STRUCTURE AND MODES OF DC GLOW DISCHARGE IN NITROGEN WITH HOLLOW CATHODE OR ANODE

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This paper studies the modes of burning and structure of the glow discharge with "hollow cathode and flat anode" and "hollow anode and flat cathode" in nitrogen. We have demonstrated that a higher discharge current is observed with a hollow cathode because its area exceeds 3 times that of a flat one. The discharge with a hollow cathode may burn in hollow or glow modes (with the cathode cavity filled with negative glow or not). We have measured the axial profiles of the emission line intensities for nitrogen molecules, atoms and ions with different gas pressure, discharge current values and electrode designs. We have observed the high intensity of the emission lines of the atomic nitrogen in the cathode sheath near the surface of the flat cathode indicating a remarkable dissociation degree of nitrogen molecules in this region of the discharge.

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INTRODUCTION

Glow discharge with a hollow cathode and/or anode is widely applied in many industrial ion devices (ion sources), in fluorescent lamps, for pumping gas-discharge lasers, for welding and melting materials with an electron gun, for modifying surfaces of solid bodies (etching, depositing thin films), in analytical and plasma chemistry [1-4].

In order to apply glow discharges optimally, one has to know their properties in various modes of burning [1, 5-7]. In the majority of papers one dealt with the glow discharge with a cylindrical hollow cathode as well as with a segmented cathode. The glow discharge with a hollow anode is less studied (see [4] and the references cited therein). And we do not know the papers comparing modes of burning and properties of the glow discharge with a “hollow cathode and a flat anode” and that of a “hollow anode and a flat cathode”.

This paper is devoted to studying the variation of the discharge modes of burning for a pair of electrodes one of which is flat and another one possesses a cavity in the form of two parallel plates when these electrodes are in turn a cathode and an anode. The discharge CVCs have been measured and the structure of a glow discharge in N_2 has been studied with the optical spectral analysis.

1. EXPERIMENTAL

To investigate the glow discharge, a discharge chamber was used schematically shown in Fig. 1. We have performed our experiments in the discharge tube with the 56 mm inner diameter. One of the electrodes was flat and of 55 mm in diameter. Another one was hollow and of the following shape. Two plates 2 mm thick were located at the distance of 8 mm one from the other and they were fixed to a flat disc of 55 mm in diameter. Ends of plates were located at the distance of 37 mm from the flat portion of the electrode. These two electrodes served in turn as a cathode and an anode, i.e. we have considered the configurations of a “hollow cathode and a flat anode” and a “hollow anode and a flat cathode”. The distance between flat parts of the electrodes was 100 mm. The study has been performed in nitrogen in the pressure range p = 0.05…1.5 Torr.

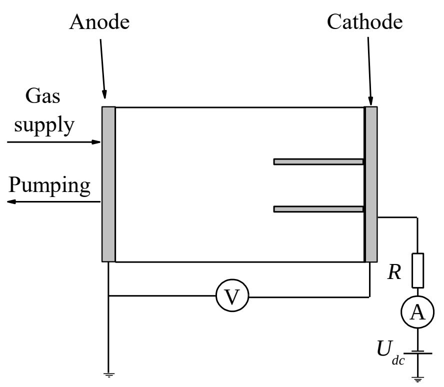

Fig. 1. The scheme of the experimental setup

With the optical spectrometer Qmini (RGB Lasersysteme) we have measured the axial profiles of emission lines of nitrogen molecules, atoms and ions in the 300…900 nm wavelength range. For the analysis of molecular gas spectra, we used the Pearse and Gaydon handbook [8].

2. EXPERIMENTAL RESULTS

Consider the results for several nitrogen pressure values. At low pressure the discharge with a hollow cathode may burn in glow and hollow modes. Fig. 2 presents the photo and the axial profiles of the emission line intensities for the molecular nitrogen (773 nm is the 1st positive system and 357 nm is the 2nd positive system), for N_2^+ molecular ions (391 nm is the 1st negative system), as well as for the atomic nitrogen (868 nm, the transition from the $^4D^0$ level to the ^4P one). In the glow mode the cathode sheath loops over the hollow cathode from the outside not filling the cavity. One observes the maxima on the emission line intensity profiles located in the discharge negative glow. And only near the edge of the cathode plates one observes a brighter glow manifesting itself in the form of a moderate maximum on the profile for the atomic nitrogen. This glow is caused by secondary electrons produced out of inner surfaces of cathode plates and accelerated in the electric field away out of the cathode cavity. When one moves away from the cathode to the anode, the emission line intensities decrease uniformly. When one moves from the edge of the cathode plates into the cavity, the line intensities are lowered with rather higher rate. We remark that the line of the 1st negative system possesses the largest of the nitrogen molecular ions (391 nm and other lines not shown in the figures).

