FLAT ELECTRODE DIAMETER EFFECT ON GLOW DISCHARGE STRUCTURE AND PROPERTIES

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This paper is devoted to studying the effect of flat electrode diameter values on current-voltage characteristics and axial structure of the glow discharge in nitrogen. We have demonstrated that the discharge current increases with the electrode diameter growing. One has to apply a considerably higher voltage across small electrodes than across large ones to transport one and the same current. The discharge structure evolves at the current fixed in such a way that a thinner cathode sheath forms near the small cathode, the negative glow length is substantially larger, and the positive column is shorter than in the case of employing large diameter electrodes. In the negative glow we have observed maxima in the axial profiles of the emission lines of nitrogen molecules and ions measured with the optical spectrometer. On moving away from the cathode, the line intensities decrease uniformly till the positive column indicating the presence of fast electrons not only in the negative glow but also in the dark Faraday space.

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INTRODUCTION

Glow discharge is widely applied in such devices employing glow discharge as gas discharge voltage stabilizers (voltage stabilizer diodes, surge protectors) as well as in fluorescent lamps, etc [1-3]. In order to apply the glow discharge correctly, one requires to know the conditions of its existence as well as its quantity characteristics in different gases, under various gas pressure values and electrode dimensions. In the most of the available publications the glow discharge was reported to be ignited between flat parallel electrodes of equal area [4-14]. However, the referred papers do not actually contain the data demonstrating how the flat electrode dimensions affect the plasma parameters of the glow discharge in discharge tubes of different length. Therefore, the aim of the present paper was to study the effect of the flat cathode and anode diameter values on the current-voltage characteristics and structure of the glow discharge.

1. EXPERIMENTAL

Dc glow разряд was ignited in the chamber, with the scheme depicted in Fig. 1. To the chamber butts the stainless steel flat anode and cathode were fixed. The discharge tube was 56 mm of inner diameter. Experiments have been performed with flat electrodes of the diameter equal to 55 mm, 35 mm, 25 mm and 12 mm. The inter-electrode distance varied from 5 to 350 mm. The electrodes were inserted into indentations of the dielectric flanges so that the surface of the flange and the electrode were located in one plane. The nitrogen pressure range studied was p = 0.1…1 Torr.

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 [15].

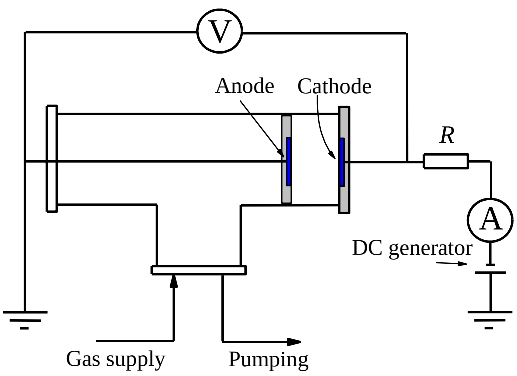

Fig. 1. The scheme of the experimental setup

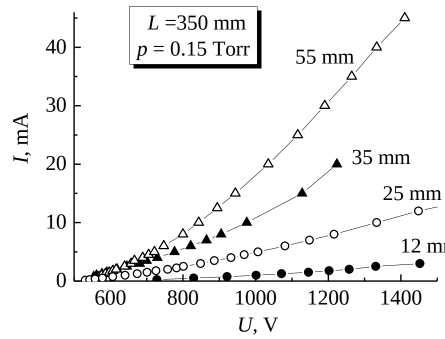

Fig.2. Current-voltage characteristics for different electrode diameters. The inter-electrode distance is 350 mm, the gas pressure is 0.15 Torr

2. EXPERIMENTAL RESULTS

We have found that at low nitrogen pressure (in Fig. 2 the results for 0.15 Torr are given) the discharge current is higher for large diameter electrodes. The reason is that more charged particles are produced in the cathode sheath near the large electrode at the same voltage compared with that near the small one.

