Diagnosis of Plasma Glow Discharge Energy Parameters in the Processes of Treatment Small Diameter Long Tubes

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Abstract — Energy characteristics of glow discharge plasma initiated in the hollow cathode while treating of inner surface of small-diameter tubes, which include waveguides for microwave radiation, were studied with a probe technique. It was shown that at the pressure in the gas discharge chamber of 53 Pa and discharge current of 75 mA, in the cathode cavity geometry studied a sufficiently dense plasma with the concentration of charged particles at 1,6•10^{10} cm^{-3} which are characterized by a high heterogeneity on cavity height (40 ... 60%) was generated. It was also shown that an effective mechanism of influence on the plasma distribution inside of the cathode cavity where L >> D is the cathode-anode distance change. Such a reduction in length from 40 to 20 mm increases the uniformity of the ion and electron distribution to 15 ... 20%, and the introduction of additional anode in the discharge circuit – to 8 ... 10%.

Keywords— glow discharge; plasma concentration; hollow cathode; probe technique.

I. INTRODUCTION

In the modern radio engineering systems for the transfer of ultra-high frequency electromagnetic waves over large distances in the form of the different cross-section long hollow metal tubes radio waveguides have gained widespread use. The experience of waveguides applying for a long period of time in the industrial conditions allowed to determine the basic requirements for this kind of items, mainly related to the increase of wave propagation speed inside of the cavity, to the decrease of transmitted power loss factor, diminution in constructions weight, the protection of the surface subjected to corrosion effects, etc. In this connection, waveguide systems of rectangular and circular cross-section made of copper, brass or aluminum gained in widespread practice in microwave technology.

The state of the waveguide tube inner surface determines the speed of propagation of high frequency waves inside of the cavity. The constant presence on the metal surface of different kinds of contaminants adsorbed atoms and residues of soldering flux, the complete removal of which from the area of fastening tubes having mounting flanges aren`t always being achieved all that contributes to dirty the precision conduct and consequently, to power losses in its walls with output signal distortion. In the light of the above, cleaning internal surfaces of such elements is compulsory operation preceding the final assembly of the waveguides links.

Traditionally applied chemical and electrochemical methods of surface treatment have significant disadvantages, are caused by the presence of residues of active detergents the treatment surface, saturation of hydrogen in the processing of electrolytes, a large amount of chemically dangerous production wastes. This led to the development of new environmentally friendly electro-physical methods and processes, related to impact on the treated surface streams of charged particles.

In recent years, the use of low-pressure plasma for the treatment of materials of tubular devices growing steadily. In particular, today the most common surface treatment method of different kind's pollution is ion sputtering using plasma glow discharge [1]. This method can effectively remove the main types of contaminants as fats, adsorbed gases, water, oxides, and enable to process of different surface configurations including the internal cavity. In addition, ion treatment causes the appearance of structure micro defects on the product surface in form of vacancies that upon further deposition will be centers of its condensation [2].

In [3] the possibility of glow discharge application in the process of treatment and deposition on the internal surface of pipe diameter of 56 mm and 120 mm in length is shown. However, a number of difficulties, mainly related to the low productivity of the process appear. Since the treatment of internal surface of pipe was carried out for 60 minutes.

The problem is significantly complicated when cleaning internal surfaces in long pipes of small diameter (D = 10 ... 20 mm) necessary, eg for subsequent deposition.

Analysis of the processes that occur during glow discharge burning with the electrons oscillation inside the cathode cavity gives grounds for the study advisability of hollow cathode effect use to treatment internal surfaces of such products.

II. EXPERIMENTAL PROCEDURE

A characteristic of low-temperature gas-discharge plasma as a physical object with a high concentration of energy, it is the presence of different kinds of high-energy particles such as ions, electrons, radicals, excited particles and photons. The main in the processes of cathode material sputtering are the intensive flows of ions bombarding the cathode surface and the fast electrons emitted by the cathode under the ion influence, causing secondary electron emission from the cathode [4]. Therefore, diagnostics of the plasma spreading from the cathode consists in measuring the distribution of ion and electron currents on the surface of cathode cavity.

