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INVESTIGATION OF A MICROSECOND-PULSED COLD PLASMA JET

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Abstract. This work presents initial results of studying a pulsed cold plasma jet with a fast voltage rise-time. The aim of the experiment is a spectroscopic investigation to the purpose of attaining the jet streamer space-time development and plasma parameters near the target. Results show a comparably fast streamer progression with strong electric field in the period of maximum current.

1. INTRODUCTION

In the last decade nonthermal; atmospheric pressure discharges have been adopted as the future of plasma application due to their many advantages, see for instance Fridman et al. 2008, Branderburg et al. 2019. A subtype of this type of plasma are low temperature plasma jets, usually obtained in the flow of inert gases Winter et al. 2015, Weltmann et al. 2017, Reuter et al. 2018. In a number of publications helium plasma jets are especially investigated as candidates for treatment of biomedical and other samples, see for instance Weltmann et al. 2017, Reuter et al. 2018, Yan et al. 2017, Nastuta et al. 2011, Teschner et al. 2019. They have also been studied from the standpoint of plasma characterization, both through modeling and experiment, Boeuf et al. 2013, Sretenović 2014, Winter et al. 2015.

One of such sources with and accompanying power supply has been developed at the Zhejiang University, Zheng et al. 2016, Deng et al. 2018. This cold plasma jet has so far been used for treatment of various bio-samples. It operates with a microsecond voltage pulse characterized with a fast rise-time. In this work, the primary aim was a spectroscopic investigation to the purpose of studying the jet streamer space-time development and plasma parameters near the target. Here we present only the initial results of a planned detailed study.

2. EXPERIMENT

The pulsed power supply and a dielectric barrier discharge (DBD) jet reactor are combined into a single device, Deng et al. 2018. The grounded electrode is a metal nozzle with its inner surface covered by a quartz tube, 6 mm in diameter. Inside the nozzle, at its center axis, a smaller quartz tube is placed, 4 mm in diameter. The high-voltage wire electrode is inserted in the smaller quartz tube. In this way a barrier discharge is formed between the two quartz tubes having 0.5 mm thickens. The low-temperature plasma jet then protrudes form the nozzle width the diameter of ~4 mm and length of 1-7 cm depending on the voltage. In this experiment a copper plate was used as a grounded target to increase the jet stability. The target was placed at a distance of 13.5 mm from the jet nozzle.

The electrodes are supplied by a pulsed power source with a pulse width of 0.8 μs, voltage of 2.6 kV and a repetition rate of 21 kHz. The rise time of the voltage pulse is 400 ns. Helium flow of 99.996% purity was controlled by means of a mass flow controller at rate of 3 l/min. The voltage was measured using the Tektronix P6015A high voltage probe, and current is determined from voltage drop over 200 Ω non inductive resistor connected in series with the discharge.

A quartz lens was used to project the jet image onto the entrance of the spectrometer. The overall time–space unresolved emission spectra in a wide range of 300–900 nm, was recorded using a low resolution spectrometer Ocean Optics USB4000. The spatiotemporally resolved measurements were done using the Solar MSDD 1000 spectrometer with the focal length of 1 m and the grating of 1200 grooves/mm. At the exit of the monochromathor the light was detected using the ICCD camera (PI-MAX2, Princeton Instruments) with 1024×1024 pixels. The camera was triggered using a time-delayed pulse signal, initially generated by the rising slope of the discharge voltage pulse. The delay camera triggering system enabled precise setting of the gate width and the delay time for the recording. This spectrometer system has an instrumental width FWHM=0.04 nm.

3. RESULTS

Several spectroscopic methods, typical for examining atmospheric pressure discharges, were employed in this experiment. Namely, axial distribution of various species emissions was used to examine the jet spatial structure. Helium and oxygen atomic line emission was used to examine the discharge axial development in time. By measuring the transverse light intensity distribution and applying the Abel inversion, the radial distribution of light intensity was obtained. The N_2^+ first negative system emission band was used to measure the molecule rotational temperature. Stark polarization spectroscopy of He I 492.2 nm line was used to estimate the electric field at the target.

Figure 1 shows the time-space development of He I 706 nm line. Since this line is exited via electron impact, this graph can be taken as development of the jet streamer. As can be seen, the graph shows typical features of the positive guided streamer, Gerling et al. 2011, Sretenović et al. 2014. Specifically, one can see the bullet-like progression towards the cathode till the time of 160 ns. The streamer travels from the nozzle to the cathode target during the current rise and reaches it at the moment of current maximum. After reaching the target, a weak back-streamer is formed towards the jet nozzle. During the strong current a long-lived atmospheric pressure glow discharge above the target is formed.

