Laboratory streamers under TLE conditions: spectroscopic analysis with emphasis on the determination of the electric field strength

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Streamers in transient luminous events (TLEs) are not easy to catch in real conditions. Typically very scarce and spectrally and temporally not well-resolved recordings were obtained so far. In this contribution, a laboratory experiment for precise spectroscopy investigations was designed based on volume dielectric barrier discharge arrangement. Positive streamers were operated in air at pressures and temperatures corresponding to selected altitudes. Nanosecond-resolved spectra were recorded in the range of 280 to 900 nm and the development of selected bands was analysed. Furthermore, streamers were scanned radially and axially with sub-nanosecond time resolution for several spectral wavelengths giving unique information about their development in space. Finally, an attempt was made to determine electric field development in time and space.

1. Introduction

The red-sprite TLE is driven by the quasi-electrostatic field in the mesosphere following a positive cloud-to-ground flash produced below [1,2]. The sprite TLE's studies performed through imaging instruments with high frame rates (up to 20 kHz) provided basic information on the dynamics of the sprite formation and propagation, as well as on associated optical emission. Spectral measurements of TLE radiation have revealed strong emissions through the $N_2(C^3\Pi_u\text{-}B^3\Pi_g)$ second positive (2.PG) and $N_2(B^3\Pi_g\text{-}A^3\Sigma_u^+)$ first positive (1.PG) systems in the UV and NIR spectral ranges, respectively and much weaker contribution by the $N_2^+(B^2\Sigma_u^+\text{-}X^2\Sigma_g^+)$ first negative (1.NG) system.

Emission spectra of single sprite events are typically acquired with quite low spectral and spatio-temporal resolutions. Moreover, signals are registered with very low signal-to-noise ratio, therefore their use to advanced analysis which might provide estimation of important sprite parameters with reasonable precision (E/n, temperatures or distributions of electronically excited species) is rather limited. To this point a suitable laboratory TLE analogue experiment may be very useful to understand better both fundamental aspects TLE's and associated phenomena (heating effects, NO_x production, key spectroscopic features) [1-3].

The most important characteristic of sprites (the most common type of TLE) is that they propagate vertically over large distances surpassing altitudes (typically from ~35–40 km to ~80–85 km above sea level) characterised by very different pressures (between ~8.9 and ~0.16 torr) and gas temperatures (between -10 and -75 °C). Because it seems quite difficult to scale-down the whole sprite event maintaining at the same time such large pressure/temperature gradients, we performed an investigation of filamentary streamers propagating in a DBD gap instead, fixing pressure/temperature conditions which are characteristic for various altitudes covering a considerable sprite occurrence range.

Although a big effort was already focused to the investigation of the TLE streamer dynamics theoretically [2] and their overall spectral signatures experimentally [3] as well as numerically [4], systematic study of emission spectra produced by streamers propagating in an environment characterized by large pressure and temperature gradients is missing. The knowledge obtained from sufficiently spatially and temporally resolved spectra is currently one of the very few methods to get closer to the basic TLE inception and dynamic mechanisms. Especial emphasis is put in this work in the determination of the reduced electric field strength from the intensity ratio of selected 1.NG and 2.PG spectral bands, usually at 391 nm and 337 nm, respectively [5,6].

2. Experimental setup and results

In this work, triggered single streamer events were produced in dry synthetic air at controlled

pressure and temperature employing volume DBD geometry. The pressure range explored during the first experimental campaign was equivalent to 35-40 km altitudes (corresponding to the lowest levels of the sprite occurrence). Characteristic emission fingerprints of such streamers were acquired in the spectral range between 280 and 900 nm. The concept is based on a pair of asymmetric metallic electrodes embedded in dielectric discs placed in a stainless-steel chamber and powered by repetitive high-voltage bursts (superimposing two sine-waves, f_{AC} = 1 kHz, with a positive pulse of a short duration of 100 ns) at fixed repetition frequency of 30 Hz [4]. Superposition of the HV pulse during a second positive AC half-cycle (with a suitable phase-shift) resulted in locking the onset of the streamer event with respect to the leading edge of the HV pulse. Trigged production of a stable single streamer discharge with high reproducibility enables acquisition of spectrometric data with high statistics, typically $(1\div5)\times10^4$, increasing significantly the signal-to-noise ratio of the registered waveforms with respect to single-event registered data.

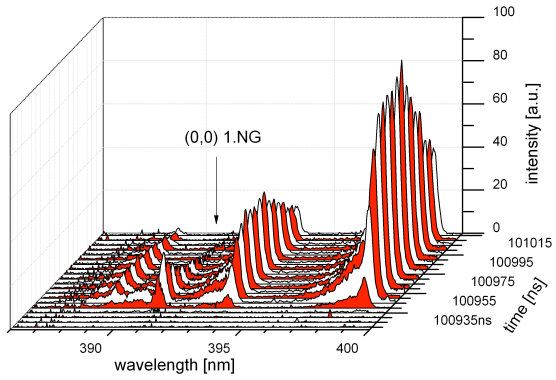

Figure 1.: Time-development of the emissions of 1.NG and 2.PG spectral bands around 390 nm at 8.9 torr and 300 K.

Our measurements have revealed strong emissions via 2.PG and 1.PG systems, and considerably weaker (0,0) band emission of the 1.NG system at 391 nm. Recording the spectra in the range of 380 to 400 nm, the key spectral bands of 1.PG and 2.PG were obtained with nanosecond (exactly: 5 ns step) temporal resolution. These data are analysed and an attempt is made to estimate the development of the electric field. Figure 1 shows a typical time-resolved spectral development of the above mentioned spectral bands emission intensities produced by the streamer passing the DBD gap at a selected axial coordinate.

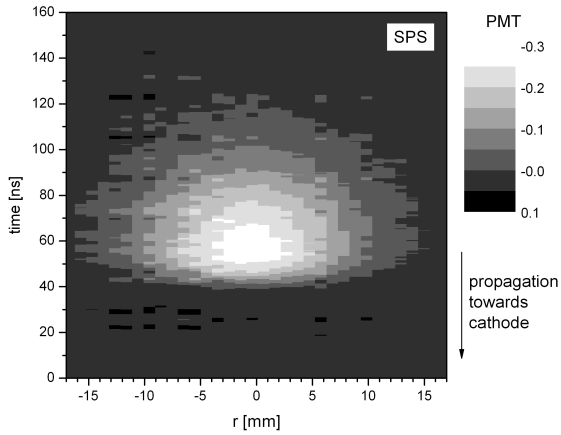

Figure 2.: Radially resolved time-development of the emissions of 2.PG at 337 nm at 8.9 torr (approx. 30 km altitude) and 300 K.

In Fig. 2., the radially resolved temporal development of the 2.PG emission is shown. It was recorded by scanning the streamer channel radially at a constant axial coordinate with a fast PMT through a spectral filter for 337 nm. Similar profiles were obtained for 1.NG at 391 nm in order to analyse the radial development of the electric field of propagating streamer at selected pressure. Finally, in order to understand the whole discharge development and its streamer velocity, the same sets of scans were also recorded axially along the streamer propagation.

3. Acknowledgement

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4. References

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