OBSTRUCTED DC GLOW DISCHARGE IN LOW-PRESSURE NITROGEN

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We studied in experiment the obstructed and abnormal modes of dc glow discharge in nitrogen as well as the transition between them. It is shown that the obstructed discharge may exist only in the gas pressure range $p < 0.2$ Torr under conditions corresponding to the left-hand branch of Paschen curve. The dc glow discharge was shown to possess an S–shaped current-voltage characteristic. The transition from the obstructed mode to the abnormal is shown to be accompanied by LF relaxation oscillations of the discharge current in a kilohertz range.
PACS: 52.80.Hc

1. INTRODUCTION

This paper studies in experiment the obstructed discharge in nitrogen between flat electrodes. We established the gas pressure range within which the obstructed discharge might be observed. Such a discharge in nitrogen is shown to possess the growing CVC. We observed that the transition from the obstructed to abnormal glow discharge occurred with the voltage across the electrodes decreasing, and low frequency oscillations of the discharge current occur simultaneously.

2. EXPERIMENTAL

In order to study a dc glow discharge of low pressure we employed the experimental setup which scheme is depicted in Fig.1.

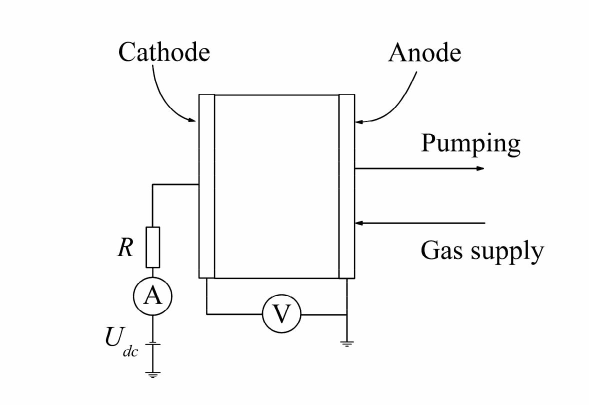

Fig.1. Scheme of the experimental setup

The vacuum chamber is made out of a section of the glass cylinder tube of 56 mm inner diameter vacuum sealed with flanges at both butts. Experiments were performed with inner cylindrical electrodes possessing flat butts and made of stainless steel. Electrode outer diameter was 55 mm, i.e. it was a little less than the inner diameter of the discharge tube. We have the opportunity to vary the distance between the cathode and the anode shifting the electrodes. Measurements were performed with the inter-electrode distance of $L = 10$ mm.

The studies were made in nitrogen within the pressure range $p = 0.08…10$ Torr. The chamber was evacuated to the limiting pressure of $1·10^{-3}$ Torr. The operating gas was fed with the SNA-1 assembly; the gas pressure was monitored with the RVT-2M thermoelectric probe. The error in registering pressure did not exceed 10 %.

In the process of studying the dc glow discharge ignition the dc potential $U_{dc} \le 4000$ V was applied to the cathode from the BP-67 power supply. A resistor of 75 kΩ was inserted in series between the cathode and the dc voltage source.

Before measurements we cleaned the cathode surface maintaining the glow discharge in nitrogen at the pressure of $p \approx 0.5$ Torr and the discharge current of $I_{dc} = 5$ mA during 10 min. We did not employ any external sources of ionization and studied exclusively the ignition of the self-sustained dc glow discharge.

We registered the breakdown curves as follows. Keeping various values of gas pressure p fixed we measured the breakdown voltage U_{dc}. The accuracy of registering the breakdown voltage was ± 1 V.

We also supplied the discharge circuit with a series resistor of 470 Ohm, and the voltage drop across it might be fed to the S 9-18 oscilloscope as well as to SK 4-58 spectrum analyzer. We used these devices for studying low-frequency oscillations occurring under discharge transition from the obstructed mode to the abnormal mode of burning.

