Advanced analysis of overlapping emission spectra induced by highly transient discharges

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Vibrational distributions of electronically excited states of N_2 obtained through dipole-allowed radiative transitions provide an important tool to study the kinetics of non-equilibrium plasmas under various discharge conditions and provide benchmark data for the validation of advanced kinetic schemes for numerical models. Our testing discharge is a streamer monofilament developed in a dielectric barrier discharge configuration, powered by a specific high-voltage waveform based on periodic (10 Hz) bursts composed of two consecutive HV AC waveforms (1 kHz) and a nanosecond HV pulse [1], see Fig. 1.

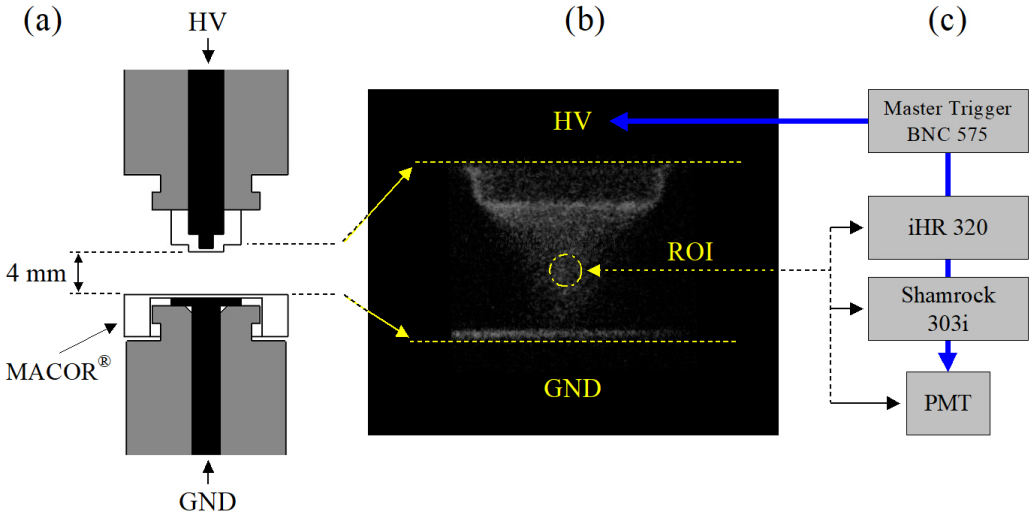

Fig. 1: Experimental setup. Credits on [2].

In this case, the active discharge phase (dominated by electron impact processes and characterized by the high reduced electric field (E/N)) persists for tens of nanoseconds. By varying the neutral gas pressure between 300 and 15 Torr, we can obtain reduced electric fields in a wide range (300-1500 Td). The experimental emission spectra considered in this work are first positive system (FPS, $B^3\Pi_g \longrightarrow A^3\Sigma_u^+$), second positive system (SPS, $C^3\Pi_u \rightarrow B^3\Pi_g$) of N_2 and first negative system (FNS, $B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$) of N_2^+. These emissions can provide information about $v = 0-21$ vibrational levels of $N_2(B^3\Pi_g)$ state, $v = 0-4$ vibrational levels of $N_2(C^3\Pi_u)$ state and $v = 0-2$ vibrational levels of $N_2^+(B^2\Sigma_u^+)$ state.

In this contribution, we will present diagnostic procedures and analytical approaches to obtain the vibrational distributions of important electronically excited states using the acquisition and processing of optical emission spectra in a wide spectral range (200 - 1100 nm) with increased spatiotemporal resolution. We show that the vibrational distribution function of $N_2(B^3\Pi_g)$ state during the first nanoseconds after the discharge onset follows the Franck-Condon-like distribution, while during the streamer relaxation, it is influenced by the complex interaction between triplet excited states of N_2. Additionally, the observed $N_2(B^3\Pi_g$, v=13-21) vibrational levels are likely produced by the interaction of high vibrational levels of $N_2(W^3\Delta_u$, $B'^3\Sigma_u^-$, $B^3\Pi_g)$ with $N_2(C^3\Pi_u)$ state [2].

