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Investigation of the functional parameters of cold plasma jet generated in device with microchannel

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Abstract. The parameters of cold plasma jet generated in devices with microchannels of various nature for a minimally invasive effect on biological objects was researched. The threshold conditions and parameters of plasma jet generation in microchannel tubes for the possible integration of a plasma jet source and laparoscopic equipment were determined. The target temperature change in the zone of interaction with the plasma jet has been researched. It has been shown that target heating caused by exposure to a plasma jet generated by a device with microchannel does not exceed 36 °C, which is not dangerous for living tissues.
Keywords: cold plasma jet, streamer, microchannel, plasma medicine.

1. Introduction

Currently, the direction of medicine investigating the effect of plasma formations on biological objects is actively developing. Chemical reactions caused by the interaction of plasma formation with the surfaces of living tissues lead to a change in the composition of active radicals and ions in cells. This leads to a change in the ongoing processes inside. In most biomedical research, cold plasma jets of atmospheric pressure are used as an impact tool [1]. One of the ways to generate a plasma jet is to apply a sinusoidal voltage to the electrodes, at which a streamer is initiated in the positive half-cycle and propagates along the gas flow pumped through the device.

Investigations conducted under *in vitro* conditions [2, 3] have shown that exposure to plasma formation suppresses the viability of cancer cells. However, it is often difficult to realize under *in vivo* conditions the effect of plasma jet on biological objects with a complex geometric shape; uneven surface; jets remote from the source or located inside closed volumes or cavities, including inside living organisms.

To implement minimally invasive methods of plasma jet influencing on the malignant tumors it is necessary to research the possibility of its propagation in microchannels with various nature for transfer to the site of impact on the target. The aim of this work was to investigate the functional parameters of a cold plasma jet generated in gas-discharge device with microchannel, the geometry of which is close to the dimensions of laparoscopic equipment.

2. Experimental setup

In this work, we used a device generating a cold plasma jet using applied sinusoidal voltage with an amplitude U = 2–6 kV and a frequency $f \approx 13$ kHz. The plasma jet was generated in a coaxial dielectric channel 100 mm long with an inner diameter of 8 mm, through which helium grade A (with a purity of 99.995%) was pumped at rate of υ = 1.5–9 L/min. Microchannel ceramic (Al_2O_3) or silicone tubes used in medicine with inner diameters d = 0.2–3 mm, wall thicknesses 0.5–1 mm, and lengths l = 10–100 mm were placed at the outlet of the coaxial channel (Figs.1–2).

3. Experimental results

The voltage U was measured by a high-resistance divider, and the current I was measured by a collector, which is a copper substrate grounded through a shunt, which was also used as an additional external electrode to increase the electric field strength in the region of plasma formation propagation in free space and its interaction zone with the target. The registration of the surface temperature in the plasma jet interaction zone was carried out with a Testo 872 thermal imager with a measurement accuracy of 0.06 °C.

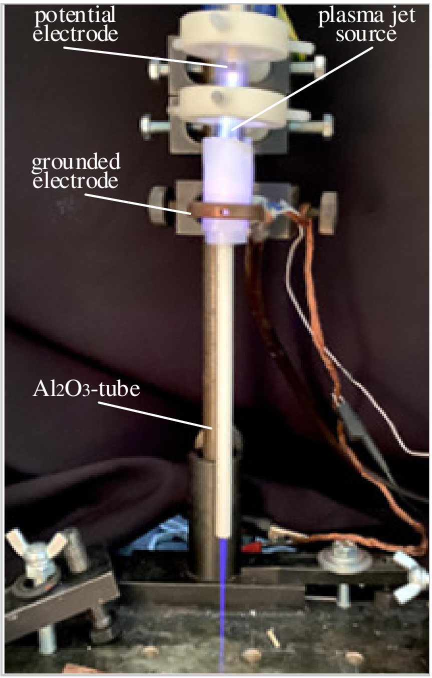

Fig.1. Cold plasma jet source with ceramic microchannel (d = 2 mm, l = 80 mm).

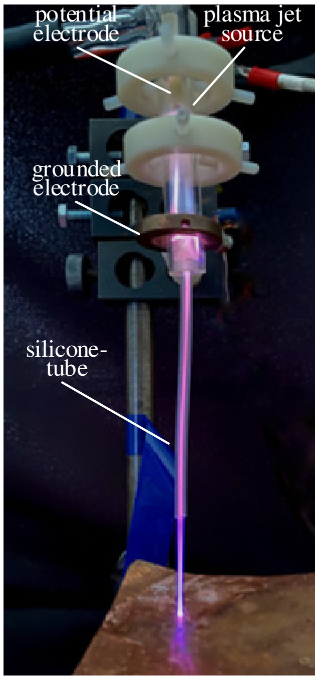

Fig.2. Cold plasma jet source with silicone microchannel (d = 2 mm, l = 60 mm).

