Conference Paper

Nonthermal Plasma Jet for Biomedical Applications

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Abstract

Low-temperature plasma has been successfully used in medicine for last 15 years. Cure of purulent wounds by means of discharge plasma with low gas temperature is a new method of medical drug-free treatment. A result of investigation of atmospheric pressure helium plasma-jet excited by capacitive discharges at various method of excitation is presented. Homogenous discharge of plasma jet and 34°C of gas temperature at helium flow 0.5L/min was achieved at short pulsed voltage excitation.

Keywords: plasma jet, nonthermal plasma, medical drug-free treatment, inactivation, pathogens

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1. Introduction

The problem of the acquired resistance of bacteria and parasites to antibiotics is already taking dangerous scale. It was discussed at the 71st session of United Nations General Assembly in September 2016. For this reason, the development of medical drug-free treatment methods (excluding the using of antibiotics) is a very important research problem in modern medicine and veterinary.

One of promising application of flow of gas-discharge plasma with low gas temperature is a treatment of septic wound cure as a medical drug-free method. Gas discharge plasma is used in medicine for last 15 years: there are plasma coagulators and plasma scalpels. However it cannot be applied for therapy. Low-temperature plasma jet generates ozone, charged particles (electrons and ions), nitrogen- and oxygen-containing radicals, UV radiation (200-300 nm of range), so it is able to destroy the membranes of pathogenic microorganisms without damage to human cells. Therefore low-temperature plasma treatment is not specific, meaning the absence of acquired tolerance of the pathogens [1].

Only flow of plasma with low gas temperature in the torch (less than 40°C) fits for painless therapy. Plasma of such type is called “nonthermal”. Main problem of development of nonthermal atmospheric pressure plasma jet sources is achievement of low gas temperature at low working gas flow rate. Moreover an electrode system of plasma jets must provide closed circuit without any sensitive leakage current to human body.

SHF sine voltage is used for plasma jet with low gas temperature obtaining at low flow rate (<1 L/min) of working gas [2]. SHF power supplies are large-size and low-efficiency. Applying of HF sine voltage gives the opportunity of use of small-size power supplies, but in this case gas temperature can be lower than 40°C at high flow rate of working gas (> 3 L/min) [3]. Authors of works [4-5] produced high efficiency of excimer DBD lamps due to feeding of discharge by short pulsed voltage. A sine-voltage power supply or other long pulse one has long current pulses which lead to the discharge contraction and increasing of gas temperature in discharge channel. The gas discharge contraction can be limited by use of short duration current pulses followed by long pauses allowing plasma relaxation.

2. Experimental setup

Tests of several electrode systems (one barrier discharge with needle electrode, double barrier discharge and glow discharge) shown high efficiency and electrical safety of double barrier discharge (DBD) construction of a plasma jet electrode system (fig. 1). High voltage applied to the ring electrodes *2* ignites gas discharge plasma inside a pipe *1* and gas flow *6* blows off the plasma in the form of jet *5*.

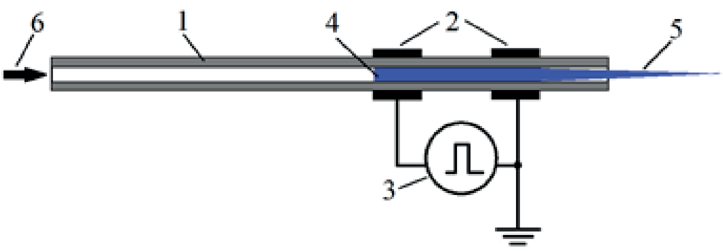

Figure 1: Electrode system of plasma jet based capacitive discharge. 1 – glass pipe, 2 - ring electrodes, 3 – pulsed power supply, 4 – gas discharge, 5 – plasma jet, 6 – gas flow.

Two power supplies were developed for comparative experiment of short-pulse and sine excitation modes. A short-pulse power supply is equipped with a full bridge MOSFET convertor and a step-up transformer *Tr1* (fig. 2a). Transistors switch DC bus voltage on primary winding of *Tr1* in such a way that high voltage pulses (2 μs of duration) with long pauses and alternate polarity are generated on electrodes. A sine voltage power supply is designed as a classical resonant generator (fig. 2b), where the circuit of elements *L2-C6-Tr2* are operate as a resonant loop. Transistors VT5 and VT6 work with 50% of duty cycle at near to the resonant loop frequency.