Fig. 3 presents the photos of the glow discharge in nitrogen for electrode diameter values of 55 and 12 mm in which the cathode is on the left and the anode is on the right. The gas pressure and discharge current values are kept constant. However, for supporting the current of 2 mA two substantially different voltage values are required: 643 V for the electrode of 55 mm in diameter and 1332 V for the electrode of 12 mm in diameter. This also affected the discharge structure. The cathode sheath thickness for the large electrode was 10 mm and for the small one it diminished to 9 mm.

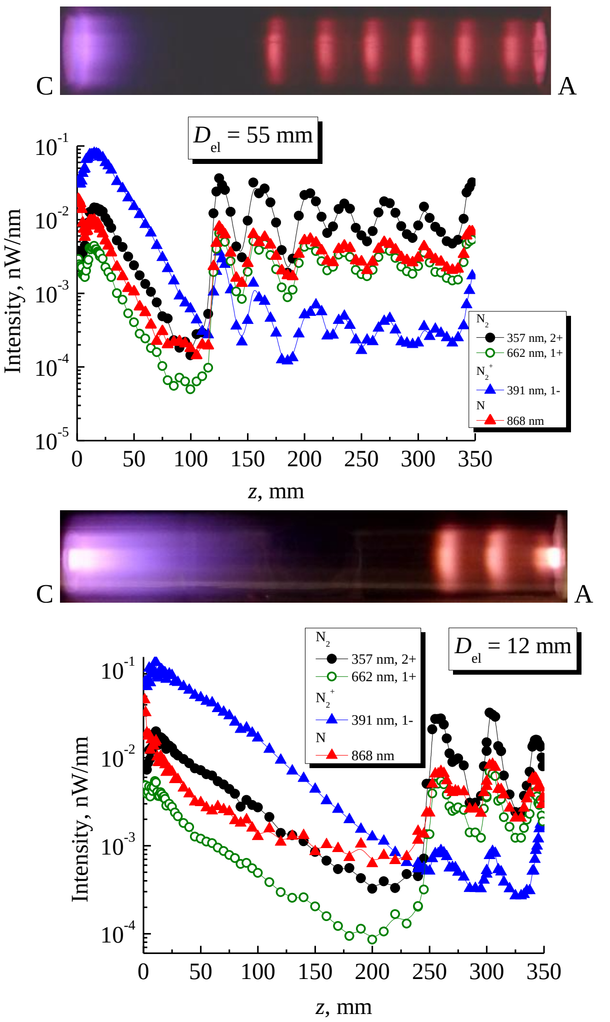

Fig. 3. Photos and axial profiles of the emission line intensities for the electrode diameter values of 55 and 12 mm. The nitrogen pressure is 0.15 Torr, the discharge current is 2 mA

The cathode surface is bombarded with positive ions produced in the cathode sheath and in the part of the negative glow close to it. Under this bombardment secondary electrons leave the cathode and they gain a considerable energy in the sheath high electric field and perform an intense ionizationи in the cathode sheath and the negative glow [16-19]. The length of this negative glow is conventionally estimated as the path length of the fastest electrons produced near the cathode not losing a remarkable portion of energy during their motion due to inelastic collisions with gas molecules. One observes in Fig. 3 that the negative glow near the small electrode spans much farther than that near the large one due to higher energy of fast electrons. The current through the negative glow is carried by the directional flow of fast electrons as well as by the diffusion flow of intermediate electrons (which had no time to thermalize but their energy is still insufficient to excite and ionize gas molecules). After the cathode sheath and the negative glow the dark Faraday space is observed in which, as assumed in papers [19, 20], there are already no fast electrons, and the current transport is accomplished via the diffusion flow of intermediate electrons. In order to compensate for their loss to tube walls because of ambipolar diffusion, the electric field strength in the dark Faraday space increases. The positive column is formed when the electric field strength becomes sufficiently large to compensate the loss of electrons to the tube walls by their production due to ionization [21-27]. It is clear from Fig. 3 that for the electrodes of 55 mm in diameter the positive column is observed at the distance of 120 mm from the cathode, whereas for the electrodes of 12 mm in diameter it is located at the distance of 247 mm. At low pressure the positive column is stratified. The long positive column with large electrodes consists of 6 complete strata with the anode glow, and the short one consists of 2 complete strata and the anode glow.