The basic energy characteristics of plasma and the ions and electrons currents ratio in the cathode region were registered with a Langmuir probe method. The probe is an auxiliary electrode made of a thin tungsten rod 0.3 mm in diameter, coated ceramic insulation to avoid the possibility of breakdown and electrical contact between the probe and the cathode. A single cylindrical probe out of tungsten 3 mm in length was used. These cross-sectional shape and size of the probe were selected to minimize the possibility of plasma disturbances formation with the following requirements: Debye radius for the studied plasma should be much less than the probe radius, $R_D << R_p$; the mean free path of the particles should be much larger than the size of picking probe $\lambda >> R_p$ [5].

Determination of the Debye radius carried out as follows:

$$R_D = \sqrt{\frac{\varepsilon_0 k T_e}{n_e^2}} \qquad (1)$$

where ε_0 - vacuum permittivity, k - Boltzmann constant, T_e - electronic temperature, n_e-plasma concentration.

The calculation showed that the radius of screening in our conditions is much less than the probe radius $R_D \sim 10^{-5}$ m. This causes the legality of our probe use.

Plasma research was carried out in accordance with the scheme Fig. 1. The cathode is designed as a hollow tube of aluminum AD1 10 mm in diameter and 110 mm in length. Axial distribution of plasma parameters at the cathode surface was determined by probe immersion deep into the cavity in increments of 10 mm. Studies were performed in argon within the pressure of p = 53 Pa, discharge current was constant at I_d = 75 mA, discharge ignition voltage U_d = 400 V. The probe potentials varied in the range of -20 V to -200 V.

It was thought that at -20 V probe would get only fast γ-electrons. The number of such particles is limited, but their contribution to the ionization is essential, while the contribution of secondary electrons is not material because they are not getting the necessary amount of energy. When the potential -200 V, probe will be saturating only positive ions because, significant negative potential, in this case, will be a barrier to getting emitted fast electrons on the probe [6].

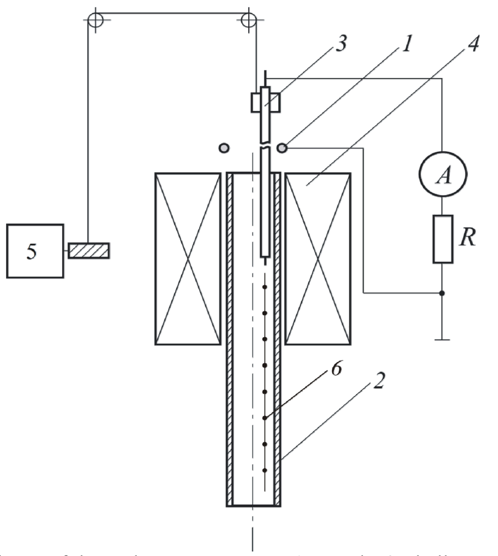


Fig. 1. Scheme of the probe measurements: 1 - anode; 2 - hollow cathode; 3 - electric probe; 4 - electromagnet; 5 – engine; 6 - measurement trajectory.

The axial distribution of plasma concentrations was studied by the change of cathode-anode distance in the range of $L_{c\text{-}a}$ = 20…40 mm, and introduction in discharge circuit an additional anode at the distance of 40 mm.

For some time after glow discharge ignition typical for aluminum micro-arc breakdown, associated with the presence on its surface oxide film layer are observed. After a while, the frequency of flashes decreases and the discharge goes into a more stable phase.

III. RESULTS AND DISCUSSION

The electrical probes method based on obtaining the current-voltage characteristics (CVC) of plasma areas and determining the main parameters that characterizes the processes that occur in it. The electron temperature determined by the tilt angle of probe CVC built in a semi-logarithmic scale Fig. 2.

The electron temperature [7]:

$$T_e = 11600 \frac{\Delta U_p}{\Delta LnI_p} \qquad (2)$$

where ΔLnI_p - the increment of the logarithm of electron current; ΔU_p - potential probe changing what caused this increment.

