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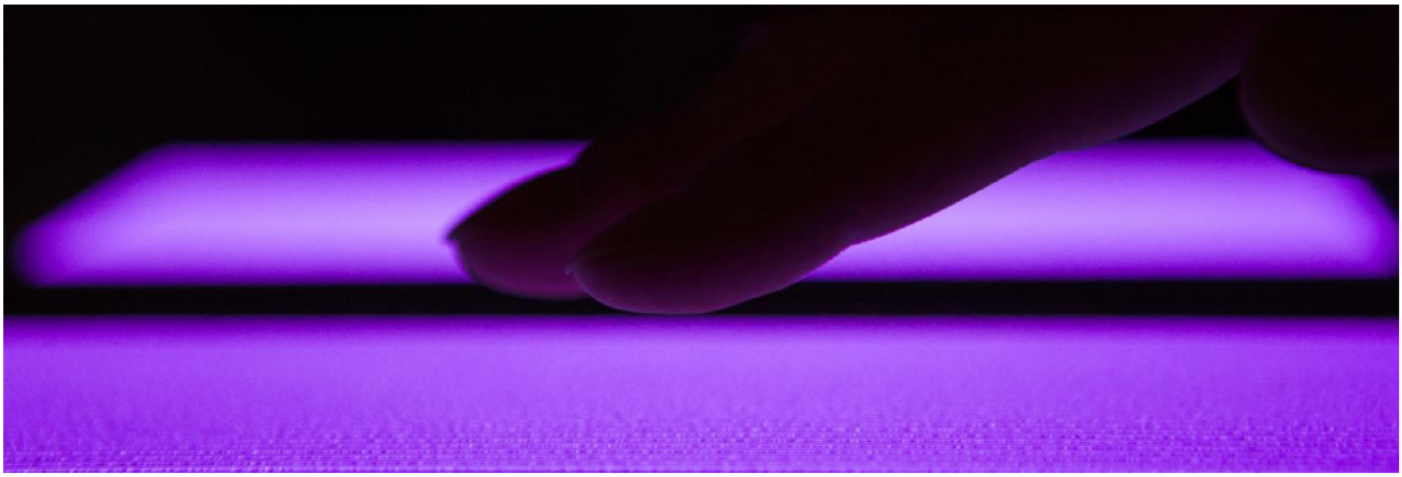
with joint COST TD1208 workshop Non-Equilibrium Plasmas with Liquids for Water and Surface Treatments



Book of Contributed Papers

Masaryk University

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Non-Equilibrium Plasmas with Liquids

for Water and Surface Treatment

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CROSS-CORRELATION SPECTROSCOPY STUDY OF THE BREAKDOWN MECHANISM IN ATMOSPHERIC PRESSURE AIR TRANSIENT SPARK DISCHARGE

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A streamer-to-spark transition in a self-pulsing transient spark (TS) discharge of positive polarity in air was investigated using cross-correlation spectroscopy. The entire temporal evolution of the TS, including the primary streamer, the secondary streamer, and the transition to spark was recorded at several wavelengths of spectral bands or lines corresponding to the second positive system of N_2 (337.1 nm), the first negative system of N_2^+ (391.4 nm), and to atomic oxygen (777.1 nm) and nitrogen (746 nm). The obtained results contribute to a deeper understanding of the breakdown mechanism in air at high repetition frequencies.

Keywords: cross-correlation spectroscopy; transient spark; breakdown mechanism

1 Introduction

The Transient Spark (TS) is a dc-driven self-pulsing discharge with the typical repetition frequency 1-10 kHz [1-3]. The TS is initiated by a primary streamer, followed by a secondary streamer generating a short spark current pulse with a maximum amplitude in the range of a few Amps. The TS spark current pulses are sufficiently short (~10-100 ns), thus significant heating of the gas in the generated plasma is avoided. Plasma generated during the spark phase of the TS is therefore highly reactive with the electron density as high as 10^{17} cm^{-3} [4]. These reactive plasma properties predetermine the TS for several biomedical and environmental applications [5, 6]. However, further basic research of TS is needed, e. g. for the explanation of TS peculiarities changes with increasing repetition frequency [7].

Based on the significant shortening of the streamer-to-spark transition delay time [7], a change of the breakdown mechanism in the TS with the increasing frequency is assumed. There are probably several 'memory' effects (especially pre-heating, residual ions and changes of the gas composition by previous TS pulses) in the gap. Residual space charges also influence the development of single dielectric barrier discharges [8].

2 Experimental

In this paper we explore the entire evolution of the TS discharge from the primary streamer to the spark breakdown at a repetition frequency in the range 8-10 kHz. Cross-correlation spectroscopy was used [9], since it is very sensitive and suitable for the investigation of self-pulsing discharges unless other techniques like iCCD cameras, which require precise synchronization with the discharge event. Figure 1 shows the schematic of the used

experimental setup. A novel CCS device as described in [10] was used. It enables multi-dimensional TC-SPC and thus automatic scanning of the discharge gap via imaging on a rotating mirror.