We have employed the optical spectrometer to measure the discharge emission spectra at different distances from the cathode, from which we have got the axial distributions of emission lines of the first and second positive systems of the nitrogen molecule, the first negative system of molecular ions as well as the emission of the atomic nitrogen (see Fig. 3). These axial profiles demonstrate that the maximum intensity of emission lines is observed in the negative glow near the cathode sheath boundary. On moving away from the cathode the intensities of all lines decrease uniformly. Note, however, that the intensities do not vanish at the boundary between the negative glow and the dark Faraday space (do not approach the spectrometer noise level) but continue decreasing until the positive column. Probably, the flow of fast electrons capable of exciting or even ionizing gas molecules does not disappear at the negative glow boundary but approaches the positive column.

The stratified positive column consists of successive bright (with high electric field strength) and dark (with weak or even negative field) layers, i.e. strata. In the regions with high field electrons are accelerated, and maxima of the emission lines of not only nitrogen molecules but also nitrogen ions and atoms correspond to each stratum. At higher pressure of 1 Torr the positive column becomes uniform with approximately constant intensity of emission lines along it.

Above we have demonstrated that the electrode diameter affects the discharge structure substantially. So for the electrode of 12 mm in diameter the positive column is located at the distance of 150 mm from the cathode with the lowest current of discharge burning of 0.06 mA, with the current growing it moves fast from the cathode and at the current of 2.5 mA it disappears completely in the tube of 350 mm long. For the electrodes of 55 mm in diameter at low current the positive column is observed at the distance of 100 mm from the cathode, and one needs currents of several tens of milliamps for its complete disappearance.

The dependences of the voltage across the electrodes on the inter-electrode distance are also differing considerably for different electrode diameter values. The results presented in Fig. 4 have been obtained with the movable anode technique when with the inter-electrode distance varying the discharge current value was kept fixed and the voltage was measured. At narrow gaps when only the cathode sheath found its place between the electrodes, the discharge was burning in the obstructed mode [28]. On removing the anode from the cathode through the negative glow one has to increase the inter-electrode voltage to keep the discharge current fixed [16-18]. In Fig. 4 the AG letters indicate the distance between the anode and the cathode, when the anode glow appears near the anode. The appearance of the positive column within the inter-electrode gap is indicated with the letters PC. These distance values from the anode to the cathode when the anode glow L_{AG} and the positive column L_{PC} appear are shown in Fig. 5 against the discharge current for different electrode diameter. The anode glow is shown to appear approximately at the one and the same place for different electrodes with the one and the same discharge current. However, the positive column is located farther from the cathode for the electrodes of lesser diameter.

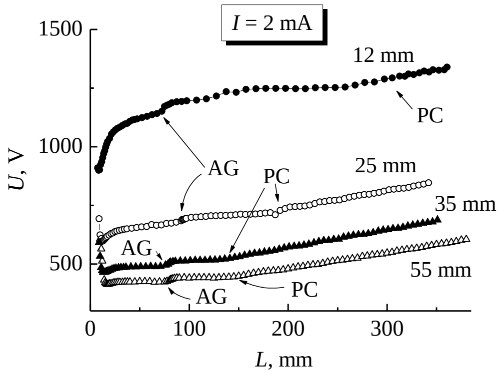

Fig. 4. Voltage across the electrodes against the inter-electrode distance for the electrode diameter values of 12, 25, 35, and 55 mm at the nitrogen pressure of 0.15 Torr and the discharge current of 2 mA