Plasma concentrations were determined by:

$$n_e = \frac{I_e}{eS}\sqrt{\frac{8kT_e}{\pi m_e}} \qquad (3)$$

where I_e - electric current to the probe at plasma potential; e, m_e - charge and electron mass; S – probe area.

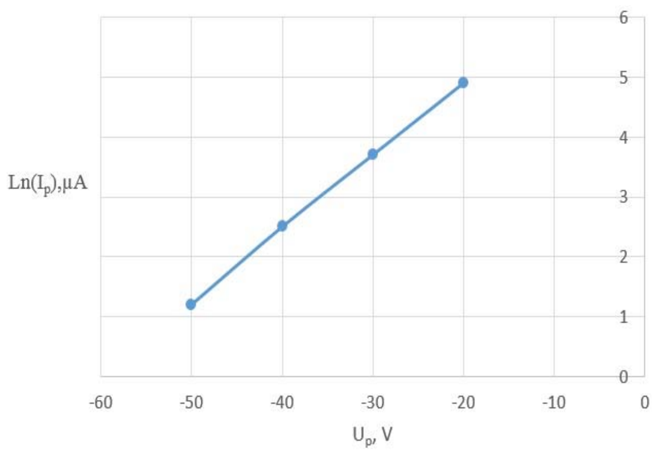


Fig. 2. Current-voltage characteristics of plasma area in a semi-logarithmic scale, in a distance of 20 mm inside the cathode when probe potential changing within the -20 to -100 V, argon pressure P = 53 Pa.

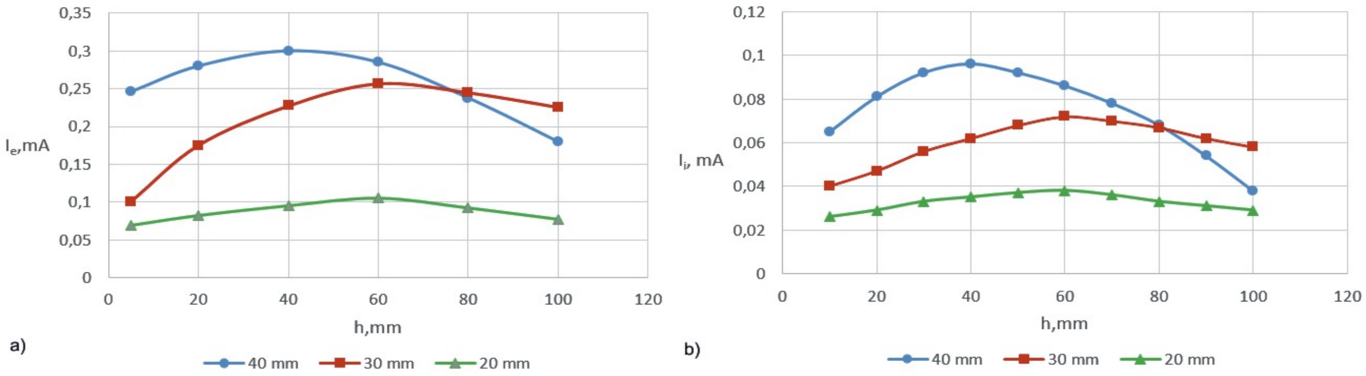


Figure 3. The results of probe measurements: the electron current (a), the ion current (b) for cathode-anode distance Lc-a = 20mm, 30mm and 40mm.

Calculations show that at the electron temperature T_e = 8 eV and a probe current corresponding potential of plasma I_e = 0,045 mA generated a dense plasma with the electrons concentration $n_e = 1.6 \cdot 10^{10}$ cm^{-3}.

