# POSITIVE COLUMN CONTRACTION OF THE GLOW DISCHARGE IN NITROGEN


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This paper studies the diffuse mode of the positive column in nitrogen, the contracted one near the threshold of its onset as well as the transition between these modes. The dynamics of the reduced electric field *E/p* variation as well as that of the electron temperature $T_e$ and the plasma concentration are investigated with a Langmuir probe in the process of this transition. The diffuse mode is observed at low pressure in the total range of discharge current values as well as at the pressure values above the threshold one of 1.5 Torr and low current values. The contracted mode sets on at the pressure values above 1.5 Torr. A jump-like transition occurs between the diffuse mode (with low *E/p* and $T_e$) and the contracted one when a critical current value is attained.



PACS: 52.80.Hc


## INTRODUCTION

Dc glow discharge has been studied already for more than 200 years (starting from the book by Petrov [1], and a large number of papers have been devoted to its physical properties and technological applications (see, e.g. [2-12]). Despite this fact, the dc glow discharge remains to be less studied than the much more «younger» discharges in alternate electric fields [13-21].

The positive column is one of the important constituents of the glow discharge used for pumping gas discharge lasers. The positive column of the glow discharge may exist in a stratified and a uniform modes [22-26] as well as in a contracted one [4]. Contraction is a reduction of plasma into a filament under pressure increasing and the current growing. Conventionally a contracted mode is observed at high gas pressure (order of 100 Torr and higher) and high discharge currents (hundreds of milliamperes). As the phenomenon of contraction usually has been studied at high gas pressure, it is expedient to establish the threshold pressure for its onset.

The present paper deals with studying the dynamics of plasma parameter variation in nitrogen with the changes in the discharge current and the gas pressure as well as the transition of the positive column from the uniform mode to a contracted one near the threshold of its onset.

## 1. EXPERIMENTAL

In order to investigate the existence conditions and characteristics of the uniform and contracted modes of the positive column of the glow discharge we have employed the discharge chamber which design is shown in Fig. 1. The tube inner radius was $R$ = 27.5 mm, the distance between the flat anode and cathode was 395 mm. The experiments have been performed at the nitrogen pressure within the range $p$ = 0.05…5 Torr whereas the dc voltage range was $U_{dc} \leq 3000$ V. The gas pressure was measured with the capacitive manometer-baratron with the maximum measured value of 10 Torr.

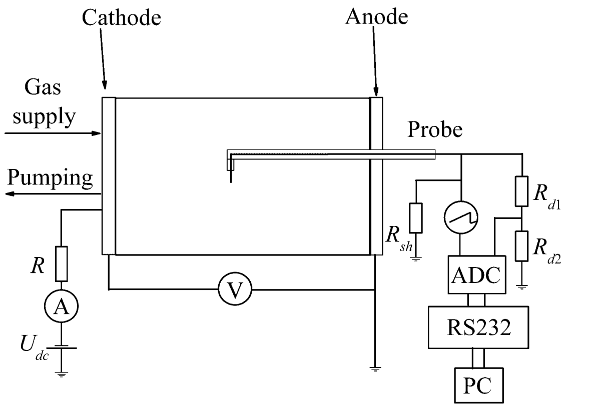


*Fig. 1. Design of the experimental setup*

The axial profiles of plasma parameters were measured with a single cylindrical Langmuir probe of 3.2 mm in length and 0.18 mm in diameter. A saw-tooth voltage was fed to the probe from the generator.

## 2. EXPERIMENTAL RESULTS

Fig. 2 presents the current-voltage characteristics (CVCs) for different nitrogen pressure values. The figure demonstrates that up to the pressure of 0.6 Torr the CVCs possess a positive tilt, and the positive column exists in the uniform (diffuse) mode. At the nitrogen pressure of 0.8 and 1 Torr the CVCs are transformed practically into vertical lines. Then, starting from the pressure of 1.5 Torr, there are observed not only the uniform (diffuse) mode but also the contracted one with a negative tilt of the CVC. A higher current density flows through the contracted positive column and gives rise to the Joule heating of gas molecules by electrons. This entails the lowering of the concentration of gas molecules $N$, the increase of the reduced electric field $E/N$ in the contracted positive column giving rise to the rates of ionization and excitation of gas molecules by electrons. Therefore for a higher discharge current to flow one needs smaller voltage drops across the