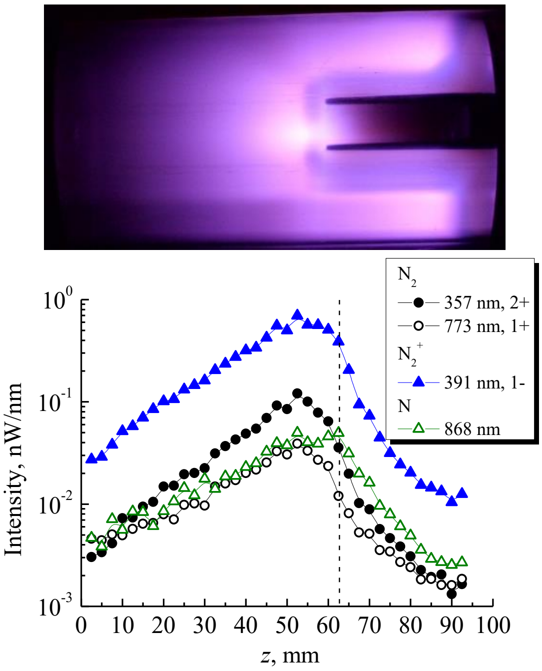

Fig. 2. Discharge photo and emission line profiles of neutral molecules and ions as well as of nitrogen atoms are depicted. A hollow cathode is on the right and a flat anode is on the left. The pressure is 0.1 Torr, the discharge current is 20 mA. Glow mode

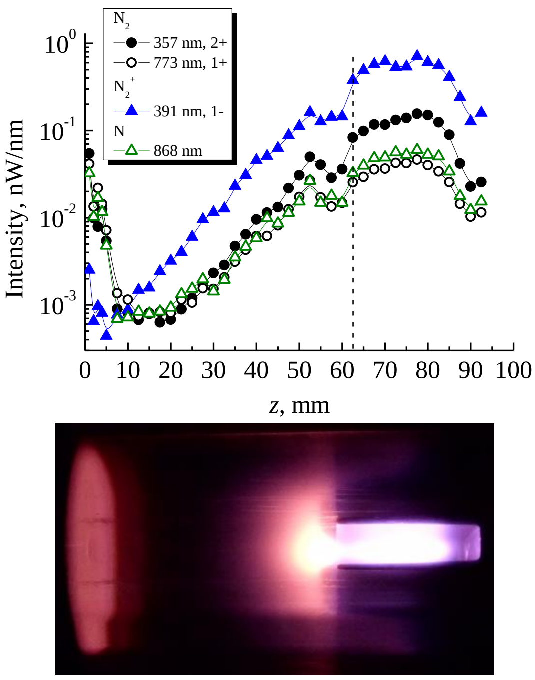

Fig. 3. Discharge photo and emission line profiles of neutral molecules and ions as well as of nitrogen atoms are depicted. A hollow cathode is on the right and a flat anode is on the left. The pressure is 0.1 Torr, the discharge current is 20 mA. Hollow mode

It is caused by the fact that for electron energies above 20 eV the cross section of the molecule ionization with the formation of ions excited to the level $N_2^+(B\ ^2\Sigma_u^+)$ becomes higher than the excitation cross sections to the B $^3\Pi_g$ and C $^3\Pi_u$ levels of the molecular nitrogen [9]. Therefore in the regions where sufficiently energetic electrons are present, the ion glow may be brighter than that of excited molecules.

