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Atmospheric-pressure cold plasma jet for medical applications

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ABSTRACT

An atmospheric-pressure plasma jet operated with air is presented. The plasma jet device is composed of a porous alumina dielectric element, an outer electrode, and a hollow inner electrode. Microdischarges in the porous alumina evolve to form a plasma jet that reaches lengths up to several tens of millimeters as the flow rate of the working gas increases. The discharge characteristics were investigated by measuring the voltage and current waveforms and by observing the optical emissions. Sterilization of *Escherichia coli* (*E. coli*) was carried out as an example for medical applications of the plasma jet. *E. coli* cells were completely removed after exposure to the air-plasma jet, even at an exposure time of less than 60 s.

1. Introduction

Atmospheric-pressure plasmas have received much attention lately as a promising physical tool for biological decontamination and sterilization. Conventional methods of sterilization involve heat, irradiation and chemical agents. However, these methods can damage a treated substrate. In this sense, non-thermal plasmas [1–3] as a sterilization method have been used in conjunction with various microorganisms.

Many plasma jet devices that produce a cold atmospheric-pressure plasma plume have been investigated for their use with thermally sensitive materials and medical applications [4–12]. For example, Nie et al. [9] presented a simple cold plasma jet with a length of several centimeters that utilized floating electrodes in a quartz tube under high voltage. In another configuration, Deng et al. [10] described a glow discharge plasma jet and its applications in protein destruction by making use of a dielectric barrier discharge arrangement. These plasma plumes ensure the stability of the plasma through the use of a noble gas at atmospheric pressure [5,9,10]. Kolb et al. [4] reported a cold atmospheric-pressure air-plasma jet in micro-hollow cathode geometry for medical applications. Their study demonstrated that an air microplasma jet can effectively treat yeast infections on skin. The utilization of atmospheric air not only reduces the complexity of the device but also enhances the production of reactive species such as hydroxyl radicals, atomic oxygen, and nitric oxide [4,9,10]. For the inactivation of *Escherichia coli* [13,14], RF-powered atmospheric plasma effectively reduced the number of viable cells within 2 s, which suggests that it is very effective for inactivating harmful microorganisms. When the afterglow plume from a hollow slot microplasma device was applied to *B. atrophaeus endospore* [15,16] for inactivation, a ten-fold reduction was achieved within 3 min. Thus, these types of plasmas can be employed to reduce or sterilize bacteria contaminations on material surfaces [17]. The present study investigates the characteristics of an air-plasma jet from preliminary tests

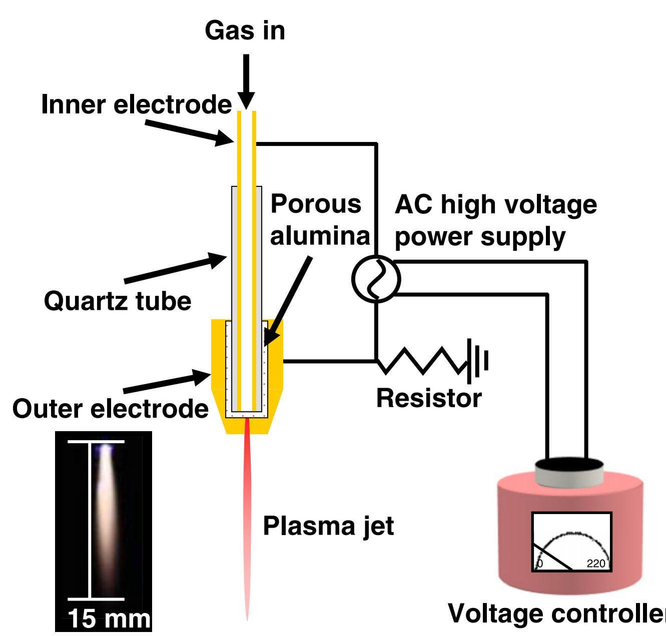

Fig. 1. Schematic presentation of the atmospheric-pressure air-plasma jet device. The inset is a photograph of the 5 slm air-plasma jet.

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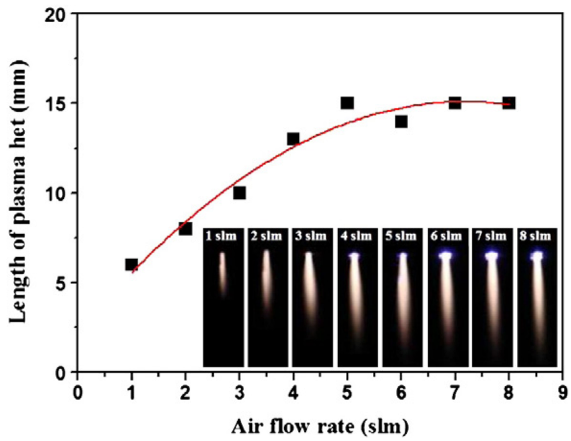

Fig. 2. Plot of the airflow rate vs. the plasma jet length. The inset shows pictures of plasma jets with different airflow rates.

and presents the experimental results of plasma sterilization tests with the *E. coli* bacteria.

