The Source with Radial-Converging Flow of Gas Plasma

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Abstract – A source with radial converging flow of gas plasma – FPS presents discharge structure with ring-shaped anode und movable poles-cathodes with make up the exit gap of gas discharge chambers. A low pressure discharge in annular chamber is initiated in inhomogeneous crossed ExB fields by the autoelectronic emission from sharp edges of the blade cathodes. Inhomogeneous plasma FPS is having max density of electrons in annular gap. The plasma of low voltage discharge penetrates through annular gap into the internal cylindrical cavity ICC by particular size of gap between cathodes. The penetrating plasma is required for a) forming beam of gas ions b) synthesis gas-metal plasma. FPS is required power supply with voltage <1 kV. One is economic und convenient in service. The useful life of FPS is defined of durability insulators und vacuum gaskets. As one step FPS was applied in two-stepped ion source coaxial geometry in pilot process complex JSC SIBNEFTEPROVOD.

1. Introduction

A mixed ion beam may be produced by means two-stepped ion source the TIS on low pressure discharge in crossed ExB fields LDC [1]. The use coaxial arrangement discharge chambers in TIS arises because of necessity obtaining broad circular beams of the gas ions or of the mixed ions [2].

The purpose this work is development the economic simplest design ring-shaped source for obtaining radial-converging flow of gas plasma for ICC. The LDC allows obtain plasma with density charged particles n_e~10^{13} cm^{-3} and more [3]. The problem is losses by transport plasma to place of her use. The use gas plasma is attractive in case if latter will be inhomogeneous. The plasma having max density charged particles closely exit gap and held by field magnetic force lines with favorable curvature that to reduce a) losses charged particles on walls chamber b) to decrease requirements to power supply.

2. Design of the Plasma Flow Source

The universal TIS (Fig. 1) consist of the outer ring-shaped discharge chamber – source of radial-converging flow of the gas plasma FPS and internal cylindrical chamber ICC where the axial isolated electrode PT is placed. ICC can by used as: a) expander cup for obtaining ion gas beam, b) chamber for synthesis gas-metal plasma for obtaining mixed ion beam.

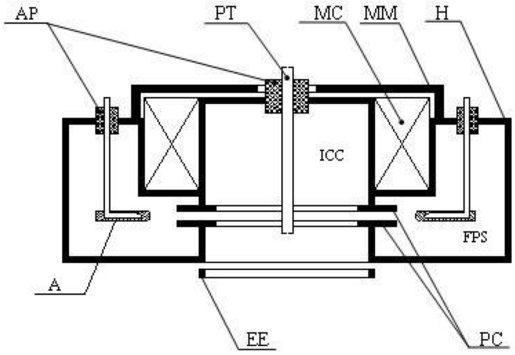

Fig. 1. A schematic diagram TIS of coaxial geometry: The source of the gas plasma FPS-I; the internal cylindrical chamber ICC-II of the TIS; A – the annular anode, PC – the cold poles-cathodes; MC – solenoid; MM – the maker for inverted flow of compound magnet; H – housing; PT – the axial isolated rode the probe; EE – the extracting elec-trode, U_a – voltage of anode, U_s and U_e – voltages of the PT and of the EE relatively housing

The device was develop with optimal configuration electrical E and magnetic B fields by means make up respectively geometry of electrodes. The scheme of the electrodes is shown in Fig. 2, *a*, *b*. The discharge structure of FPS consist of the two main parts a) anode A and upper CU and lower cathodes CL with a vertical movement. A ring-shaped stainless steel hollow anode A is fastened to the housing with three pipe unions AP insulated from the body and serving for supplying cooling water and a gas respectively. In order to ensure uniformity E field on toroidal surface a faces CC anode section was constructed as part round. The housing H has a circular groove for mounting a coil MC which creates a branched magnetic flux. The central problem in development of the cathodes system is geometry electrodes of device allowed to combine magnetic poles and cathode in the alone construc-tional element. The successful solution this problem was find by means of the compatibility the cathodes and the magnetic poles in the alone element making in form of the thick-walled moving cylinders. It can by means of the axially moving poles-cathodes to induce requiring the configuration ExB fields and the particular properties discharge in FPS.

