Generation of beam-plasma formation in a cylindrical extended hollow grid anode

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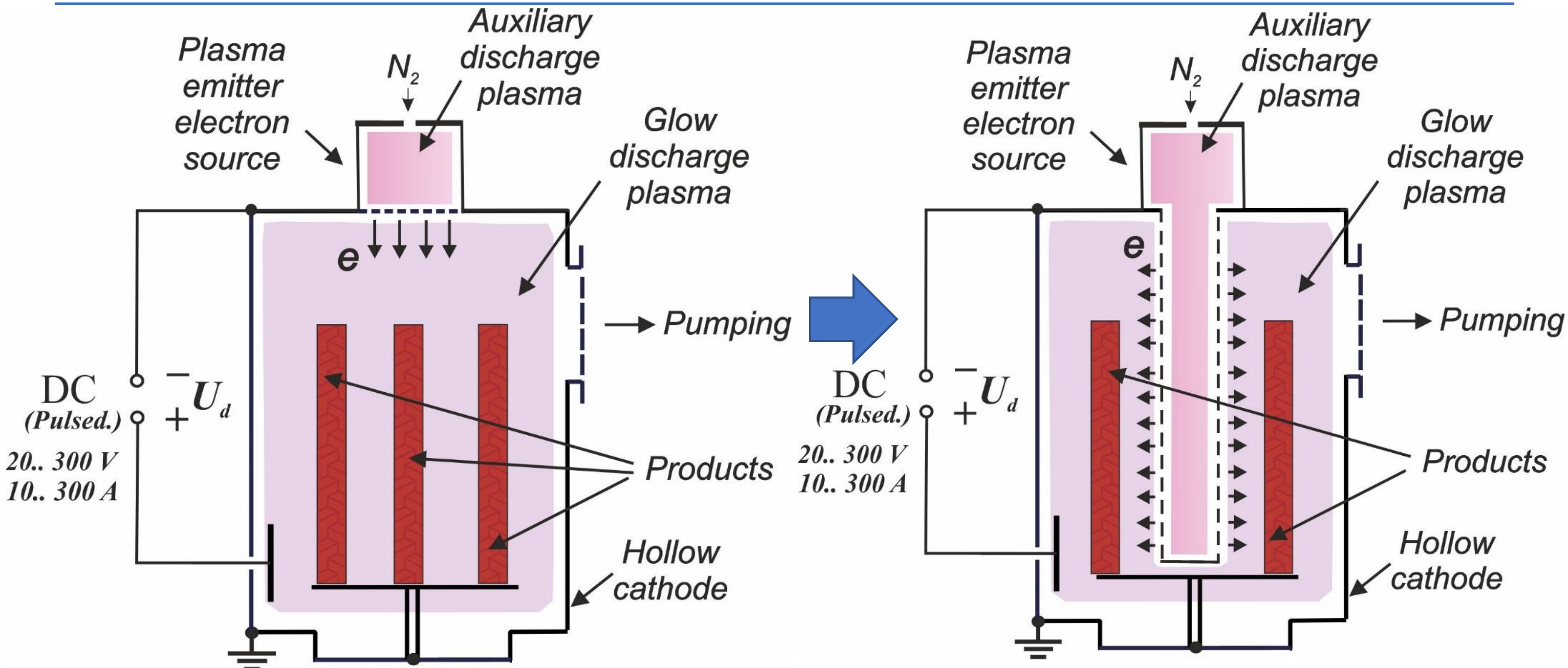
Generation of Beam-Plasma formations in low-pressure non-self-sustained glow discharge with hollow cathode for surface treatment



Features of a beam-plasma formation in such type of discharge:

- Possibility of plasma generation in a wide range of concentrations (10^9 - 10^{12}) cm^{-3};
- Independent adjustment of all operating parameters (pressure, burning voltage, discharge current, etc.);
- Generation of gas-metal plasma for plasma-assisted deposition;
- The ability to activate physico-chemical processes on the surface of materials due to the flow of electrons on it.

Denisov et al., *Phys. Plasmas*, V.26, 123510 (2019).

Drawback:

- High degree of plasma inhomogeneity in an extended grid electron emitter along workpieces.

