On the discharge mechanism and electric field strength development in negative corona Trichel pulses in atmospheric pressure air

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A time-correlated single-photon counting technique has been used to examine the mechanism of repetitive Trichel pulse in negative corona discharge in atmospheric pressure air. Long lasting pre-breakdown phase in the free space apart from the cathode point electrode was detected. The propagation of positive as well as negative streamers was recorded and the corresponding velocities were estimated. Calibration of the single-photon counting device by means of emission from a Townsend discharge configuration the development of the reduced electric field strength E/n within the Trichel pulse was determined quantitatively. The obtained maximum of E/n of 3300 Td at the cathode after the positive streamer impact is in good agreement with theoretical results.

The self-pulsing mode of the negative corona at certain condition was reported for the first time by Trichel [1] and its development has been the object of controverse discussions. The occurence of the positive streamer (also named as ionizing front or wave) within the breakdown was discussed by means of current pulse measurements and simulations [2-4]. However, the complete simultaneous experimental recording of the spatio-temporal development of the discharge emission including measurements of the pre-breakdown phase, the electric field development and corresponding current pulse is still missing. Nowadays however, this is possible due to the application of highly sensitive and fast time-correlated single-photon counting (TC-SPC) techniques, also known as cross-correlation spectroscopy (CCS, [5]). Here, the CCS has been used to examine the mechanism of repetitive Trichel pulses. Based on the fact, that the ratio of the band intensities of 0-0 vibrational transitions of the first negative system of nitrogen with the band head at 391.5 nm (FNS) and the second positive system of nitrogen with the band head at 337.1 nm (SPS) shows strong dependency on E/n [5,6], the spatio-temporal development of this basic plasma parameter can be done. For quantitave measurements the CCS has been calibrated by the emission from a Townsend discharge according to the proven kinetic model [5,6]. The measurement of the Trichel pulse and the E/n calibration has been performed on the same setup, differing only by the adjustment of a mirror (see Fig.1 and its description). Experimentally, we have obtained the E/n values with high resolution - independent on simulation results or solving of Boltzmann equation.

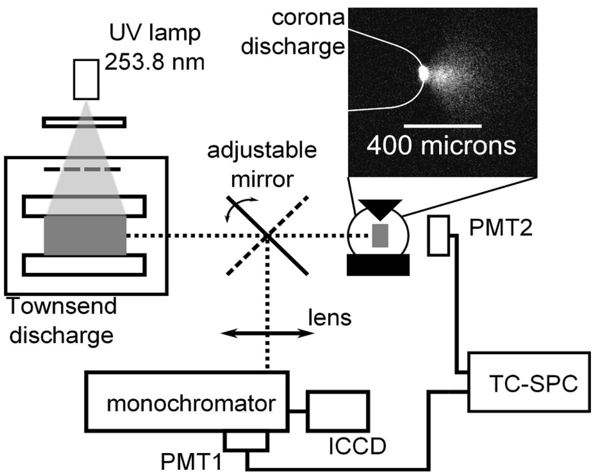

Fig. 1: Experimental setup for the E/n-determination of Trichel pulses. Embedded intensified CCD camera picture was made with exposure time of 1ms. PMT stands for photomultiplier, TS-SPC for time-correlated single photon counting module.

The measured signal distribution of the emission of the FNS is shown in Fig.1. This measurement can be interpreted as the spatio-temporal distribution of electrons with relatively high energy ≥ 18.7 eV. Thus under the local field approximation and neglecting stepwise exitational ionisation [5] the trace of the maximum E/n can be visualized. The increase of the signal starts 110 µm apart from the negative point due to the accumulation of a positive charge. Few nanoseconds later the positive streamer is started with maximum E/n of about 300 Td as it follows from our E/n measurements (not shown here). It propagates towards the cathode with rapidly increasing E/n to values of more than 3000 Td at the moment if streamer impact. Such values are in agreement with simulations of Odrobina et al. [7] and Braun et al. [8] describing positive streamers interacting with metallic cathodes. As the positive streamer reaches the cathode and the sheath is created the current rises to its maximum. From SPS and FNS measurements we estimated the approximate velocity of the positive and negative streamers which are $6{\cdot}10^4$m/s and $7{\cdot}10^5$m/s respectively. Short after ignition the velocity of the positive streamer is smaller than by the negative one which is in agreement with other experimental studies [9].

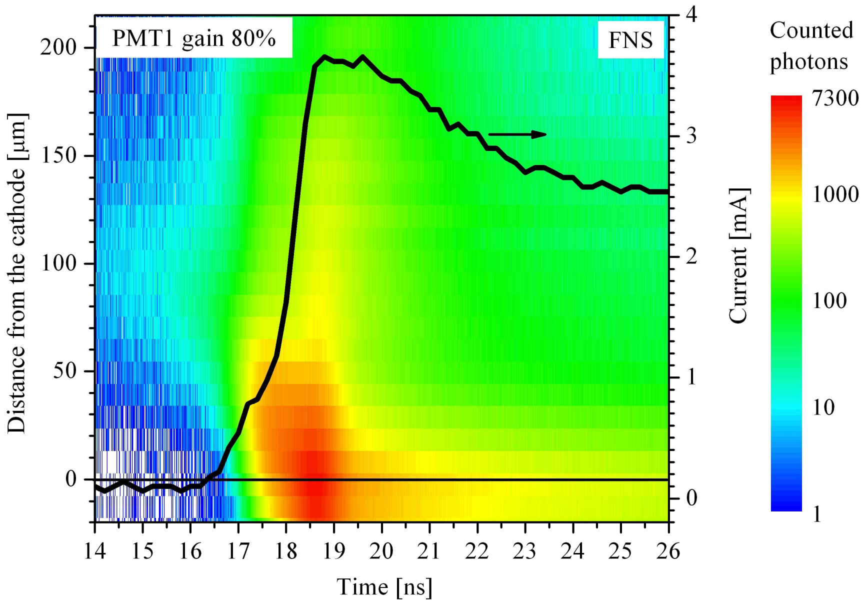

Fig. 2: FNS signal distribution in Trichel pulses of negative corona in atmospheric pressure air.

Apart from the E/n determination a special measurement was made revealing the emission from the pre-breakdown phase of the discharge. On the spatio-temporal distribution of the SPS (not shown here) a long lasting emission of almost 1 µs was observed. This charge accumulation phase leading to the ignition of positive streamer reminds to the Townsend pre-breakdown phase investigated in barrier dishcarges in air [10]. It shows that using sensitive diagnostic technique a hundred of nanoseconds long pre-breakdown phases of the short nanosecond breakdowns can be revealed.

References

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