NORMAL MODE OF DC DISCHARGE IN ARGON, HYDROGEN AND OXYGEN

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This paper reports the current-voltage characteristics and the j/p^2 similarity parameter determination in argon, hydrogen and oxygen in the pressure range from 0.1 to 10 Torr. Experiments have been performed in the discharge tube of 56 mm inner diameter and with stainless steel electrodes. Anode diameter was 55 mm whereas the diameters of the cathodes employed were 55 and 12 mm. The j/p^2 parameter has been shown to remain constant only at the gas pressure above 1 Torr. Its values comprise $j/p^2 = (0.092 \pm 0.02)$ mA/(cm^2·Torr^2) for argon, $j/p^2 = (0.072 \pm 0.02)$ mA/(cm^2·Torr^2) for hydrogen and $j/p^2 = (0.33 \pm 0.05)$ mA/(cm^2·Torr^2) for oxygen. On lowering the pressure (below 1 Torr) the j/p^2 parameter grows fast and at the pressure of 0.1 Torr it may be two orders of magnitude higher than one at 1 Torr.

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INTRODUCTION

Direct current glow discharge is widely employed in a multitude of technological processes and devices, e.g. for pumping gas discharge lasers [1], in the processes of plasma nitriding [2], in xenon and mercury high pressure lamps [3], surge protectors / transient voltage surge suppressors [4], for plasma sterilization of medical instruments and equipment [5] etc. Therefore a considerable attention is devoted to studying the modes of existence and the processes in different parts of the discharge [6-15].

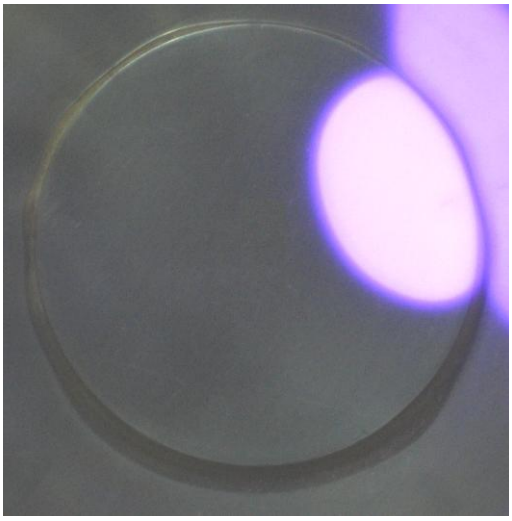

Fig. 1. The image of the glow discharge in the normal mode

The dc glow discharge may exist in two different modes [6, 7, 16-21]. In the normal mode the discharge spot occupies only a part of the cathode surface (Fig. 1), and increasing the current is accompanied by the growth of the area occupied by the discharge on the cathode. Conventionally it is assumed that the ratio of the current density to the gas pressure squared j/p^2 and the voltage drop across the cathode sheath remain constant in the normal mode [6, 7]. When the cathode surface is completely covered with the plasma the discharge experiences a transition to the abnormal mode in which the current through the discharge and the voltage drop across the electrodes increase simultaneously.

However it has been demonstrated in experiment in papers [19, 20] that the similarity parameter j/p^2 in the normal mode experiences weak changes only at the sufficiently high gas pressure whereas lowering the pressure entails the remarkable j/p^2 growth. Note that these data have been obtained for nitrogen [19] and N_2O [20]. It is of interest to study the j/p^2 similarity parameter behavior in other gases in low as well as high pressure values.

In this paper we report the current voltage characteristics (CVC) measurements and the similarity parameter j/p^2 determination in argon, hydrogen and oxygen in a wide range of gas pressure values.

1. EXPERIMENTAL

Experiments have been performed in the discharge tube of 56 mm inner diameter equipped with the stainless steel electrodes. The anode diameter was 55 mm whereas the diameter of the cathodes used were equal to 55 and 12 mm. The cathode of larger diameter has permitted to study the normal mode of the glow discharge at low pressure from 0.1 Torr to several Torr. The cathode of smaller diameter has been employed with the gas pressure above 1 Torr. The inter-electrode distance amounted to 10 mm. The discharge chamber design is shown in Fig. 2. Experiments have been performed at the pressure of argon, hydrogen and oxygen $p = 0.05…10$ Torr in the range of constant voltage $U \leq 3000$ V. The gas pressure has been measured with the capacitive manometer-baratron with the maximum registered value of 10 Torr.

