Time-resolved images and detection of positive and negative ion species of atmospheric pressure plasma jet with spiral electrodes

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The potential use of cold atmospheric pressure plasma sources has emerged in recent decades in number of fields, including metalurgy, agriculture, biology, medicine, and more. The use of atmospheric pressure plasma jet (APPJ) with spiral electrodes introduces an interesting approach to plasma generation, offering increased source length and extention of potential applications in medicine [1]. In this study, we explore the experimental setup and diagnostic techniques employed to characterize the APPJ and its chemical composition. Our focus lies on the potential application of non-thermal plasma in sterilization, particularly in sterilizing catheters and infusion hoses [2]. By utilizing spiral electrodes wrapped around a glass tube, we aim to harness the benefits of APPJ for practical applications, while also gaining insights into discharge dynamics and chemical composition through diagnostic techniques such as time resolved ICCD imaging and mass spectrometry [3].

The experimental setup (shown in Fig. 1) consisted of a 30 cm long glass tube wrapped with two isolated copper wires arranged in a spiral configuration (10 mm interelectrode gap), ensuring no contact between them. One wire was powered by a sine wave at 70 kHz excitation frequency and the second wire served as grounded electrode. A signal generator was used to provide a sine voltage of few volts, which was then amplified to the range of kV and applied to the powered electrode. A high voltage probe and oscilloscope were employed to measure voltage and current signals, enabling the calculation of power delivered to the discharge. Helium gas was used as the feeding gas at a rate of 4 slm The discharge appeared inside the glass tube as the ionization front that followed closely the shape of electrodes and then propagated as a plume a few centimeters outside the glass tube.

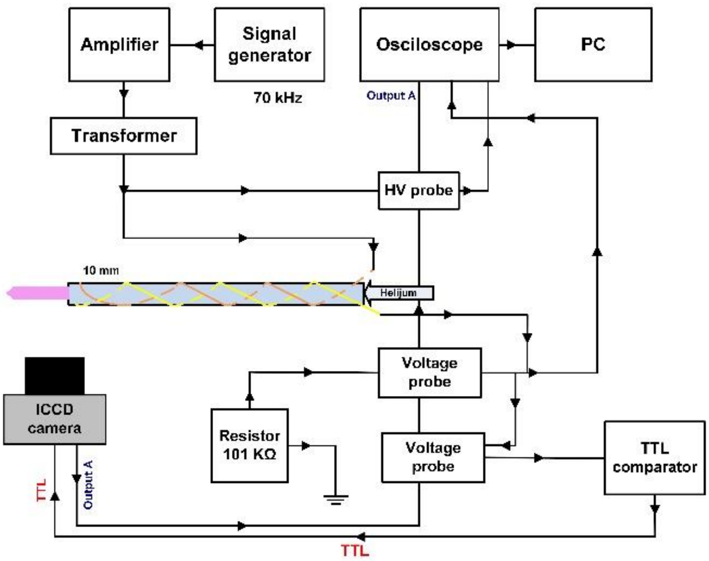

Fig. 1: Experimental setup of APPJ with spiral electrodes

We have performed time resolved ICCD imaging for various applied voltages and used these images to determine the velocity of PAPS (Pulsed Atmospheric Plasma Streamer). A frame of the temporal evolution captured by the ICCD camera is shown in Fig. 2, where the occurrence of PAPS (Pulsed Atmospheric Plasma Streamer) is displayed for the highest voltage value. This demonstrates that the discharge is not continuous but rather it consisted of plasma packages traveling at a velocity far faster than the working gas flow.

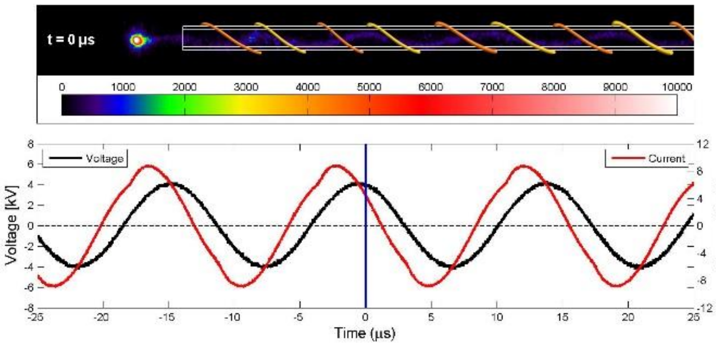

Fig 2.: Time-resolved ICCD frame synced with V-I signals

The positive ion mass spectrum acquired by the Hiden HPR60 MBMS mass spectrometer is shown in Figure 3. The predominant ions of N^+, O^+, N^+, O^+, H_2O^+, H_3O^+, $He^+$and HeH^+ were produced by ionization in a combination of the working gas with atomic and molecular species from the surrounding air, humidity and atmospheric impurities.

Additionally, oxygen species like O^-, OH^-, O_2^-, and O_3^- dominate the mass spectra of negative ions that we have obtained (spectra not shown here). Observations of the $O^- \cdot (H_2O)_n$ and $OH^- \cdot (H_2O)_n$ indicated a potential for water cluster chemistry in the APPJ plume.

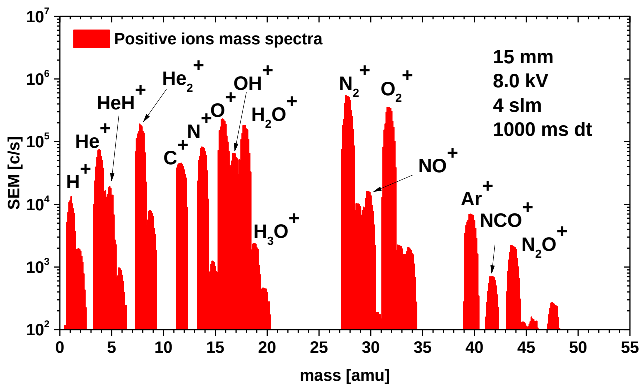

Fig 3.: Positive ions mass spectra

The rich spectrum of positive and negative ions produced in APPJ with spiral electrodes makes this source of non-thermal plasma interesting for potential application in sterilization of long tubes. The appearance of the discharge outside of the glass tube expands the potential application to the other area of interest such as medicine, biotechnologies, agriculture, and more.

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