Properties of Atmospheric Pressure Microdischarges in a Surface Dielectric Barrier Device

I. Biganzoli[1], R. Barni[1], C. Riccardi[1]

[1]*Dipartimento di Fisica Occhialini, Universita' degli Studi di Milano-Bicocca,*
p.za della Scienza, 3 I-20216 Milano, Italy

Dielectric barrier discharges (DBDs) are widely employed as cold plasma sources for plasma processing and applications [1]. The presence of an insulating layer interposed between electrodes prevents the formation of a diffuse plasma, inducing electrical discharges to assume the form of intermittent, fast and localized channels where current flows. In a Surface Dielectric Barrier Discharge (SDBD) these microdischarges develop in a thin air layer just above the dielectric material surface. Besides other applications, this feature makes these devices interesting for aerodynamics, being particularly suitable in order to energize the boundary layer of airflows surrounding objects [2]. As a matter of fact, many experimental studies have proved that SDBDs can generate an induced airflow of several m/s [3]. Here we present experimental results concerning the temporal and spatial structure of single microdischarges produced in a SDBD developed in our laboratories.

The device consists of a pair of electrodes placed at the opposite sides of a square dielectric panel (3 mm thick) in the asymmetrical configuration displayed Fig.1. The lower electrode is grounded and buried in a plexiglass frame, in order to prevent discharges on the lower side.

The upper electrode (aluminium, 80 μm thick) is connected to the secondary coil of a transformer, whose primary circuit is linked to a tunable sine-wave generator. The whole system constitutes a resonant circuit. The delivered voltage and frequency are controlled by the power level setting [4].

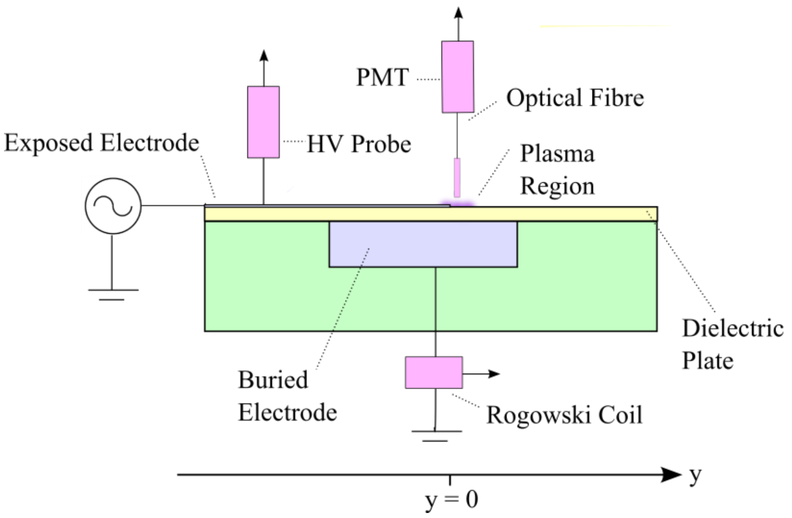

Fig.1 –Experimental layout of the SDBD device. The origin of the y coordinate corresponds to the edge of the exposed electrode.

In order to investigate the properties of individual microdischarges we have collected the emitted light with a fast photomultiplier (PMT), as well as the electrical current flowing through the buried electrode.

At this purpose, current signals have been measured with a fast current probe (Rogowski coil, 100 MHz bandwidth [5]). A PMT by Hamamatsu (H10721-210, 0.6 ns rise time) was chosen for its fast temporal response and high sensitivity. Eventually, we have used a HV probe (Tektronix P6015A, 75 MHz bandwidth) to measure the voltage at the exposed electrode. This was used to provide the phase reference of the discharge cycle too. The outputs of the three probes were registered with a large bandwidth digital oscilloscope (Agilent MSO8104A, sampling rate 2 GSa/s).