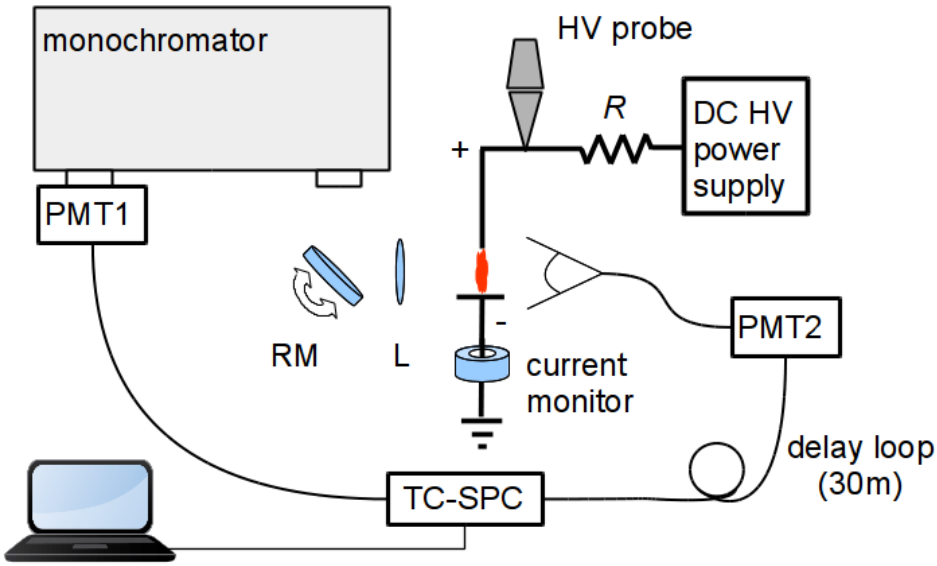

Fig. 1: Schematic of the experimental setup, PMT – photo multiplier, TC-SPC – time correlated single photon counting board, RM – rotating mirror, L – lens, R – external resistor.

The positive polarity TS was generated in atmospheric pressure air between steel electrodes in point-to-plane configuration with the gap length d = 4 mm, by a DC HV power supply connected to the electrodes via a series resistor R = 6.85 MΩ (Figure 1). The discharge voltage was measured by an HV probe (Tektronix P6015A) and the discharge current was measured by a current monitor (Pearson Electronics 4100 1V/A). Both voltage and current signals were recorded by a 1 GHz digitizing oscilloscope (Tektronix DPO 4104).

3 Results and Discussion

The entire temporal evolution of the TS, from the primary streamer to the transition to spark was obtained. The emission from the discharge at several wavelengths was recorded (Figure 2), corresponding to the second positive system (SPS) of N_2 (0-0 transition at 337.1 nm), the first negative system (FNS) of N_2^+ (0-0 transition at 391.4 nm), and the emission lines of atomic oxygen (777.1 nm) and nitrogen (746 nm).

During the primary streamer (time ~0-8 ns in Figure 2), the emission of the SPS dominates, but the emission of the FNS was also observed. The interesting fact of the FNS being constantly ahead of the SPS signal during the streamer propagation was discussed and clarified in detail in [11].

A transition to the spark (developed at time ~13-27 ns) within ~5 ns after the primary streamer was observed. The spark itself was preceded not only by the primary streamer, but also by a feature (time ~8-11 ns in Figure 2) that probably represents a secondary streamer [12]. During this period, only the emission of the 2nd positive system of N_2 was observed.

During the spark phase, only the emission of the 1st negative system of N_2^+ and atomic lines were detected. This can be partially attributed to a high degree of ionization and dissociation of molecular species during the spark phase. Moreover, the lack of the SPS emission could be explained by lower electron mean energy during the spark phase, so that the direct electron impact excitations are not efficient. On the other hand, the emitting atoms and N_2^+ ions are probably populated by different stepwise mechanisms.