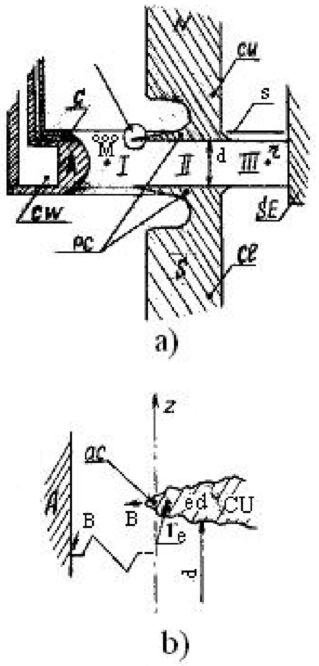

Fig. 2. a) Geometry of the electrodes in spacing in the plane rZ. A – annular anode; CW – water cooling channel; G – feed gas supply; ed – edge disc-shaped moving poles-cathodes – PC, upper CU and lower-CL; S-plasma screen; SE-axial isolated rode – PT; d-width of gap; I – spacing A – C (inhomogeneous field); II – space of gap (homogeneous field B by I_s=const); III – cavity of ICC-second step of TIS; S and N – poles of magnet of solenoid MC; b) Micrograph auto-emitter on surface of disc shaped blades

A coil MC creates a magnetic field which is closed through magnetic circuit include the electrodes: the circuit closes through the upper CU and lower cathodes CL of FPS. The magnetic fields were measured by a Ш1-8 meter at a current I_c=0–5 A through the solenoid [2]. The induction of the arc-shaped magnetic field (Fig. 3), which is applied to the spacing A-PC, has the form $B=B_0e^{-kx}$; thus, the transverse magnetic field is significantly attenu-ated from the cathode to the anode. At I_k=1 A, the induction in the gap between the CU and CL is B~65 mT. In the internal cylindrical chamber halfway between the SE and the annular slot (in point **r**), the induction is B~30 mT.

The induction in the gap is proportional to the cur-rent in the solenoid in the entire range of currents I_c.

The source was evacuated through the emission hole. The gas-supply system consisted of inlet needle valve supplied via a reducer. The operating nitrogen pressure in the ring-shaped chamber was 10^{-2}–1 Pa. The anode was being powered by high-voltage rectifiers with falling characteristic. The working gas was supplied through the upper hollow in the annular anode A and radial holes in it uniformly distributed over the anode surface facing the cathode rings.

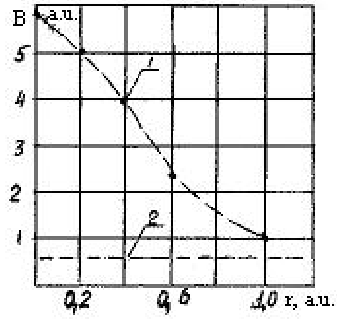

Fig. 3. Distribution induction of the axial magnetic field versus the radius in spacing. 1 – The dependence B_s from gap (II) to the anode (I); (by I_s=1A); 2 – Residual magnetic field in gap by I_s=0.The all measurements was made in the median plane of the gap rθ

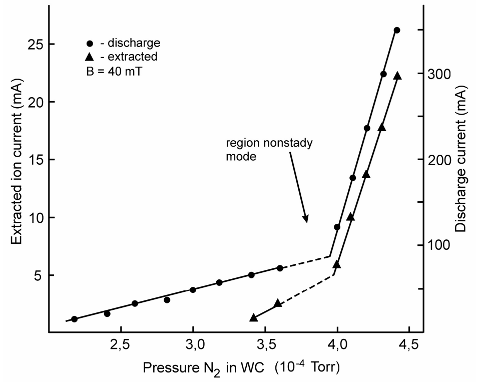

Fig. 4. Dependence discharge and extracted currents versus the working gas pressure

3. Operation of Plasma Source

A LDC in the FPS is initiated at a pressure of 10^{-2}–1 Pa at a firing voltage of ~1 kV. i.e., at pd<<$(pd)_{min}$ (d – is the electrode spacing in the region of the left branch of the Paschen curve) [4]. LDC is caused by the autoelectronic emission from the sharp edges of the blade cathode and the presence of a magnetic trap for electrons created by an arc-shaped magnetic field.

The typical curve of dependence discharge current on the pressure working gas is shown in Fig. 4.

