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Visualization of the temperature distribution in a DBD driven helium atmospheric pressure plasma jet

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Abstract. A technique to visualize a gas temperature field in DBD-driven helium plasma jets is presented. It is implemented with recording infrared images on a thin glossy paper sheet placed into the jet in the line of the gas flow. The entrapment of the ambient air by the helium flow produces distortions in the measurement result; therefore, additional post processing of the images obtained has been carried out.
Keywords: Atmospheric pressure plasma jet, temperature field, dielectric barrier discharge.

1. Introduction

Cold atmospheric plasma sources are often used in modern studies of plasma interaction with biological objects. Atmospheric pressure plasma jets are of such plasma sources [1]. Heating control is a crucial factor for their application, especially for the treatment of living tissues [2]. Visualization of temperature fields is strongly necessary in these applications.

In the work, we present a simple qualitative technique to visualize a gas temperature field in the cold plasma jet by using a thermal imaging camera. It consists in recording thermal images of a thin paper sheet placed into the plasma flow and acting as an infrared emitter. This method makes it possible to visualize the time-averaged temperature parameters of the gas flow.

A plasma jet consists of guided consecutive streamers traveling along the gas flow [3]. Earlier, we revealed a transition from one pass propagation to stepwise propagation of a guided streamer along the plasma jet at varying the gas flow rate [4]. Here, we have determined the temperature conditions accompanied by it and considered temperature fields for a jet interacting with a target simulating a living object.

2. Experimental setup

The plasma jet [4, 5] was generated by a dielectric barrier discharge in a quartz tube (Fig.1) with the inner diameter of 4.6 mm and the thickness of the wall of 1 mm. An electrode system consists of an inner electrode (1), a copper wire of 1.5 mm in diameter, located along the tube (2) central line at the distance of 7.5 mm from the edge of the tube and an outer electrode (3), a copper foil strip of 5 mm wide wrapped around the tube at the distance of 5 mm from its edge. The two different high voltage signals with the peak to peak value of 4.6 kV were used: the 52 kHz sinusoidal voltage and the special waveform. Both were generated as bunches with a duty cycle of ≈90% [5]. The oscillograms of them are shown in Fig.1 (a) and (b).

Helium flow rates were set 2, 4, 6 and 8 l/min for experimental conditions as in [4]. The jet (4) was generated in the helium flow effluent into ambient air. The environment temperature was 20 °C. To visualize temperature fields in the plasma jet, a sheet of paper (5) was placed along the gas flow in the middle of the discharge tube cross-section and, then, recorded thermal images with an IR camera in 2 minutes after switching a power supply on. Their resolution was 0.2 millimeters per pixel.

Two cases were considered. In the first case, a free helium jet was directed upward. The jet interacting with a target surface was studied in the second case. A surface of artificial skin BIOBRANE 1643A steeping with saline MucoClear 6% (NaCl) was used as a target. The substrate under the skin was grounded through an equivalent circuit corresponding to the impedance of the human body [6].

