ANODIC ELECTRON SHEATHS IN LOW PRESSURE HOLLOW CATHODE DISCHARGE WITH LARGE SIZE ANODE

V.Yu. Bazhenov, S.V. Matsevich, V.M. Piun, V.V. Tsiolko

Institute of Physics, Kyiv, Ukraine

E-mail: smatsevich@gmail.com

Researches of the features of “electron” sheath formed between the negative glow plasma and the anode of hollow cathode discharge in oxygen and nitrogen at low pressure are performed. Peculiarities of behavior of spatial distributions of current onto the anode, plasma density and electron temperature are determined at different gas pressure and discharge current.

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INTRODUCTION

Anodic sheaths, that is, zones in vicinity of positively charged electrodes are investigated since Langmuir’s day. Such interest is due to fact that in gas discharges namely in this zone a transition from axially uniform and radially non-uniform positive column plasma to location of electron loss at equipotential anode surface occurs. Appearance of spatial charge layers (electron, ion or double, in dependence on the system parameters) in vicinity of the anode results in considerable influence on the plasma features in the near-anode zone. In case of low pressure discharges, anode region properties are defined, first of all, by non-local kinetics behavior of electrons [1].

Works devoted to researches of plasma parameters in the near-anode sheaths can be roughly subdivided into two groups, one of them dealing with the sheaths near discharge anode [2-5], and another one – with the sheaths occurring near positive electrode placed into preliminarily formed uniform positive column plasma [6-9]. In spite of certain differences in these systems, in both cases it is assumed that creation and heating of ”bulk” plasma is performed by electric field, and spatial profile of electron flow onto the anode/positive electrode is close to the plasma density profile. Edge effects at the anode are usually neglected.

Peculiarity of the hollow cathode discharge plasma consists in fact that main role in its generation and heating is performed by fast electrons accelerated in the near-cathode region up to energy of about eU_d (U_d is the discharge voltage), and electric field in the plasma is small – just about 0.01…0.1 eV. Actually, hollow cathode discharge plasma is the negative glow one. Typical design of such discharge is cylindrically shaped cathode with anode placed near one of the ends. At location far from the anode, electric field of cathode sheath is perpendicular to the cathode surface (that ism parallel to the anode plane). Due to fact that, at energy up to ≈50…100 eV, electron scattering in elastic collisions occurs mainly in forward direction, fast electrons have low chance to come the anode before the loss of their energy in non-elastic processes. The situation is complicated in case of acceleration of secondary electrons emitted from the cathode surface in vicinity of the anode. In this case, probability of fast electrons coming to the anode before the loss of major portion of their energy is considerably higher because: a) electric field of cathode sheath has a component directed towards the anode; b) anode may become in the scattering cone. These effects should be essentially exhibited in case of the anode size being close to the cathode diameter.

A general goal of our researches was the study of features of “electron” sheath formed between the negative glow plasma of hollow cathode discharge in oxygen and nitrogen and the discharge anode at different discharge parameters. Results of the first stage of these researches are presented in this paper.

1. EXPERIMENT SET-UP AND MEASUREMENTS

The measurements were performed in the discharge chamber having 38 cm diameter and 42 cm length, which simultaneously served as the discharge cathode, at that the discharge anode having 30.5 cm diameter was located near back side of the chamber. Chamber was evacuated down to pressure of about 5 ≈ 10^{-3} Pa, and after that working gas O_2 or N_2) was supplied to the chamber until reaching of predetermined pressure value. Working gas pressure P in the chamber was varied in range of 1…16 Pa.

The discharge power supply was provided by DC source with controlled voltage and current values in ranges of 400…800 V and 100…600 mA, respectively. Power introduced in the discharge varied in range of 50…350 W, which corresponded to specific power in the discharge $W_d \approx 1…7$ W/cm^{-3}.

The plasma density, electron temperature and electric field in the plasma were measured using single Langmuir probes made of a 100 μm tungsten wire with the collecting length 10…12 mm. The probe characteristics were measured using the home-made PC-controlled system [10]. To avoid the effect of contamination of the probe surface on the probe current-voltage characteristic, the probes were heated to ≈ 800°C after each measurement.

The plasma potential was determined from the inflection point of the probe current–voltage characteristic, and the plasma density was calculated from a saturation of the electron current to the probe. Temperature of the plasma electrons was determined from semi-logarithm dependency of current to the probe on the voltage.