2. EXPERIMENTAL RESULTS

One clearly observes on the current-voltage characteristics we have measured the part with the negative tilt corresponding to the normal mode of the glow discharge (Fig. 3). After the discharge have covered the total cathode surface a further current

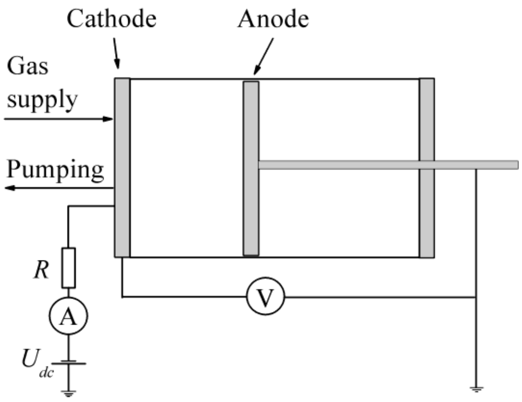

Fig. 2. The design of the experimental device

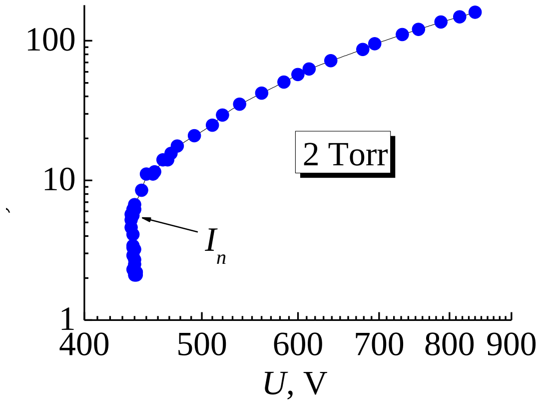

Fig. 4. Current-voltage characteristics of the discharge in hydrogen at the pressure of 2 Torr

growth is possible only under a higher ionization in the cathode sheath, therefore the current-voltage characteristic assumes a positive tilt, i.e. the growth of the discharge current is accompanied by the increase of the voltage across the electrodes. A transition between the parts with a negative and a positive tilt (namely, the transition from the normal model to the abnormal one) is observed at the moment of the complete covering the cathode surface by the discharge in the normal mode. In this case we know the area the normal discharge occupies on the cathode and we can determine the normal current density dividing the magnitude of the total current I_n (shown in Fig. 4) by the cathode area.

Fig. 3 shows quite clear that in the total gas pressure range studied the current-voltage characteristics contain a part with the normal mode when the cathode surface is partially covered by the discharge. At low pressure the discharge consists only of the cathode sheath and the negative glow (across which the voltage drop is small), therefore almost all voltage drop applied across the electrodes is concentrated in the cathode sheath. From Fig.3 it follows that at low pressure the voltage drop across the cathode sheath in the normal mode is large and it decreases with the gas pressure growing. At the same time it is not conserved what is in contradiction with the notion of the constancy of the normal cathode voltage drop. At the hydrogen pressure of 3 Torr the normal cathode voltage drop achieves the minimum value of 424 V. Further increasing the gas pressure leads to the appearance of the additional new parts of

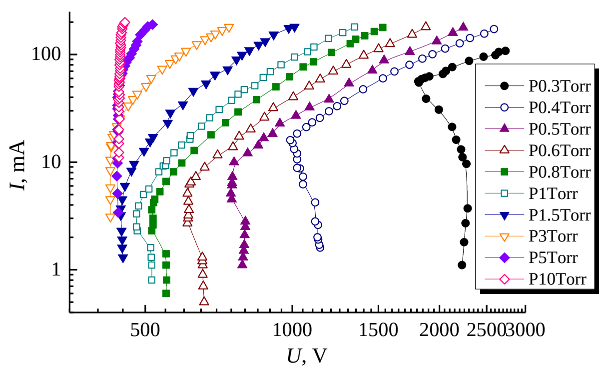

Fig. 3. Current-voltage characteristics of the discharge in hydrogen at different gas pressure values with the cathode of 55 mm in diameter

the glow discharge, namely, the dark Faraday space (with the small voltage drop across it) as well as the anode glow and the positive column across which the voltage drop may achieve considerable values. Therefore at high gas pressure values one can no longer claim that the voltage drop across the cathode sheath is approximately equal to the voltage across the electrodes. Respectively, the smallest voltage at which the discharge burning is possible increases with the gas pressure growth.