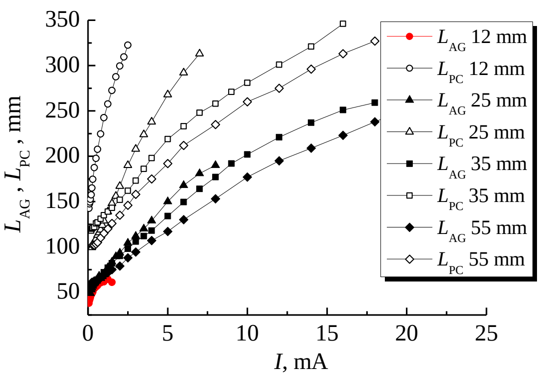

Fig. 5. Distance from the cathode at which the anode glow appears near the movable anode and the positive column boundary is observed against the discharge current for the electrode diameter values of 12, 25, 35, and 55 mm at the nitrogen pressure of 0.15 Torr

CONCLUSIONS

This paper is devoted to the experimental study into the effect which the flat electrode diameter values have on the structure and properties of the glow discharge in nitrogen. We have measured the current-voltage characteristics and showed that the discharge current increases with the electrode diameter growing keeping constant the current density with the voltage fixed. Therefore, one requires to apply higher voltage across small electrodes in order to transport a definite current than one needed for large electrodes. Increasing the voltage across the cathode sheath of small electrodes entails the decrease of its thickness, elongation of the negative glow and shorter positive column. Axial profiles of emission line intensities of nitrogen molecules and ions possess maxima in the negative glow near the cathode sheath boundary due to the flow of fast electrons leaving the sheath. On moving away from the cathode sheath boundary line intensities decrease uniformly not only in the negative glow but also in the dark Faraday space until the positive column.

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ВЛИЯНИЕ ДИАМЕТРА ПЛОСКИХ ЭЛЕКТРОДОВ НА СТРУКТУРУ И СВОЙСТВА ТЛЕЮЩЕГО РАЗРЯДА

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Исследовано влияние диаметра плоских электродов на вольт-амперные характеристики и осевую структуру тлеющего разряда в азоте. Показано, что разрядный ток с ростом диаметра электродов увеличивается. Для переноса одного и того же тока нужно прикладывать к малым электродам гораздо более высокое напряжение, чем к большим. Это приводит к тому, что при фиксированном токе вблизи малого катода формируется более тонкий катодный слой, длина отрицательного свечения существенно больше, а положительный столб короче, чем при использовании электродов большого диаметра. На измеренных с помощью оптического спектрометра осевых профилях интенсивности линий излучения молекул и ионов азота максимумы наблюдаются в отрицательном свечении. При удалении от катода интенсивности линий монотонно уменьшаются вплоть до положительного столба, что указывает на наличие быстрых электронов не только в отрицательном свечении, но и в темном фарадеевом пространстве.

ВПЛИВ ДІАМЕТРА ПЛОСКИХ ЕЛЕКТРОДІВ НА СТРУКТУРУ ТА ВЛАСТИВОСТІ ТЛІЮЧОГО РОЗРЯДУ

В.О. Лісовський, Р.О. Осмаєв, В.Д. Єгоренков

Досліджено вплив діаметра плоских електродів на вольт-амперні характеристики і осьову структуру тліючого розряду в азоті. Показано, що розрядний струм із зростанням діаметра електродів збільшується. Для перенесення одного і того ж струму потрібно прикладати до малих електродів набагато більш високу напругу, ніж до великих. Це призводить до того, що при фіксованому струмі поблизу малого катода формується більш тонкий катодний шар, довжина негативного світіння істотно більша, а позитивний стовп коротший, ніж при використанні електродів великого діаметра. На виміряних за допомогою оптичного спектрометра осьових профілях інтенсивності ліній випромінювання молекул і іонів азоту максимуми спостерігаються в негативному світінні. При віддаленні від катода інтенсивності ліній монотонно зменшуються аж до позитивного стовпа, що вказує на наявність швидких електронів не тільки в негативному світінні, а і в темному фарадеєвому просторі.