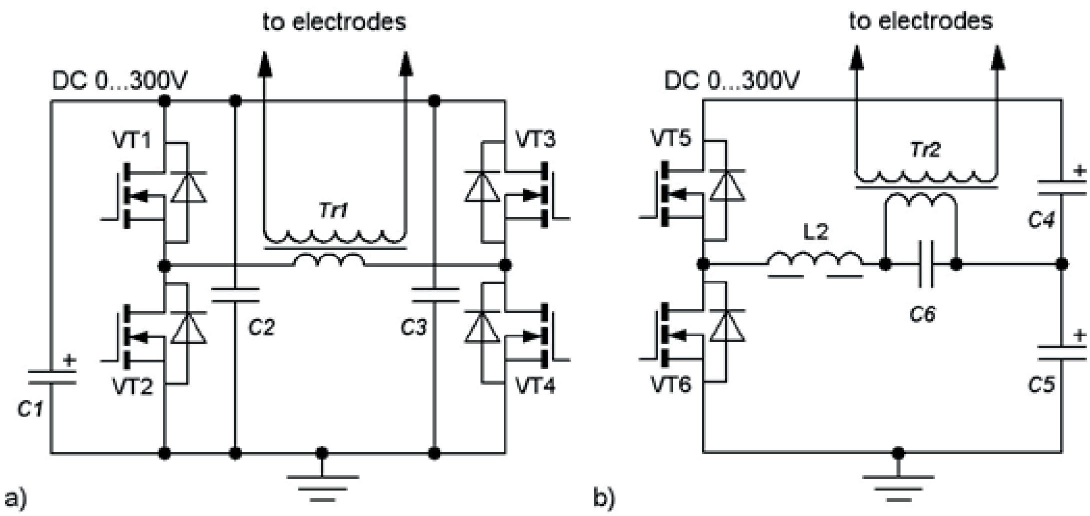

Figure 2: Electrical circuits of short pulse (a) and sine (b) voltage power supplies.

Voltage on electrodes and current of gas discharge were measured by a high voltage probe PPE6KV (LeCroy Corp.), a 50 Ohm resistor shunt and an oscilloscope TEKTRONIX TDS2024C. A flow rate of helium has not any influence on the voltage and current oscillograms. A flow level of helium is adjusted and controlled by a proportional valve PVQ13 and a flow sensor PFMV530 (SMC Corp.). Gas temperature of plasma was measured by a bimetal thermometer.

3. Results and discussion

At the first stage the experiments for influence of pipe diameter, length of ring electrodes, interelectrode gap on gas temperature were carried out. Optimal parameters of the electrode system in terms of low gas temperature of plasma jet were the same for both voltages (short pulse and sine excitation): pipe diameter – 5.5 mm (glass thickness 0.5 mm), length of rings – 3 mm and interelectrode gap – 5 mm.

Decrease of helium flow rate led to increase of gas temperature of plasma jet (fig. 3). Especially fast increase of gas temperature was registered at flow rate less than 1 L/min. Nevertheless it was much less for short pulse excitation. So, for 0.5 L/min gas temperature was 34°C at short pulse excitation and 53°C for sine one. Dependence on fig. 3 at frequency 33 kHz and 4.2 W of excitation power for both excitation methods was drawn up. Excitation power was calculated by the method described in [6].

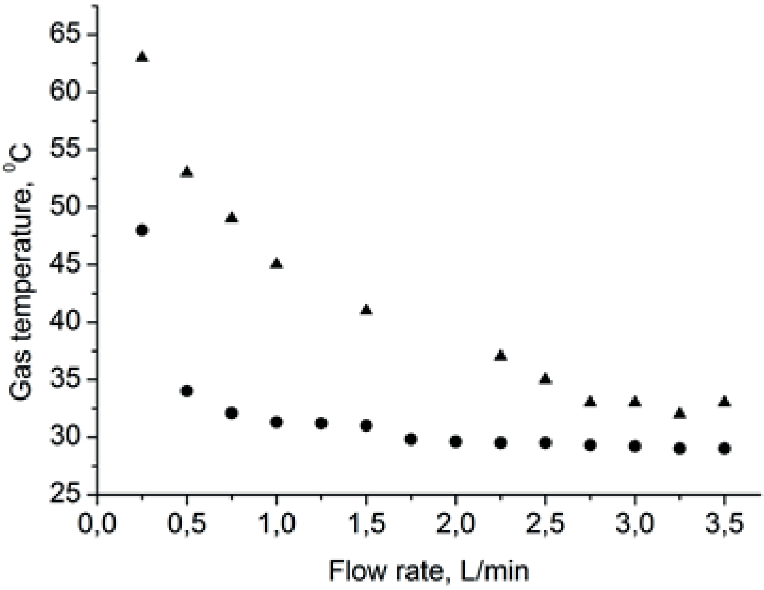

Figure 3: Dependence of plasma jet gas temperature on flow rate at short pulse (o) and sine (Δ) excitation voltage.