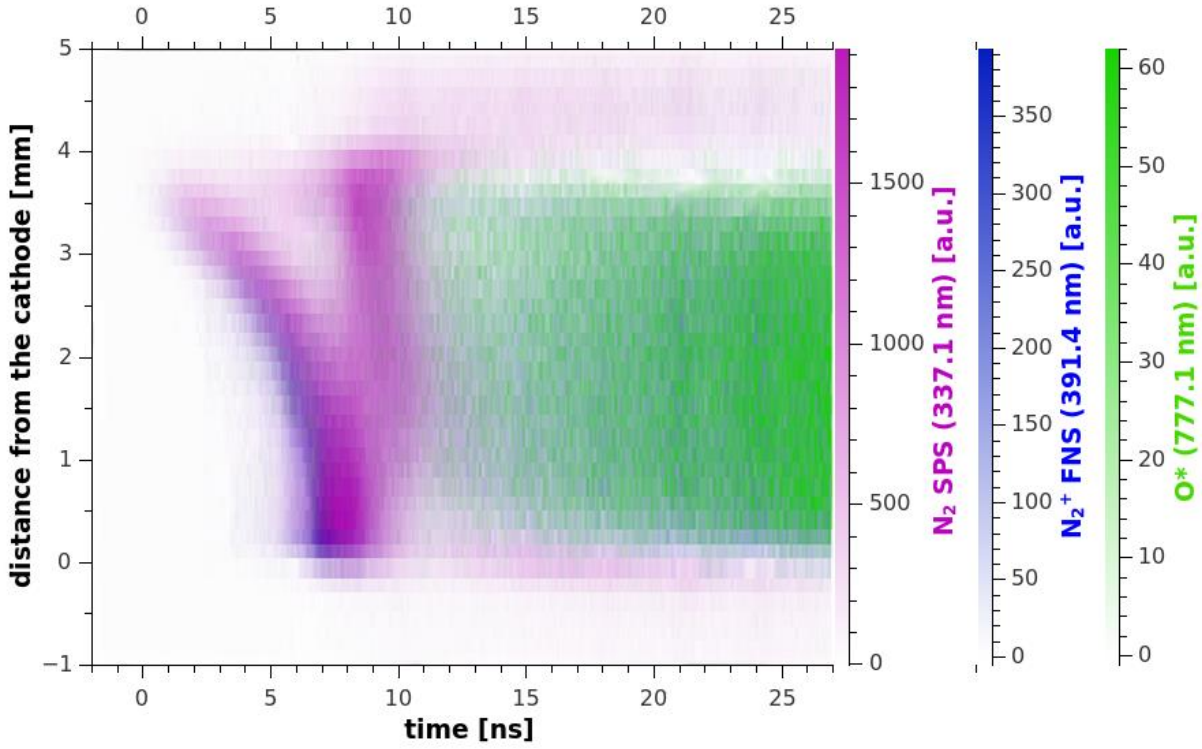

Fig. 2: Cross-correlation spectroscopy record of the TS evolution, positive polarity (anode at the top), repetition frequency 8-10 kHz, gap 4 mm.

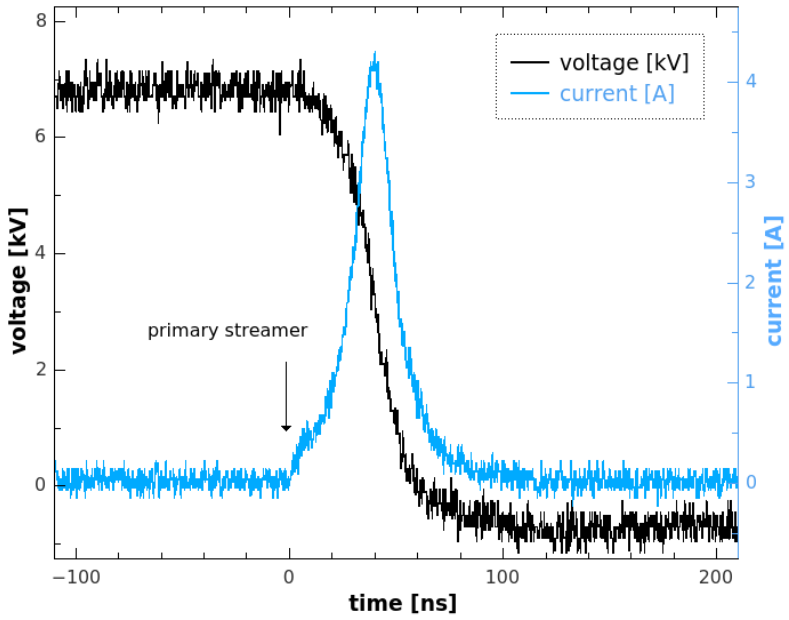

Fig. 3: Typical waveforms of transient spark discharge, repetition frequency 8-10 kHz, gap 4 mm.

The high degree of ionization results from a narrow discharge channel (~50-150 μm [4]) and a high current (Figure 3) during the TS spark phase. Subsequently, the high density of electrons and ions can significantly contribute to the dissociation of the molecular species via dissociative electron-ion recombination reactions:

$$e + O_2^+ \rightarrow O + O\ (O^*), \qquad (1)$$

$$e + N_2^+ \rightarrow N + N\ (N^*). \qquad (2)$$

4 Conclusion

We investigated the streamer-to-spark transition mechanism in the Transient Spark (TS) discharge in atmospheric pressure air using cross-correlation spectroscopy. The TS is a self-pulsing discharge initiated by a primary streamer followed by short spark current pulse. The TS repetition mean frequency can be controlled in the range 1-10 kHz by the applied voltage, but the self-pulsing frequency is not regular, which makes the synchronized diagnostics of the TS difficult. The cross-correlation spectroscopy proved to be a suitable technique for the investigation of such self-pulsing discharges.

Our obtained results show that the transition from the streamer to the spark proceeds within about 10 ns. This could be attributed to the fast propagation of the secondary streamer through the whole gap, probably due to memory effects – the pre-heating of the gas in the gap, or the accumulation of species such as oxygen atoms generated by the previous TS pulses. Further research is required, including kinetic modeling to verify this hypothesis.

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