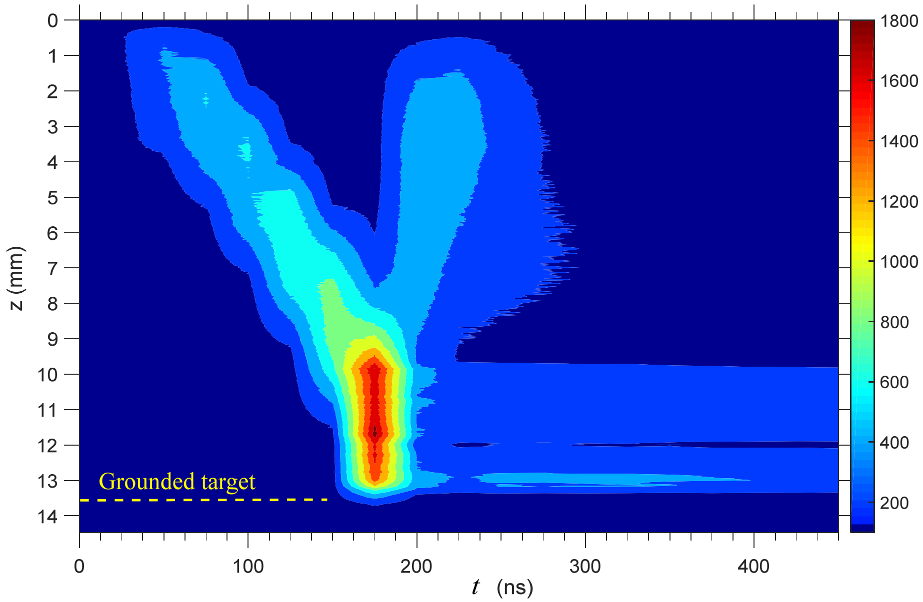

Figure 1: Contour plot of He I 706.5 nm emission, gate width 25 ns.

From the graph, the average velocity is estimated at $8.4 \cdot 10^4$ m/s which is much higher than typical jet bullet velocity, see for instance Sretenović et al. 2014, Gerling et al. 2012. This can be explained by the short rise-time of the voltage in our case. Namely, it was shown in Lu et al. 2014, that the short voltage rise-time crucially increases the streamer velocity. The velocity obtained here agrees with the trends given in the mentioned paper.

Figure 2 shows the spatial distribution of different species in the time when the streamer has reached the target and a stable atmospheric pressure discharge lasts for several hundreds of nanoseconds. The light emissions of different species show similar patterns. Especially interesting is the formation of light and dark zones, similar to the glow discharge, in the vicinity of the target. The exception to the shape of the distribution is hydrogen H_β line. It is well known that at atmospheric pressure the hydrogen Balmer lines have a delayed excitation due to the necessity of molecule dissociation and excitation from helium metastables, see Navratil et al. 2006.

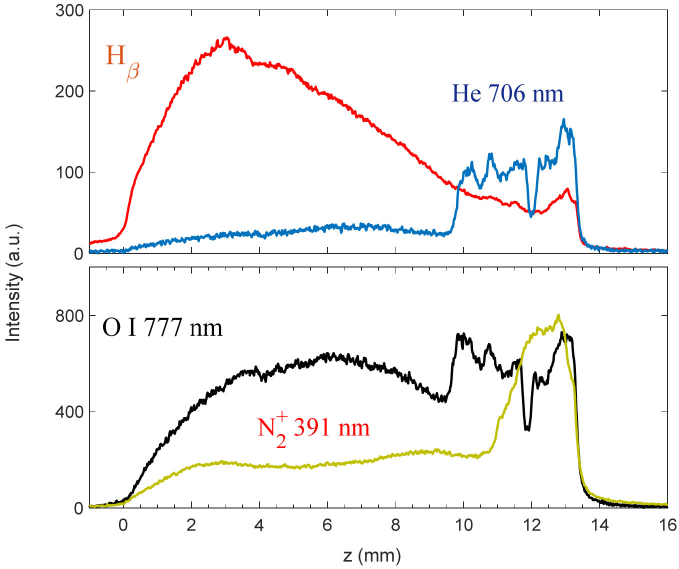

Figure 2: Axial distribution of emission from different species after *t*=200 ns.

The jet gas temperature near the target, estimated form the rotational temperature of nitrogen molecule ion was T=340±30 K. Stark spectroscopy showed interesting the features of the spectral line profile near the target. Specifically, strong electric fields ~25 kV/cm were observed, with the field inhomogeneity in the observed region.

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