PROPERTIES OF MICRODISCHARGE PLASMA IN THE VORTEX AIR FLOW

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In this paper the microdischarge in a vortex gas flow was studied. The important values in it are components of the flow velocity transverse to the current channel. This provides both enhanced heat-mass transfer of the plasma to the surrounding environment and the gliding of the discharge along the surface of the electrodes. The first contributes to the nonisothermal nature of the plasma, and the second reduces the removal of the material of the electrodes into the plasma. The temperatures of excited vibrational levels and excited rotational levels of molecules ware determined from an emission spectra of the microdischarge by using a Specair code. The electric field in the microdischarge plasma was estimated by the dependence of the voltage drop on the discharge at different interelectrode distances. The average electron energy and the electron energy distribution function were determined using code Bolsig +.

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INTRODUCTION

The atmospheric pressure (P_{atm}) microdischarge plasma is the one of the most promising directions in the nonequilibrium plasmachemistry today [1]. It is confirmed by a large number of researches which are devoted to usage of microdischarge plasma in plasma-medicine. The most current interest in this direction are such things as: wound treatment starting from blood coagulation and finishing with healing acceleration; dental application of plasma; sterilization of medical equipment or living tissue, etc.

A high number of devices for plasma jets generation are already been implemented for those purposes. The overwhelming number of designs in this area is based on using of dielectric barrier discharge, corona discharge or high-frequency types of discharges. It is known that such discharges have low gas-kinetic temperature of heavy components and very high level of a reduced field (E/N ~ 500 Td). As a result, average electron energy in the plasma jet is ~ 10 eV.

Such energies can become a reason for stimulation of radiochemical processes in living tissues. It can cause pathologies in the treatment tissues. We have to pay special attention to the fact that there is large variety of living things that have narrow boundaries of existence in the environment. Therefore, the significantly affect the living tissues can be caused even by relatively insignificant changes in the conditions of existence. For this reason, developing of plasma generators with substantially lower values of the reduced field for medical applications is highly promising.

Consequently microdischarges can rightly be considered as one of the most promising plasma jet generators for their use in biomedicine, which can operate at substantially lower E/N values. Known that in discharge with submerged plasma electrodes can be realized in electric fields smaller than in a barrier discharge. But we must take into account that in such discharges can be a significant removal of the material of electrodes in the plasma, which is the smallest in the sliding discharges [2].

In this paper the microdischarge in a vortex gas flow was studied. The important value in it is components of the flow velocity transverse to the current channel [3].This provides both enhanced heat-mass transfer of the plasma to the surrounding environment and the sliding of the discharge along the surface of the electrodes. The first contributes to the nonisothermal nature of the plasma, and the second reduces the removal of the material of the electrodes into the plasma. The plasma-forming gas injection was realized in the way to maximize exchange between the plasma and the environment.

1. EXPERIMENTAL SETUP

Schematic representations of the studied a microdischarge system and interelectrode space (in zoom) are presented in Fig. 1. The microdischarge is axisymmetric plasma generator. A vortex supplying of plasma forming gas in the interelectrode space is the peculiarity of these system. Power supply of discharge provides the output voltage of 7 kV (high voltage electrode – cathode). Plasma forming gas was supplied in the discharge chamber through the gas supply channel (2) tangential to the inner cylindrical dielectric wall (4) of the reaction chamber Ǿ15 mm. Microdischarge burning between copper electrodes (3), which were located at a distance about 1 mm apart (Fig. 1,a). The high-voltage electrode was a cathode. It was a wire with a rounded tapered tip ~ 0,6 mm. The external grounded electrode (anode) has the axial hole in the middle. Microplasma jet was blown out through the axial hole. Generated microdischarge plasma was blown out by flow of plasma forming gas (Air) from discharge gap through a hole in the anode (d = 1 mm) in open air space. The gas flow was G = 2 L / min. All construction had water cooling (1).

