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Electric wind induced by sliding discharge in air at atmospheric pressure

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Abstract

This paper deals with an experimental study about the electric wind induced by three different surface discharges based on dielectric barrier discharges and sliding discharges, at atmospheric pressure in ambient air. These discharges are established between two or three electrodes, flush mounted at the wall of a flat plate. A typical industrial application of such surface discharges may be, for instance, airflow control, because they may be used as an air-moving actuator, usually called "plasma actuator". First, the electrical current of these different discharges is analyzed. Secondly, the time-averaged velocity of the electric wind produced by each discharge is measured with a Pitot tube sensor. Then, their effect on the boundary layer of a low-velocity airflow is studied by particle image velocimetry (PIV).

Keywords: Electric wind; Surface sliding discharge; DBD; Corona

1. Introduction

Several studies have shown that the electric wind produced by non-thermal surface plasmas may be used for airflow control [1]. In our laboratory, two types of surface discharges are usually used as plasma actuators. The first one is a DC surface corona discharge. This DC discharge, which is usually established between two wires flush mounted at the wall of a dielectric, can produce an electric wind velocity up to 5 m/s. The produced electric wind, which flows tangentially to the wall, has shown its efficiency for airflow control in various aerodynamic conditions (for instance [1–3]). But the main drawback of this discharge is that it becomes unstable under certain atmospheric conditions. For instance, corona-to-arc transition appears when the relative air humidity exceeds a certain threshold. The second type of discharge is the dielectric barrier discharge usually called "DBD". It seems that this discharge has been first perfected at atmospheric pressure in air by Masuda and Washizu [4] for ionic charging of particles. Roth used it for the first time for airflow applications at the end of the 1990s [5]. It is now the most used discharge for airflow control [6–8]. Typically, it can generate an ionic wind up to about 7 m/s [9]. Nevertheless the plasma area extension is limited to about 2 cm. This might be a crucial drawback for large-scale applications.

Consequently, we have recently perfected a new type of electrode configuration, which consists of a three-electrode geometry [1,10]. This geometry is based on the device used to produce "sliding discharge", initially developed in pure gas for others applications [11,12]. The sliding discharge in air has the advantage of producing wide plasma sheet, which might allow large-scale applications, and this discharge is very stable, whatever the environmental conditions.

This paper deals with the electric wind induced by DBDs, established with the well-known two-electrode geometry (this actuator is usually called *single* DBD actuator), and with a new geometry based on a three-electrode configuration.

First, the electrical current of these discharges is discussed. Secondly, the electric wind induced by each discharge is measured with a Pitot tube, in order to plot time-averaged velocity profiles. In the last part of the present paper, the effect of these discharges on the boundary layer of a 5 m/s airflow is characterized by particle image velocimetry (PIV).

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2. Experimental setup

Two experimental setups have been used to produce both different discharges. The single DBD actuator is based on a two-electrode geometry (Fig. 1a). Electrodes (1) and (2) are placed on each side of a Plexiglas (PMMA) plate. The electrode placed below the dielectric plate is encapsulated with an epoxy resin. Electrode (2) is grounded while electrode (1) is excited by a sine high voltage V_{AC} generated here by a TREK 20/20C power amplifier (20 mA, 20 kHz). In such conditions, a surface plasma sheet of a few millimeters wide is generated on the upper side of the plate and close to the AC electrode (1), as illustrated by the top-view picture of the plasma in Fig. 1b. The electric wind flows tangentially to the wall, as illustrated by the arrow in Fig. 1a.

The second geometrical setup is similar to the first one but a third electrode is added above the plate (electrode (3) in Fig. 2a). Electrode (1) is still supplied by an AC high voltage, but electrodes (2) and (3) are excited by a DC high voltage V_{DC}, with the help of a DC power supply DEL ($\pm$40 kV, 3.75 mA). This DC component may be positive or negative. In one hand, if V_{DC} is negative, then a wide and luminous plasma sheet is visible between electrodes (1) and (3), as illustrated by Fig. 2b. In the other hand, if V_{DC} is positive, the visible plasma sheet is not modified, and it is still as illustrated by Fig. 1b.

All electrodes are aluminum foils ($\approx$15-µm thick, 10-mm wide, 200-mm long) stick on the surface of a PMMA flat plate (4-mm thick, 200-mm wide and 300-mm long). The currents I_2 and I_3 are measured with a 1 kΩ shunt resistor connected to a 1 MHz oscilloscope. The gap between electrodes (1) and (3) is here equal to 40 mm.