The FPS can operate in two modes: the high-voltage (with a negative anode drop) and low-voltage (with anode and cathode drops) modes [5]. The gas ionization efficiency is much higher in the second case and is determined by two ionization zones in a near-anode layer with a closed drift of electrons and the space with magnetized electrons oscillating along the lines of force of the axial homogeneous magnetic field in the gap.

Fig. 5 shows the current-voltage characteristic (CVC) of the FPS. The electron and ion discharge components be have differently, because the axial fields B in the gap barely affect the ion trajectories. The CVC of the FPS substantially affected by the gas desorption and sputtering. A fraction of the sputtered neutral atoms of the SE target and gas ions neutralized on it returns to the annular slot. Basically, both S- and N-type CVCs are possible in this design [2]. During an operating cycle, which usually lasts no longer than 1 h, desorption and sputtering processes have different effects on the CVCs in the FSP.

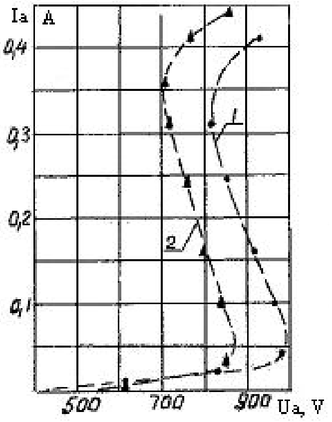

Fig. 5. Dependence discharge current versus of the anode voltage

Autoelectrons from some number of microprodjectures on the edge blades of CU and CL are emitted by the action of U_a [6]. The arc-shaped magnetic field focuses these electrons. Near the sharp edges of the cathodes facing the toroidal surface of the anode with their blades (Fig. 2, *b*), electrons acquire energy approximately equal to the potential difference at a length comparable with the sizes of microprodjectures on the edges of the blades. Inhomogeneous axial field of B_a in spacing A – C effects in with case as pressure increase of working gas in chamber from P to P_m.

$$P_m = P\cdot(1-\omega_e^{\;2}\cdot\tau_e^{\;2})^{\frac{1}{2}}. \qquad (1)$$

Here P – pressure measured by vacuum gauge; Torr.; P_m – equivalent pressure Torr.; ω_e – cycloctron frecquency; τ_e – mean free time. The motion of electrons in crossed inhomogeneous $E\times B$ fields has very complex nature and it can lead to rise of various instabilities (Fig. 4, 6, 7). Breakdown spacing-I (Fig. 2, *b*) occurs by increase U_a to the required magnitude that provides sufficient amount of microemitters giving total electron current on blades of cathodes. Intensive ionisation of the gas begins on the projectures of the blade edges. For the-II in plane rZ prevail oscillatory motions along magnetic force lines and in plane zO they are cycloidal.

Dependence discharge current versus magnitude of axial magnetic field B_a (measured in point M Fig. 2, *a*) shows critical magnitude B_a by which occurs transition of discharge from high voltage form in high current (by given P=const and B_a ~ several hundred Gs.) and it roughly corresponds one to [5]. Boundary of transition is as sharp as one giving authors [5] for

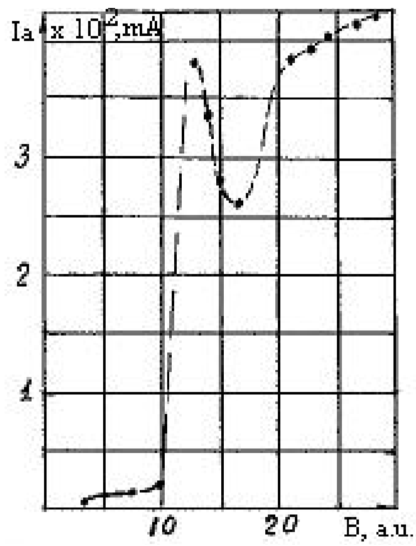

Fig. 6. The current of the LDC discharge as a function of induction B_a (of the Is) in spacing