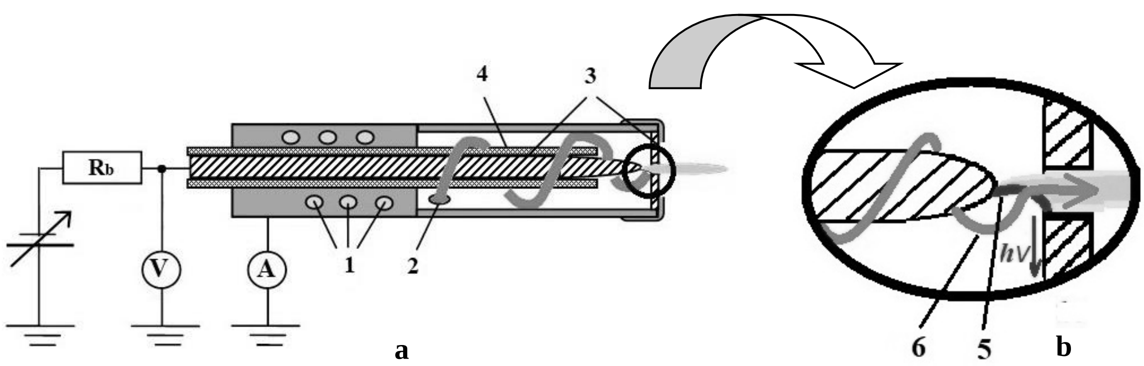


Fig. 1. Schematic representation of the studied microdischarge system (a) and interelectrode space (b) (1 – cooling; 2 – gas input; 3 – electrodes; 4 – dielectric; 5 – current channel; 6 – gas flow)

In Fig. 1,b presented interelectrode space in zoom. The optical emission spectroscopy was detected inside the discharge chamber perpendicular to the current channel (5).

The discharge behavior of the system was studied by video and photo observations method also. The microplasma emission spectra inside the chamber was recorded by using CCD-line based spectrometer with the instrumental function width at 0.3 nm. Spectrometer was operating in the wavelength range 200…1080 nm. Optical emission spectroscopy was carried out in the area between electrodes near the surface of the anode.

The temperatures of excited vibrational levels (T^*_v) and excited rotational levels (T^*_r) of molecules was determined from the emission spectra of the microdischarge plasma (in cases of I = 5…30 mA) by using the Specair code.

Also, the reduced electric field of the microdischarge was evaluative from current-voltage characteristics at different interelectrode distances. The average electron energy and the electron energy distribution function were determined using the Bolsig + code at experimental values E and $T_{translational} = T^*_r$.

2. RESULTS AND DISCUSSION

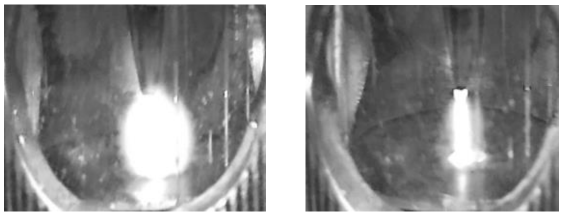
Fig. 2 shows a discharge channel in a chamber, where a micro-discharge plasma is formed without a gas stream (a) and with a stream of plasma-forming gas (b). The discharge current in both cases was the same and corresponded to I = 30 mA. The discharge voltage level of burning was higher in the second case.

As can be seen from the figure, the vortex flow of plasma-forming gas allows concentrating and directing the plasma jet.

During visual observation, it seemed that a plasma jet completely fills a hole at the out of discharge chamber. For a more detailed study, we used a recording device (Nikon DIGITAL CAMERA D7100 with lens Nikon DX VR AF-S NIKKOR 18…140 mm 1:3.5…5.6 G ED) that allowed to take photos of small time exposure.