3. EXPERIMENTAL RESULTS

As is known, in an obstructed discharge the cathode sheath occupies the total inter-electrode gap, and under formation of a negative glow in the anode vicinity the discharge experiences a transition to the abnormal mode of burning. It was already shown in [1] that the obstructed discharges was observed at low gas pressure corresponding to the left-hand branch of the breakdown curve of the glow discharge (Paschen curve). However it is not clear from [1], whether the obstructed discharge is observed near and to the left of the breakdown curve minimum or there is a certain pressure value (below the Paschen curve minimum) to the left of which the obstructed discharge may exist. Therefore we registered the dc breakdown curve and depicted it in Fig. 2. The breakdown curve minimum is clearly observed at nitrogen pressure of $p \approx 0.55$ Torr. However the visual observation of the discharge reveals that at such pressure the

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2010. № 6.
Series: Plasma Physics (16), p. 156-158.

discharge consists not only of the cathode sheath but also of the negative glow. Therefore the obstructed discharge may obviously be observed at lower pressure values. The studies have shown that for the existence of the obstructed discharge in nitrogen with the inter-electrode gap of 10 mm the pressure should be in the range $p \leq 0.2$ Torr. This pressure value is shown in Fig.1 with a broken line.

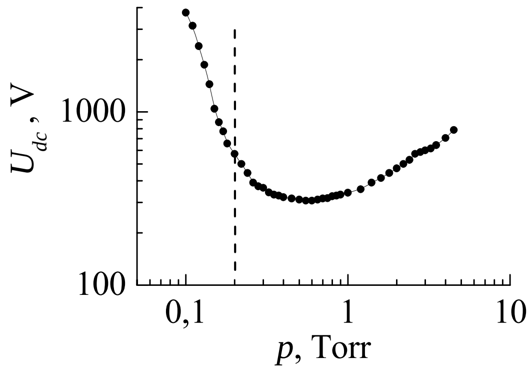

Fig.2. Breakdown curve of dc glow discharge in nitrogen. Broken line shows the maximum pressure at which the obstructed discharge may be observed

Fig.3 depicts CVCs of obstructed and abnormal modes as well as a transition between them. We observe that the CVC of the obstructed discharge is growing, i.e. the current increase is accompanied by the increase of voltage across the electrodes. At gas pressure of 0.1 and 0.11 Torr only the obstructed discharge was observed. At higher pressure, when discharge current approaches some critical value, a negative glow starts to form near the anode, and the transition from the obstructed to the abnormal mode of burning is observed. This transition is accompanied by lowering the voltage across the electrodes with current growing, the CVC assumes an S – like shape, and the oscillogram demonstrates the current oscillations of several kilohertz in frequency. These LF oscillations exist in the limited ranges of pressure and current. Fig. 3 also depicts the upper and lower boundaries of this region. After the negative glow is formed completely, the

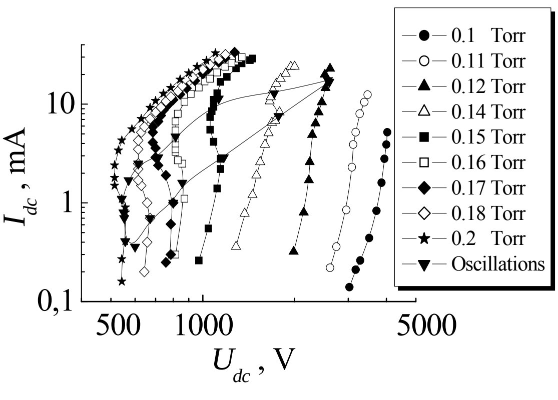

Fig. 3. CVCs of dc glow discharge at different nitrogen pressure values, and the range of low frequency oscillations

discharge is burning in the abnormal mode in which the current grows with the voltage increase across the electrodes.

The current oscillogram (Fig. 4) shows clearly that the oscillations exhibit a relaxation pattern, i.e. the sections with abrupt increase and a smoother decrease of the current. The oscillation amplitude amounted to 5% of the total current.

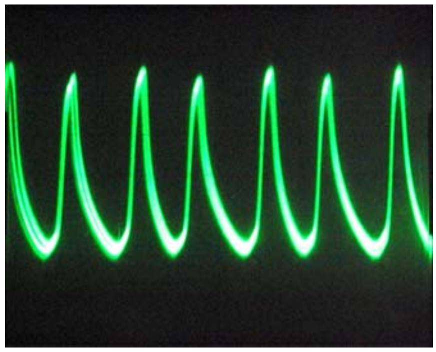

Fig. 4. Oscillogram of discharge current oscillations appearing under transition from the obstructed to abnormal mode of burning at nitrogen pressure of 0.15 Torr