In [10, 11] it was shown that electron energy distribution function (EEDF) in the plasma of hollow

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cathode discharges in nitrogen and oxygen possesses essentially non-Maxwellian behavior. In discharges in N_2, there is a significant dip in the EEDF in the energy range ε = 2…4 eV. The dip is associated with the vibrational excitation of N_2 molecules. In the energy range of 0.2 < ε < 2 eV, the EEDF is Maxwellian with a temperature T1 ≈ 0.2…0.3 eV. In the case of O_2 plasma, the EEDF can be described by two Maxwellian functions with different temperatures – T1 ≈ 0.2…0.3 eV in the energy range ε ≈ 0…2 eV and T2 ≈ 3…4 eV at ε > 2 eV. Two-temperature EEDF behavior in energy range of ≈ 0…10 eV is, first of all, is due to influence of excitation of metastable states and vibrational levels of O2. In subsequent considerations namely "cold" electron temperature T1 in energy range 0…2 eV will be used.

Radial distributions of discharge current onto the anode were measured by means of 7 mini-collectors, each having 0.1 cm^2 square, located with 20 mm step at the anode. Planes of receiving sections of the mini-collectors were flush with the anode plane.

2. EXPERIMENTAL RESULTS

At the first stage of researches, measurements of radial dependencies of current density onto anode J_a at different discharge current values I_d were performed with oxygen use as working gas at 4 and 11 Pa pressure values (Figs. 1,a,b). At I_d variation from 80 to 480 mA, the discharge voltage U_d grew from ≈ 550 up to ≈ 700 V, and from ≈ 400 up to ≈ 500 B at O_2 pressure values 4 and 11 Pa, respectively.

One can see from the figures that: a) behavior of the dependencies at various O_2 pressure values are essentially different; b) at the same pressure value, behavior of the dependencies does not change with I_d current variation. At smaller pressure value, radial dependence of J_a has non-monotonous behavior – J_a density initially grows up slightly with R increase, reaches a maximum at R ≈ 30 mm, after that decreases down to minimum value at R ≈ 100 mm and, finally, grows up monotonously till the anode edge. At the same time, at P = 11 Pa current density J_a grows up practically monotonously with R increase at all I_d values. But the most interesting feature consists in fact that behaviors of these J_a dependencies do not correlate with radial dependencies of the plasma density n_e inherent to the main part of the discharge plasma (Fig. 2). Although the plasma density at 4 Pa pressure decreases monotonously with R increase, current density J_a exhibits essentially non-monotonous behavior. Inverted behavior is observed at oxygen pressure increase up to 11 Pa – non-monotonous one for radial distribution of n_e and monotonous J_a growth with R increase. Thus it is obvious that in vicinity of anode deformations of initial distributions of plasma density, as well as and electric field, occur.

For determining how essential is dependence of this effect on the gas kind, subsequent set of the measurements was performed with the use of nitrogen as working gas at the same values of pressure and current density, as in the case of oxygen use. One can see from Fig. 3 that, in spite of certain differences, behavior of dependencies J_a vs R remains the same – non-monotonous one al lower pressure value, and practically monotonous J_a growth with R increase at P = 14 Pa.

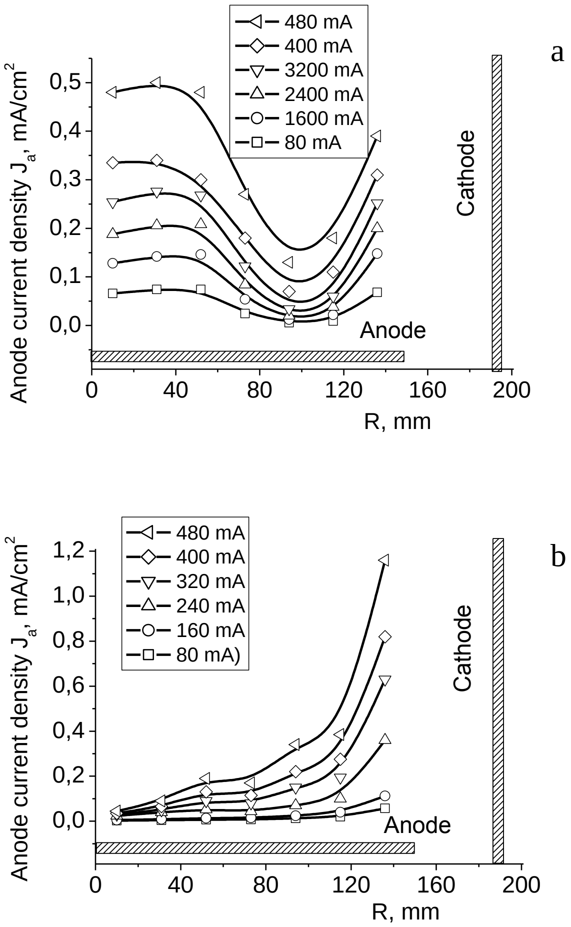

Fig. 1. Radial dependencies of current onto anode at different current values I_d of the discharge in oxygen: a) P = 4 Pa; b) P = 11 Pa