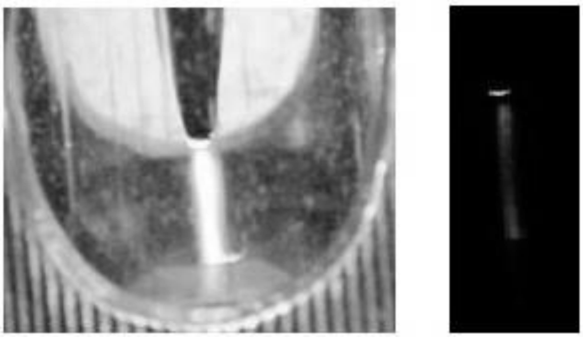
In Fig. 3 shows a photo of a current channel with different exposure times. As can be seen, there is a current channel that slides along the anode surface around the outlet through the gas flow (Fig. 4).

This is due to the fact that the plasma-forming gas is fed tangentially to the lateral surface of the discharge chamber.



a *b*

Fig. 2. Photo of microdischarge inside the discharge chamber without –(a) and with – (b) gas supply



a *b*

Fig. 3. Photo of current channel for exposition time: a – 0,03; b – 0,001. G(Air) = 2 L/min, I = 15 mA, z = 4 mm, d = 2 mm

The demonstration of the last assumptions you can see in (see Fig. 4). It represented video footage of the current channel with exposure time $5\cdot10^{-4}$ s. The discharge parameters was: G(Air) = 2 L / min, I = 15 mA, z = 4 mm, d = 2 mm. We determined thet thickness of the current channel was about 0.3 mm.

Current-voltage characteristics were measured at a distance between electrodes of 0.5…4.0 mm without gas flow and at an air flow of 2 L / min. The electric field in the microdischarge plasma was estimated by the dependence of the voltage drop on the discharge from the interelectrode distance (Figs. 5, 6).

As can be seen from Fig. 6, the dependency of voltage to interelectrode distance (U (L)) is significantly different in the absence and presence of gas flow. In case of L ≤ 2.5 mm, the electric field is twice large then in case L > 3.0 mm. In the absence of gas flow U (L) dependence is linear in the whole interelectrode distance range changes.

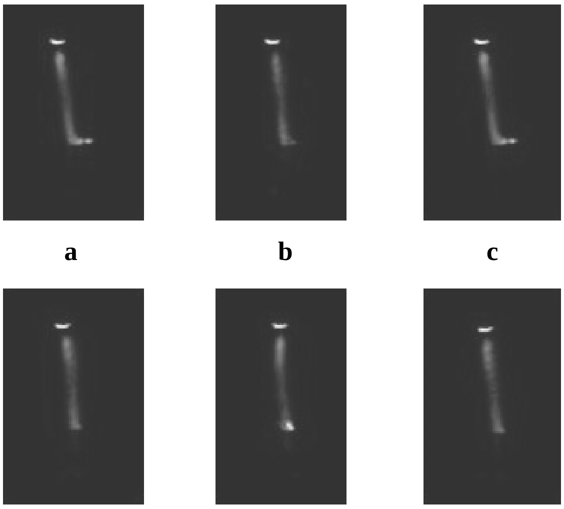


Fig. 4. Photo of current channel for exposition time 5×10^{-4} s (a – frame 1; b – frame 2; c – frame 3; d – frame 6; e – frame 7; f – frame 8). The thickness of the current channel is 0.3 mm. G(Air) = 2 L/min, I = 15 mA, z = 4 mm, d = 2 mm