On increasing the current, the discharge fills the cathode cavity jump-like, a so-called hollow mode sets on (Fig. 3). Within the cavity a bright negative glow is built up which partly may reach outside over the edge of the cathode plates. Correspondingly, one observes two maxima on the glow intensity profiles– one is inside the cavity, and another one is outside it. As an overwhelming majority of fast electrons oscillate in the cathode cavity and produce effective ionization of gas molecules in it, and a flow of fast electrons to the anode is small, a positive anode drop forms near the anode to produce the current transfer. The anode glow near the anode surface [10-16] is its consequence, and the emission line intensities in this discharge region grow considerably.

Now consider how the discharge structure changes for the “hollow anode” (Fig. 4) and “flat cathode”. Near a flat cathode a cathode sheath of equal thickness is formed, then there goes a negative glow approaching the hollow anode. One observes the maxima on the profiles of all emission lines in the negative glow. On approaching the cathode the intensities of the 2nd positive (N_2) and the 1st negative (N_2^+) systems in the cathode sheath decrease and the intensity of the 1st positive system increases. However the concentration of the atomic nitrogen near the cathode grows several times indicated by an abrupt growth of the 868 nm line intensity. The processes in the cathode sheath have been studied earlier, see, e.g papers [17-24]. As the hollow anode possesses a large area and fast electrons approach its surface, then a sheath with a negative voltage drop is formed near the anode [15]. The hollow anode serves as a collector of fast electrons in this case, and due to their loss the intensities of all emission lines lower near it.

Fig. 5 demonstrates that the current in the discharge with a hollow anode (and a flat cathode) is considerably less than one in the discharge with a hollow cathode. The CVCs of the discharge with a hollow cathode possesses two branches. The lower one corresponds to the glow mode. The hollow cathode area 3 times exceeds that of the flat one and therefore the current values for the hollow cathode are always higher. When the negative glow fills the cathode cavity, a hollow mode is observed with a high current. The transition between glow and hollow modes has a hysteretic pattern.

Consider now the case of higher pressure of 0.5 Torr. At such pressure and low current the discharge with a hollow cathode is burning first outside the cathode cavity, but with the current growing it fills the cavity gradually. The current-voltage characteristic possesses the S-pattern without hysteresis. A brighter spot is observed inside the cavity (with the maxima on the line intensity profiles), the negative glow is partially spread out the limits of the cathode cavity. Further, similar to the case of low pressure, line intensities decrease when one moves away from the cathode, and the anode glow appears near the anode surface.

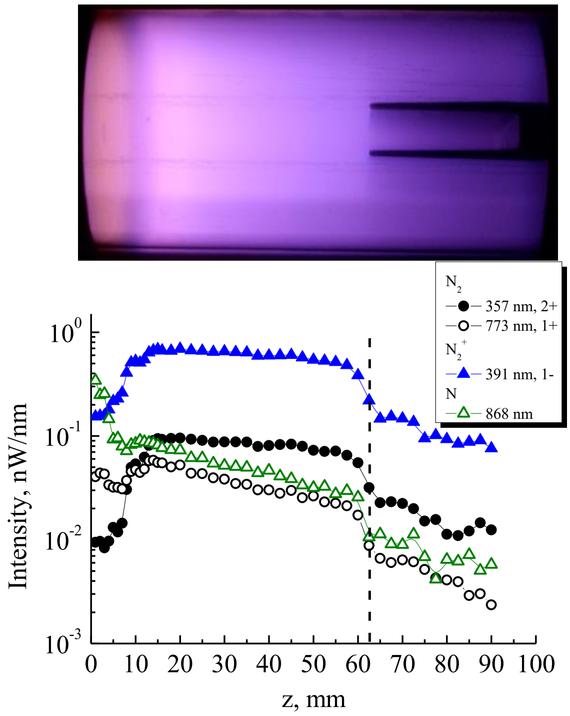

Fig. 4. Discharge photo and emission line profiles of neutral molecules and ions as well as of nitrogen atoms are depicted. A hollow anode is on the right and a flat cathode is on the left. The pressure is 0.1 Torr, the discharge current is 20 mA

