INFLUENCE OF GAS MIXTURE WITH VARIOUS MASS NUMBERS OF GASES ON OPERATION PRESSURE RANGE OF PLASMA ELECTRON SOURCE WITH HOLLOW CATHODE

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The influence of electric nonsymmetry in plasma electron source with hollow cathode as well as gas mixture with various mass numbers of gases on performances of the source was investigated. The operating pressure ranges for various working gases were determined. The intensive low-energy electron beams were obtained in fore-vacuum working pressure range at relatively low extraction potentials.

PACS: 52.50.Dg

INTRODUCTION

At present effective electron sources operating at fore-vacuum pressures [1, 2] are required for a row of technological processes, such as annealing and melting of materials, treatment of surfaces etc [2, 3]. For these purposes it are widely used the plasma electron sources on basis of reflective discharge with hollow cathode. However, such sources effectively operates only using of high extraction potentials owing to existence of the potential barrier for electrons between emitting plasma and extraction electrodes. Moreover, increased working gas pressure in accelerating gap results in reduction of the breakdown strength of accelerating gap [1, 2] that complicates the application of such sources at fore-vacuum pressures. Therefore, the perspectives of their use are connected with extension of the operating pressure range and providing of the needed current and power efficiencies at relatively low extraction potentials.

In the present paper, we suggested to use the mixture with light and heavy gases, such as argon and hydrogen, as well as the electric nonsymmetry between reflective cathodes to extend the operating characteristic of the plasma electron sources on basis of reflective discharge with hollow cathode.

SOURCE CONSTRUCTION

The construction of the plasma electron source on basis of penning cell with hollow uncooled cathode is schematically shown in Fig.1. The electrode system consisted of hollow cathode 1, reflective cathode 2, cylindrical anode 3, extraction electrode 4 and collector 5. The anode was 18 mm in inner diameters and 18 mm in length. The hollow cathode cavity diameter and length were 4,7 mm and 35 mm, respectively. The hollow cathode 1 and the reflective cathode 2 were made of graphite, but the anode 3 was stainless steel. The interelectrode clearances between cathodes and anode were 9 mm each. The electrode system was placed in the uniform axial magnetic field.

The electron beam was extracted from discharge in axial direction from emissive orifice of the cathode 2, which was 3,5 mm in diameter. The extraction voltage $U_{ext} = (0 \div 600)$ V was applied between the cathode 2 and the extraction electrode 4, but the collector potential was about extraction voltage.

To increase the electron extraction efficiency of the source the electric nonsymmetry was created between cathodes [4]. In run of experiments it were used both the symmetric and nonsymmetric electric circuits connecting the cathodes. In the first case both cathodes were grounded. In the other case, the cathode 2 was grounded, but the potential of the hollow cathode 1 was varied in range of $U_{C1} = (0 \div -600)$ V. The electric nonsymmetry was created by the potential difference between cathodes $dU = U_{C1} - U_{C2}$, where U_{C1} is the potential of the cathode 1, but U_{C2} is the potential of the cathode 2. The anode was always under positive potential.

The base pressure of vacuum chamber was about $4 \cdot 10^{-6}$ Torr.

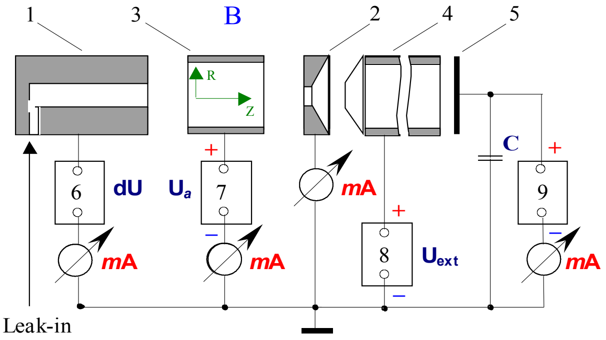

Fig. 1. Plasma electron source diagram.
1 - hollow cathode, 2– reflective cathode, 3 – anode, 4 - extraction electrode, 5 – collector, 6, 7, 8, 9 - power supplies.