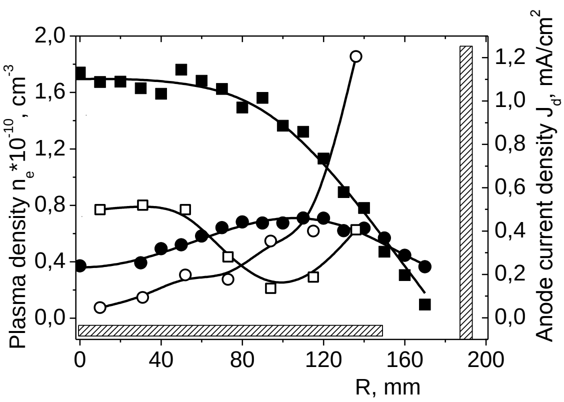

Fig. 2. Radial dependencies n_e (close points) and J_a (open points) obtained at close values of current I_d. Dependencies of n_e vs R are taken at distance L = 200 mm from the anode.
-■- P = 4 Pa; -●- P = 11 Pa

Measurements of radial distribution of the plasma density far from the anode (L ≈ 180 mm) have also shown absence of correlation of these dependencies with J_a radial dependencies.

For determining changes of the plasma parameters in vicinity of anode, measurements of the plasma potential U_p, electron temperature T1 and plasma density were performed at distances of 7 and 107 mm from the anode.

The measurements have shown that plasma potential in the main volume of the plasma is about 5…10 V lower than the anode potential practically in all studied regimes of the discharge glow. This value is less than ionization potentials of O_2 and N_2 (12.1 and 15.6 eV, respectively), so that additional gas ionization by the plasma electrons can be neglected.

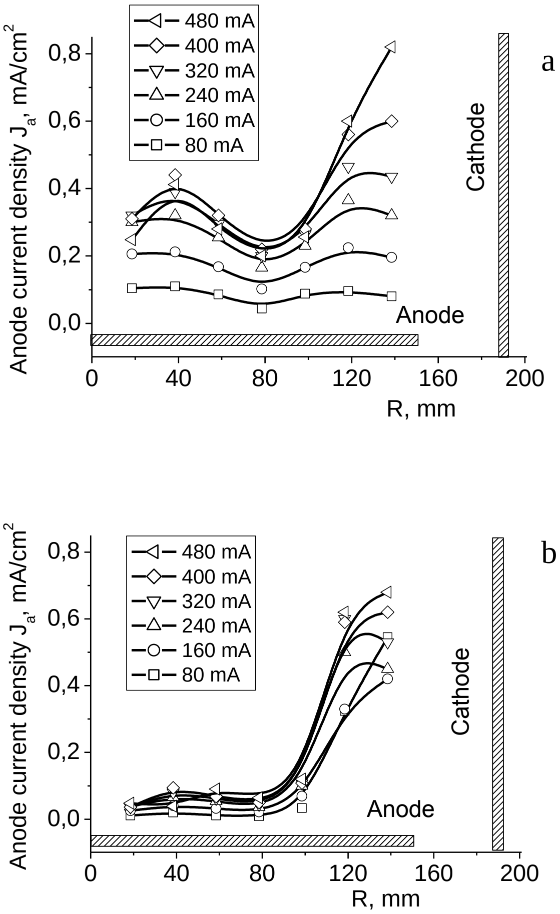

Fig. 3. Radial dependencies of current density onto anode J_a at different current values I_d of the discharge in nitrogen: a) P = 4 Pa; b) P = 14 Pa

One can see from Fig. 4 that at 107 mm distance temperature T1 generally decreases with R increase, and by its value corresponds to T1 in the main plasma volume [10], whereas at small L abrupt decrease of temperature T1 is observed. It should be noted once again that here “cold” electrons with energy in range of 0…2 eV are considered, that is, actually, the electrons of isotropic section of EEDF. It should be noted that EEDF in high energy range should be also “distorted” at the expense of electric field influence in the anode electron sheath. Accurate EEDF measurements (taking into account its becoming anisotropic under action of longitudinal electric field) in this energy range are required for clarification of nature of the processes taking place in the near-anode region.

Abrupt T1 decrease at short distance from the anode can be due to formation of potential well with negative field in vicinity of the anode [2, 3]. It results in forming two groups of electrons – trapped and free ones, at that trapped electrons cooled down to low temperature under certain conditions.