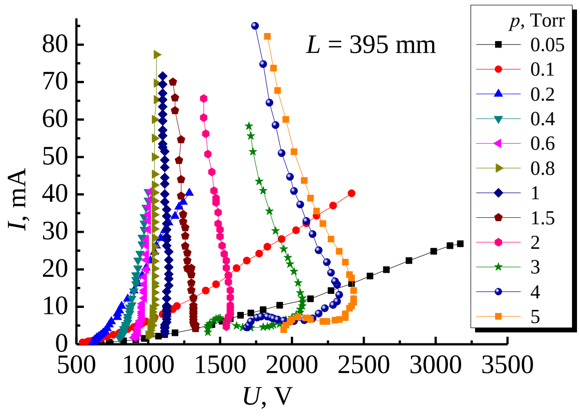


*Fig. 2. Discharge current-voltage characteristics at different nitrogen pressure values*

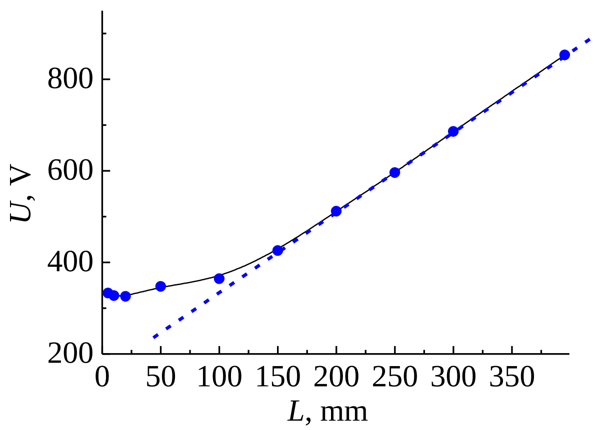


*Fig. 3. Voltage across the electrodes versus the distance L between them for the nitrogen pressure of 0.5 Torr and the discharge current of 5 mA*

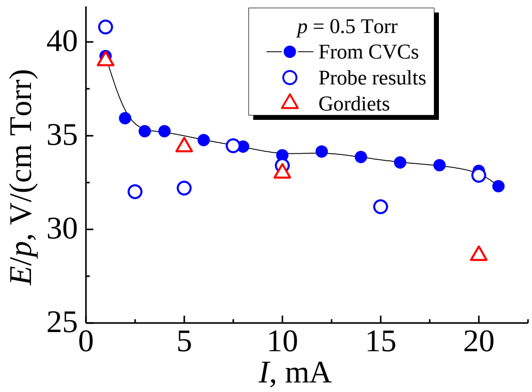


*Fig. 4. Reduced electric field E/p in the positive column versus the discharge current for the nitrogen pressure of 0.5 Torr. Solid and empty circles are for the data obtained in this paper, empty triangles depict the data obtained in paper by*

contracted positive column what makes the CVC of the complete discharge negative.

Varying the distance $L$ between the anode and the cathode one may obtain the dependence of the voltage across the electrodes on $L$ for different gas pressure and discharge current values (Fig. 3). If the anode is located in the region of the positive column then the voltage across the electrodes grows with $L$ according to a linear law. Then one may determine the electric field strength $E$ in the positive column. The electric field $E$ has been also determined with a Langmuir probe measuring the plasma potential at two fixed points of the positive column in the diffuse as well as in the contracted modes.

Fig. 4 demonstrates the dependence of the reduced electric field $E/p$ in the positive column on the discharge current for the nitrogen pressure of 0.5 Torr. At such gas pressure the positive column has been observed only in the diffuse mode and it has occupied the total tube cross section. The reduced electric field has been found in the range $E/p$ = 30…40 V/(cm·Torr) and it has decreased uniformly with the current growing. At the same time one observes the satisfactory agreement between the $E/p$ values measured with the Langmuir probe as well as calculated from the dependence of the voltage across the electrodes on the distance between them and the data from paper [27].