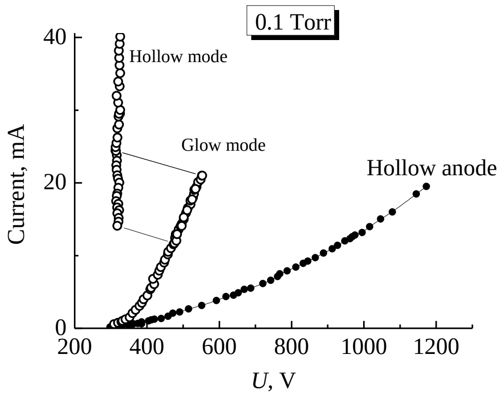

Fig. 5. Current-voltage characteristics for hollow anode and cathode. The pressure is 0.1 Torr. Glow and hollow modes of the discharge with a hollow cathode are indicated

On employing a hollow anode with an increased gas pressure, the thickness values of the cathode sheath and negative glow decrease. Fast electrons lose their energy traversing only a part of their way from the cathode sheath boundary to the anode. Therefore in order to collect a sufficient number of electrons, a sheath is formed near the anode with the positive voltage drop in which electrons get additional acceleration.

At the gas pressure of 1.5 Torr and low current values the discharge covers only a part of the cathode area and it is burning in the normal mode. Dealing with the discharge with the hollow cathode at low current values, one may observe a section of the CVC with a negative tilt, corresponding to the normal mode. After the cathode is completely covered with plasma the discharge experiences a transition to the abnormal mode [10, 11, 21]. However in the case of a hollow cathode the width of the section with the negative tilt exceeds 230 V and it is associated not only with the normal mode. Between the flat anode and the outer surface of cathode plates a narrow positive column is being formed at low current values. Its length decreases with the discharge current growing. In this case the reduced electric field *E/N* decreases with the current growth [13, 14, 25, 26]. Correspondingly, the voltage drop across the positive column as well as the total one across the electrodes become lower. Therefore the simultaneous expanding of the discharge spot over the hollow cathode area and narrowing of the positive column lead to the presence of the clearly expressed CVC branch with the negative tilt.

CONCLUSIONS

So, in the present paper, a glow discharge in N_2 has been studied with optical emission spectroscopy. We have considered two cases with the hollow cathode and hollow anode. Employment of the hollow anode has shown to furnish a rather low discharge current than it has been observed with the hollow cathode, because the area of the hollow cathode is larger than that of the flat one, therefore the area of the cathode sheath and negative glow (and the number of charged particles produced in them) is always larger for the hollow cathode. The glow and hollow modes of burning have been observed. The concentration of atomic nitrogen grows substantially near the surface of the flat cathode.

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СТРУКТУРА И РЕЖИМЫ ТЛЕЮЩЕГО РАЗРЯДА В АЗОТЕ С ПОЛЫМИ КАТОДОМ ИЛИ АНОДОМ

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Исследованы режимы горения и структура тлеющего разряда с «полым катодом и плоским анодом» и «полым анодом и плоским катодом» в азоте. Показано, что более высокий разрядный ток наблюдается для полого катода, так как его площадь в 3 раза больше, чем плоского. Разряд с полым катодом может гореть в полом или тлеющем режимах (с катодной полостью, заполненной отрицательным свечением или нет). Для различных давлений газа, разрядных токов и геометрий электродов построены осевые профили интенсивности линий излучения молекул, атомов и ионов азота. Вблизи поверхности плоского катода в катодном слое наблюдается высокая интенсивность линий излучения атомарного азота, что указывает на значительную степень диссоциации молекул азота в этой области разряда.

СТРУКТУРА ТА РЕЖИМИ ТЛІЮЧОГО РОЗРЯДУ В АЗОТІ З ПОРОЖНИСТИМИ КАТОДОМ ЧИ АНОДОМ

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Досліджені режими горіння і структура тліючого розряду з «порожнистим катодом і плоским анодом» і «порожнистим анодом і плоским катодом» в азоті. Показано, що більш високий розрядний струм спостерігається для порожнистого катоду, оскільки його площа в 3 рази більша, ніж плоского. Розряд з порожнистим катодом може горіти в порожнистому або тліючому режимах (з катодною порожниною, заповненою негативним світінням чи ні). Для різних значень тиску газу, розрядних струмів і геометрій електродів побудовані осьові профілі інтенсивності ліній випромінювання молекул, атомів та іонів азоту. Поблизу поверхні плоского катоду в катодному шарі спостерігається висока інтенсивність ліній випромінювання атомарного азоту, що вказує на значний ступінь дисоціації молекул азоту в цій області розряду.