Measurements of Excited Metastable Species and Associative Ionization in a Heated Nonequilibrium Plasma Flow Reactor

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Time-resolved, absolute number densities of metastable nitrogen molecules, $N_2(A^3\Sigma_u^+,v=0,1)$, and molecular ions, N_2^+, as well as the gas temperature, are measured in nitrogen and N_2-NO mixtures in a heated plasma flow reactor with optical access for laser diagnostics, at the pressure of P=100 Torr and temperatures of T=300-1000 K. The gas mixture in the reactor is excited by the ns pulse discharge bursts operated at a high pulse repetition rate, up to 100 kHz, generating a diffuse plasma with well-defined boundaries. The measurements are made by the cw Tunable Diode Laser Absorption Spectroscopy (TDLAS) and pulse UV Cavity Ring Down Spectroscopy (CRDS). The results illustrate the generation and decay of $N_2(A)$, a precursor for metastable excited atoms, during the discharge burst. Time-resolved N_2^+ measurements in the afterglow exhibit its transient rise with a subsequent decay, indicating the effect of associative ionization of excited species accumulated during the discharge burst. Since $N_2(A)$ decays significantly during the discharge burst, due to the accumulation of N atoms [1], this suggests that the excited species resulting in the associative ionization are the metastable N atoms generated during the $N_2(A)$ quenching by the ground state nitrogen atoms, e.g.

$$N_2(A^3\Sigma_u^+) + N \rightarrow N_2\left(X^1\Sigma_g^+\right) + N(\,^2P,\,^2D)\,, \tag{1}$$

$$N(^2P) + N(^2P) \rightarrow N_2^+ + e^-. \tag{2}$$

Future work will focus on the direct measurements of the excited atoms by the vacuum UV absorption spectroscopy, and of NO^+ ions by mid-IR, cw Cavity Ring Down Spectroscopy.

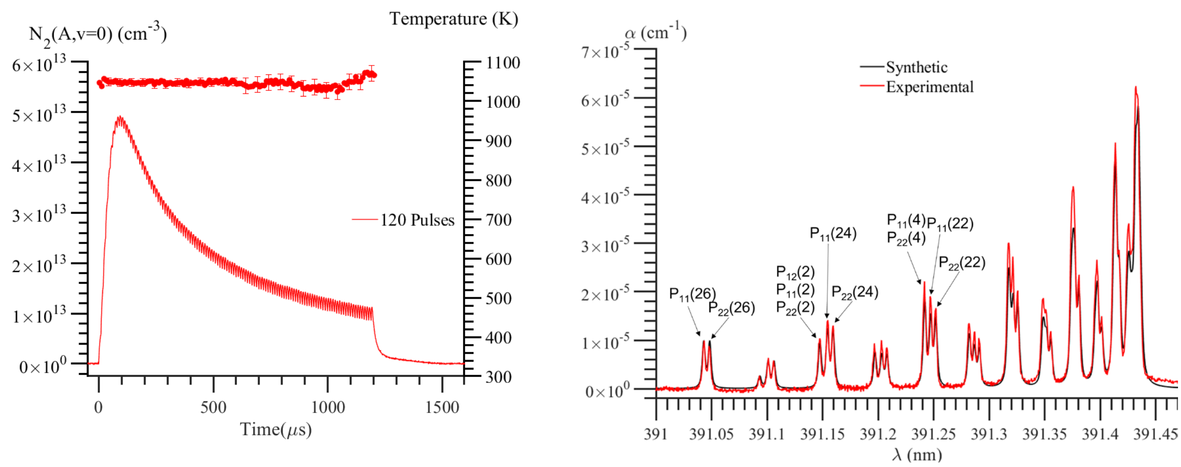

Fig. 1: **Left:** $N_2(A^3\Sigma_u^+,v=0)$ population during a 120-pulse burst (pulse repetition rate 100 kHz, burst repetition rate 10 Hz) and gas temperature, inferred from the $P_{11}(26)$ and $R_{23}(4)$ rotational line ratio in the $N_2(B^3\Pi_g$, v = 2 ← $A^3\Sigma_u^+$,v = 0) band. **Right:** CRDS spectrum of $N_2^+(B^2\Sigma_u^+$, v=0 ← $X^2\Sigma_g^+$,v=0) band at the furnace temperature of T=1000 K. Nitrogen, P=100 Torr, 15 μs after a 60-pulse discharge burst, pulse repetition rate 100 kHz.

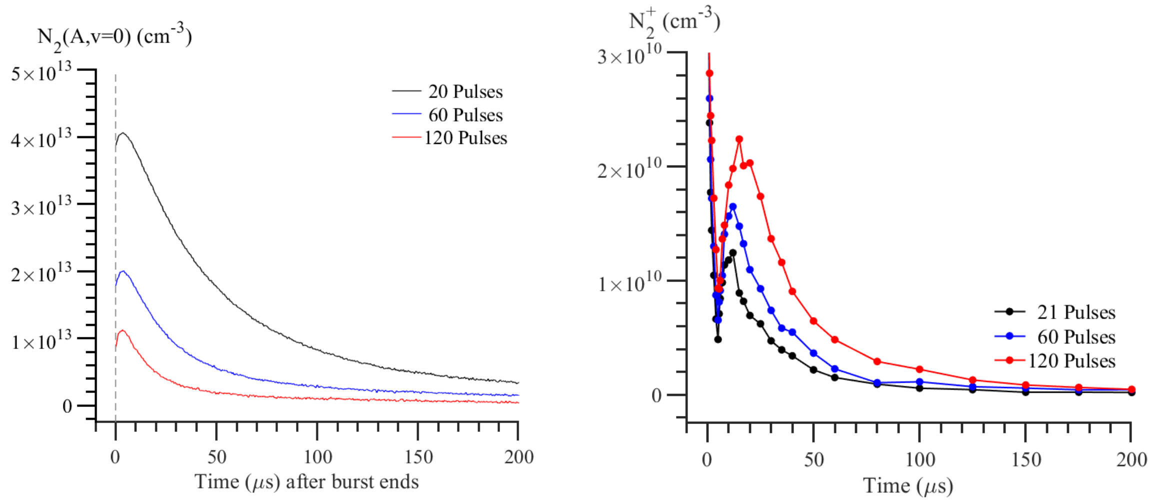

Fig. 2: Time-resolved time-resolved $N_2(A^3\Sigma_u^+,v=0)$ population **(left)** and N_2^+ number density inferred from the CRDS data **(right)** after 21, 60, and 120-pulse discharge bursts, at the conditions of Fig. 1.

[1] X. Yang, E.R. Jans, C. Richards, S. Raskar, D. van den Bekerom, K. Wu, and I.V. Adamovich, *Plasma Sources Science and Technology* **31** (2022) 015017