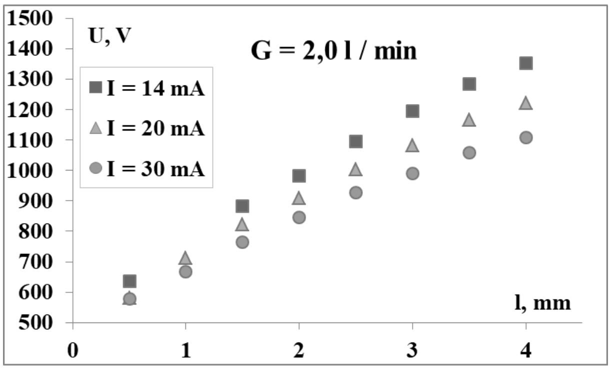


Fig. 5. Dependences of voltage to interelectrode distance for different current

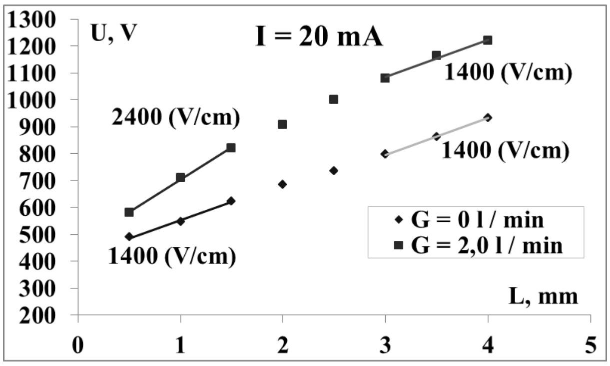


Fig. 6. Determining of electric field of microdischarge (≤ 2.5 mm) and anower type of discharge (> 3.0 mm)

Accordingly, the given electric field of discharge E / N = 20…35 Td is typical for the studied microdischarge plasma in the electric current range of 5…30 mA and the plasma-forming gas flow G (Air) = 2 L / min.

A typical emission spectrum of micro-discharge plasma for currents I = 5 and I = 30 mA is shown in Fig. 7. Emission spectra of the microplasma are multicomponent. It contain molecular bands of second positive nitrogen system (N_2 (C-B)), OH (A-X) and N_2^+. The main component of the microdischarge plasma is N_2 (C-B). The T^*_v and T^*_r levels of molecules was determined from the emission spectra by using the Specair code.

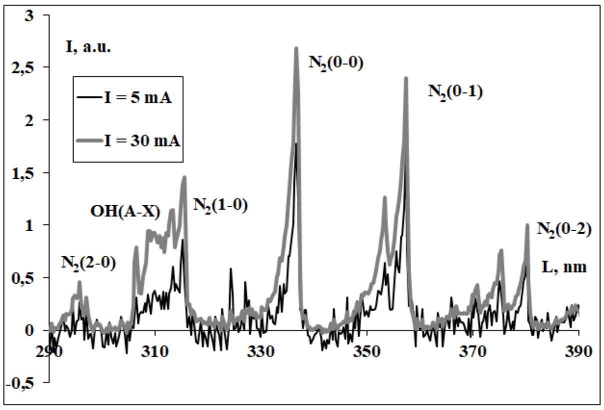


Fig. 7. Microdischarge spectra for interelectrode distance 1 mm

T^*_v determination was made by using of second positive nitrogen system bands correspond to (0…2) and (1-3) energy levels transfers and T^*_r – through (0…2) on a wavelength range λ = 370…380 nm (Fig. 8).

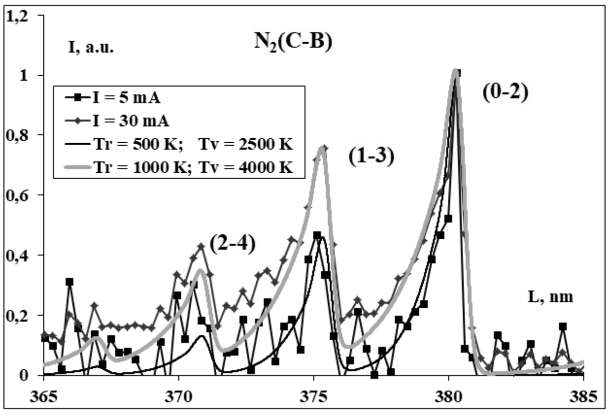


Fig.8. Experimental and simulation spectra for I = 5 mA and I = 30 mA. Experiment was made for d = 1 mm, l = 1 mm, G = 2 l / min

Fig. 8 shows that increasing the discharge current leads to an increase T^*_r. The microdischarge plasma of atmospheric pressure is non-isothermal.

