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Cold atmospheric pressure air plasma jet for medical applications

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By flowing atmospheric pressure air through a direct current powered microhollow cathode discharge, we were able to generate a 2 cm long plasma jet. With increasing flow rate, the flow becomes turbulent and temperatures of the jet are reduced to values close to room temperature. Utilizing the jet, yeast grown on agar can be eradicated with a treatment of only a few seconds. Conversely, animal studies show no skin damage even with exposures ten times longer than needed for pathogen extermination. This cold plasma jet provides an effective mode of treatment for yeast infections of the skin. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2940325]

In recent years, several devices have been presented that were able to generate a cold plasma plume at atmospheric pressure in air. Different designs have been investigated for their ability to treat heat sensitive surfaces and for prospective use in medical applications. Stoeffels *et al.*[1] developed a device generating a plasma which extends to about 1 mm around a needle electrode. A plasma plume of about 1–2 cm length can be obtained in a design by Foest *et al.*[2] Another arrangement, with a 5 cm long plasma jet was recently presented by Laroussi and Lu.[3] Shin *et al.*[4] developed a plasma needle of 2–5 cm length, while Cheng *et al.*[5] presented a 1–2 cm long plasma jet with a temperature of 20–30 °C. Another arrangement, generating a 6.5 cm long plume and notably operated in nitrogen, was presented by Hong and Uhm.[6] Another nitrogen operated device that generates a 1–2 cm plasma jet was described by Dudek *et al.*[7] Other plasma torches have also been developed for plasma processing and decontamination of surfaces or semiconductor manufacturing applications at atmospheric pressure. However, these are generally running at temperatures too high to be considered for use on human tissue or any material with low melting point.[8–14]

All but one of the above plasma sources are either operated with radio frequency high voltages of several kilohertz up to several megahertz, or pulsed high voltages applied with repetition rates in the kilohertz range. Only in the configuration of Dudek *et al.* is a direct current applied to generate the plasma. Moreover, with the exceptions of Hong and Uhm's arrangement[6] and the setup used by Dudek *et al.*[7] the operation with a noble gas is required to ensure the stability of the plasma at high pressure. In all these units air is only incorporated from the jet's periphery, accounting for the air admixture to be only a few percent. The biological efficacy of the plasma flow is usually attributed to reactive species such as hydroxyl groups and atomic oxygen, and the use of atmospheric air rather than noble gas greatly enhances their generation. In addition, the operation with ambient air considerably reduces the complexity of the system. However, for direct current operation in atmospheric pressure air, glow discharges are prone to filamentation and will eventually transition into an arc.[15] A way to overcome that problem is using microdischarge geometries. By confining the glow discharge in a hollow cathode geometry with dimensions on the order of 1 mm, a stable discharge can be generated by means of a dc high voltage source.[16–18] This confinement allows the sustainment of a high pressure air dc glow discharge with gas temperatures in the range of 2000 K[19] but electron energies estimated in excess of 10 eV.[18,20]

We were successful in generating a plasma (afterglow) jet in this microhollow cathode geometry by operating it at atmospheric pressure with and into ambient air by utilizing the concept of microhollow cathode discharges.[21] The setup is shown in Fig. 1. A discharge channel through an insulator with a thickness of about 0.2–0.5 mm and a diameter of 0.2–0.8 mm separates anode and cathode. A hole with the same diameter in the cathode opens the discharge to ambient air. Air or any other operating gas is ejected from the anode side through the discharge canal. When a dc voltage of 1.5–2.5 kV is applied between anode and cathode (depending on the thickness of the insulator separating the electrodes), breakdown is initiated in the gap between the electrodes. Subsequently, a glow discharge is sustained at voltages of 400–600 V with the current limited to 20 mA by a ballast resistor of 51 kΩ. (The current can be decreased, for example, by increasing the value of the ballast resistor. A stable discharge can be sustained for currents as low as

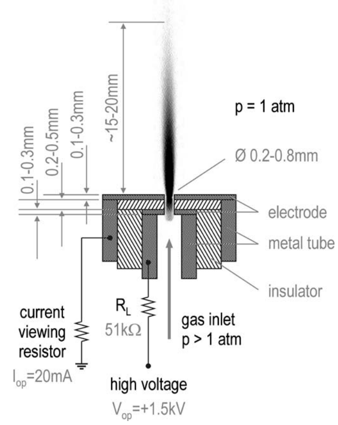

FIG. 1. Schematic of discharge geometry and electric circuit overlaid an actual negative image of the plasma jet.

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