Journal of Electrostatics 71 (2013) 547–550

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Measurement of the surface charging of a plasma actuator using surface DBD

D. Hong [a,*], H. Rabat [a], Y.-K. Pu [b], A. Leroy [c]

[a] GREMI, UMR 7344 CNRS/University of Orléans, 14 rue d'Issoudun, 45067 Orléans, France
[b] Tsinghua University, Department of Engineering Physics, Beijing 100084, China
[c] PRISME, University of Orléans, 8 rue Léonard de Vinci, 45072 Orléans Cedex 2, France

ARTICLE INFO

Article history:
Received 23 August 2012
Accepted 18 November 2012
Available online 3 December 2012

Keywords:
Surface dielectric barrier discharge
Charges
Plasma actuator

ABSTRACT

In order to quantify the surface charging of a plasma actuator using surface Dielectric Barrier Discharge, we propose a new equivalent circuit for this surface DBD and a new simple method allowing the measurement of the surface charging during the first half cycle and the discharging during the other half cycle. Using this method, we observed the temporal evolution of the total charge on the dielectric surface during an operation of a SDBD starting with positive cycle. We also observed the same phenomenon during an operation starting with a negative cycle. The comparison between these two observations suggests that the high electro-negativity of oxygen plays an important role in these discharges. Finally, we compare the total amount of charge transferred over a cycle under different experimental conditions and we find that the transfer is the lowest in oxygen and the highest in nitrogen.

1. Introduction

As described by Moreau in his review paper [1], non-thermal plasmas have been intensively investigated for active airflow control. After 2007, the number of teams investing on this research topic is growing. Most of these teams use a surface dielectric barrier discharge (SDBD) [2,3], since each micro-discharge (filament) in DBD discharge is self-extinguished, thus the discharge cannot become an electric arc. In case of the actuator using a DC Corona discharge [4,5], an arc can occur occasionally and it may damage the actuator and the neighboring body.

The operation of a DBD discharge is well known, we recall here very briefly: mechanically, the discharge consists of two electrodes separated by a dielectric. An AC high voltage, often sinusoidal, is applied between these two electrodes, with one of them is generally connected to ground. With increasing voltage, the electric field near the high voltage electrode increases and microdischarges are initiated when the electric field exceeds the critical field. Each micro-discharge deposits charges on the dielectric surface which induce an electric field opposite to that generated by the applied high voltage. This opposition leads to the extinction of the micro-discharge whose lifetime is several tens nanoseconds. If the applied voltage rises enough yet, the total electric field may again exceed the critical field and another micro-discharge begins. Moreover, a micro-discharge has a very small size, the deposition of charge is local. Thus the electric field should not be spatially homogeneous. Therefore, a micro-discharge can be initiated independently of others. Generally, when the voltage reaches its maximum value, all the micro-discharges stop, then when the voltage decreases, the local field increases due to that generated by the charges deposited on the surface and the discharge restarts when the critical field strength is reached.

Given the operation of the DBD, it is clear that the extent of the deposited charge is paramount. However, because of the difficulty of this measurement, there are still very few published papers on this subject. Recently, Font et al. [6] have measured the surface potential in a DBD actuator using a V-dot probe technique, while Opaits et al. [7] have measured the surface potential due to the residual charge after the operation of their actuator, using an electrostatic voltmeter. They did not calculate the residual charge, because a two dimensional scan of the surface potential is necessary for such a calculation [8,9].

In this paper, we present a new technique for measuring the total charge deposited on the surface of the dielectric as a function of time. In the next section, we present the experimental setup and experimental conditions; then we describe the proposed measurement method. In the third section, results and discussion will be presented.

2. Experimental setup and equivalent circuit

In this study, the dielectric is composed of two Kapton sheets of 35 μm in thickness with a Mylar sheet of 0.5 mm placed in the middle. The dielectric thus constructed is called KMK. All the

---

* Corresponding author.
E-mail address: dunpin.hong@univ-orleans.fr (D. Hong).

0304-3886/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.elstat.2012.11.017

measurements presented here were made with the KMK dielectric. Two parallel strip electrodes are placed on each side of the dielectric. An electrode is connected to the high voltage and the other is connected to ground via a capacitor of suitable capacitance. The second electrode is covered with a Kapton sheet to inhibit the discharge on this side. The width of the strips and their relative position can be easily changed from one experiment to another. Generally for actuator applications, we use the configuration called 6–3–6, which means that the width of the two strips was 6 mm and the gap between the two electrodes is 3 mm [10,11]. In this study, the electrode exposed to air has a width of 6 mm, while the buried electrode has a width of 50 mm (see Fig. 1). The area of the facing surface of the two electrodes S_{ES} is about 720 mm^2. The capacitance of the corresponding capacitor is about 57 pF knowing the relative permittivities of Kapton and Mylar. Actually, the true value should be slightly less because the thickness of adhesive was not taken into account.

To measure the active power, the method “Lissajous Figure” is generally used by using a capacitor placed between the buried electrode and ground [2]. In this study, such a capacitor is used to measure the deposited charge. The capacitance of this capacitor, named C_m, is 2 nF, and is much larger than the capacity C_{ES} due to the electrodes. So, the presence of this capacitor has a negligible influence on the discharge. With a relatively low voltage, for instance 450 V, there is no initiated discharge. The circuit of Fig. 2 is reduced to a voltage divider and we find a ratio of $k = 44.8$ between U_{HV} and U_m. We deduce a value of 46 pF for C_{ES} because $C_{ES} = C_m/(k-1)$. This experimental value is quite close to the value previously estimated.