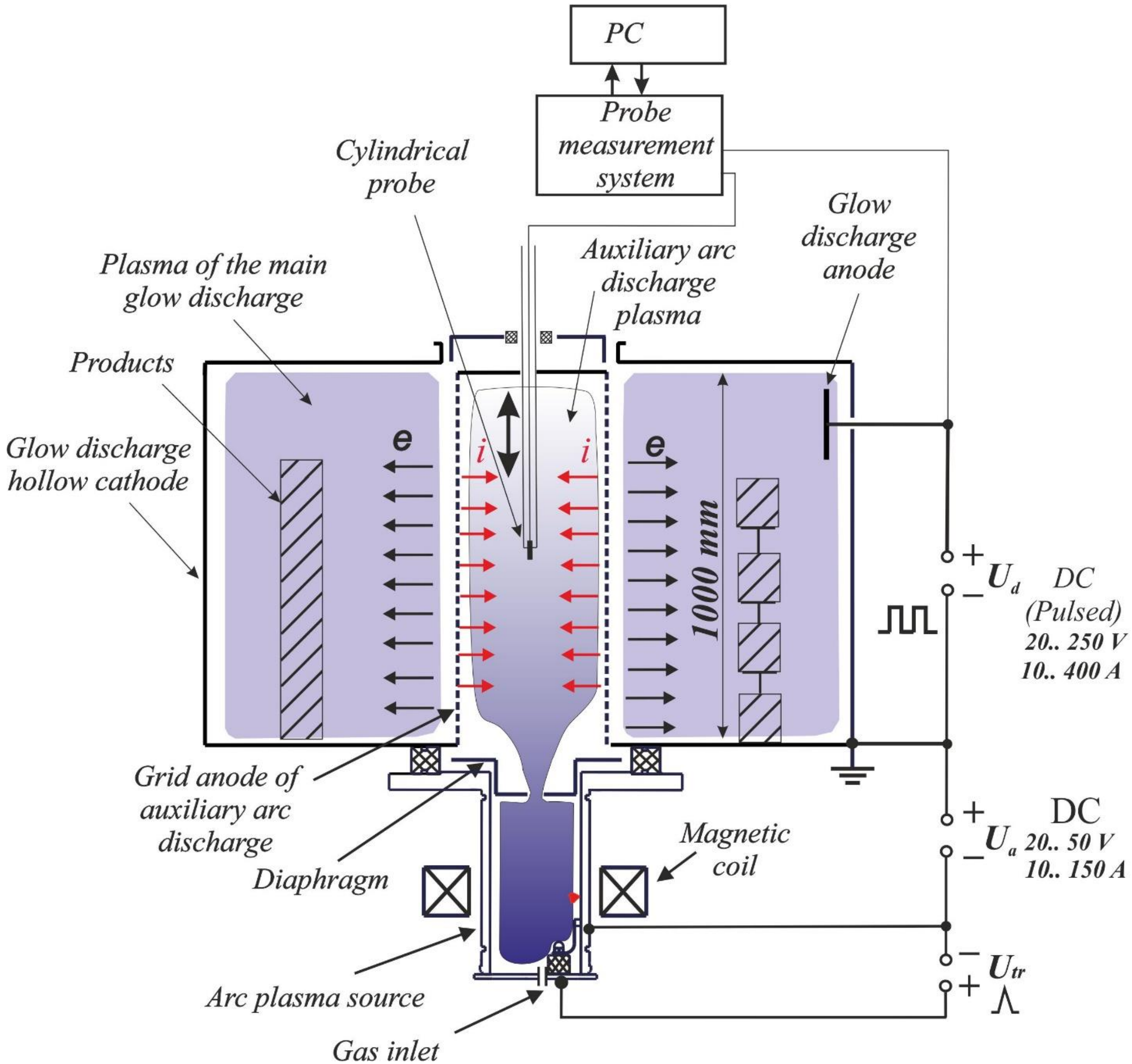
The Goal of the Investigation

To determine the influence of the conditions of burning of electric arc discharge in a system with a cold hollow cathode and an extended hollow grid anode on the longitudinal (axial) degree of inhomogeneity of the plasma density formed in the beam-plasma formation inside the grid plasma emitter.

Operating parameters:

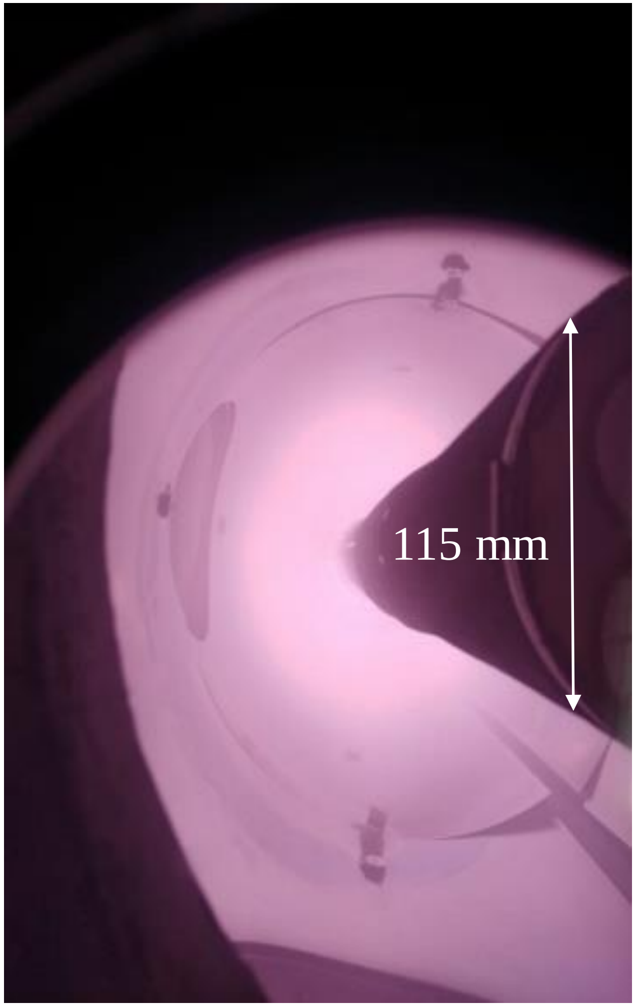
- Pressure;
- Discharge voltage;
- Arc discharge current;
- Diameter of the hollow grid anode.