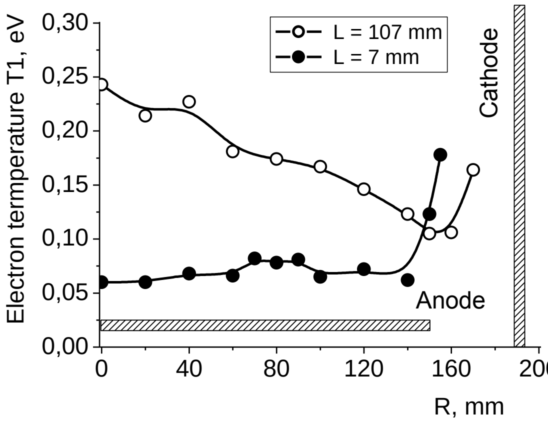

Fig. 4. Radial dependencies of electron temperature T1 at different distances L from the anode. Nitrogen pressure P = 4 Pa, I_d = 160 mA

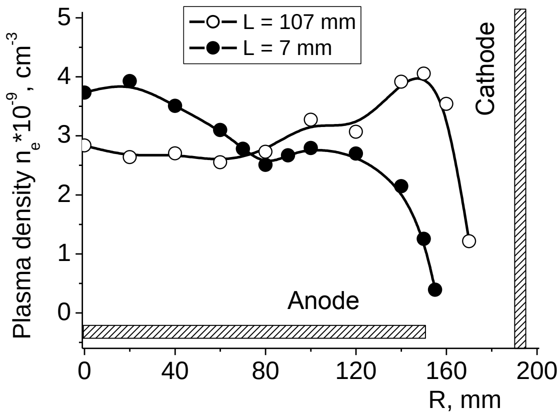

Fig. 5. Radial dependencies of plasma density n_e at different distances L from the anode. Nitrogen pressure P = 4 Pa, I_d = 160 mA

Distribution of cold electron density n_e vs R at L = 7 mm (Fig. 5) exhibits behavior which is similar enough to that of J_a radial dependence at low values of the discharge current (see Fig. 3,a), thus also giving an evidence to essential change of the plasma parameters. Somewhat unexpected is also difference of n_e radial distribution at L = 107 mm from bell-shaped in central part of the discharge, which may tell about an influence of the processes in anode sheath also on “bulk” plasma parameters.

Researches of the anode sheath parameters at high discharge current values, as well as those with the use of atomic gases, are planned in the future.

CONCLUSIONS

It was determined that at pressure of working gases of ≈ 12…14 Pa, radial distribution of the density of electron flow to the anode J_e was in qualitative agreement with radial distribution of the plasma density possessing maxima at mid-values of the chamber radius, whereas the pressure decrease down to ≈ 2…4 Pa resulted in drastic change of the situation. Although in this case n_e in the main volume of the discharge monotonously decreased from the system radius towards the periphery, J_e radial distribution exhibited essentially non-monotonous behavior – at first, it reached intermediate maximum at certain R value, and in subsequent, after passing a minimum it grew up again. The measurements also have shown that similar behavior near the anode is exhibited as well by the plasma density. Abrupt cooling of electrons with energy of 0…2 eV in vicinity of the anode is also determined.

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АНОДНЫЕ ЭЛЕКТРОННЫЕ СЛОИ В РАЗРЯДЕ НИЗКОГО ДАВЛЕНИЯ С ПОЛЫМ КАТОДОМ И БОЛЬШИМ АНОДОМ

В. Ю. Баженов, С.В. Мацевич, В.М. Пиун, В.В. Циолко

Проведены исследования свойств электронного слоя, формирующегося между плазмой отрицательного свечения и анодом разряда с полым катодом в кислороде и азоте низкого давления. Установлены особенности поведения пространственного распределния плотности тока на анод, плотности плазмы и электронной температуры при различных давлениях газов и разрядных токах.

АНОДНІ ЕЛЕКТРОННІ ШАРИ В РОЗРЯДІ НИЗЬКОГО ТИСКУ З ПОРОЖНИСТИМ КАТОДОМ ТА ВЕЛИКИМ АНОДОМ

В.Ю. Баженов, С.В. Мацевич, В.М. Піун, В.В. Ціолко

Проведено дослідження властивостей електронного шару, що формується між плазмою негативного світіння та анодом розряду з порожнистим катодом у кисні та азоті низького тиску. Встановлено особливості поведінки просторового розподілу густини струму на анод, густини плазми та електронної температури при різних тисках газів та розрядних струмах.