Paper [2] got the experimental evidence that in the obstructed discharge the electric field remains to be large in the total inter-electrode gap. This conclusion is supported by calculations of [3]. With the growth of the current the concentration of charged particles within the gap increases, the field strength near the cathode grows but near the anode it falls. In the conventional abnormal glow discharge the plasma concentration quickly grows while departing from the cathode and it approaches maximum in the negative glow. Obviously in an obstructed discharge the concentration of charged particles also must approach maximum near the anode surface. Perhaps, when the obstructed discharge current approaches some threshold value, a region of negative glow forms near the anode. Besides, the plasma concentration near the anode increases abruptly and the current grows. Then, according to Ohm’s law for the total circuit, the voltage across the electrodes decreases. This involves the ionization lowering within the cathode sheath. The region of dense plasma formed near the anode expands, a portion of electrons go to the anode, and positive ions move to the cathode. With the ionization decreased the charged particle loss involves the discharge current lowering observable in the oscillogram of Fig. 3. After a portion of positive ions leave the discharge gap and the current decreases, the voltage across the electrodes increases, and intense electron avalanches develop in the cathode sheath again. In its turn this leads to a fast growth of the discharge current, and the processes is repeated.

At low pressure the oscillation frequency approaches 8 kHz. This low frequency is associated with a large departure time of positive ions out of the discharge gap. Increasing pressure causes the increase in the collision rate between ions and molecules and increases the time required for ions for travelling from the anode to the cathode thus leading to the decrease in the oscillation frequency (Fig. 5).

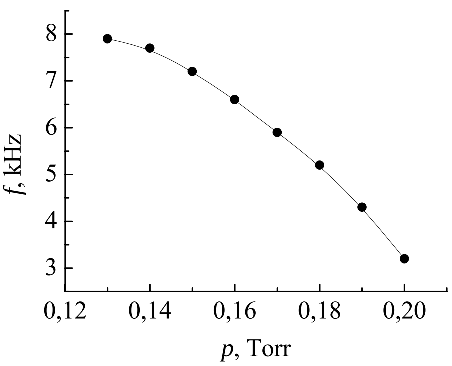

Fig. 5. Discharge current oscillation frequency arising under transition from the obstructed mode to the abnormal mode of burning against nitrogen pressure

A cathode glow possessing a pink tint is observed near the cathode. Secondary electrons leaving the cathode surface as a result of ion-electron emission acquire energy in the strong electric field of the cathode sheath and, first, excite the low energy levels of gas molecules. With subsequent acceleration in the electric field their energy goes through the maximum of the excitation cross section for low energy levels, but the electrons now excite higher energy levels as well as ionize gas molecules. Therefore the glow of the discharge near the anode possesses the blue tint. On increasing the discharge current, the concentration of charged particles near the anode increases thus lowering the electric field strength near the anode and increasing it near the cathode. At some threshold value of the current a negative glow may form near the anode which is still unstable under these conditions. A narrow peak of glow intensity appears near the anode pressed to its surface. A further increase of the current stabilizes the negative glow; the peak of glow intensity near the anode grows and becomes broader. The discharge under these conditions is burning in the abnormal mode.

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Article received 17.09.10

ЗАТРУДНЕННЫЙ ТЛЕЮЩИЙ РАЗРЯД ПОСТОЯННОГО ТОКА В АЗОТЕ НИЗКОГО ДАВЛЕНИЯ

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Экспериментально исследованы затрудненный и аномальный режимы горения тлеющего разряда постоянного тока в азоте, а также переход между ними. Показано, что затрудненный разряд может наблюдаться только в диапазоне давлений газа $p < 0.2$ Торр при условиях, соответствующих левой ветви кривой Пашена. Получено, что тлеющий разряд постоянного тока в исследованном диапазоне давлений азота имеет S-образную вольт-амперную характеристику. Обнаружено, что переход из затрудненного в аномальный режим сопровождается низкочастотными релаксационными колебаниями разрядного тока в килогерцовом диапазоне.

УТРУДНЕНИЙ ТЛІЮЧИЙ РОЗРЯД ПОСТІЙНОГО СТРУМУ В АЗОТІ НИЗЬКОГО ТИСКУ

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Експериментально досліджено утруднений та аномальний режими горіння тліючого розряду постійного струму в азоті, а також перехід між ними. Показано, що утруднений розряд може спостерігатися тільки в діапазоні тиску газу $p < 0.2$ Торр за умов, які відповідають лівій вітці кривої Пашена. Отримано, що тліючий розряд постійного струму має S-образну вольт-амперну характеристику. Виявлено, що перехід із утрудненого в аномальний режим супроводжується низькочастотними релаксаційними коливаннями розрядного струму в кілогерцовому діапазоні.