**Publ. Astron. Obs. Belgrade No. 89 (2010), 307-310** *Contributed Paper*

# CURRENT–VOLTAGE CHARACTERISTICS OF ATMOSPHERIC PRESSURE PLASMA JET

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**Abstract.** We have constructed a plasma jet that can operate in the frequency range 25-150 kHz and within the range of 5-10 kV of applied peak-to-peak voltages. High voltage probes are used in order to obtain current and voltage waveforms. In this paper, we will show $V_{RMS}$-$I_{MRS}$ plasma jet characteristics for the working frequency of 80 kHz. Current and voltage measurements were made both for the increase and decrease of the applied voltage in order to see if there is a hysteresis effect.

## 1. INTRODUCTION

Atmospheric pressure discharges cover a wide range of dimensions, starting from micrometer-scale plasmas convenient for localized and precise treatment, up to dimensions suitable for the treatment of large-scale samples. So far, many different configurations and applications of non-thermal atmospheric plasmas have been developed and studied (see Kundthart et al. 2000, Fridman et al. 2008, Puač et al. 2006, von der Gathen et al. 2007). Recently, several authors have reported on various means of generating cold plasma jets at atmospheric pressure. More interestingly, these jets turned out not to be a continuous plasma, but trains of small high-velocity plasma packets-bullets (see Kong et al. 2008, Teschke et al. 2005).

We have constructed plasma jet that can operate in the frequency range from 25 kHz to 150 kHz and within the range of 5-10 kV of applied peak-to-peak voltages. In this paper, we will show $V_{RMS}$-$I_{MRS}$ plasma jet characteristics for the working frequency of 80 kHz. High voltage probes are used in order to obtain current and voltage waveforms. Measurements are made for the increase and decrease of the applied voltage in order to see if there is a hysteresis effect.

## 2. EXPERIMENTAL SETUP

The atmospheric pressure plasma jet is made of a Pyrex glass tube with inner diameter of 4 mm and outer diameter of 6 mm. Electrodes that were used were made of a thin copper foil wrapped around the glass tube. The distance between the powered and the grounded electrode was 13.5 mm. The width of both electrodes was 13 mm. One of the electrodes (the left electrode, see Fig. 1) was grounded. The other electrode, closer to the end of the glass tube, was the powered one (see Fig. 1). The distance between the powered electrode and the end of the glass tube was 11 mm. The feeding gas was helium and the flow rates used in this work were 2, 3 and 4 slm. The flow rate is adjusted with a mass flow controller (Omega FMA5400/5500).

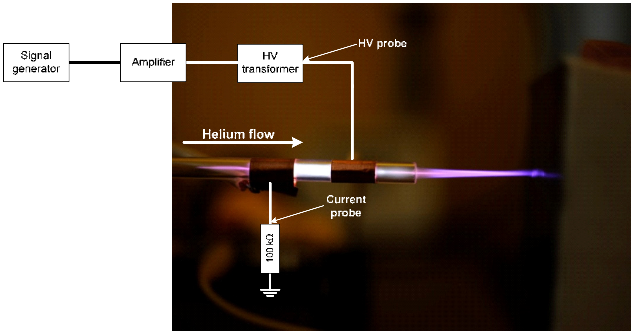


**Figure 1:** Experimental setup.

For powering the plasma jet, we used a signal generator (Peak Tech DDS FUNCTION GENERATOR 4025) connected to the custom-made amplifier. Highest voltages that we could obtain from the amplifier were up to 1 kV, which was not enough to ignite the plasma. In order to the increase applied voltages to the values higher than 5-6 kV, we had to use an additional homemade transformer.

Current and voltage measurements were made with two commercial probes. The first probe, used for obtaining voltage waveforms, was a high-voltage probe (Agilent N2771A) and it was connected to the HV-output (see Fig. 1). In order to obtain current waveforms, we used the second probe (Agilent 10076A) which measured the voltage drop on a 100 kΩ resistor placed in the grounded branch of the electrical circuit. The working frequency was 80 kHz and the applied voltage was in the range of 6-10 $kV_{peak\text{-}to\text{-}peak}$.