However at higher nitrogen pressure values one may observe the diffuse as well as contracted modes of the positive column. Such a case is shown in Fig. 5 for the gas pressure of 3 Torr. The diffuse mode has been observed up to the current values of 10 mA whereas the contracted mode might be supported starting from the current value of 5 mA. In the diffuse mode the reduced electric field has been approximately equal to $E/p$ = 10 V/(cm·Torr), and in the contracted positive column it has decreased uniformly with the current growing from 22 to 13 V/(cm·Torr). Note that the $E/p$ values measured from the discharge CVC agree satisfactorily with the data of probe measurements in the diffuse as well as contracted modes.

Fig. 6 demonstrates the results of probe measurements of $E/p$ in the positive column at different gas pressure values and the discharge current of 5 mA. One clearly sees there that at the pressure values below 1.5 Torr only the diffuse mode is observed, and the contracted one also appears at higher nitrogen pressure. For the diffuse mode the $E/p$ parameter decreases uniformly with the growth of the gas pressure whereas for the contracted mode this parameter experiences weak changes and it is located within the range of 20…25 V/(cm·Torr).

At low pressure the positive column glows rather brightly even with low discharge current values but it becomes dark at the pressure above 1 Torr in the diffuse mode. At the pressure of 0.5 Torr the $E/p$ ratio uniformly decreases on the average with the current growing. However, already at the pressure of 0.6 Torr with low current values before the discharge extinction the $E/p$ ratio diminishes abruptly, it approaches maximum with the current increasing and then it lowers. Such a behavior of the $E/p$ ratio also remains at higher nitrogen pressure values (to 1.5 Torr) i.e. with low current values the $E/p$ ratio keeps its values invariably small and it lowers with the pressure growing. Starting from the nitrogen pressure value of 1.5 Torr one observes not only the diffuse but also the contracted modes. The diffuse mode with low $E/p$ and $T_e$ experiences transition with a jump to the contracted one with high values of the $E/p$ and $T_e$ parameters. In the

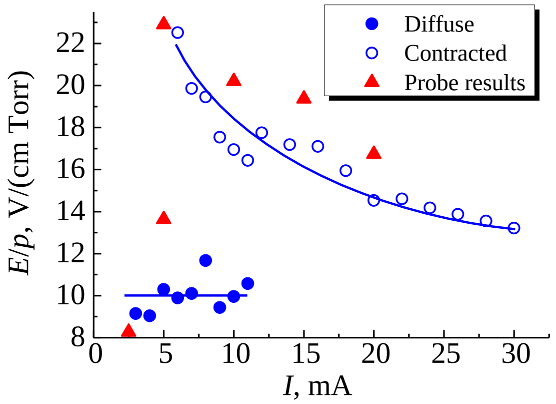


*Fig. 5. Reduced electric field E/p in the positive column versus the discharge current for the nitrogen pressure of 3 Torr*

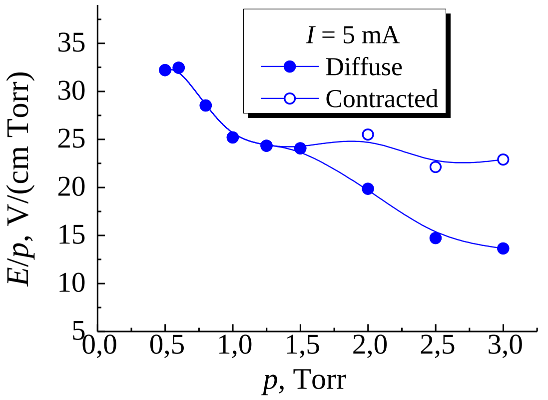


*Fig. 6. Reduced electric field E/p in the positive column versus the nitrogen pressure for the discharge current of 5 mA registered with the probe technique*

brightly glowing contracted mode the electron temperature is approximately 1.5…2 times higher than one in the diffuse dark positive column.

The images shown in Fig. 7 make evident the presence of the diffuse and contracted discharge modes. The first image (a) depicts the diffuse mode in which one practically cannot see the glow of the positive column against the background of the negative and anode glows. On increasing the current the contracted positive column is being formed near the anode occupying the part of the tube cross section. On increasing the current further the length of the positive column increases to a certain maximum value depending on the gas pressure. The higher is pressure, the shorter are the cathode sheath, the negative glow and the dark Faraday space and the longer is the positive column.