Experimental bench for the generation of beam-plasma formations in a non-self-sustained glow discharge

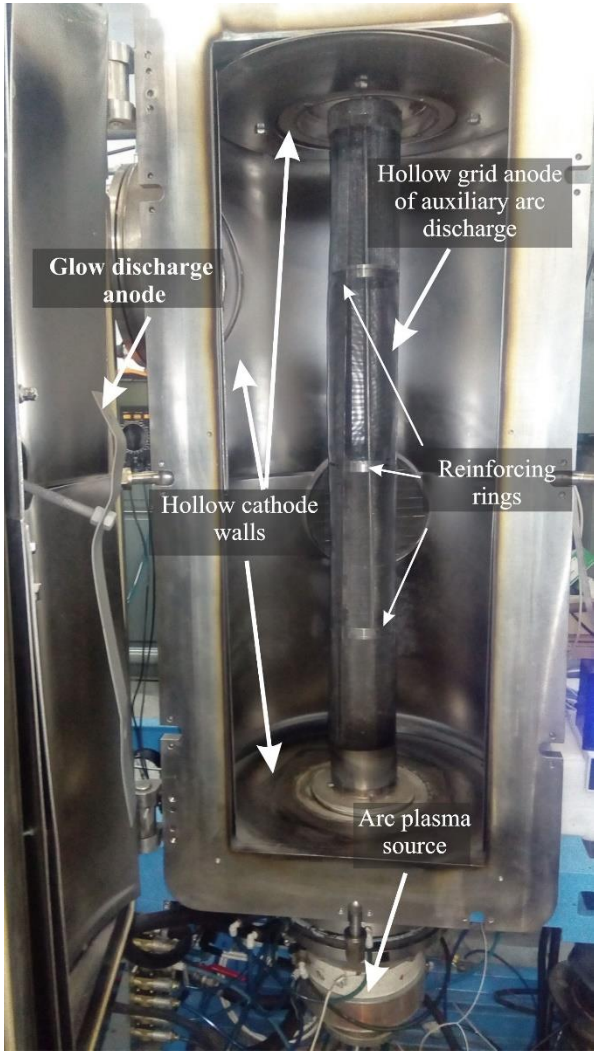


Experimental bench for the generation of beam-plasma formations in a non-self-sustained glow discharge

Glow of a glow discharge plasma with an extended grid electron plasma emitter with a diameter of 115 mm