## 3. RESULTS AND DISCUSSION

The current and voltage waveforms when there is no discharge, and with plasma on, are shown in Fig. 2. We can see that when the plasma is not ignited, the phase difference between the current and the voltage is approximately $\pi/2$. The impedance is practically capacitive (the voltage waveform lags behind the current waveform). When plasma is ignited, the phase difference between the voltage and the current reduces significantly. Signal for the current is increased and deformed, while the peak-to-peak value for the voltage is smaller than in the case when there is no plasma (no He flow). By igniting the discharge we have employed additional nonlinear load into the electrical circuit.

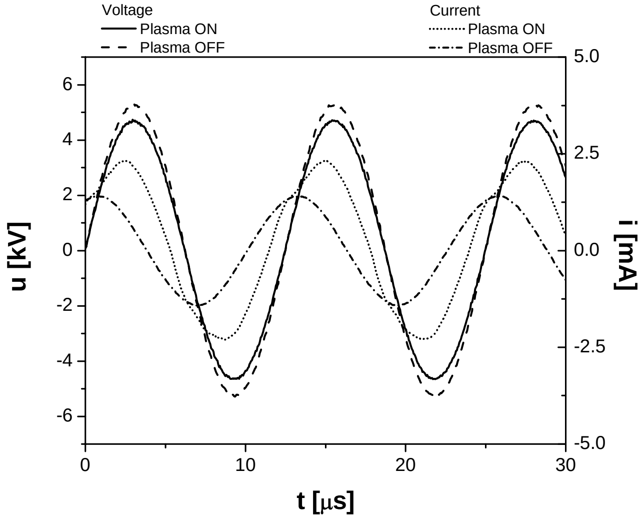


**Figure 2:** Current and voltage waveforms for the helium flow rate of 3 slm. Dashed lines represent case when discharge is OFF and solid lines when discharge is ignited.

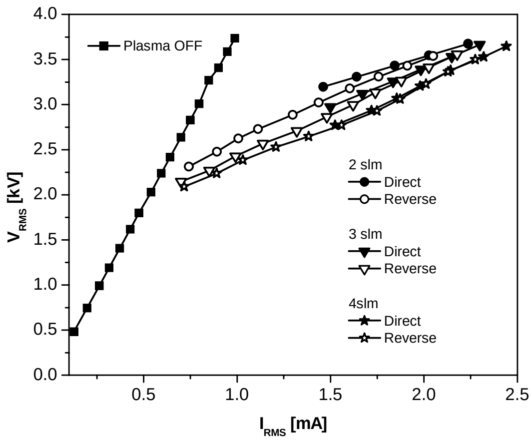


**Figure 3:** Current-voltage characteristics for three different flows of helium.

In Fig. 3 $V_{RMS}$–$I_{RMS}$ characteristics are shown for three different flows of the feeding gas. In case when plasma is off, the RMS values of the current are lower than in the case when the plasma is ignited. On the other hand, the voltage is decreased with the plasma ignition.

When the plasma is off, the phase difference between the current and voltage is close to 90˚. In this case, we have a capacitive impedance of several MΩ, corresponding to the capacitance of about 0.5 pF. On the other hand, the plasma ignition introduces a parallel nonlinear load into the electrical circuit. and in this case the slopes of the $V_{RMS}$–$I_{RMS}$ curves are lower (see Fig. 3.).

With the increase of the helium flow, the voltage needed for the ignition of the discharge decreases. When reducing the applied voltage, the plasma stayed on even for lower values than those needed to ignite the discharge, i.e., the plasma exhibited a hysteresis. The mean power in all cases was less than 10 W.

## 4. CONCLUSION

We have constructed a plasma jet which can operate in a range of frequencies 25-150 kHz. In this paper, we have shown results for the frequency of 80 kHz and several gas flows of the feeding gas (helium). High-voltage probes were used in order to record the current and voltage waveforms. The ignited plasma behaves like a nonlinear load introduced into the electrical circuit. With the increase of the helium flow, the ignition voltages reduce for the same current range. The power in all cases did not exceed 10 W, which makes this device suitable for the applications with biological samples.

## Acknowledgement

This research has been supported by the Ministry of Science, Serbia, under the contract number 141025 of the project Physics Fundamentals of Applications of Non-Equilibrium Plasmas in Nanotechnologies and Treatment of Materials.

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