## CONCLUSIONS

The present paper deals with investigating into the transition of the positive column from the uniform mode to the contracted one near the threshold of its onset. The dynamics of plasma parameters in the positive column in nitrogen is studied varying the discharge current and the gas pressure in the process of this transition. At low pressure the positive column exists in the diffuse mode, it is glowing rather brightly even at small discharge

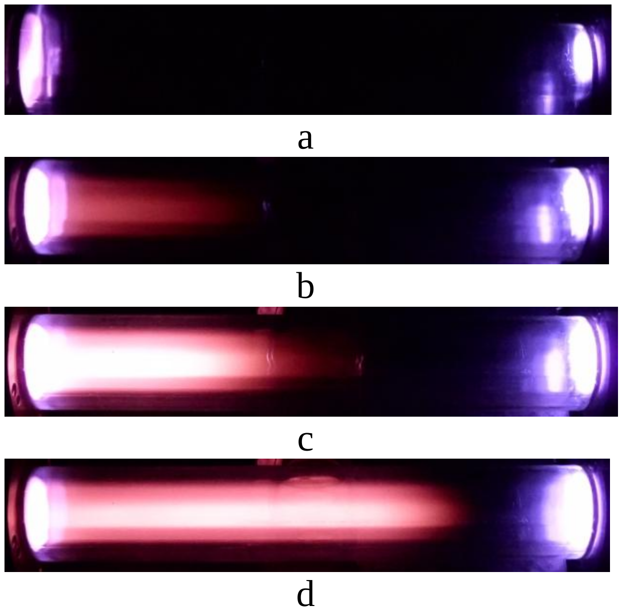


*Fig. 7. Discharge image at the nitrogen pressure of 3 Torr and the current values 5 mA (a), 7 mA (b), 10 mA (c) and 30 mA (d). The anode is located to the left and the cathode is to the right*

current values, but it becomes dark at the pressure above 1 Torr. At the pressure above 1.5 Torr diffusion (with low $T_e$) and contracted (with high $T_e$) mode are observed with a jump-like transition between them. The diffusion mode is characterized by the low reduced electric field *E/p*, and the contracted one possesses the high *E/p* values.

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*Article received 16.11.2016*

## КОНТРАКЦИЯ ПОЛОЖИТЕЛЬНОГО СТОЛБА ТЛЕЮЩЕГО РАЗРЯДА В АЗОТЕ

***В.А. Лисовский, В.А. Деревянко, В.Д. Егоренков***

Исследован положительный столб в азоте в однородном режиме, в контрагированном режиме вблизи порога его появления, а также переход между этими режимами. С помощью Ленгмюровского зонда изучена динамика изменения приведенного электрического поля *E/p*, температуры электронов $T_e$ и плотности плазмы в процессе данного перехода. Диффузный режим наблюдается при низких давлениях во всём диапазоне разрядных токов, а также при давлениях выше порогового 1,5 Торр и низких токах. Контрагированный режим появляется при давлениях выше 1,5 Торр. Между диффузным режимом (с низкими *E/p* и $T_e$) и контрагированным (с высокими *E/p* и $T_e$) при достижении критического тока происходит скачкообразный переход.

## КОНТРАКЦІЯ ПОЗИТИВНОГО СТОВПА ТЛІЮЧОГО РОЗРЯДУ В АЗОТІ

***В.О. Лісовський, В.О. Дерев'янко, В.Д. Єгоренков***

Досліджено позитивний стовп в азоті в однорідному режимі, в контрагованому режимі поблизу порога його виникнення, а також перехід між цими режимами. За допомогою Ленгмюрівського зонда вивчена динаміка зміни зведеного електричного поля *E/p*, температури електронів $T_e$ і густини плазми в процесі цього переходу. Дифузний (однорідний) режим спостерігається при низькому тиску у всьому діапазоні розрядного струму, а також при тиску вище порогового 1,5 Торр і низькому струмі. Контрагований режим з'являється при тиску вище 1,5 Торр. Між дифузним режимом (з низькими *E/p* і $T_e$) і контрагованим (з високими *E/p* і $T_e$) при досягненні критичного струму відбувається стрибкоподібний перехід.