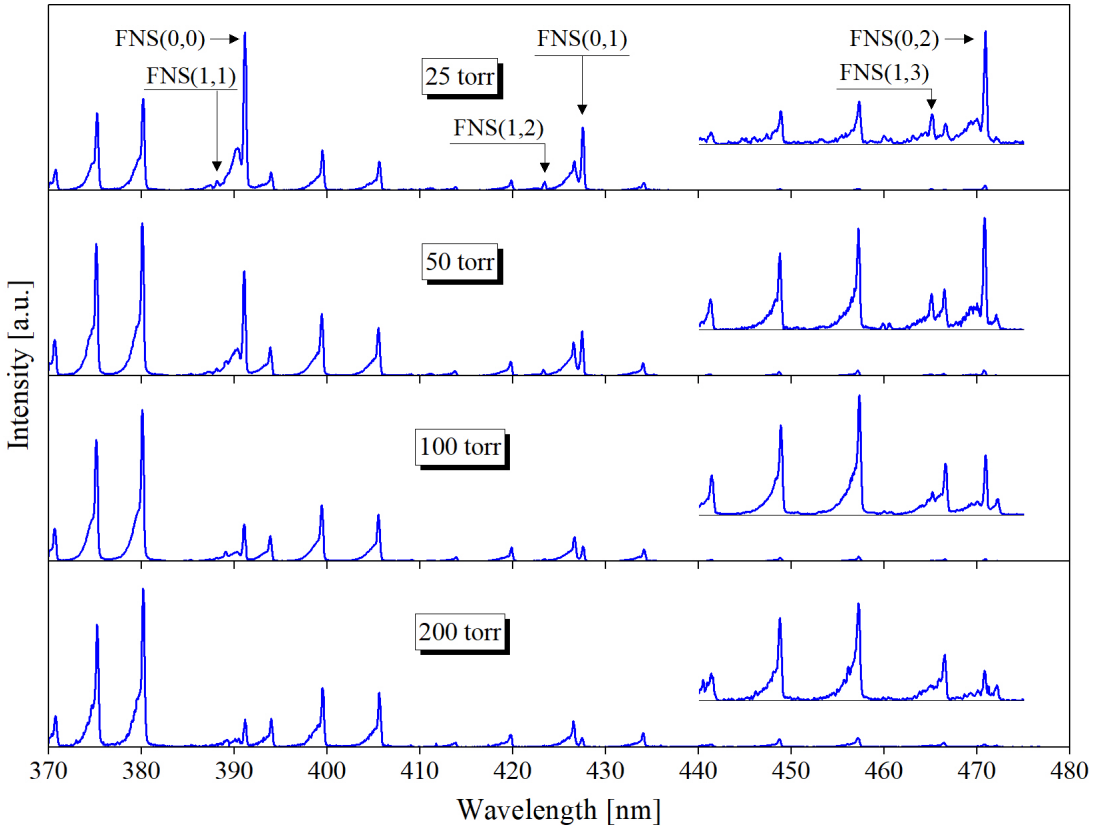

Fig. 2: Examples of time-resolved emission obtained in wavelength region 370-480 nm in pure nitrogen for pressures ranging from 25 to 200 Torr.

The VDFs of $N_2(C^3\Pi_u)$ and $N_2^+(B^2\Sigma_u^+)$ states are investigated at various pressures in air as well as pure nitrogen [3], see Fig. 2. The measurements of VDFs over such different ranges of conditions bring new insight into processes influencing the production of these states and set the limits of the use of FPS, SPS and FNS bands for diagnostic purposes. Moreover, the measured VDFs serve as reference data suitable for testing and validation of complex collisional-radiative models for N_2, N_2-O_2 and air streamer discharges.

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[2] P. Bílek, T. C. Dias, V. Prukner, V. Guerra and M. Šimek 2024 *Plasma Sources Sci. Technol.* **33** pp 015011.
[3] Bílek, Arora, Šimek 2024 in prep.