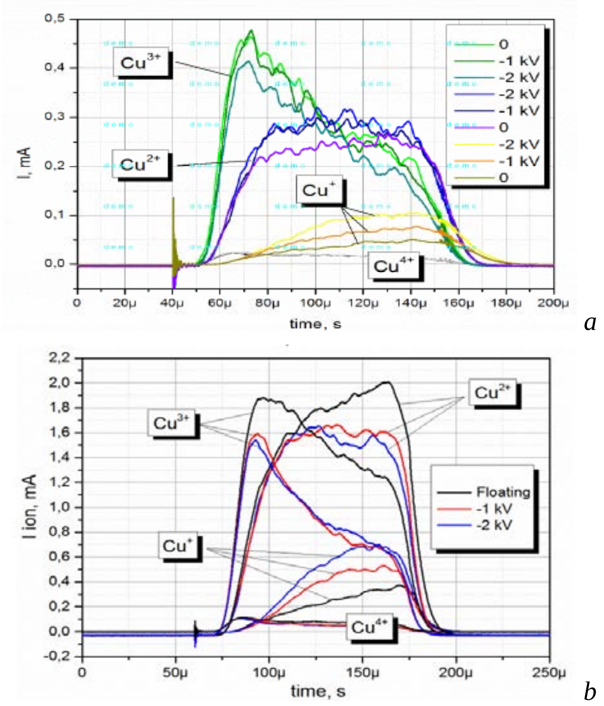

Fig. 6. The examples of charge state distribution of Cu ions, p= 1.5·10^{-6}, B=0 (a) and B=0.03 T (b)

Carried out computer modeling has shown the appearance of high-energetic secondary electrons under negative potential applied to the central lens electrode. These electrons accumulate at the axis and could provide the ion flow focusing.

Note that appearance of electron beam formed self-consistently by ion-electron secondary emission in the near-wall plasma layer from the internal surface of the lens central electrode significantly affects on evaporation and removal of the micro-droplets from the plasma flow and thereby improves the quality of obtained metal coating. Preliminary studies demonstrate that with negative potential increase the number of droplets essentially decreases in case of the filter use. Maximum size of droplets reaching the sample surface also decreases.

CONCLUSIONS

Here we present and discuss the new upgraded system that combines the MEVVA plasma source with an axially symmetric electrostatic plasma-optical lens. We have studied peculiarities of plasmodynamical, optical, charge state characteristics and the Cu film deposition under different conditions. The obtained results show the presence of the fast electrons and their effect on a low energy high-density metal plasma flow propagating through PL, improvement of charge state distribution and increase of total ion beam extraction current.

These results open up a new attractive way for further development and application the erosion plasma sources for syntezis thin films with given properties as well as creation new generation MEVVA ion sources.

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ПОСЛЕДНИЕ РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ СОВРЕМЕННЫХ ПЛАЗМООПТИЧЕСКИХ УСТРОЙСТВ

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Предложена и исследуется комбинированная система из вакуумно-дугового испарителя и плазмооптического устройства в геометрии плазменной линзы (ПЛ). Исследованы плазмодинамические характеристики низкоэнергетического плазменного потока высокой плотности, проходящего через ПЛ. Использование ПЛ для транспортировки низкоэнергетических ионных потоков с большим током позволяет улучшить прохождение плазмы к мишени и уменьшить содержание микрокапель благодаря наличию быстрых электронов в объеме линзы.

ОСТАННІ РЕЗУЛЬТАТИ ДОСЛІДЖЕНЬ СУЧАСНИХ ПЛАЗМООПТИЧНИХ ПРИСТРОЇВ

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Запропонована та досліджується комбінована система, що складається з вакуумно-дугового джерела плазми та плазмооптичного пристрою в геометрії плазмової лінзи (ПЛ). Досліджено плазмодинамічні характеристики низькоенергетичного плазмового потоку високої щільності, що проходить крізь ПЛ. Застосування ПЛ задля транспортування низькоенергетичних іонних потоків з великим струмом дозволяє покращити проходження плазми до мішені та зменшити вміст мікрокрапель завдяки присутнім в об’ємі лінзи швидким електронам.