We have recorded the spatial profile (along the y coordinate) of the emitted light over several voltage cycles. Since the light emitted from each microdischarge appears in the PMT output as a few nanosecond pulse, we have calculated the average microdischarge light intensity falling into a particular phase interval, as well as the integrated light intensity (by adding the amplitudes of all the recorded pulses). We point out that light is emitted only during two disjointed active phases, known as Backward Discharge (BD) and Forward Discharge (FD), depending if the voltage is increasing or reducing. During the FD electrons are pushed in the direction of the dielectric surface, and in the course of the backward stroke they tend to return back towards the exposed electrode, whereas positive ions move towards the buried one [6]. We have chosen as the zero phase-reference the voltage minimum, so the BD manifests in the phase interval 0°÷180°.

Fig.2a shows the spatial-phase map of the mean microdischarge light intensity. It is clear that the brightest microdischarges happen in the region straddling the exposed electrode edge and

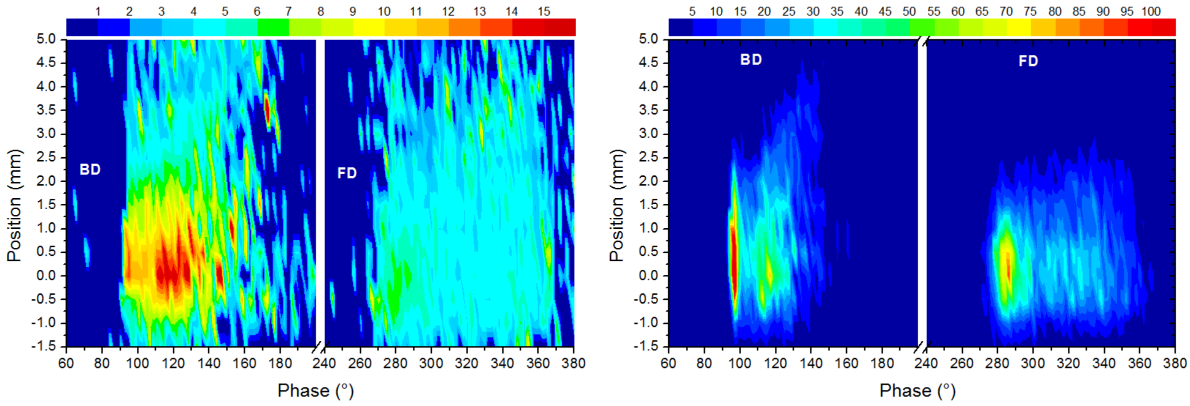

Fig.2 –Single microdischarge mean light intensity (a) and integrated light intensity (b), as a function of the phase and of the y position (voltage amplitude 8.5 kV at a frequency of 40.7 kHz).

in the first half of the backward stroke. Nevertheless, a few intense microdischarges have been detected also in the final stage of the BD and further away on the dielectric surface. On the contrary, the FD mean intensity is smaller and almost homogeneous in the whole time window and spatial region.

Fig.2b shows the spatial-phase map of the integrated light intensity. Here the highest intensity is detected at the beginning of the two strokes. During the rest of the backward discharge the total plasma emission is weaker, but the discharge progressively spreads away from the exposed electrode, thus increasing the effective volume involved in the discharge processes. Such a spreading does not occur during the FD, but the time window associated to it is significantly longer.

In Fig.3a we show the number of microdischarges and the total light they emit, as a function of the phase, obtained by collecting light from the whole discharge region.