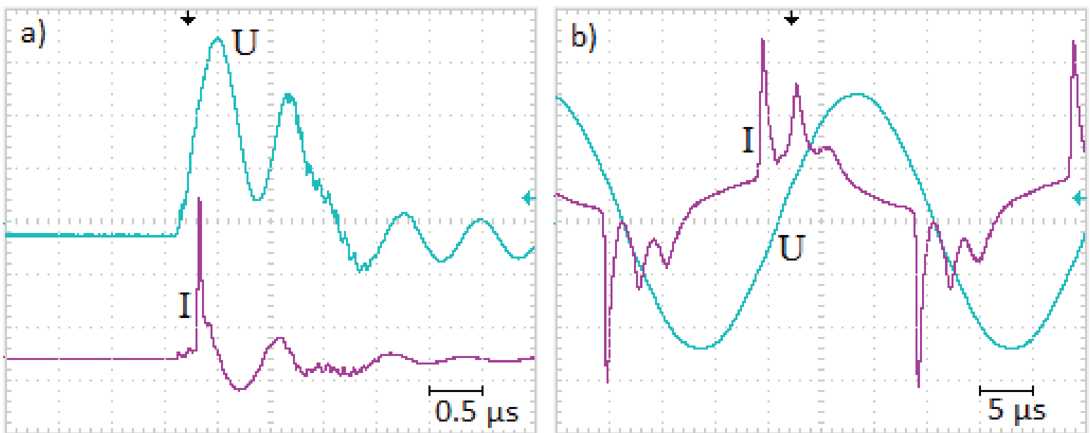

Figure 4: Voltage (2V/div.) and current (1A/div.) of plasma jet at short pulse excitation (a). Voltage (2V/div.) and current (20mA/div.) of plasma jet at sine voltage excitation (b).

As shown on fig. 4 current of gas discharge is much shorter at pulse excitation than at the sine one. Short excitation current pulses exclude overexcitation of gas discharge and long pauses provide plasma relaxation. The short pulse excitation method makes possible to obtain a diffuse jet of plasma without contracted overheating plasma channels (fig. 5). Long current excitation pulses, on the other hand, lead to plasma contraction, plasma resistance reduction and gas temperature increasing.

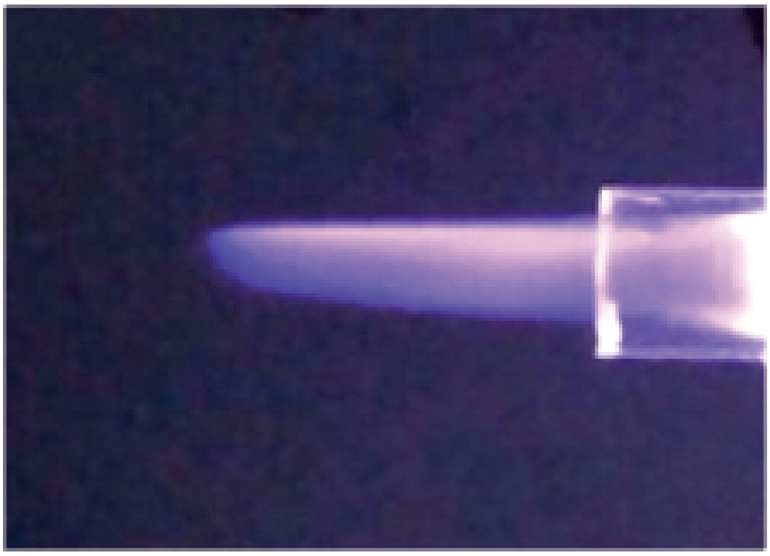

Figure 5: Helium plasma jet at short pulse excitation.

4. Summary

Use of short pulse excitation voltage allows decreasing gas temperature of plasma jet. Following this method low gas temperature of plasma jet at low flow rate of helium was obtained. This result can be used for development of equipment based on nonthermal plasma jet for biomedical applications, in particularly, for treatment of septic wounds.

Acknowledgments

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