Conventional textbook on gas discharge [6, 7] claim that with the gas pressure fixed the normal current density has to be conserved and the ratio of the normal current density to the gas pressure squared j/p^2 is one of the similarity parameters that also has to be constant. However the present paper demonstrates that the j/p^2 ratio remains to be constant only at sufficiently high gas pressure values (Fig. 5). At the hydrogen pressure values above 1.5 Torr we obtain for the normal mode $j/p^2 = (0.072 \pm 0.02)$ mA/(cm^2·Torr^2). But with the pressure lowering (below 1 Torr) the quantity j/p^2 experiences a fast growth and at the pressure of 0.3 Torr this quantity j/p^2 approaches 26 mA/(cm^2·Torr^2), and this value is almost 400 times higher that the similarity parameter j/p^2 for high hydrogen pressure. Such a behavior of the similarity parameter j/p^2 may be attributed to the charged particles loss from the plasma column in the normal mode due to ambipolar diffusion as well as to the enhanced escape of fast electrons (having left the cathode surface or produced in the cathode sheath and acquired a considerable energy while moving in this sheath) to the anode in the case of narrow gaps between the electrodes and low gas pressure. The ambipolar diffusion coefficient as well as the length of electron flight through a gas (the relaxation length of the energy of fast electrons) are inversely proportional to its pressure. Therefore at low pressure the ambipolar escape of charged particles and sweeping of fast electrons to the anode are large, and for supporting a stationary discharge burning both the voltage across the electrodes and the current density grow. At high pressure the loss of charged particles decreases, the similarity parameter j/p^2 approaches saturation and ceases to depend on gas pressure.

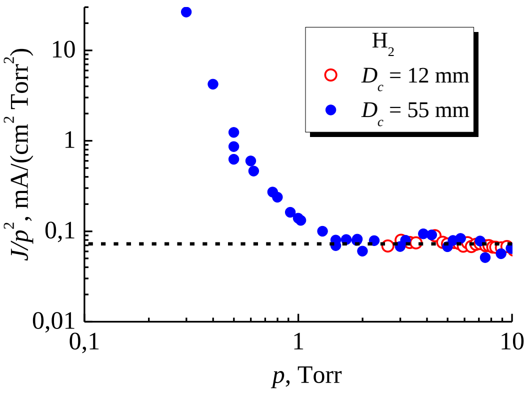

Fig. 5. Similarity parameter j/p^2 versus hydrogen pressure p with the cathodes of 55 and 12 mm in diameter

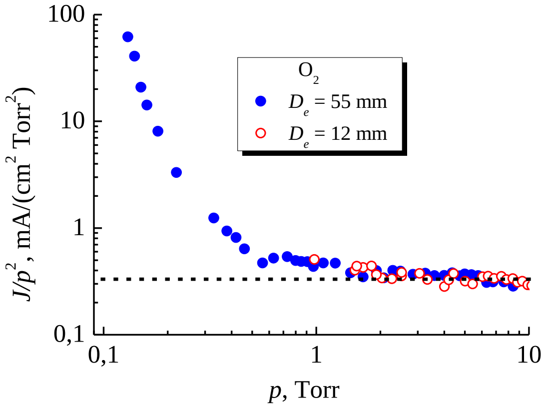

Fig. 6. Similarity parameter j/p^2 versus oxygen pressure p with the cathodes of 55 and 12 mm in diameter

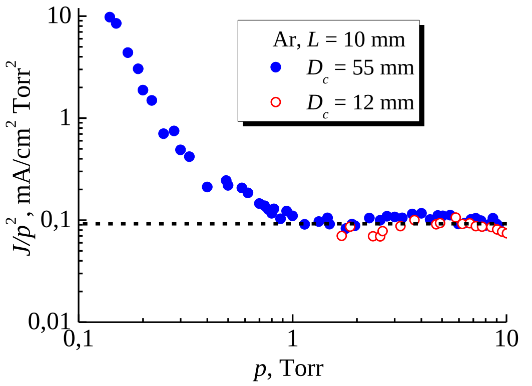

Fig. 7. Similarity parameter j/p^2 versus argon pressure p with the cathodes of 55 and 12 mm in diameter