EXPERIMENTAL METHODS AND OPERATING CONDITIONS

The investigation were carried out in a stationary discharge burning regime at operating pressures $P = (0,01 \div 4) \cdot 10^{-2}$ Torr, at magnetic induction $B = (0,01 \div 0,1)$ T, at anode voltages $U_a = (0 \div 4)$ kV and anode currents $I_a = (0 \div 0,9)$ A. The plasma density $n_o \sim (0,1 \div 2) \cdot 10^{11}$ cm^{-3} and the electron temperature

$T_e \sim (1 \div 4)$ eV in emitting region were determined by probe techniques. Collector 5 measured the total extracted electron current. The retardation curves of extracted electrons were obtained by using a multigrid electrostatic analyzer.

Argon, clear hydrogen and argon-hydrogen mixture were used as working gases. The working gases, such as argon and hydrogen, flowed into the hollow cathode. When the source was operated with the gas mixture, argon and hydrogen flowed into the hollow cathode via gas mixer. The working gas flow rate was varied in rang of $v_{flow} = (0{,}1 \div 1{,}1)$ Atm·cm^3·c^{-1}.

EXPERIMENTAL RESULTS

The reflective discharge initiated a discharge burning regime with hollow cathode. The high voltage discharge burning regime with growing volt-ampere characteristic was realized at low discharge currents (Fig.2). The initiation of the hollow cathode burning regime was accompanied by increase of the discharge current and reduce of the anode voltage. These changes of discharge burning regimes are marked in Fig.2 by dotted lines. For hydrogen the initiation currents $I_a \sim (250 \div 550)$ mA were significantly higher, but the discharge voltages $U_a = (0{,}3 \div 0{,}4)$ kV were lower, than their values for argon ($I_a \sim (50 \div 180)$ мA, $U_a = (0{,}55 \div 0{,}8)$ kV). For argon-hydrogen mixture the initiation currents ($I_a \sim (40 \div 200)$ мA) corresponded to those for argon, as to the discharge voltages ($U_a = (0{,}3 \div 0{,}4)$ kV) for same mixture they corresponded to those for hydrogen.

When hydrogen was used the initiation of the hollow cathode discharge burning regime was observed under a higher operating pressure ($P_o \geq 3\cdot10^{-3}$ Torr), then for argon and argon-hydrogen mixture ($P_o \geq 10^{-4}$ Torr), as seen from Fig.3.

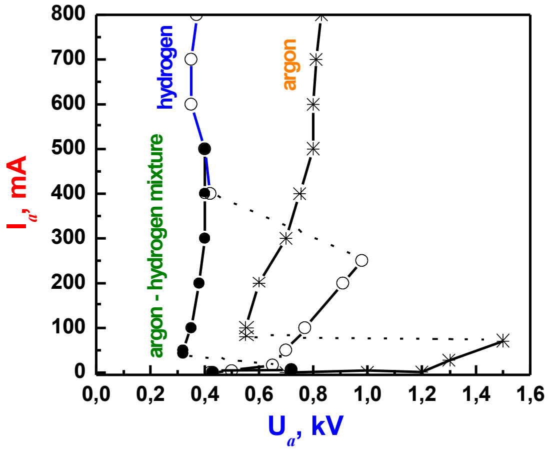

Fig.2. Volt-ampere characteristics of the plasma electron source. H = 600 Oe, dU = 0 V, $U_{ext} \sim 400$ V.
Working gas - hydrogen.
$P = 10^{-2}$ Torr, $v_{flow} = 1{,}1$ Atm·cm^3/c.
Working gas - argon.
$P = 10^{-3}$ Torr, $v_{flow} = 0{,}5$ Atm·cm^3/c.
Working gas – argon - hydrogen mixture.
$P = 10^{-3}$ Torr,
hydrogen - $v_{flow} = (0{,}7 \div 0{,}8)$ Atm·cm^3/c,
argon - $v_{flow} = (0{,}3 \div 0{,}4)$ Atm·cm^3/c.