Fig. 3 shows the results of probe measurements at cathode-anode distance change. The experimental curves indicate that increasing the cathode-anode distance in a range of $L_{c\text{-}a}$ = 20 ... 40 mm leads to changes of axial plasma concentration distribution with a decrease of uniformity from 20 to 60% for both ions and electrons. It is noteworthy that such change of interelectrode distance leads to a slight increase both ionic and electronic component probe currents. The shift of charged particles concentration peak towards to the outlet cathode cavity is observed. Thus, increasing the interelectrode distance leads to some plasma displacement toward the anode ring. This is confirmed by a sharp decline in the charged particles concentration at the periphery of the system. The exterior of curves with the plasma concentration peak at the center of the cathode caused by a sharp uneven potential distribution on its height, due to cavity geometry in the form of a long tube. This leads to the fact that at a given gas pressure, plasma penetrates inside the cathode to some depth and can`t reach its base.

Dependences also show that the distribution curves of ions and electrons temperature are nearly identical but the values of currents are slightly different towards to increase of electronic. This is due to the peculiarities of nonequilibrium low-temperature plasma because the electrons energy in such plasma is significantly higher than ions.

In order to increase of plasma distribution homogeneity, a series of studies on the introduction of auxiliary anode to a gas-discharge system for enhance of ionization and emission processes at the periphery of the cathode was conducted.

Fig. 4 illustrates the dependence obtained in experiments with two anodes. The experimental dependences of ion and electron concentration show that the introduction of additional anode to the discharge circuit leads to some redistribution of plasma concentration inside the cathode with close to the linear character. This distribution is associated with an increase of charged particles generation on cathode remote areas. Since placement second anode on the other side of cathode cavity it initiates the activation of the emission processes in these areas with the increasing number of ions that bombard the cathode surface. It also leads to a slight increase in ion and electron temperature in a two anodes system. Thus the appearance of additional anode on the opposite cavity side on the distance of 20 mm increases the uniformity of plasma distribution to 8 ... 10%.

In addition, to activate the ionization and emission processes at the cathode periphery, studies to determine the applied magnetic field influence on the behavior of charged particles were conducted. The cathode tube is placed inside the electromagnet cavity, made in the form of copper coil with brass core of 60 mm in width, which corresponds to half the length of the cathode. The electromagnet windings DC supplied of 2...4 A. Studies were performed in argon at a pressure of 53 Pa, discharge current I_d = 75 mA at a voltage U_d = 400 V.

The experimental results are shown in Fig. 5. The experimental dependencies show that the application of an external magnetic field transforms greatly the type of distribution of charged particles with the maximum of electron concentration near cathode outlet.

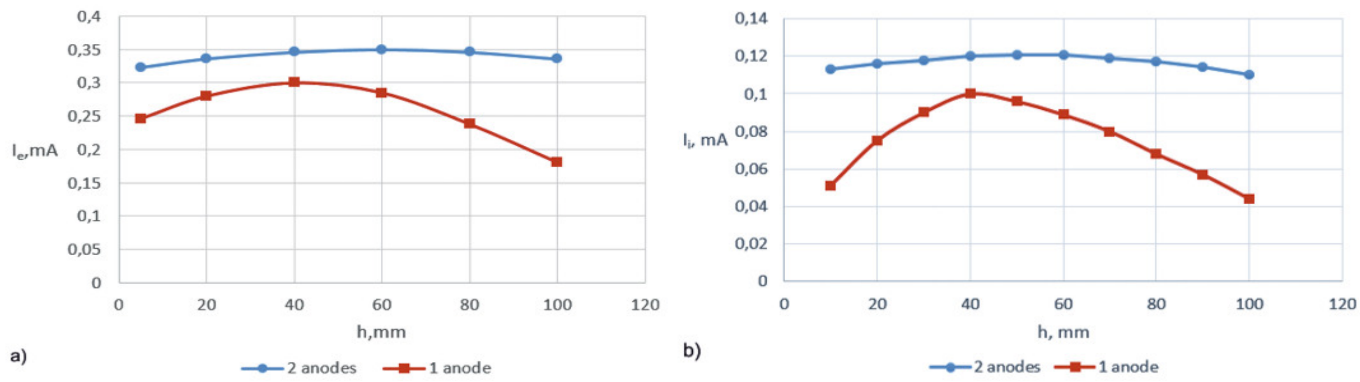


Figure 4. The results of probe measurements: the electron current (a), the ion current (b) with additional anode in the discharge system.

