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Cross-correlation spectroscopy study of the Transient Spark discharge

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A streamer-to-spark transition in a self-pulsing transient spark (TS) discharge of positive polarity 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.

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 transforming to a short spark current pulse. The TS spark current pulses are sufficiently short (~10-100 ns) to avoid thermalization in the generated plasma. 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, for example for the explanation of TS changes with increasing repetition frequency [7]. Based on the significant shortening of the steamer-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, pre-ionization and gas composition changes by previous TS pulses) in the gap. The pre-ionization also influenced the development of surface dielectric barrier micro-discharge [8, 9].

In this paper we explore the entire evolution of the TS discharge from the primary streamer to the spark breakdown at high repetition frequency 8-10 kHz. Cross-correlation spectroscopy was used [10]: a time-resolved optical diagnostic technique suitable for self-pulsing discharges that are difficult to study by other methods needing precise synchronization with the discharge event. Figure 1 shows a schematic of the used experimental setup.

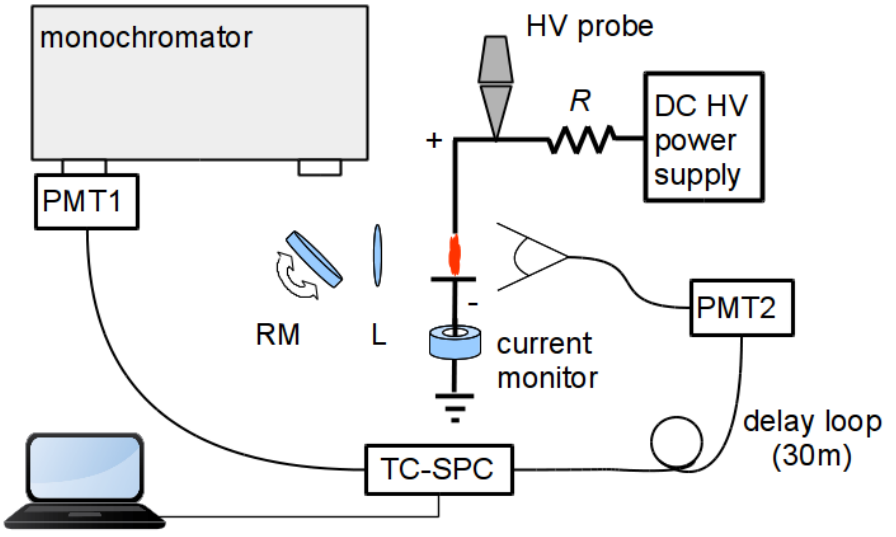

Fig. 1:
Schematic of the experimental setup, PMT – photo multiplier tube, TC-SPC – time correlated single photon counting board, RM – rotating mirror, L – lens, *R* – external resistor.

The entire temporal evolution of the TS, including the primary streamer, the secondary streamer, and 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 (337.1 nm), the first negative system (FNS) of N_2^+ (391.4 nm), and the emission lines of atomic oxygen (777.1 nm) and nitrogen (746 nm). The interesting fact of the FNS being constantly ahead of the SPS signal during the primary streamer propagation (time ~0-8 ns in Figure 2) was discussed and clarified in detail in [11].

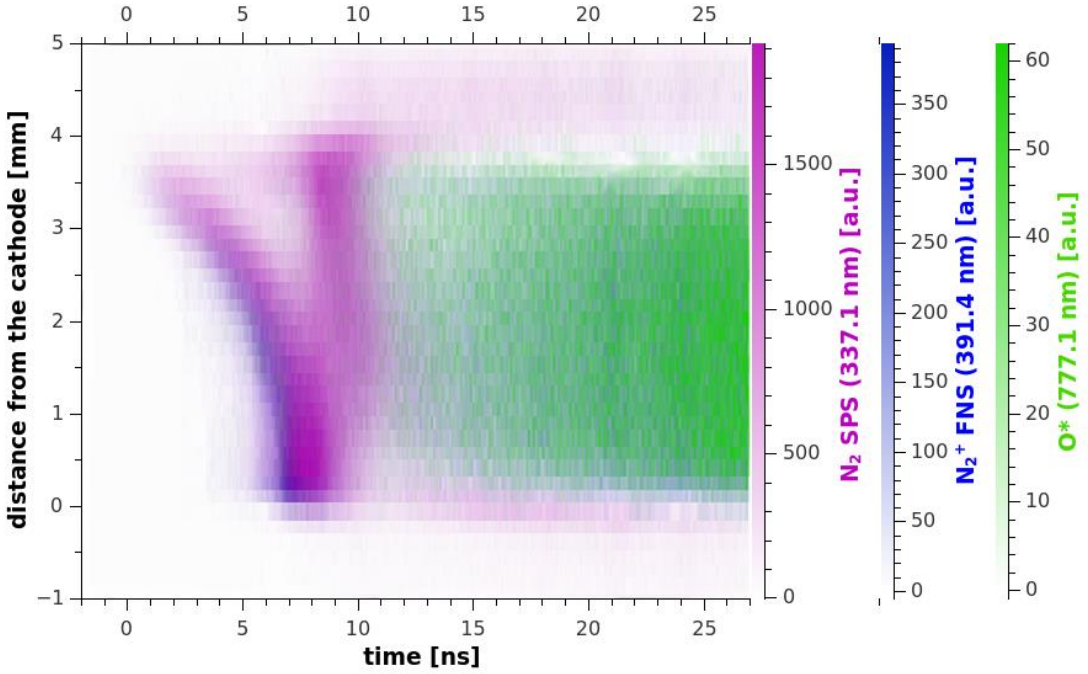

Fig. 2: Cross-correlation spectroscopy record of the TS evolution, positive polarity (anode at the top), repetition frequency 8-10 kHz, gap 4 mm.

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 attributed to a high degree of ionization and dissociation of molecular species during the spark phase.

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