spacing with uniform magnetic field. Distribution density of charged particles in our case is essentially inhomogeneous in the spacing here and the max density of electrons is in annular gap between poles-cathodes. In weak mag-netic field B_a<0 3 mT almost all ions arising from sphere with radius equal to the height projecture fall on it and heat it. The growth temperature of blades will secquently to initiate processes striving to the establishment of thermodynamic equilibrium between gas medium and cathode surfaces. It is connected with desorption of atoms in the beginning and with the release of dissolved gasses from surface of cathodes and further with the sublimation atoms of metal and doping atoms on the surface [6]. In the following heating of projectures and edges blades autoemission can be transformed into thermoautoemission accompanied by forced evaporation of cathode materials and by growth of partial pressure vapor Me with lower potential of ionisation. The total pressure will grow in FPS by B_a=const and U_a=const because of the increase of local temperature of projectures and evaporation of them. The influence of temperature active surface of cathodes blades on the conductance spacing is shown on Fig. 5. The ions arising in spacing not are confined by small magnetic field B<0,1 T and by small concentration of charged particles freely move to the cathode. The growth of density current ions on the surface cathodes by increase Ua (beginning part of curve Fig. 5 leads to transition low current form of discharge into high current one. The area of cathodes bombarded by ions in this case fast grows (part of the curve with negative drop). The electrons knocked out from surface of cathodes make forced motions in plane rZ and effectively ionize molecules of gas. The evolution of avalanche of charged particles and followed by filling plasma spacing and gap with leads to drop of discharge resistance (and origin of part of curve with negative drop). The confinement of plasma in spacing A–C is performed by the magnetic arc field with keeps electrons in plane rZ electrons in turn because of electrical neutrality of plasma holds ions from depositing on walls of chamber.

4. Experimental Results

The curve on the Fig. 7 shows the current of ions on the isolated axial rode PT placed in ICC by means of which is measured density of penetrating plasma [2]. The assessment is shown that density n_i~10^{12} cm^{-3} by U_a=630 V and I_a=400 mA and P=1,6·10^{-3} Torr. The ions passing through a thin layer edge of blades (Fig. 2, *b*) evolve heat. The most part of energy ions goes into heating the thin layer of the blade and dissipates almost completely by means irradiation and removal heat.

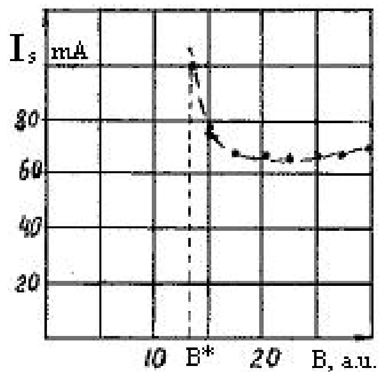

Fig. 7. Dependence of an ion current on the PT as function magnetic field in the gap

The blades of cathodes obtain features of underheated cathodes in steady regime of the burning discharge. In this case the thermoautoemission of electrons and sublimation of atoms Me from edges of blades will decreased of voltage of burning discharge. The power evolved by ions in a surfacing layer of halfring blade (Fig. 2, *b*) with radius of several tens mcm heat this volume to the high temperatures. Many of the materials Ti Fe Mo et al with high pressure vapor already by the T~05Tf fusion temperature is available to create conditions for growth of whiskers and other nonuniformities microprojecturies of type on the active surface of blades. The stationary distribution of temperatures on the surface blades can be set at equality of density of dissipated power – I_iU_a (here I_i – current density of ions) and removal heat from blades because of 1) knocked out electrons $Q_1=I_e\varphi$; where I_e – current of knocked electrons and φ – work of exit of electrons; 2) Q_2 – heat irradiation blades; 3) Q_3 – removal heat across section blade annular cathodes.

$$I_i \cdot U_a = Q_1 + Q_2 + Q_3. \qquad (2)$$

The concentration charged particles of gas plasma in ICC were estimated with a big ion probe PT. The wall of EAC was used as the basic-electrode in experiment. The axial rode with geometry SE was used as ion probe. The data of measurements showed, that average in area of probe ion concen-tration N_i>10^{12} cm^{-3} can be obtained.

Conclusion

The FPS was made as annular chamber on the low pressure discharge in crossed inhomogeneous $E\times B$ fields. The FPS in which the unincandescent cathodes and magnetic poles are combined in alone constructional element the discharge is burned by pressure (10^{-2}–10^{-4}) Torr. by anode potential U_a<1 kV. The moving blade cathodes and configuration ExB of fields produced of them allow to obtain radial-converging plasma flow for ICC of TIS coaxial geometry [2]. The density of ions measured by the large probe SE was achieved $\boldsymbol{n}_i$~10^{12} cm^{-3} FPS does not need the power supply U_a>1 kV. It can serve for long time by careful handling.

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