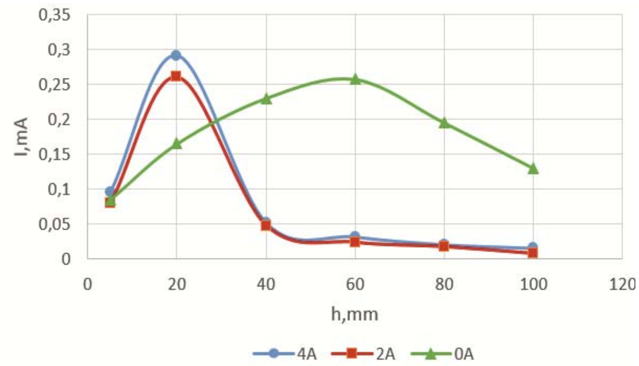
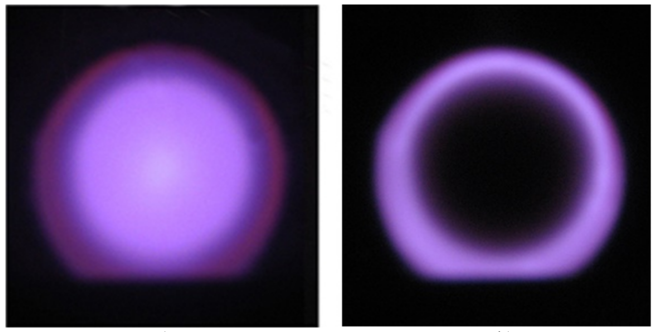


Figure 5. Longitudinal depending of fast electrons concentration on probe in the glow discharge with hollow cathode in the magnetic field.



a) b)

Figure 6. The influence of an external magnetic field at the existence of hollow cathode effect: a) no magnetic field - the effect is observed; b) a magnetic field - no effect.

Such redistribution of plasma concentration due to the deviation of movement curvature of emitted electrons caused by the appearance of the magnetic field in the discharge gap. As a result, the electrons leave the cathode cavity quickly almost without making collisions. This causes a sharp decline of electron current on probe almost zero in the peripheral areas of the cathode.

To fully understanding the pattern of discharge phenomena occurring in the external magnetic field the visual observation were conducted which allowed clarify the situation and make the following conclusions. The introduction of cross magnetic field at the discharge gap leads to the disappearance of a hollow cathode effect. The observed picture is more typical for the circuit with two flat cathode plates when plasma discharge is pressed to the walls of the cathode. This reduces the effective length of the cathode dark space that participating in electron energy saturation and the cathode walls behave as independent electrodes (Fig.6). All this leads to a reduction in ionization and generation of charged particles in a discharge gap as a whole.

Our results are consists satisfactorily with the results given in [8]. This paper is shown that applying an external magnetic field in the discharge scheme at a given pressure, self-discharge existence form is not possible to support due to insufficient ionization caused by deviation of electrons trajectories across the magnetic field.

IV. Conclusions

It is shown that the treatment of the long tubes inner surface in which L / D ~ 10 by glow discharge using a hollow cathode effect is complicated by several factors mainly related to the high heterogeneity of plasma distribution in such cathode due to the low charged particles concentration in the peripheral areas of cathode.

Established that the glow discharge system with the long hollow tube cathode configuration generates sufficiently dense charged particles concentration in the plasma of $1.6 \cdot 10^{10}$ cm^{-3} with the high heterogeneity on cavity height of 40 ... 60%.

It is shown that an effective mechanism of influence on the axial distribution of plasma particles inside the cathode is the change of cathode-anode distance, reducing of which 40...20 mm resulted in a decrease in their heterogeneity to 15 ... 20%.

For homogeneous of plasma concentration axial distribution in such system is necessary to ensure of activation the ionization and emission processes in peripheral cathode areas.

In our experiments, this is achieved by introducing an additional anode in discharge system from the opposite side of the cathode cavity, whose appearance allowed reducing the heterogeneity of the charged particles concentration to 8 ... 10%.

V. References

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