2. Experimental detail

Fig. 1 shows a schematic presentation of an air-plasma jet device with a porous alumina dielectric. The plasma jet system is mainly composed of electrodes, dielectrics, and a high-voltage power supply, which is a commercially available transformer for neon light operated at 20 kHz and is connected to two electrodes. The voltage controller regulates the primary voltage of the high-voltage transformer. The inner electrode is a typical injection needle made of stainless steel with an inner diameter of 1.2 mm and a thickness of 0.2 mm; it is tightly covered with a quartz tube with an outer diameter of 3.2 mm. Porous alumina 10 mm in diameter and 20 mm in length is machined for the inner electrode, through which the quartz tube is inserted. The tip of the inner electrode and the inner surface of the porous alumina are in contact. The outer electrode is fabricated from stainless steel and has a somewhat conical shape; it is centrally perforated with a hole of 1 mm through which the plasma jet is ejected to the surrounding ambient air. As shown in Fig. 1, the porous alumina with the inner electrode is installed within the outer electrode. The discharge gap, which is 2 mm in this work, is the distance between the tips of the porous alumina and the inner electrode. It can be adjusted by controlling the depth at which the inner electrode is inserted into the porous alumina. The inner surface of the outer electrode and the tip of the porous alumina are also in contact. Air is injected into the injection needle and is then ejected through the 1 mm hole in the outer electrode via the porous alumina. The alumina used in this work has approximately 30 vol.% porosity and has an average pore diameter of 100 μm. The preparation of the alumina dielectric is described in an earlier study [18]. Once air is introduced through the inner electrode and high-voltage ac power is applied, a discharge is fired in the porous alumina between the electrodes, and a long plasma jet reaching lengths of up to several tens of millimeters is ejected into the open air, as shown in the inset of Fig. 1. *E. coli* was used as a sample microorganism in the sterilization experiments. After attachment of the *E. coli* from a cover glass, the samples were directly exposed to the plasma jet. The distance between the jet exit and the cover glass was

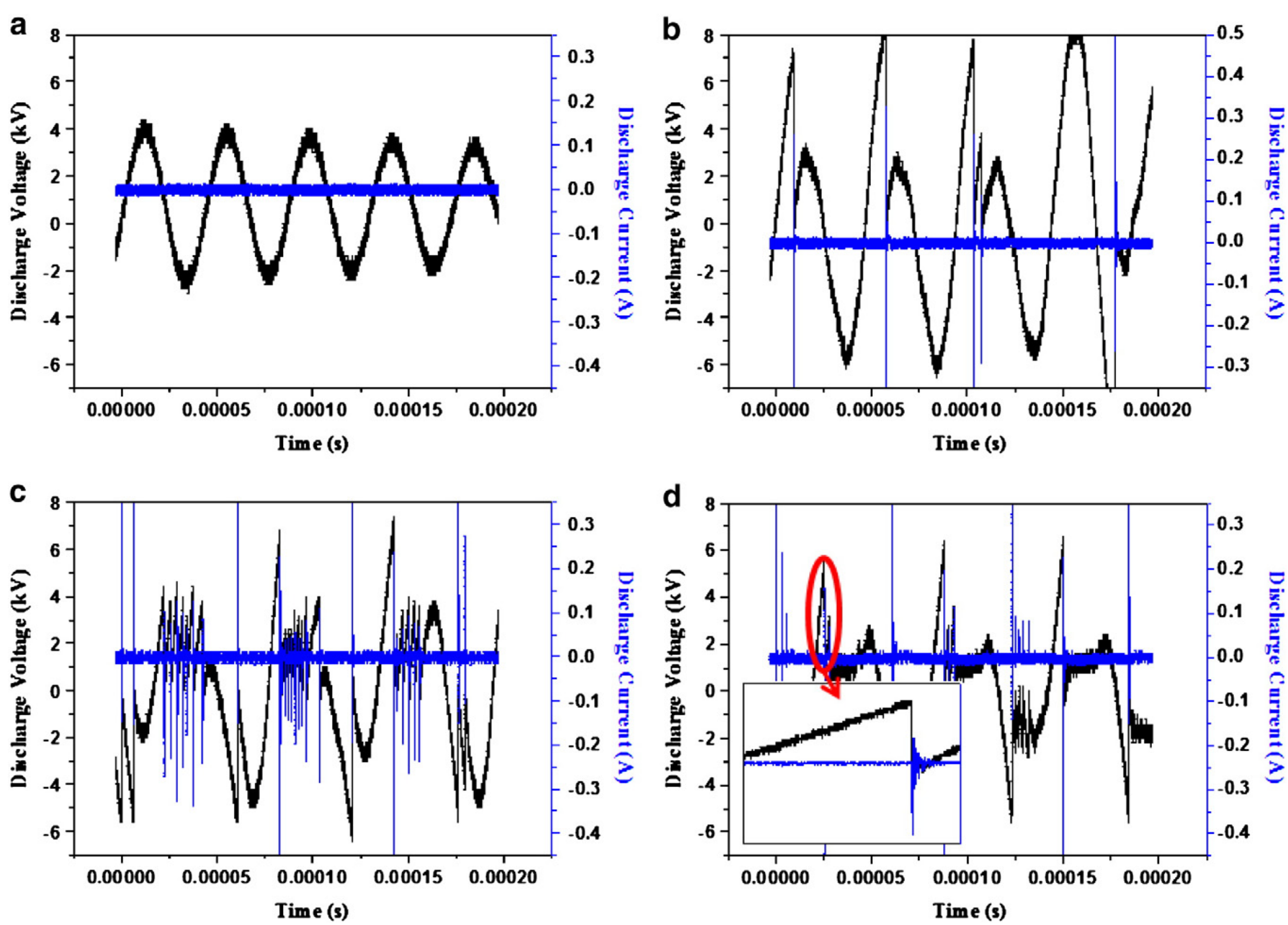

Fig. 3. Voltage and current waveforms of the air-plasma jet at different input power levels. (a) Before discharge. (b) $V_{rms} = 4.69$ kV and $I_m = 0.18$ mA. (c) $V_{rms} = 3.54$ kV and $I_m = 0.24$ mA. (d) $V_{rms} = 1.57$ kV and $I_m = 1.6$ mA.