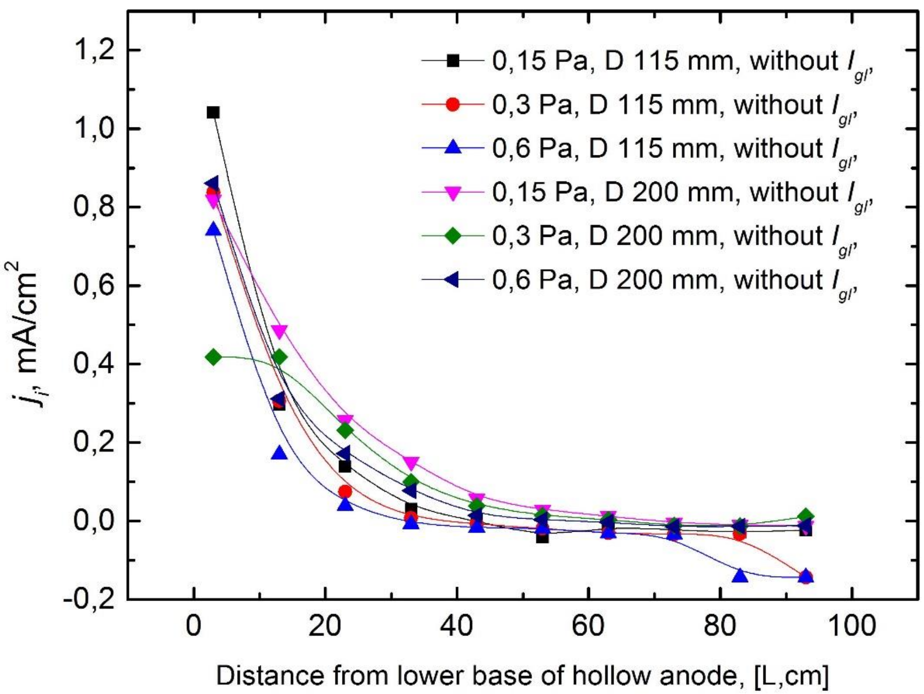


The image of electrode system

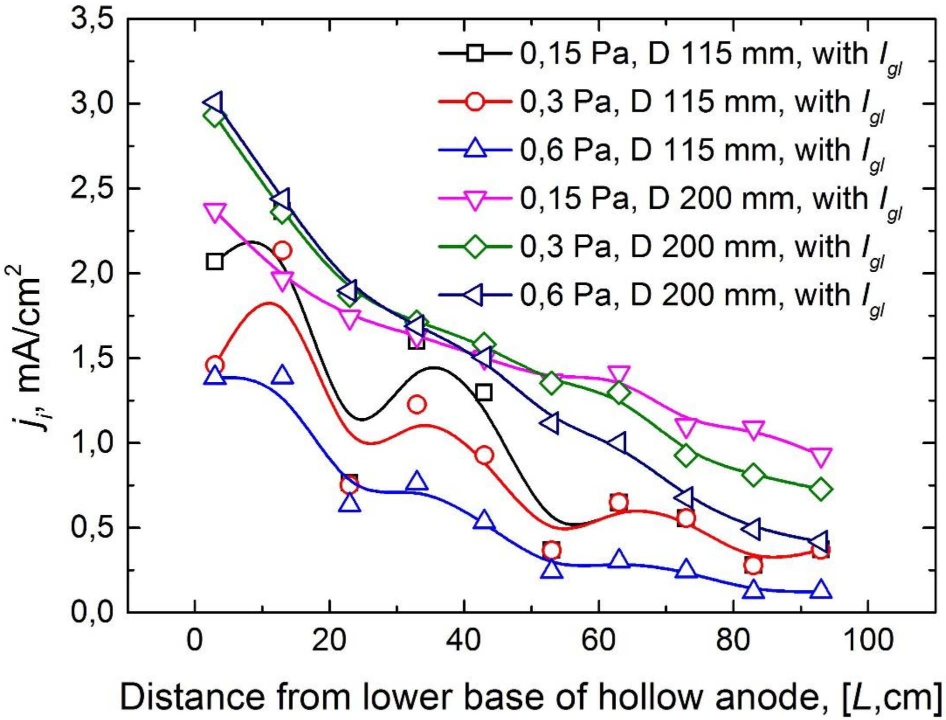


Distributions of the ion current density to the probe along the hollow grid anode of an arc discharge in a nitrogen atmosphere

