Features of forming atmospheric pressure plasma jet in helium and argon flows

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Introduction

Argon and helium gases are the main common substances to generate atmospheric pressure plasma jets (APPJ) for plasma biomedicine [1, 2]. The two gases have different electro-physical properties that provide various conditions for a discharge ignition and burning [3, 4]. In practice, to obtain a cold plasma jet, that is stable against the transition to a high-current mode, in an argon flow is much more difficult than in helium. Due to the phenomenon of the plasma column contraction [5], argon plasma jets without any additional engineering solutions are almost impossible used in treatments of thermosensitive materials, whereas helium plasma jets remain cold at a rather wide range of discharge parameters.

We studied the features of forming APPJ in helium and argon flows passing through a dielectric-barrier discharge (DBD) at the gas flow rates of 1–10 l/min. The inner diameter of the discharge tube was equal to 5.6 mm. Discharge structure for helium and argon jets has been described according to the data on high-speed shooting along and across them.

Experimental setup and techniques

To generate DBD, an electrode system assembled as a high-voltage inner electrode inside a quartz tube and a grounded electrode – ring was used. The quartz tube served as a dielectric barrier. To supply the discharge a high-voltage power with a tunable frequency and controlled duty cycle was applied. The electrical scheme of the experimental set-up can be found in [1, 6]. Fig. 1 shows the experimental assembly for the electrical and high-speed shooting diagnostics of the discharge and plasma jet.

A discharge inside the tube and jet's propagation along the helium and argon flows into an ambient air was registered by an intensified charge coupled device (ICCD) camera Andor Tech (iStar performance sheet DH340T, pixels: 2048×512, minimum optical gate: 1.9 ns) with exposition of 50-1000 ns. Gas flow rates were controlled with a flowmeter.

Results

APPJ propagates in an ambient air with ionization waves (guided streamers) along a working gas flow. Two distinct spatial regions, a main discharge and a plasma jet, can be separated [7]. After initiating the discharge inside the tube, the deposited energy is redistributed between the discharge and plasma jet. How it occurs depends on several factors, including the electro-physical properties of working gas and, consequently, parameters of the main discharge. Thus, to study the formation of the plasma jet, we need to examine the discharge inside the tube along with the propagation of a luminous gas flow (plasma jet) outside the tube.

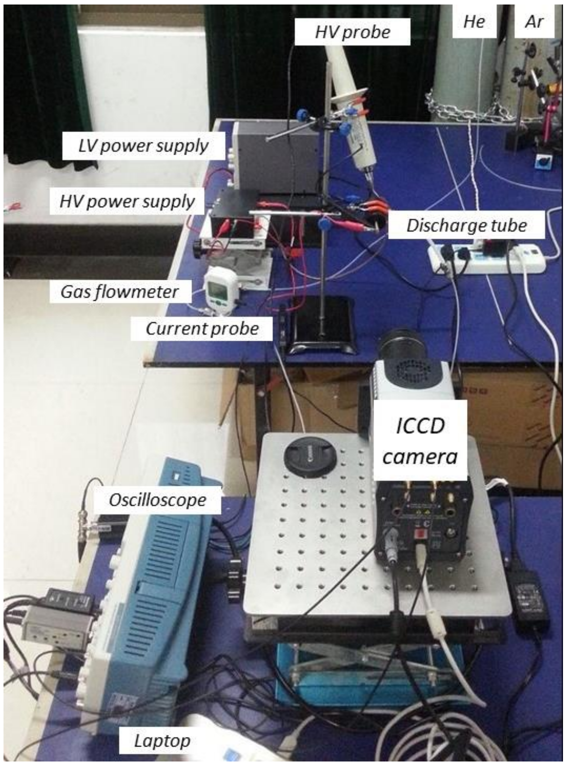
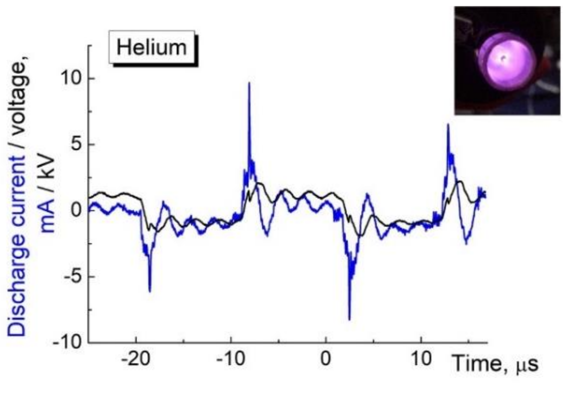


Fig. 1. Experimental set-up

Discharge

We provided electrical measurements of the parameters: the signals of the voltage across the discharge gap and current passing through it. Oscillograms of them recorded for helium and argon are shown in Fig 2(a)-(b). They look significantly different. In the case of helium two short peaks of current up to 10 mA happen at a positive and negative half a period of the voltage, whereas in the case of argon the current signal has small peaks of the discharge current (not more than 3 mA), and the most part of the recorded signal is a displacement current.