Within the framework of the research, the threshold conditions for the operation of plasma source with microchannel tubes under which the length of the plasma jet that emerged from the microchannel exceeded 10 mm were determined. The Fig.3 shows a three-dimensional characteristic (U, υ, l) of the threshold conditions for plasma jet generation for a device with a ceramic microchannel with a diameter d = 2 mm upon excitation by a sinusoidal voltage with a frequency f = 13 kHz. The Fig.4 shows a similar characteristic (U, d, l) of threshold conditions at a constant gas flow rate υ = 9 L/min. It has been established that with an increase in the length of the microchannel l, an increase in the applied voltage U is requird at a fixed internal diameter of the tube d and gas flow rate υ in order for the plasma jet to go beyond the microchannel.

The Fig.5 shows an oscillogram of the applied voltage and current delivered by the plasma jet to the collector through Al_2O_3 microchannel with diameter d = 1.5 mm and different lengths of channel l (U = 5.5 kV, υ = 4.5 L/min). The Fig.6 shows the dependence of the current delivered to the copper substrate on the amplitude of the applied voltage $I(U)$ (υ = 3 L/min). It can be seen from the figures that the amplitude of the delivered current decreases with an increase in the length of the microchannel.

Comparative investigations of the emission spectra in the interaction zone of culture medium with plasma jet generated in a device with and without a silicone and ceramic microchannel in the spectral range of 200–750 nm was carried out. In addition to the emission lines of the main helium gas, the spectrum contains lines of molecular nitrogen N_2 (λ = 204; 244; 315; 357 nm), molecular nitrogen ions N_2^+ (λ = 330; 380; 427; 470 nm), nitric oxide NO (λ = 214; 272; 288; 290 nm), hydroxide OH (λ = 284; 309 nm) and the Balmer series of the hydrogen line in the UV range of the spectrum, weak O_2 (λ = 323 nm) and O_2^+ (λ = 239; 283; 297 nm) lines are observed.

Analysis showed that the component compositions in cases of exposure to plasma jets generated with and without a ceramic, silicone microchannel are identical. The use of microchannels leads to a decrease the intensity of the spectral lines of OH hydroxide (λ ≈ 309 nm, the $A^2\Sigma$-$X^2\Pi$ transition) in proportion to an increase the tube length *l*, which can be explained by a decrease in the amplitude of the current reaching the target.

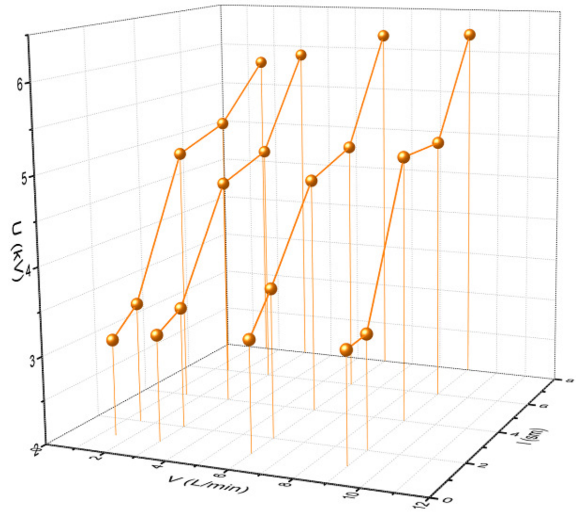

Fig.3. Threshold conditions for generating a cold plasma jet in ceramic microchannels at *d* = 2 mm.

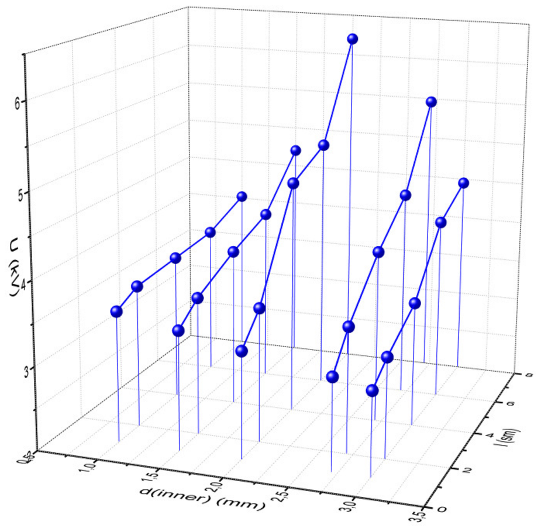

Fig.4. Threshold conditions for generating a cold plasma jet in ceramic microchannels at *υ* = 9 L/min.