Without glow discharge



Glow discharge current – 150 A

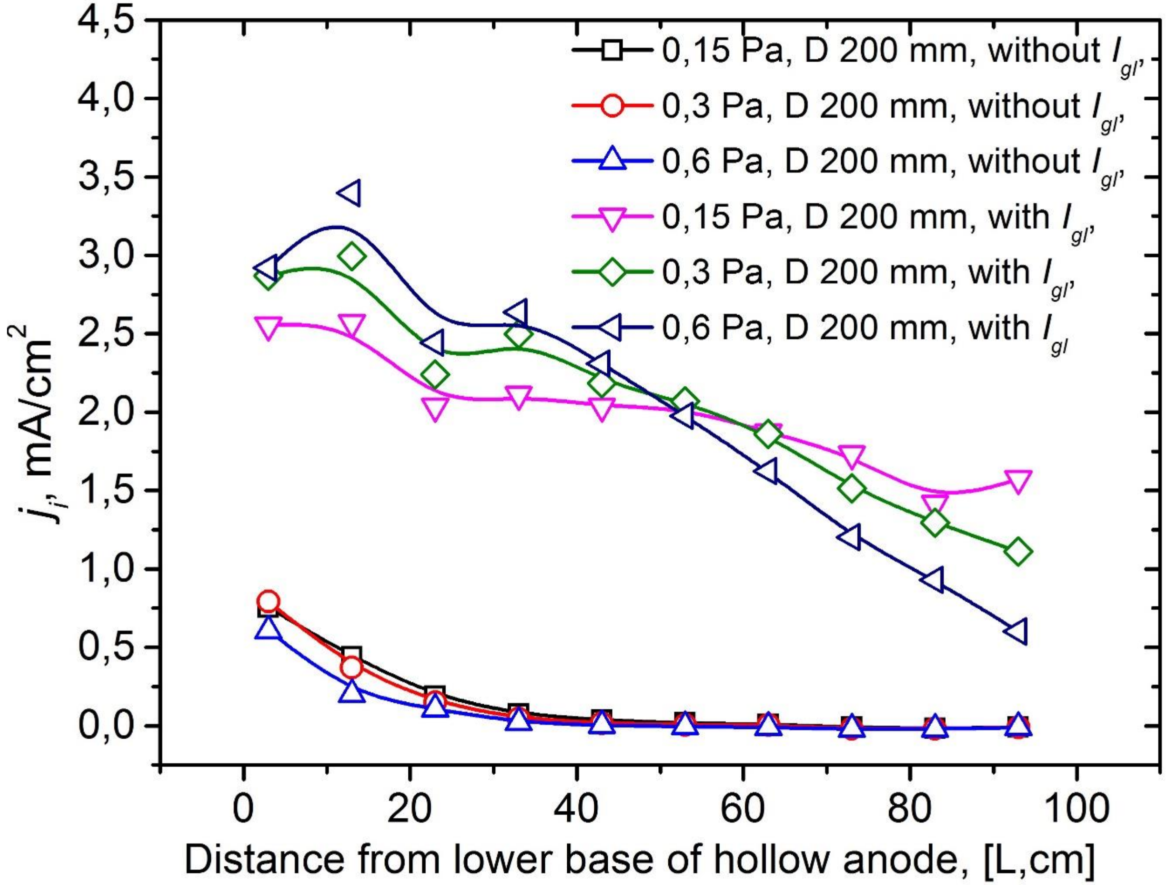


0 cm is the plane of the lower base of the hollow anode)

The minimum heterogeneity of the longitudinal distribution of the ion current density at the arc discharge current of 50 A is achieved at a diameter of 200 mm, a pressure of 0.15 Pa, and is about ± 40%.

Distributions of the ion current density to the probe along the hollow grid anode of an arc discharge in an argon atmosphere

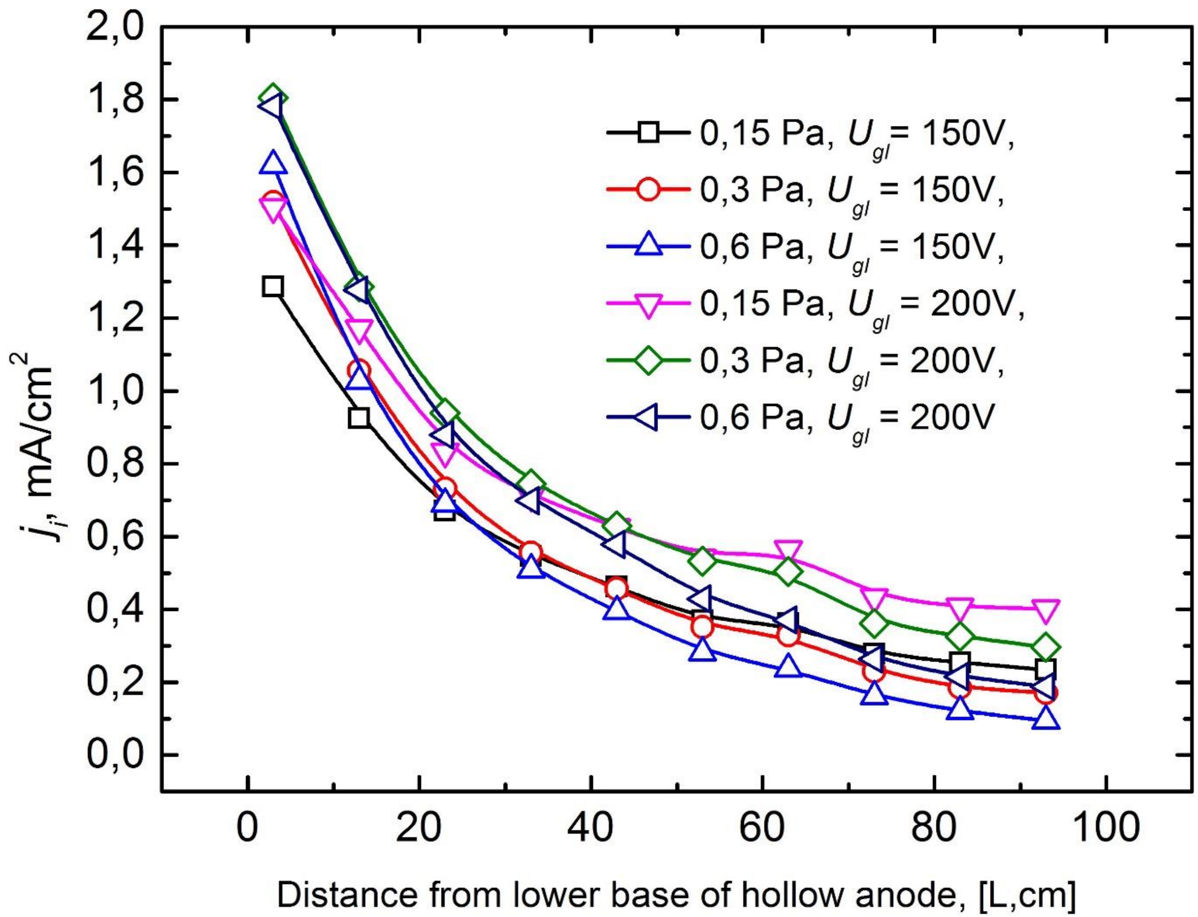
Glow discharge current – 150 A



0 cm is the plane of the lower base of the hollow anode)

