10th Frontiers in Low Temperature Plasma Diagnostics

April 28th – May 2nd 2013

Rolduc, Kerkrade, The Netherlands

Book of Abstracts

TU/e Technische Universiteit Eindhoven University of Technology

DIFFER Dutch Institute for Fundamental Energy Research

The memory effect on the breakdown of atmospheric pressure air studied on transient spark discharge using fast iCCD camera.

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1. Introduction

Transient spark (TS) is a streamer-to-spark transition type discharge initiated by a streamer followed by the gas breakdown and a short (~10 ns) spark current pulse (~ 1 A) [1-3]. We studied this discharge of positive polarity in atmospheric pressure air in point-to-plane geometry. Despite using DC high voltage (HV) power, TS has a repetitively pulsed character: and the streamer-to-spark transition repeats in the kHz frequency range. It is due to periodical charging and discharging of the internal capacity C of the used electric circuit. Thanks to the small value of C (~10-40 pF), the plasma formed during the short spark pulse of TS cannot reach LTE conditions and so differs from a classical spark. TS generates highly reactive non-equilibrium plasma, as indicated by optical emission spectroscopy (OES). Several excited species, such as $N_2(C)$, $N_2(B)$, O*, N* or $N_2^+(B)$ were observed [1].

Transition to an arc and generation of thermal plasma is also prevented by a large external resistor R (5-10 MΩ) placed between the HV power supply and the needle HV electrode. The product of R and C determines the repetition frequency f that can be controlled by the onset voltage U_{oo} [2]:

$$f = 1 \Big/ RC \ln\left(\frac{U_{oo}}{U_{oo} - U_{TS}}\right).$$

Here, U_{TS} represents breakdown voltage at which streamer initiating the transient spark appears.

The U_{TS} was found to decrease with the growing f. It was attributed to the influence of a 'memory' effect [2]. We performed time resolved OES study using a fast photomultiplier tube and a fast intensified CCD camera coupled with high resolution spectrometer in order to find more about the role of the increasing f and the induced 'memory' effect on TS and the breakdown processes.

2. Results and Discussion

Time resolved emission spectra of the N_2 2[nd] positive system were used to estimate time evolution of the gas temperature T during the streamer-to-spark transition [3]. The value of T at the beginning of the streamer $T^{streamer}$ was used to estimate the pre-heating effect of increasing f. Next, the emission spectra of H_α line were used to calculate the electron density during the spark phase of TS (Stark broadening). Finally, the imaging of TS was used to observe the influence of f on the propagation of the streamer, and the evolution of the plasma channel diameter.

Both electrical and optical data showed differences between TS at 'low' f (below ~3 kHz) and at 'high' f (~6 kHz). There was almost no delay between the streamer and the spark at ~6 kHz. The OES and imaging showed disappearance of atomic lines and no constriction of plasma channel during the spark phase at ~6 kHz.

The increase of $T^{streamer}$ with growing f explains the observed decrease of the breakdown voltage, while the reduced electric field E/N, at which streamer initiating TS starts, does not change with f. We suppose that for TS below ~3 kHz, the breakdown mechanism suggested by Marode [4] is crucial, i.e. heating of the channel → increase of the pressure → hydrodynamic expansion → decrease of N in the core of the channel → increase of E/N → acceleration of ionization processes. The 'memory' effect on U_{TS} can be thus reduced on the influence of pre-heating. However, we assume that pre-ionization or accumulation of reactive species can play important role on TS characteristics and breakdown processes at higher f (~6 kHz). Under these conditions, the chemical and stepwise ionization [5] or accumulation of metastable species influence the breakdown significantly.

Acknowledgement

Effort sponsored by the Slovak Research and Development Agency APVV SK-FR-0038-09, and Slovak grant agency VEGA 1/0668/11 and 1/0998/12.

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