Fig. 9 shows the functions of the distribution of electrons by energy and the average electron energy T^*_r = 500 K calculated by the code Bolsig +. It is seen that an increase in the discharge current leads to a decrease in the number of electrons with higher energies.

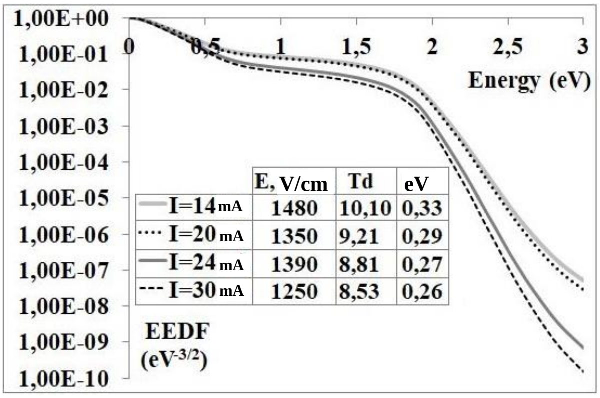


Fig. 9. Electron energy distribution function of microdischarge: G(Air) = 2 l / min; T^*_r = 500 K

CONCLUSIONS

The dependence of of voltage to interelectrode distance is considerably different in the absence and presence of gas flow. In case of L ≤ 2.5 mm, the electric field is twice large then L > 3.0 mm. In the absence of gas flow U (L) dependence is linear in the whole interelectrode distance range changes.

Emission spectra of the microplasma contain molecular bands of N_2 (C-B), OH (A-X) and N_2^+. The main component of the microdischarge plasma is N_2 (C-B) in visible range of wavelangth.

The microdischarge plasma is nonisothermal nature of the plasma, the T^*_v of the plasma components are much higher then T^*_r in case of studied parameter range of discharge.

Increasing of the discharge current leads to a decreasing of number of electrons with higher energies.

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СВОЙСТВА МИКРОРАЗРЯДНОЙ ПЛАЗМЫ В ВИХРЕВОМ ПОТОКЕ ВОЗДУХА

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Изучался микроразряд в вихревом потоке газа, в котором существенны составляющие скорости потока, поперечные к токовому каналу. Это обеспечивает как усиленный тепломассообмен плазмы с окружающей средой, так и скольжение по поверхности электродов. Первое способствует неизотермичности плазмы, второе уменьшает вынос материала электродов в плазму. Температуры заселения возбужденных колебательных и вращательных уровней молекул определялись с эмиссионных спектров микроразрядов с использованием кода Specair. Электрическое поле в плазме микроразрядов оценивалось по зависимости падения напряжения на разряде от межэлектродного расстояния. Средняя энергия электронов и функция распределения электронов по энергии определялись с использованием кода Bolsig +.

ВЛАСТИВОСТІ МІКРОРОЗРЯДНОЇ ПЛАЗМИ У ВИХРОВОМУ ПОТОЦІ ПОВІТРЯ

В.Я. Черняк, О.В. Коломієць, В.В. Юхименко, О.М. Цимбалюк, В.О. Хом'як, Д.О. Черниш

Вивчався мікророзряд у вихровому потоці газу, в якому істотними є складові швидкості потоку, поперечні до струмового каналу. Це забезпечує як посилений тепломасообмін плазми з оточуючим середовищем, так і ковзання по поверхні електродів. Перше сприяє неізотермічності плазми, друге зменшує винос матеріалу електродів у плазму. Температури заселення збуджених коливальних і обертальних рівнів молекул визначались з емісійних спектрів мікророзрядів з використанням коду Specair. Електричне поле в плазмі мікророзряду оцінювалось за залежністю падіння напруги на розряді від міжелектродної відстані. Середня енергія електронів і функція розподілу електронів за енергією визначались з використанням коду Bolsig +.