A similar behavior of the normal current density has been observed also for other gases we studied. So for the pressure above 1 Torr the similarity ratio is $j/p^2 = (0.33 \pm 0.05($ mA/(cm^2·Torr^2) for oxygen (Fig. 6), and for argon we get $j/p^2 = (0.092 \pm 0.02)$ mA/(cm^2·Torr^2) (Fig. 7). But at still lower pressure the similarity parameter j/p^2 becomes tens and hundreds times higher than one at high pressure.

CONCLUSIONS

This paper is devoted to studying the normal mode of the glow discharge in hydrogen, oxygen and argon. The current-voltage characteristics have been measured from which the ratio of the current density to the gas pressure squared j/p^2 has been determined. It has been found that the j/p^2 ratio is conserved only at a sufficiently high gas pressure (approximately above 1 Torr). At such pressure values the similarity parameter for the normal mode is equal to $j/p^2 = (0.092 \pm 0.02)$ mA/(cm^2·Torr^2) for argon, $j/p^2 = (0.072 \pm 0.02)$ mA/(cm^2·Torr^2) for hydrogen and $j/p^2 = (0.33 \pm 0.05)$ mA/(cm^2·Torr^2) for oxygen. However at lower pressure values the j/p^2 parameter experiences a fast increase and it approaches the values tens and hundreds of times higher than those for high pressure. This phenomenon may be caused by an enhanced escape of fast electrons to the anode for the case of low gas pressure and narrow gaps as well as by the loss of charged particles out of the normal mode plasma column due to ambipolar diffusion.

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НОРМАЛЬНЫЙ РЕЖИМ ТЛЕЮЩЕГО РАЗРЯДА В АРГОНЕ, ВОДОРОДЕ И КИСЛОРОДЕ

В.А. Лисовский, Е.П. Артюшенко, В.Д. Егоренков

Были измерены вольт-амперные характеристики и определены величины параметра подобия j/p^2 в аргоне, водороде и кислороде в диапазоне давлений газа 0,1…10 Торр. Эксперименты проведены в разрядной трубке с внутренним диаметром 56 мм и электродами из нержавеющей стали. Диаметр анода был 55 мм, в то время как диаметры используемых катодов были равны 55 и 12 мм. Показано, что j/p^2 сохраняется постоянным только при давлениях газа выше 1 Торр. При этом j/p^2 = (0,092 ±0,02) мА/(см^2·Торр^2) для аргона, j/p^2 = (0,072 ±0,02) мА/(см^2·Торр^2) для водорода и j/p^2 = (0,33 ±0,05) мА/(см^2·Торр^2) для кислорода. При понижении давления (ниже 1 Торр) j/p^2 быстро возрастает, и при давлении 0,1 Торр j/p^2 может быть на два порядка выше, чем при 1 Торр.

НОРМАЛЬНИЙ РЕЖИМ ТЛІЮЧОГО РОЗРЯДУ В АРГОНІ, ВОДНІ ТА КИСНІ

В.О. Лісовський, К.П. Артюшенко, В.Д. Єгоренков

Були виміряні вольт-амперні характеристики та визначено величини параметра подібності j/p^2 в аргоні, водні та кисні в діапазоні тиску газу 0,1…10 Торр. Експерименти проведені в розрядної трубці з внутрішнім діаметром 56 мм і електродами з нержавіючої сталі. Діаметр анода був 55 мм, в той час як діаметри катодів, що використовуються, були рівні 55 і 12 мм. Показано, що j/p^2 зберігається постійним тільки при тиску газу вище 1 Торр. При цьому j/p^2 = (0,092 ±0,02) мА/(см^2·Торр^2) для аргону, j/p^2 = (0,072 ±0,02) мА/(см^2·Торр^2) для водню та j/p^2 = (0,33 ±0,05) мА/(см^2·Торр^2) для кисню. При зниженні тиску (нижче 1 Торр) j/p^2 швидко зростає, і при тиску 0,1 Торр j/p^2 може бути на два порядки вище, ніж при 1 Торр.