Such behaviour of a reflective discharge is responsible for peculiarities of existence of high-current discharge burning regime at various working pressures, anode voltages and working gas sorts [3, 5].

Upper bound of the operating pressure range was determined by appearing the electrical breakdown of the accelerating gap. The electrical breakdown was occurred at the operating pressures: $P_{max} \geq 4\cdot10^{-3}$ Torr for argon, $P_{max} \geq 3\cdot10^{-2}$ Torr for hydrogen and $P_{max} \geq 1{,}5\cdot10^{-2}$ Torr for argon-hydrogen mixture. The operating pressure ranges for various working gases are shown in Fig.3 by arrows.

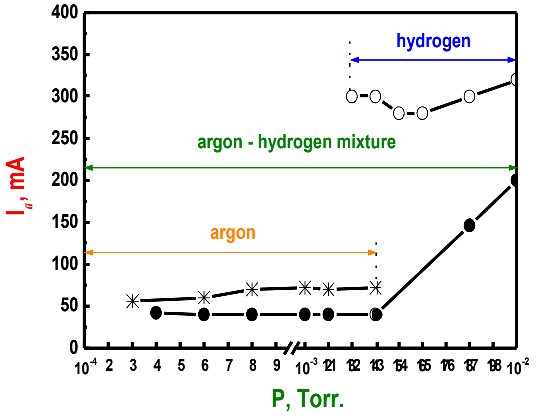

Fig.3. Dependencies of initiating current values I_a on a working gas pressure P. H = 600 Oe, dU = 0 V, $U_{ext} \sim 400$ V.
Working gas - hydrogen.
$v_{flow} = 1{,}1$ Atm·cm^3/c.
Working gas - argon.
$v_{flow} = 0{,}5$ Atm·cm^3/c.
Working gas – argon - hydrogen mixture.
Hydrogen – $v_{flow} = (0{,}7 \div 0{,}8)$ Atm·cm^3/c,
argon – $v_{flow} = (0{,}3 \div 0{,}4)$ Atm·cm^3/c.

The main disadvantages of application of clear gases were the restriction of the operating pressure for argon because of electrical breakdown of accelerating gap and the impossibility to operate at low working pressures and discharge currents for hydrogen. The application of argon-hydrogen mixture allowed to extend the operating characteristics of the source at the expense of reduce of discharge currents and voltages, as well as extension of operating pressure range.

The electric nonsymmetry in the discharge resulted in significant increase of the extracted electron currents and the power efficiency of the source for all working gas sorts. The dependencies of the extracted electron current I_{beam} on a potential difference dU between cathodes is shown in Fig.4. At an operation with hydrogen, the power efficiency of the source and the extracted electron current reached of H = 0,77 mA/W and $I_{beam} = 250$ mA, respectively, at dU = -100 V. At dU < -100 V it was observed disruption of a hollow cathode regime. In this case, the anode voltage increased, but the anode current decreased abruptly.