Studies of the ion current density distributions in the argon atmosphere show that with a decrease in operating pressure, the degree of heterogeneity decreases, amounting to about ± 25% at the working pressure of 0.15

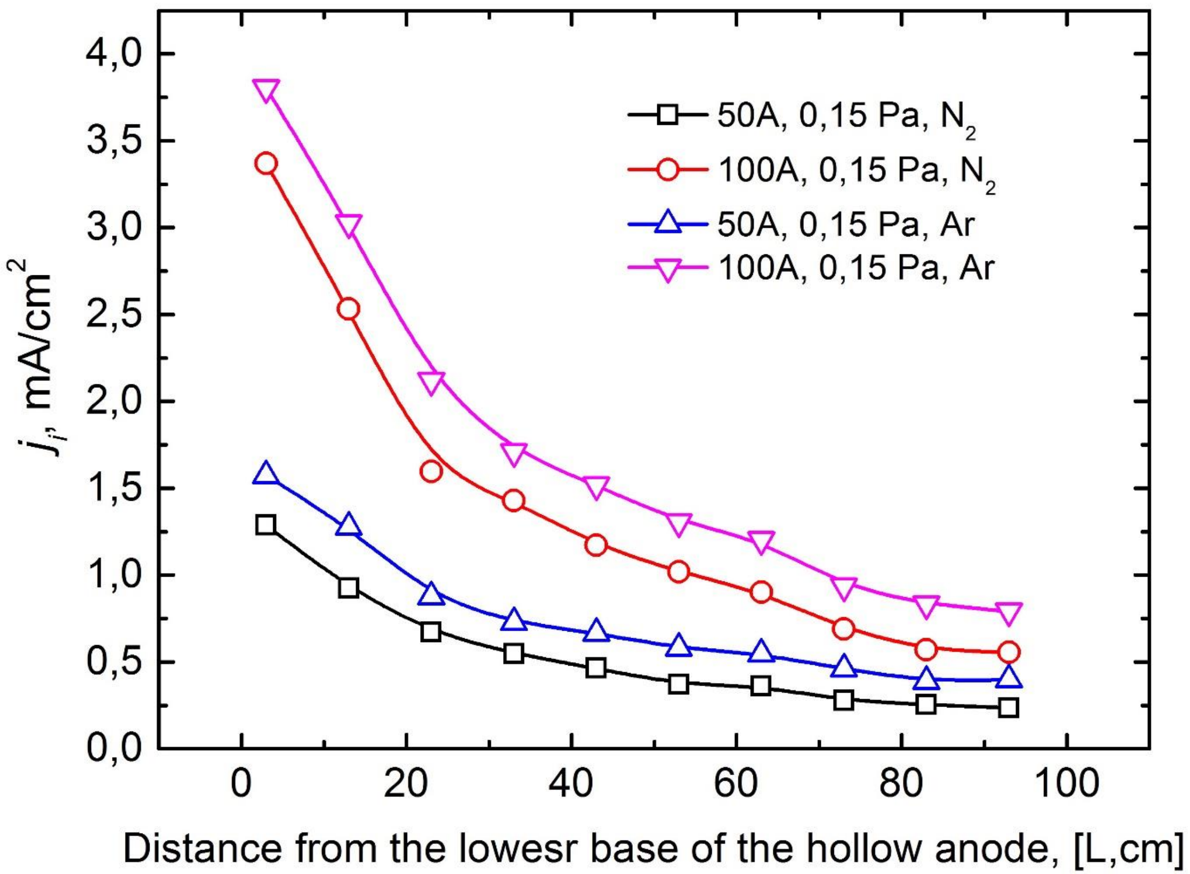
Influence of discharge voltage on distributions of the ion current density to the probe in the nitrogen atmosphere



0 cm is the plane of the lower base of the hollow anode)

An increase in the glow discharge burning voltage from 150 V to 200 V in nitrogen leads to a proportional increase in the glow discharge current with an identical value of the auxiliary arc discharge current of 50 A and, accordingly, an increase in the ion current inward the electron emitter through the grid cells. This only leads to an increase in the ion current density to the probe, which is demonstrated by the obtained dependences.

