Patterns of Plasma Filaments Propagating on a Dielectric Surface

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Abstract—The special behavior of dielectric barrier discharges (DBDs) and surface DBDs (SDBDs) in argon at atmospheric pressure is presented. Images show complex discharge patterns due to the interaction of the microdischarges and the dielectric. The pictures presented in this paper correspond to only one current peak and exhibit the complexity which lies in a current peak in a barrier discharge. Discharge patterns in volume and SDBDs are compared for the positive and negative polarities of applied voltage. By impacting the dielectric surface, the streamer branches to form the famous Lichtenberg figures.

Index Terms—Argon, atmospheric pressure, branching, dielectric barrier discharge, iCCD imaging, Lichtenberg figures, plasma filaments, surface dielectric barrier discharge.

Dielectric barrier discharges (DBDs), also known as barrier or silent discharges, and surface DBDs (SDBDs) are widely used for industrial applications [1], [2]. At 1 atm (for gaseous gaps on the order of a few millimeters or centimeters), DBDs and SDBDs are mainly constituted of nonequilibrium, transient, and unstably triggered plasma filaments, which are known as microdischarges [3]. The short duration of a few tens of nanoseconds, the small radii, and the unpredictability of these filaments make them difficult to study experimentally. Recently, for cylindrical DBD configurations, it was shown that most of the energy is transferred via a few large amplitude current peaks due to the phenomena called collective effects [4]. When the discharge is ignited directly onto the surface (SDBD), collective effects appear as the self-triggering of synchronous plasma filaments [5], [8]. Residual surface charge also strongly influences the spatial organization of the volume microdischarges [6]–[8].

The images presented in this paper show discharges in argon at 1 atm (impurities of <1 ppm). The same 50-Hz sine wave power supply and gas flow rate of 500 sccm were used to generate both the SDBDs and the DBDs. The pictures in Figs. 1 and 2 have been taken by using an Andor iStar 734 CCD camera equipped with an YF5028 Pentax lens and are shown in false colors. The electrical behavior of the DBDs and SDBDs in this paper consists of the appearance of several current peaks during the positive half cycle, and every picture presented in this paper corresponds to an event associated with only one current peak. The exposure times were 2 ms for the pictures in Fig. 1 and 500 µs for the pictures in Fig. 2, which have not been seen to cause any changes in the pictures since the lifetime of the microdischarges is much shorter (about 50 ns).

In Fig. 1, the discharge was generated by using a configuration with a tungsten “tip cylinder” over a Pyrex plane, and salt water was used as a counterelectrode to allow imaging through it [8]. The three pictures on the top in Fig. 1 were taken beside the reactor and in perspective from an angle, whereas the three pictures at the bottom were taken through the water and the dielectric. Although [8] showed the appearance of several filaments in volume and at the same time in air, one sees mainly only one filament per current peak in argon during the positive half cycle. A second current peak occurs rarely in the positive half cycle [Fig. 1(b)], but when it does, the microdischarge features are very different from that of the first current peak. In this special case, the diameter of the dielectric plate is too small to contain the discharge, causing the plasma filaments to leave the plate and creep onto the sides of the reactor, which are made of Pyrex. Although both the first and second current peaks have about the same value (0.7 A), the images are quite different. We suspect that the discharge structure of the second peak is affected by the residual surface charge deposited by the first peak. Fig. 1 shows that in the filament in the gas finishes on the dielectric with significant branching on the surface (Lichtenberg figures), which is a characteristic of both the first and second current peaks. The discharges in negative half cycles are much more diffuse and interact very differently with the surface than the microdischarges in positive half cycles. In order to understand the role of the surface on the self-patterning of the plasma filaments, discharge structures on the dielectric with SDBD devices have been studied.

Fig. 2 shows the pictures of such discharge. The setup consists of two disklike electrodes glued to both sides of a 2-mm-diameter glass plate. The upper electrode, with a diameter of 2 cm, is connected to the power supply. The lower electrode, with a diameter of 8 cm, is grounded. In such configuration, the plasma initiates only on the upper side. Fig. 2(a) shows the picture of a positive current peak, which is initiated at 2 kV, and Fig. 2(b) shows a negative peak, which is initiated at −2 kV. The filaments in Fig. 2(a) are synchronous, similar to what was shown in air [5]. Unlike in air, the filaments are not in parallel with argon and exhibit a strong and sophisticated surface branching. Fig. 2(b) shows a single plasma filament initiated during the negative phase, transferring a large amount of charge (71 nC). The central channel is very bright and leads to a complex branched pattern.

The images presented in this paper show the discharge structures on the dielectric, which are initiated either with a
Filament in the gaseous gap reaching the dielectric (Fig. 1) or the electrode on the dielectric surface (Fig. 2). In both cases, there is significant branching on the dielectric (Lichtenberg figures), and in fact, a single current peak reflects the behavior of many filaments. Generally, negative polarity leads to more diffuse discharges. In SDBDs, they change into filaments when the charge increases [the case in Fig. 2(b)], and then, the discharge is composed of one main channel that is close to the cathode and many secondary filaments.

REFERENCES


