Advanced Plasma Optical Devices (Status and New Developments)

A.Goncharov[1], A. Dobrovosky[1], I. Litovko[2], A. Bugaev[3], V. Gushenets[3] and E. Oks[3]

[1] *Institute of Physics NAS of Ukraine, Kiev, Ukraine*

[2] *Institute for Nuclear Research NAS of Ukraine, Kiev, Ukraine*

[3] *High-Current Electronics Institute of SB RAN, Tomsk, Russia*

Abstract This is the review of current status of ongoing research and development the new generation plasma devices based on the cylindrical electrostatic plasma lens configuration attractive for application in the state-of-the-art ion-plasma technologies for surface treatment and synthesis of the new materials by intense beam-plasma flows.

Introduction

The electrostatic plasma lens is a well-explored tool for focusing high-current, large area, energetic, heavy ion beams, providing a convenient, affordable and quick way of carrying out particularly high-dose ion implantation [1,2]. The fundamental concept of this kind of the lens is based on plasma optical principles of magnetic insulation of electrons and equipotentialization of magnetic field lines for the control of over-thermal electric fields introduced into the plasma medium. The crossed electric and magnetic fields inherent to the plasma lens (PL) configuration provide the attractive method for establishing a stable plasma discharge at low pressure. With the use of PL configuration in this way, several low cost, low maintenance, high reliability plasma devices using permanent magnets and possessing considerable flexibility towards spatial configuration were developed. These devices can be applied both for fine ion cleaning, activation and polishing of substrates before deposition, and for sputtering. One particularly interesting result of this background work was observation of the essential positive potential at the floating substrate [3]. This suggested to us the possibility of an electrostatic PL use for focusing and manipulating high-current beams of negatively charged particles, electrons and negative ions that is based on the use of the dynamical cloud of positive space charge under condition of magnetic insulation electrons [4]. The experimental and theoretical investigations of high-current wide-aperture non-relativistic electron beams focusing due to plasma lens with positive space charge cloud are presented. We describe also the original approach to effective additional filtering of micro droplets in a dense, multi component low temperature plasma flow generated by erosion plasma sources like vacuum arc and laser produced plasma.

High-current electron beams focusing by PL with positive space charge cloud

The experiments on high-current electron beam focusing by the lens with a positive space charge have been carried out on a setup shown in **Fig. 1** (see elsewhere for detail [4,5]). An electron beam (8) from the plasma electron source (1-4) passed through the lens volume (5-7) to the sectioned collector (9-13), where electron beam current distribution along radius has been analyzed.

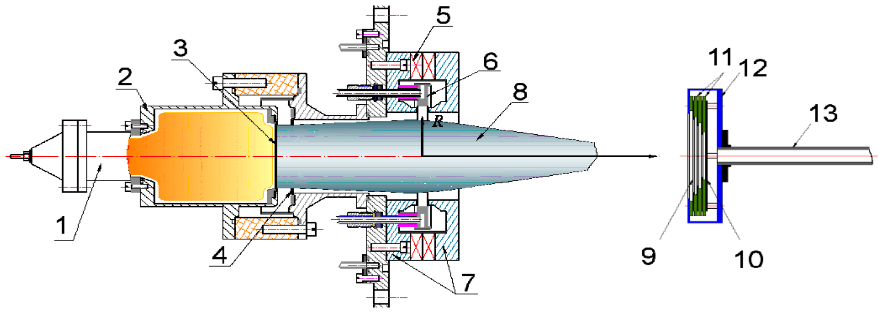

Fig. 1. The setup scheme. Plasma electron source: 1 – plasma cathode, 2 – hollow anode, 3 – emission grid, 4 – accelerating electrode. PL: 5 – permanent magnets, 6 – anode, 7 – cathode. 8 – electron beam, 9,10 – collector rings, 11 – isolators, 12 – shield, 13 – moving rod.

In these experiments the plasma lens operates in the plasma mode and provides plasma density required for the accelerating, formation and stable transport of the high-current pulsed electron beam. We were able to provide the passing electron beam with energy up to 20 keV and current up to 100 A (see **Fig. 2**) through PL. The lens discharge current was about 100 mA (working gas Ar), pressure above 4x10^{-4} Torr. The discharge current was limited by the power scattered at the lens electrodes. The discharge in the lens added stability to the pulse shape of the electron beam current, decreasing its fluctuation amplitude and enhancing the current transport. It can be seen from comparison of oscillograms 2 and 3 in **Fig. 2** showing, respectively, the beam currents before ignition and after ignition of the discharge in the lens. One can see the higher discharge current is in the lens, the more fluctuations are suppressed.

As we have shown theoretically in work preliminary described here [4,5] when beam space charge density equals or exceeds space charge cloud density – the cloud is quickly destroyed and Ar+-ions continuing to come from lens volume couldn't reconstruct it. Electron beam with current larger than 1A takes away with it a significant part of the cloud particles that decreases the cloud potential, and PL focusing properties get worse. The situation could be improved with increasing energy and current density of ion stream which creates positive space charge cloud. However, the electron beam with current on the order of tens amperes, for which the beam space charge density is much more than space charge of the plasma lens can be effected only by magnetic focusing. Plasma lens continues to produce positive ions to compensate space charge of propagating electron beam, in this case providing the stable transport of the high-current electron beam. The beam was focused solely by the magnetic field of the lens. It allowed compression of the electron beam from its initial diameter of 6 cm to a diameter of 1 cm. It was also confirmed under experimental conditions [5], for which the current density increased more than 30 times and was greater than 100 A/cm^2.