Influence of arc discharge current on distributions of the ion current density to the probe in the nitrogen atmosphere

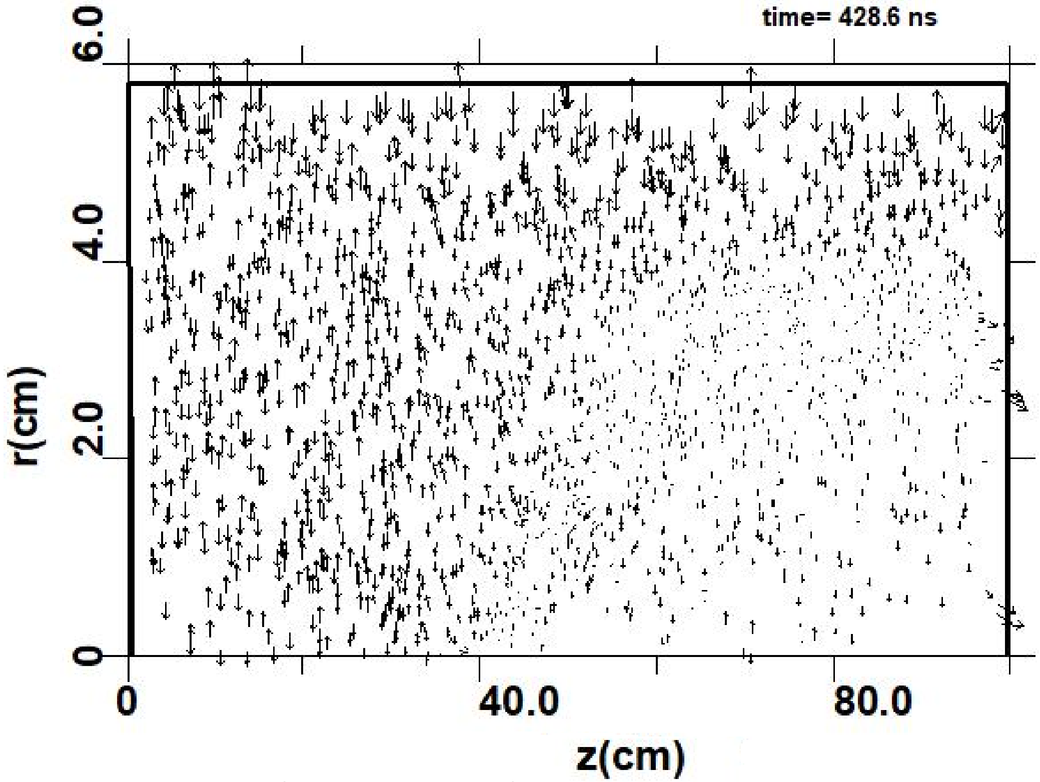


0 cm is the plane of the lower base of the hollow anode)

An increase in the arc discharge current from 50 A to 100 A during the injection of argon or nitrogen leads to an increase in heterogeneity.

Numerical simulation

The calculated region of the cylindrical hollow anode. Arrows are the velocity vectors of ions entering through the grid cells from the discharge plasma



(0 cm is the plane of the lower base of the hollow anode).

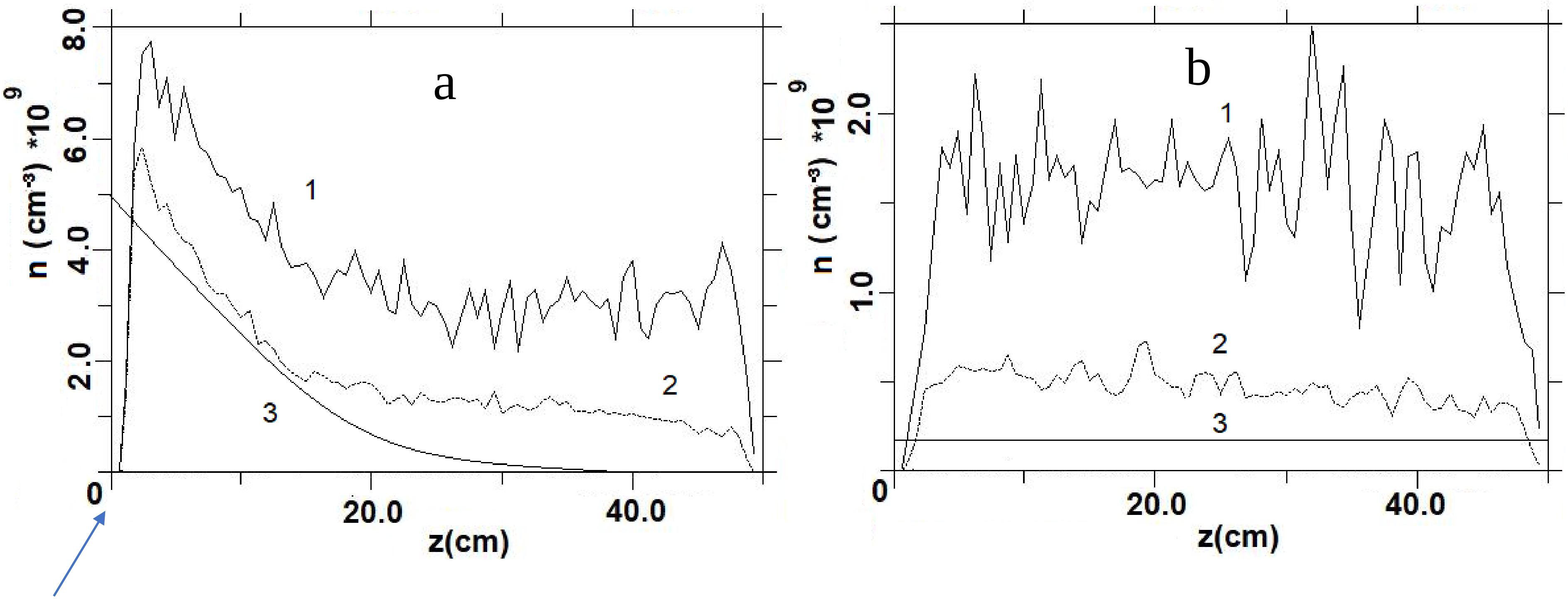
The model uses 6 types of PIC particles:

- plasma PIC electrons with a temperature of 5 eV and PIC ions;
- PIC ions of the beam with the energy W;
- plasma particles arising in the course of gas (nitrogen) ionization PIC-ions and PIC-electrons;
- PIC-electrons of an external arc source and PIC-electrons arising from ion-electron emission from the boundaries of the computational domain. The coefficient of ion-electron emission $\gamma = 0.05$.

With ballistic focusing, the current density increases inversely with the distance to the axis of symmetry, and the inhomogeneous distribution of the plasma concentration determines different conditions for the transport of ions injected from the side boundary. In the region bounded by the cross sections z = (0 – 50) cm, (region I), the plasma concentration n_{pl} is 2 orders of magnitude higher than the concentration of fast ions; the charge compensation of fast ions allows them to pass through the entire drift space (cylinder section). In region II (z = 50–100 cm), an insufficient number of plasma electrons leads to an increase in the positive potential U, the deceleration of ions, and their reflection at $W = eU$. In figure arrows indicate the velocity vectors in the space of the drift of the beam ions. Based on the computational difficulties associated with the spatiotemporal scales, the dynamics of the formation of a plasma formation were studied in regions I and II at the injected ion current density 0.13 mA/cm^2.

Numerical simulation

The distribution of electrons of the plasma formation in regions I (a) and II (b) at different radii: 1 - r = 0.6 cm, 2 - r = 3 cm, 3 - plasma distribution without ion current



(0 cm is the plane of the lower base of the hollow anode).

In Figure "a" is shown the distribution of the density of plasma electrons in region I at different radii of the system and the initial distribution of the plasma density. Upon injection of an ion beam, the nonuniformity of the plasma distribution is the same. In region II, during the formation of a virtual anode, gas ionization by plasma and secondary (due to ion-electron emission) electrons accelerated in the potential field of an ion beam is one of the main processes of formation of a beam-plasma formation. The time of formation of an ion-beam plasma and its concentration depend on the gas pressure, ion current density and their energy. In Figure is shown the density distribution of plasma electrons at different radii of the system (without ion beam current, a density below 10^8 cm^{-3}). The plasma density distribution is almost uniform.

Conclusions

- It was experimentally shown that the system for generating extended beam-plasma formations in a non-self-sustained glow discharge with a plasma electron emitter based on an arc discharge allows one to obtain a longitudinal degree of inhomogeneity of the concentration of the formed plasma over a length of 1 m in a hollow grid anode of an arc discharge at a pressure of 0.15 Pa in an argon atmosphere about ± 25%, and in pure nitrogen ± 40% at absolute values of the ion current density on the axis of the anode 1-3 mA/cm^2.

- A numerical simulation using the coarse-particle method has been used to study the effect of burning parameters of an arc discharge in a hollow anode and the ion flux entering it, on the uniformity of the generated plasma formation. The agreement of the results of numerical simulation with experiment suggests that the main mechanisms for the formation of a beam-plasma formation in an extended cylindrical hollow anode are the recharging of fast ions of the main discharge and ionization of the residual gas. The longitudinal heterogeneity of the beam-plasma formation is determined by the external source of the arc plasma and depends on the parameters of the external ion flux (ion current, their kinetic energy) and the hollow anode (working gas pressure, geometry).

- The results obtained allow us to optimize the dimensions of the hollow extended grid anode and the control of the beam-plasma system as a whole.

Thank you for attention!