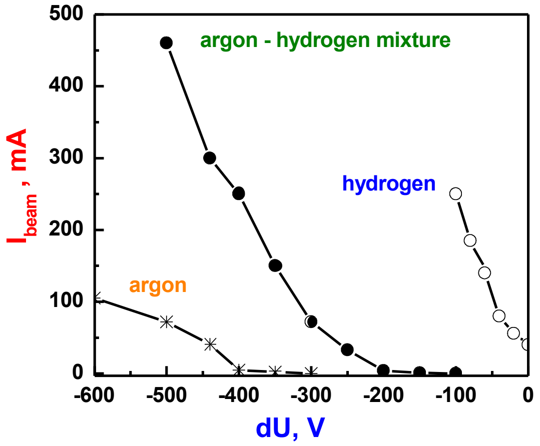

Fig.4. Dependencies of extracted electron currents I_{beam} on a potential difference between cathodes dU.
U_{ext} ~ 400 V.
Working gas - hydrogen.
$P = 10^{-2}$ Torr, I_a = 800 mA, H = 800 Oe,
v_{flow} = 1,1 Atm·cm^3/c.
Working gas - argon.
$P = 10^{-3}$ Torr, I_a = 300 mA, H = 600 Oe,
v_{flow} = 0,5 Atm·cm^3/c.
Working gas – argon-hydrogen mixture.
$P = 10^{-3}$ Torr, I_a = 300 mA, H = 600 Oe,
hydrogen – v_{flow} = (0,7 ÷ 0,8) Atm·cm^3/c,
argon – v_{flow} = (0,3 ÷ 0,4) Atm·cm^3/c.

For argon the power efficiency and the extracted electron current were H = 0,43 mA/W and I = 145 mA, respectively at dU = -600 V.

For argon-hydrogen mixture their values (H = 1 mA/W, I_{beam} = 460 mA) at dU = –500 V, were a higher, than for clear gases. However, further increase of the extracted electron current was impossible without forced cooling of constructive elements of the source.

When the electric nonsymmetry was used, the amount of change of the extracted electron current corresponded to change of the hollow cathode current for all working gas sorts. Besides, the extraction of electrons was effective at relatively low extraction potentials U_{ext}. As can been seen from Fig.5 (curve 1), with increasing U_{ext}, the electron emission rises and at U_{ext} > 100 V the extracted electron current is saturated. In this case, the beam energy was about 15 eV in all range of operating pressures (Fig.5, curves 2, 3).

CONCLUSIONS

As a result of performed experiments it was shown, that the electric nonsymmetry in plasma source of given type resulted in increase of the electron stream incoming into discharge from hollow cathode cavity. This provides the high electron extraction efficiency at relatively low extraction potentials. The application of argon-hydrogen mixture permits to extend the operation pressures in fore-vacuum range at conservation of electron beam performances.

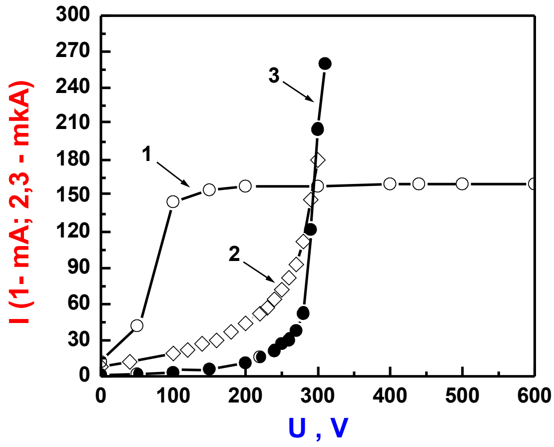

Fig.5. Dependence of extracted electron current on an extraction potential (1) and retardation curves of extracted electrons (2, 3).
Working gas – argon-hydrogen mixture.
$P = 10^{-3}$ Torr, H = 600 Oe,
hydrogen – v_{flow} = (0,7 ÷ 0,8) Atm·cm^3/c,
argon – v_{flow} = (0,3 ÷ 0,4) Atm·cm^3/c.

1 – $P = 10^{-3}$ Torr, I_a = 300 mA, dU = -400 V,
2 – $P = 10^{-3}$ Torr, I_{beam} = 100 mA, dU = -440 V, U_{ext} = 300 V.
3 – $P = 10^{-2}$ Torr, I_{beam} = 100 mA, dU = -270 V, U_{ext} = 300 V.

The obtained experimental results can be used for create of new technological plasma electron sources with high performances.

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