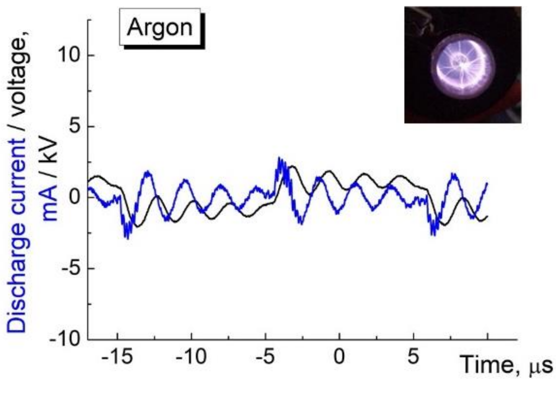


Fig. 2 Oscillograms of the voltage and current signals recorded at the gas flow rate of 1 l/min and corresponding images of the discharge in helium (a) and argon (b)

Photo images of the discharges inside the tube show different structures of them. Helium discharge is diffuse and irradiates homogeneously around the tube volume. Argon discharge is filamentary and has a number of narrow bright channels radially directed.

Plasma jet

ICCD images of the discharges and plasma jets are presented in Fig. 3 – for the case of helium, and in Fig. 4 – for the case of argon. Despite that the discharge in helium has a diffusive structure, at the increasing of gas flow rate some channels with the brighter glow start to appear (Fig. 3). The plasma jet is formed by a set of so-called “plasma bullets”.

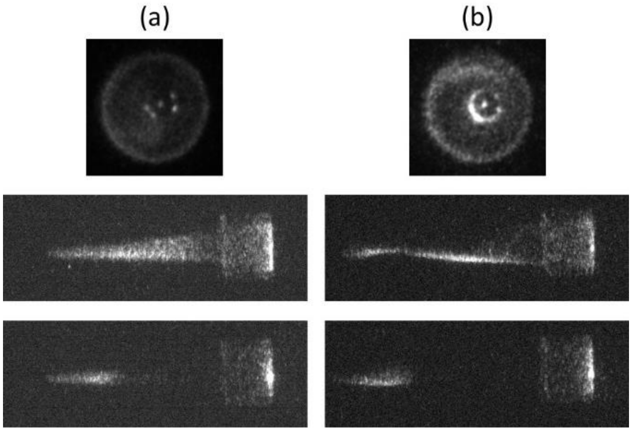


Fig. 3 ICCD images of the discharge (across the tube, exposure is of 500 ns) and plasma jet (in the line of the tube, exposure is of 100 ns) generated in helium at the gas flow rate of 1 (a) and 10 (b) l/min. The time of shooting corresponds to 15 μs from the beginning of the negative half-cycle of the discharge voltage.

The discharge in argon differs from the discharge in helium because of a high inhomogeneity with the formation of the bright filaments and broken streamers. They pass out into the surrounding air from the tube and form a luminous image of the jet that we can see. ICCD images (Fig. 4) suggest that every channel exists during about 100 ns. The streamers start to form in the environment air on the stage of discharge current extinction at saving a high electrical field in a gas flow outside the tube. The higher gas flow rate, the brighter channel structure of the discharge.

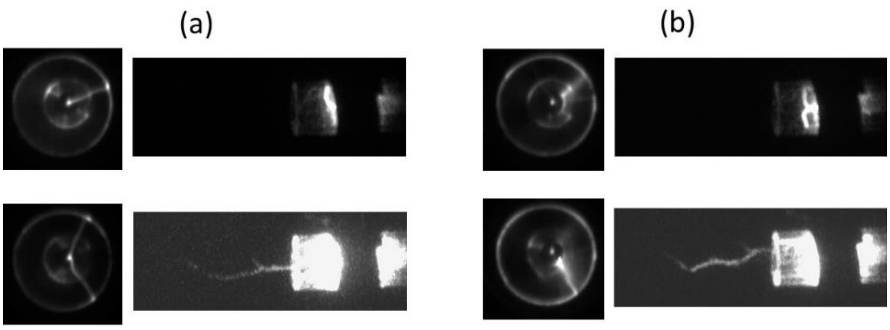


Fig. 4 ICCD images of the discharge (across the tube, exposure is of 500 ns) and plasma jet (in the line of the tube, exposure is of 100 ns) generated in argon at the gas flow rate of 1 (a) and 4.5 (b) l/min. The time of shooting corresponds to 19 (above) and 28 (below) μs from the beginning of the negative half-cycle of the discharge voltage.

Conclusion

ICCD diagnostics of the formation of the DBD plasma jets in helium and argon gas flows along with the electrical measurements of the discharges parameters has been carried out. Diffusive and filamentary structure of the DBD in helium and argon, correspondingly, have been described. The findings suggest that diffusive nature of helium discharge gets along with the narrow single discharge current peaks of 10 mA at the positive and negative half-cycles of the discharge voltage, whereas filamentary structure of argon discharge is recorded along with the numerous small peaks of the discharge current that almost indistinguishable against the displacement current.

Acknowledgements

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