Investigation of a cold atmospheric plasma jet generation in single and multichannel planar devices

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Abstract. A plasma source of atmospheric pressure with a planar geometry of the device and an adjustable number of planar discharge channels has been developed. The dependence of the recorded collector current on the amplitude of the applied voltage is investigated. It was found that the current in each of the channels consists of a set of independent current channels whose propagation does not depend on each other.

1. Introduction

Currently, plasma medicine is actively developing, studying the effect of plasma formations on biological objects. Such an effect on living tissues leads to the stimulation of chemical reactions in the gas phase and in the liquid at the plasma-biological object interface. Such reactions lead to an increase in the level of oxygen and nitrogen-containing active radicals and ions in cells due to diffusion, actively influencing the processes taking place inside them. Through cold plasma generated in a flow of inert gas at atmospheric pressure, it is possible to control, diagnose and stimulate biological processes in living organisms.

Recently, considerable attention has been paid to the study of plasma effects on cancer cells of various histological origins with reliable demonstration of the suppression of their vitality, which has demonstrated an antitumor effect on more than twenty different cell and tumor models in vitro and in vivo.

The instruments for such effect are devices that generate cold atmospheric pressure plasma, for example, a gas discharge plasma or a plasma jet propagating in the environment in an inert gas flow. Plasma is cold and, due to its non-equilibrium nature, it allows you to create chemically active substances without excessive heating of the gas and to affect targets, including living organisms that are sensitive to heating, and the temperature increase in the contact zone of the plasma and the biological object does not exceed several degrees [1, 2].

The methods for generating cold plasma at atmospheric pressure are quite well developed, and devices with different geometries of the discharge gap, gaseous media (including mixtures), and methods of energetic action on the gas are used. Cold plasma jets are of particular interest [3-7]. In this case, the discharge zone is a dielectric channel in which the flow of the working gas is organized and where the contact (gas discharge between the electrodes) or non-contact (microwave, HF, barrier
discharge) excitation of the medium is carried out [2, 8 and the literature cited therein]. The plasma jet is a sequence of streamers propagating in the environment in a flow of inert gas pumped through a gas discharge device.

Typical is the simplest coaxial geometry of the cold plasma jet source design, which is characterized by small geometric dimensions of the plasma-object contact zone. To increase the effect zone of plasma jet and, especially, to improve the uniformity of the plasma effect on larger targets, either scanning the object and the plasma jet relative to each other is used, or an increase in the zone of the plasma interacting with the target due to the use of multichannel coaxial sources. Another possibility is the use of cold plasma jet sources of planar geometry, generating a plane plasma jet [9].

The aim of this research was to investigate the functional parameters of plasma generation in single and multichannel plasma devices.

2. Experimental setup
The design of the planar cold plasma jet source shown in figure 1, was a dielectric casing (1). Using quartz plates (2) one or several plane discharge channels (3) were formed. Dielectric plates (4) formed a nozzle at the outlet of the discharge channels. The discharge gap was formed by an internal copper electrode (5), multipoint plates of which were located along each gap, and an external grounded electrode (6). A sinusoidal voltage $U = 0-10$ kV with a frequency of $f = 10-50$ kHz was applied to the internal potential electrode from a power source (7). Obviously, the linear size of the plasma formation is determined by the limiting size of either the potential electrode or the nozzle.

![Figure 1. Design of a planar cold plasma jet source.](image)

In the experiments, the nozzle length was 40 mm. The main experiments were carried out using gaseous helium of grade A (purity 99.995%) and grade B (purity 99.99%).

The heating of a dielectric plate placed on an additional grounded electrode under the impact of a plasma jet generated in the single-channel geometry of the device was investigated. It was found that the surface heating, similar to the effect of the jet generated in the coaxial geometry of the device, did not exceed 40°C.

The voltage was measured with a high-resistance divider, and the current was measured by recording the voltage across the shunt when the current of the plasma jet was closed to the copper collector. The distance between the manifold and the nozzle was 20 mm and was the standard distance between the nozzle and the target in biological experiments.
3. Experimental results

When a working gas is supplied at a rate of \( v = 12-15 \text{ L/min} \) and a sinusoidal voltage is applied, glowing spots appear at the tips of the potential electrode. With an increase in voltage \( U > 2.7 \text{ kV} \), a glow is formed, followed by its propagation inside the discharge channel. With a further increase in \( U > 3 \text{ kV} \), the plasma jet leaves the channel and propagates in free space. In contrast to the coaxial design, the generation of a plane plasma jet requires a higher pumping rate of the working gas, and the ignition and combustion voltages exceed the analogous values of the plasma jet generated in the coaxial geometry of device [10]. Comparative studies have shown that, when using grade A helium, the breakdown voltage of the discharge gap and discharge burning is \( \sim 1.5 \) times higher than when using grade B helium. Therefore, this gas was used in further experiments. Figure 2 shows photographs of one, two and three-channel design of the device, respectively.

![Figure 2. Planar design of the device: (a) single-channel; (b) two-channel; (c) three-channel.](image)

A typical oscillogram of voltage and current for the flow rate of helium \( v = 15 \text{ L/min} \) and voltage \( U = 3.75 \text{ kV} \) for a single-channel device design is shown in figure 3 (a). It can be seen that the current of a cold plasma jet in a planar geometry, similar to the current in a coaxial source, has a complex character and consists of a fast part (directly a streamer with a duration of 10–100 ns) and a slow part (with a duration of 5–10 μs). The \( I(U) \) dependence has a sublinear character, the maximum achieved current did not exceed 14 mA, as shown in figure 3 (b).

![Figure 3. For a single-channel device design (a) oscillogram of voltage and current for \( v = 15 \text{ L/min} \) and \( U = 3.75 \text{ kV} \), (b) current-voltage characteristic for \( v = 15 \text{ L/min} \).](image)
It is obvious that by changing the number of discharge channels in the design, it is possible to increase the effect zone of the plasma formation. Generation of plasma jets in a multichannel design of the device is similar to the generation process in a single-channel design. Figure 4 shows an oscillogram of the total current to the collector. Diagnostics of the plasma jet showed that it consists of a set of current channels. The organization of independent collectors made it possible to separately register the plasma jet current in each channel. The oscillograms show the asynchronous development of the current in each of the channels. It has been demonstrated from similar current measurements (when closing to separate collectors) and from optical recording that the current in each of the channels consists of a set of independent current channels.

![Figure 4](image)

**Figure 4.** Measured voltage (red) and currents recorded from different channels (green — 1 channel, yellow — 2 channel, blue — 3 channel).

When a common sinusoidal voltage is applied to all interconnected potential electrodes, the plasma jet is determined by the stochastic generation of streamers from the tips of the potential electrodes. Figure 4 shows that at each moment of time, a separate current develops. Thus, the large area and visible homogeneity at high frequencies of the sinusoidal voltage of the jet is determined by the multifrequency overlap of the current pulses.

4. **Conclusion**

Thus, a source of a cold plasma jet with a planar geometry was developed, which makes it possible to generate one or several plane plasma jets. The dependence of the recorded collector current on the amplitude of the applied voltage is investigated. It is shown that current channels are generated at each
positive half-wave of the applied sinusoidal voltage, and their propagation both within one discharge channel and through different channels are independent of each other.

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