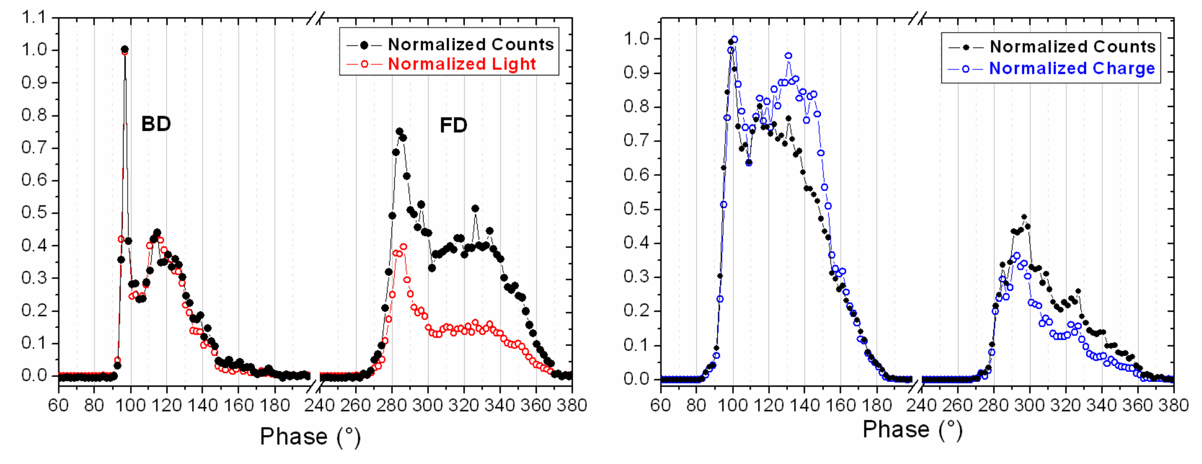

Fig.3 – (a): Number of light pulses and total light intensity of the discharge, as a function of phase. (b): Number of current pulses and total charge, as a function of phase. Values are normalized to their maximum.

The highest values occur at the beginning of the two strokes. In particular, a considerable signal is associated to the BD breakdown, when a great amount of microdischarges happens within a few hundred nanoseconds after the beginning of the backward stroke. During both the BD and FD, the trends with phase of the number and light signals are quite similar. Moreover, the total light associated to the two semi-cycles is comparable, even though the number of light pulses detected in the course of the FD is greater.

Fig.3b shows the number of electric current pulses and the total charge they carry, as a function of the phase, obtained by measuring the current coming from the whole buried electrode. These data reveal that a strong asymmetry exists in the charge transported by current microdischarges: the backward contribution is 80% (and equal to 40 nC at 8.5 kV). This difference is mainly due to the number of current pulses detected during the two strokes. As a matter of fact, the trends with phase of the number of current microdischarges and of the charge moved by these current pulses are quite similar (Fig.3b). Only in the second half of the BD (120°-150°), the number of microdischarges reduces with phase, contrary to the total charge. This is related to a change in the distribution of the charge transported by each current pulse, which is displayed in Fig.4. In particular, at later BD phases, the fraction of events carrying more charges increases.

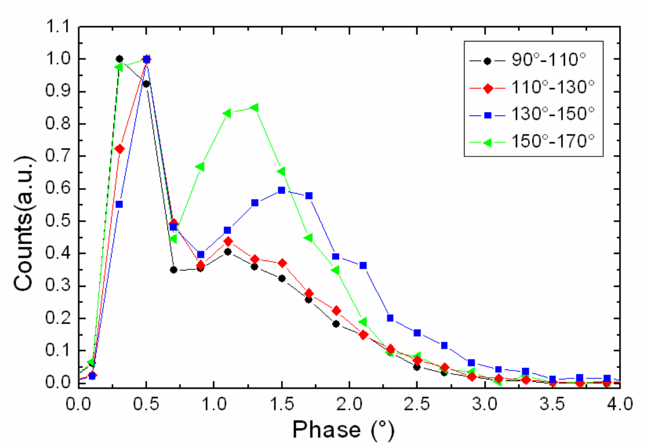

Fig.4 – Relative frequency distribution of the charge transported by single current microdischarges detected at different phases of the backward stroke.

In conclusion, some plasma characteristics can be inferred from both the time-resolved current and light measurements, detecting single microdischarge events. In particular, asymmetries between the backward and forward strokes have been discussed.

References

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