3. Electrical current measurements

In this section, measurements of the different currents (I_2 and I_3) of every discharge are presented and discussed.

3.1. Dielectric barrier discharge

Here, experiments are conducted in using the two-electrode device presented in Fig. 1a. Electrode (2) is grounded and the other one is connected to a sine high voltage V_{AC} of several kV and a frequency of 1 kHz. In such conditions, the amplitude of V_{AC} to ignite the plasma must be greater than 8 kV (16 $kV_{p\text{-}p}$). Then, above 8 kV, a plasma sheet of blue ionized air is visible on the surface of the dielectric and starting from the AC electrode (1). It appears visually to be a quasi-uniform glow, but, in fact, it consists of micro discharges distributed uniformly in time and space along the electrode length. The plasma extension increases with V_{AC}, and depends on the surface conductivity, but it is limited to a maximum value of about 20 mm [9]. For example, Fig. 3a presents a typical behavior of the applied voltage and the associated discharge current versus time, for an AC sine voltage V_{AC} of 20 kV at 1 kHz.

The current is composed of two components: a capacitive component plus the discharge current. The capacitive component is a sine component with a phase shift of $\pi/2$ compared to the voltage. It is due to the dielectric between the upper electrode and the lower one (capacitor geometry). This capacitive component is determined by measuring the capacitor before the plasma ignition. Here, its amplitude is about 2 mA. If the capacitive current is removed, we obtain only the discharge current (Fig. 3b). This one consists in current pulses,

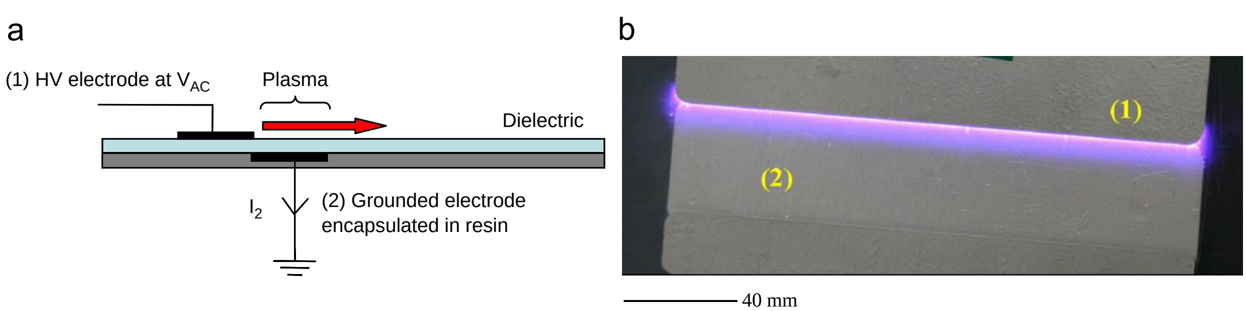

Fig. 1. Schematic side view of the dielectric barrier discharge device (a) and picture (top view) of the induced visible plasma (b).

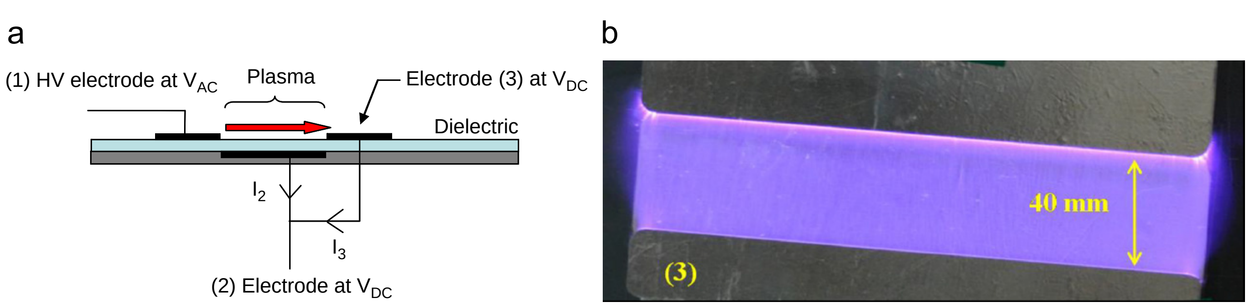

Fig. 2. Schematic side view of three-electrode device (a) and picture (top view) of the extended plasma when V_{DC} is negative (b).