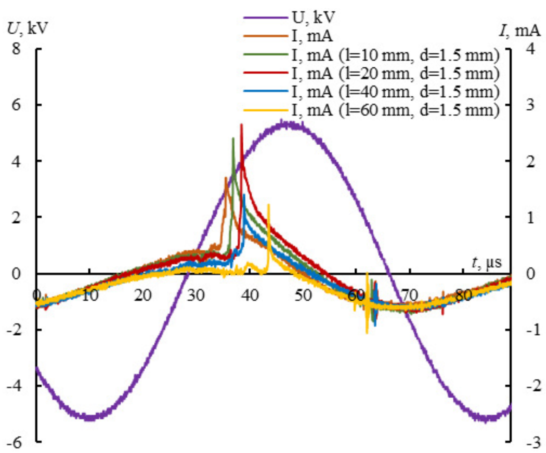

Fig.5. Oscillogram of the applied voltage and current of a plasma jet generated in microchannels with different lengths at *d* = 1.5 mm, *U* = 5.5 kV, *υ* = 4.5 L/min.

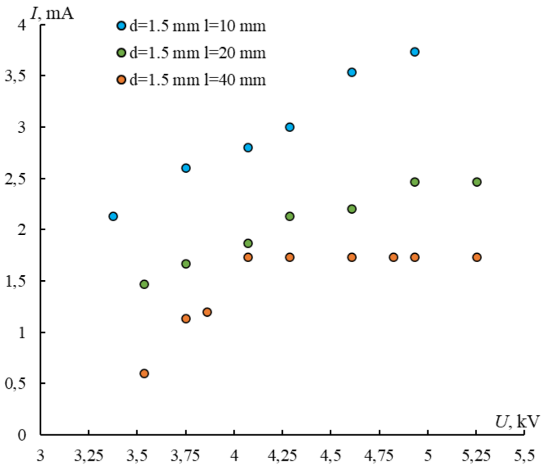

Fig.6. Dependence of the current delivered to copper substrate on the applied voltage.

Investigation of the target temperature *T* in the plasma jet interaction zone at *f* = 13 kHz was carried out. An Al_2O_3 plate (1×25×34 mm) located at a distance of 20 mm was used as a model. Experiments have shown that the temperature of objects increases with increasing voltage, with an increase in the gas flow rate, the temperature decreases. Thus, at *U* = 6 kV and flow rate *υ* = 6 L/min, the temperature reaches *T* ≈ 70 °C at *υ* = 9 L/min, T ≈ 57 °C, and at *υ* = 12 L/min, *T* ≈ 44 °C.

Investigation of target heating under the action of a plasma jet on Al_2O_3, late located on an additional grounded electrode at a distance of 10 mm from a silicone microchannel integrated into a device was carried out. The microchannel with a diameter of *d* =2 mm and with a length of *l* = 10, 20, 40, 60 и 80 mm was used. The measurements were carried out for a plasma jet generated at *f* = 13 kHz, *υ* = 3 L/min at *U* = 4, 4.5 and 5 kV. It has been established that the target heating temperature decreases in proportion to the increase in the length of the microchannel tube, which is associated with a decrease in the amplitude and duration of the current pulse (Fig.7).

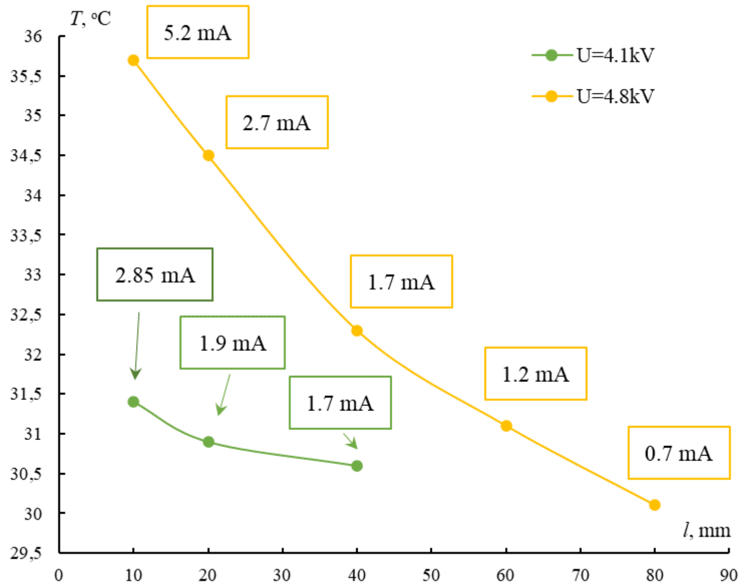

Fig.7. Dependence of the target heating on the ceramic microchannel length.

4. Conclusion

As a result of the work, gas-discharge devices based on streamer breakdown integrated with dielectric microchannels of various nature and geometry were developed. The functional parameters of plasma jet generation in a device with a microchannel have been investigated; the dynamics of changes in the object temperature under direct action of a plasma jet transported through a microchannel has been investigated; areas of safe impact on biological objects have been shown.

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5. References

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