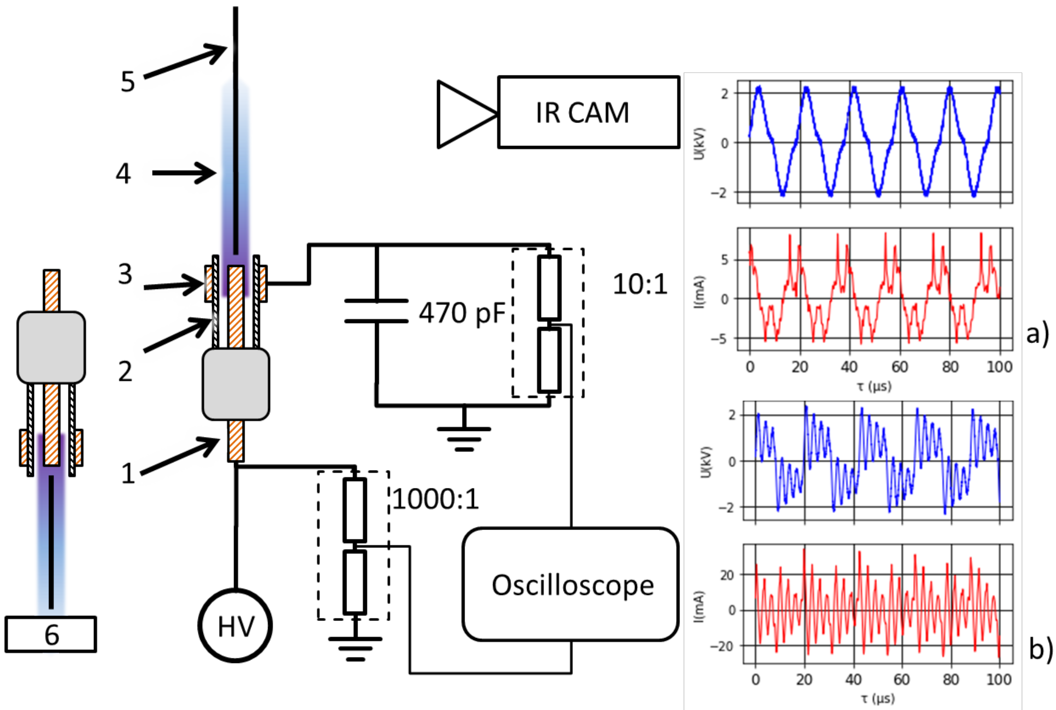

Fig.1. Experimental setup (1 – high voltage electrode, 2 – quartz tube, 3 – grounded ring electrode, 4 – plasma jet, 5 – paper sheet, 6 – target. Oscillograms: a) 52 kHz sinusoidal signal; b) special waveform signal.

3. Results and discussion.

The thermal imager converts the radiation intensity into temperature, using the albedo parameter, which differs for different materials. Figure 2 clearly shows the elements of the setup when the discharge is turned off (Fig.2, left). A quartz tube (1), sheet of paper (2) and helium jet (3) are visible in the thermal image. Admixing the ambient air into the helium produces significant changes in thermal images and results in incorrect interpretation of the recorded data.

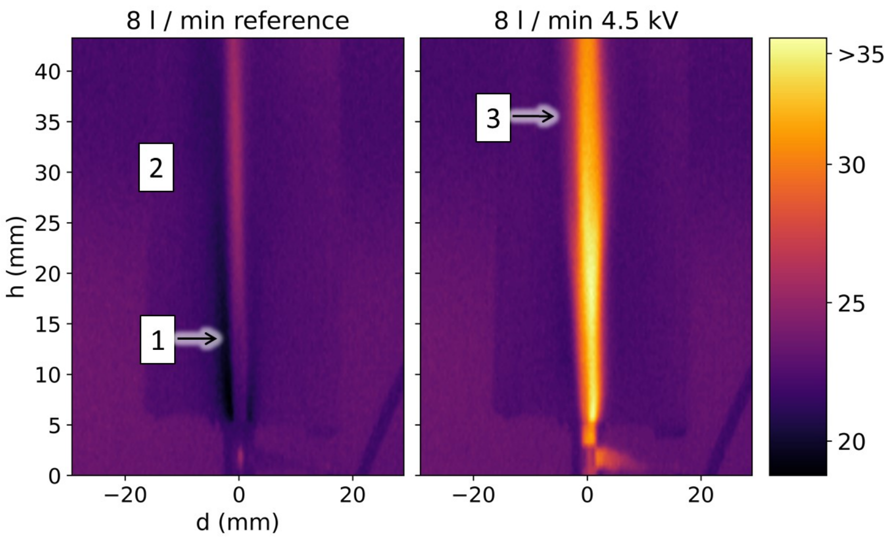

Fig.2. Thermal image of the helium flow without thermal correction (left – discharge off; right – discharge on): 1) quartz tube; 2) paper sheet; 3) free helium jet.

To obtain the temperature of the jet and compensate for disturbance caused by the mixing of helium with air, the reference image was subtracted from the discharge image. In Fig.3, the difference of the recorded temperature and environment temperature is presented. The maximal heating of the gas is revealed at the lowest gas rate near the discharge tube edge. In all considered cases, the gas heating does not exceed 25 °C.