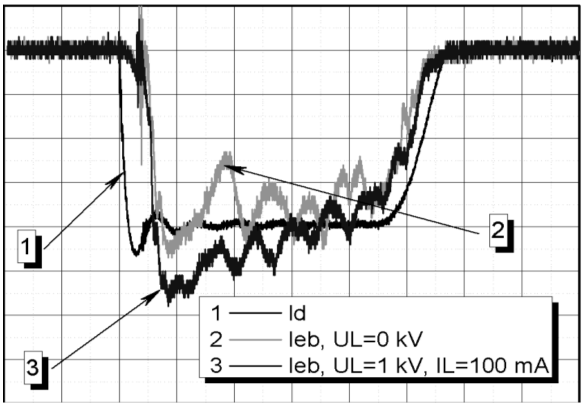

Fig. 2 Oscillograms of the discharge current (1) and electron beam current before switching-on the lens (2), and with the lens switched-on (3).Vertical scale 20 A/cm. horizontal scale 20 mks/cm sweep speed.

New plasma-optical tool for cleaning high –current plasma flow generated by erosion plasma sources.

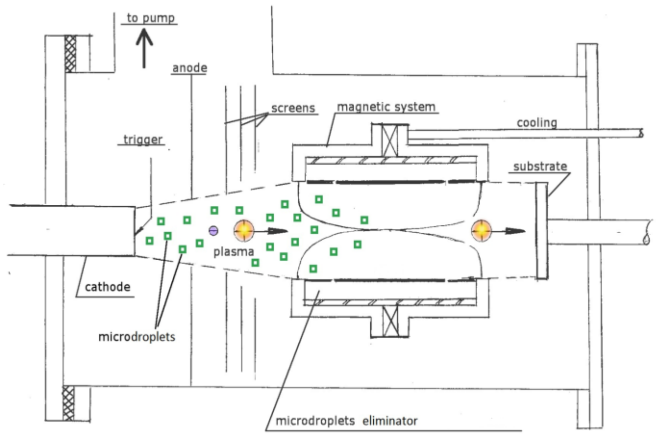

Fig.3.Set up.

Experimental conditions:

Discharge arc current:60A, •Discharge Voltage: 22 V at H= 0 Gauss; Discharge Voltage: 30 V at H =360 Guass; Substrate Bias=-200V, •Substrate area: 1 cm^2 ; Deposition time: 3 min; Distance between substrate and target: 250 mm; Cathode diameter (Cu): 20 mm.

As said above, we suggest for the first time a new more practical approach for the effective elimination of the micro-droplets, as well as its conservation and incorporation into the plasma stream produced by erosion plasma sources. This approach is based on application of the cylindrical plasma lens configuration for introducing in a volume of propagating along axis dense low temperature plasma flow radial convergent energetic electron beam produced by ion-electron secondary emission from electrodes of plasma optical tool for effective additional destroying (evaporation and crushing) of micro droplets. The first experiments and theoretical estimations [6] demonstrate the workability an idea of application the new plasma-optical tool based on plasma lens configuration with convergent and oscillating fast electrons for effective additional evaporation, destroying and filtering of liquid metal droplets in a passing intense flow of dense low temperature plasma. The Fig.3 shows the experimental set up using vacuum arc for testing the idea and Fig.4 presents the results of SEM studies.

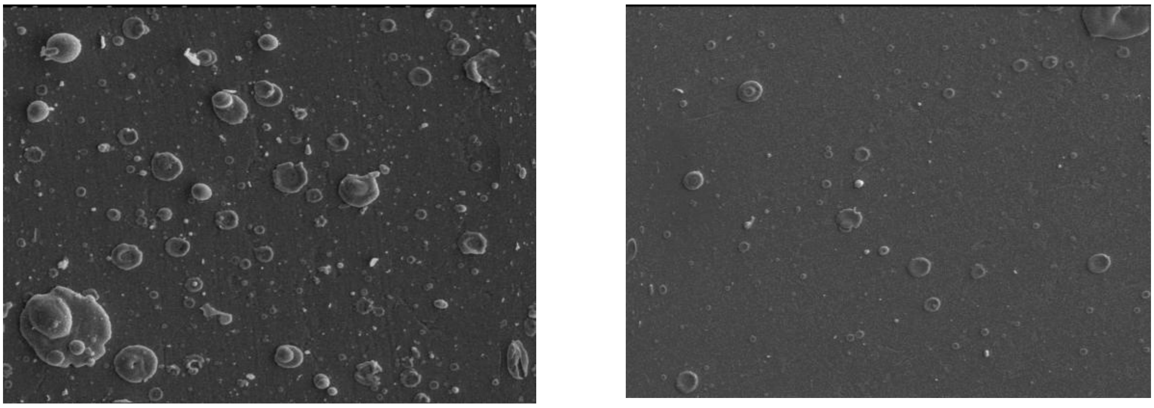

Fig. 4. **H=0 Gauss, U=0 Volts** **H=360 Gauss, U=-900 Volts**

Conclusion

We presented here two new generation plasma optical devices that open up novel attractive possibility for effective practical applications in modern high-tech.

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