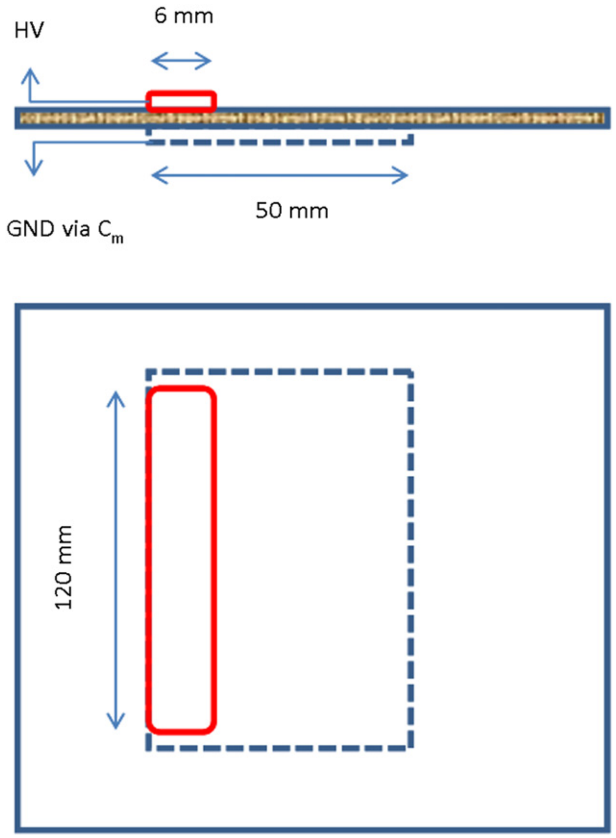

Fig. 1. The geometrical configuration of the two electrodes of the actuator. The narrower electrode is air exposed and connected to HV, while the larger electrode is buried and connected to ground via a capacitor for measurement.

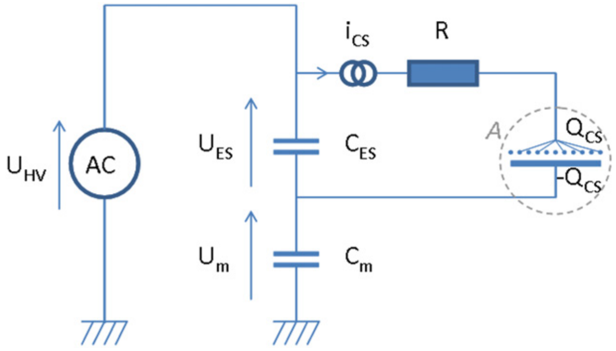

Fig. 2. The electrical setup and the equivalent circuit. Note that the component A represents the actuator part where the charges are localized on dielectric surface.

To analyze the operation of such a SDBD, similar equivalent circuits have been used by many authors. Pons et al. [12] considered the SDBD as a resistor R in parallel with a capacitor C_3 (notation used in that paper) and the assembly is in series with a capacitor C_2 (notation used in that paper). In this paper, we propose to consider the discharge as a variable current source with a resistor R in series to take into account the dissipated power. The current source deposits randomly the charges on the surface of the dielectric.

Charge distribution is necessarily inhomogeneous and the total amount of charges is called Q_{CS}. This quantity increases when the current is positive, decreases when the current is negative. We assume, like all other authors, that the presence of this charge Q_{CS} induces a charge of same amount but of opposite sign, that is to say $-Q_{CS}$. Therefore, regarding the capacitor C_m, the electrode connected to the DBD contains an electric charge of $Q_m = Q_{CS} + Q_{ES}$, where Q_{ES} is the charge stored in the capacitor C_{ES}, that is to say, the product of U_{ES} with C_{ES}.

Since $U_{ES} = U_{HV} - U_m \approx U_{HV}(k-1)/k$ and $Q_{CS} = Q_m - Q_{ES}$, one deduces:

$$Q_{CS} = U_m C_m - (U_{HV}(k-1)/k)\, C_m/(k-1) = (U_m - U_{HV}/k)\, C_m$$

Therefore, the measurement of U_m and U_{HV} as a function of time gives information about the temporal evolution of the total amount of charge on the surface of the dielectric.

In this work, the experiments were performed with high voltage U_{HV} of 6 kV in amplitude and of 1 kHz in frequency which are typical parameters used in our other studies [10,11]. The high voltage U_{HV} is measured using a Tektronix P6015 probe and the voltage U_m is measured with a voltage probe whose input impedance is 100 MΩ. The time constant calculated with this impedance and the value of capacitance C_m (2 nF) is 200 ms and measuring a voltage across the capacitor as a function of time allowed to obtain a time constant of about 240 ms. This means that the capacitor is systematically emptied between two series of measurements. The signals were stored using a LeCroy oscilloscope (HRO 66Z, 600 MHz, 12 bits) with in general 10,000 samples over 10 ms. Some measurements were made under a controlled atmosphere with pure nitrogen or pure oxygen gas. The device for theses latter experiments has been described in Tong et al. [13].

3. Results and discussions

In Fig. 3, a typical result is reported. The values given in this paragraph may vary slightly from one shot to another. The first curve in dotted line shows the applied high voltage as a function of time, while the second curve gives the total charge on the surface as a function of time.

The high voltage is applied at time $t = 0$ ms, during the first 10 μs, the discharge is not initiated and there is no charge on the