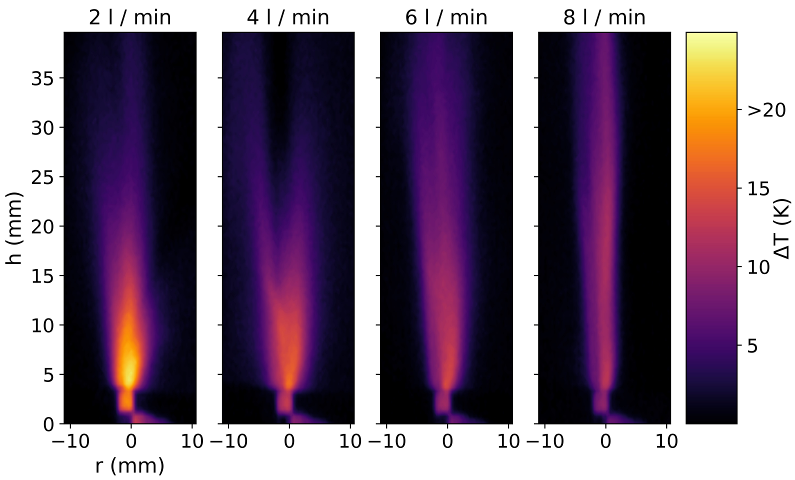

Fig.3. Thermal fields in the free helium jet, directed upward and fed by the special waveform voltage signal. ΔT is the difference between the recorded temperature and environment temperature.

In Fig. 4, the thermal fields of the plasma jet interacting with the surface of the target are shown. As in the case of the free jet, the maximum temperature difference does not exceed 25 °C; near the target surface, in all flow regimes, the temperature of the plasma flow is close to the environment one.

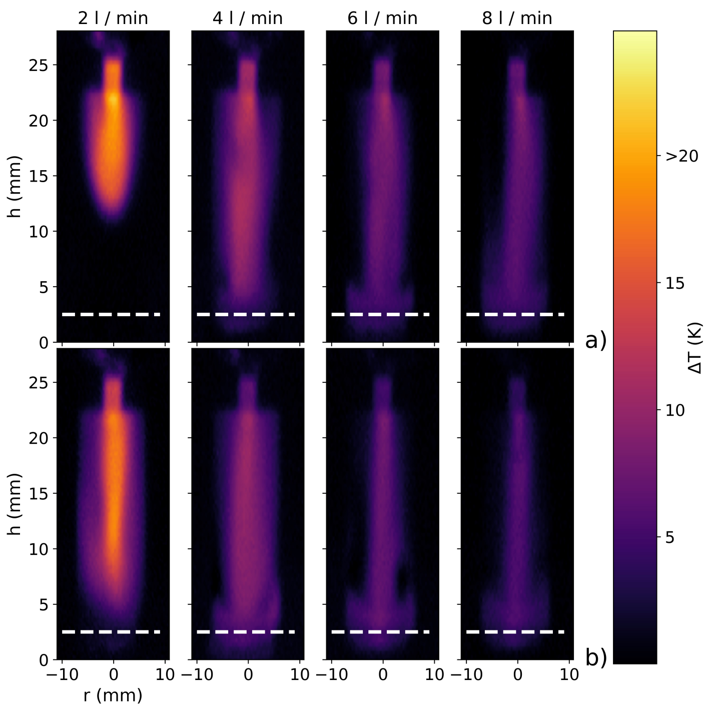

Fig.4. Thermal fields in the downward jet interacting with the target: a) powered by sinusoidal voltage; b) powered by the special waveform voltage. The surface of the target is marked by a dashed line. ΔT is the difference between the recorded temperature and environment temperature.

The diagnostics conducted did not reveal additional gas heating, apart from the main discharge region inside the tube. The temperature distribution obtained using the shadow method and temperatures obtained using thermocouples [7] coincides with the data obtained using the presented technique.

4. Conclusion

As a result of the work, a simple technique for visualizing the temperature fields of the DBD plasma jet has been developed. A qualitative correspondence of the temperature, obtained by this method, and the temperature values, obtained from shadow and thermal probe diagnostics, was observed.

Acknowledgement

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5. References

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