NO Formation in Nanosecond Pulse Afterglows Plasma

Walter R Lempert[a] and Igor V. Adamovich[a]

(a) Departments of Mechanical & Aerospace Engineering and Chemistry, The Ohio State University, Columbus, OH, adamovich.1@osu.edu

Laser Induced Fluorescence (LIF), Two-Photon Absorption Laser Induced Fluorescence (TALIF), and Picosecond Coherent Anti-Stokes Raman Scattering (CARS) have been used in studies of nonequilibrium plasma chemistry in a diffuse, single filament, pin-to-pin discharge in dry air. The discharge pulse (12 kV, pulse, 200 ns, 12 A) sustained between two spherical electrodes 7.5 mm in diameter and 10 mm apart, produces a filament with dimensions of 2-3 mm in diameter. Results at P=100 Torr are summarized in Fig. 1, which shows experimental data and coupled Poisson equation / Boltzmann equation / master equation / air plasma chemistry kinetic model predictions for number densities of O atoms, N atoms, and nitric oxide (NO). There is good agreement. Absolute number densities of O and N atoms have been measured by TALIF with Xe and Kr calibration, respectively. NO number density have been measured by calibrated LIF. The model predictions for gas temperature and vibrational level populations of the ground electronic state of nitrogen, $N_2(v=0\text{-}4)$, measured by ps CARS, are also in good agreement with the data. This demonstrates that the model correctly reproduces discharge energy loading per molecule and input energy partition among different energy modes (vibrational excitation, electronic excitation, and dissociation by electron impact).

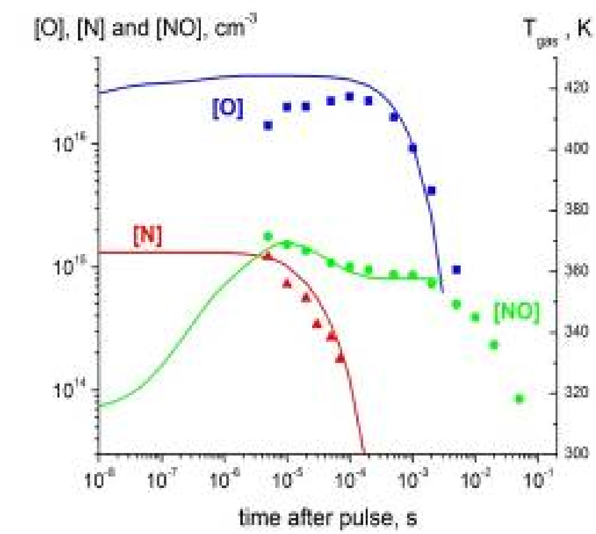

Figure 1 – Experimental and predicted temporal evolution of vibrational energy and total vibrational quanta in 100 Torr N_2 nsec pulsed discharge.

The modeling predictions for species number densities plotted in Fig. 1 have been obtained using an "expanded" version of the model, which incorporates reactive collisional quenching of $N_2(A^3\Sigma_u^+)$, $N_2(B^3\Pi_g)$, $N_2(W^3\Delta_u)$, $N_2(B'^3\Sigma_u^-)$, $N_2(C^3\Pi_u)$, $N_2(a'^1\Sigma_u^-)$, $N_2(a^1\Pi_g)$, $N_2(w^1\Delta_u)$, $N_2(a''^1\Sigma_g^+)$, and $N_2(E^3\Sigma_g^+)$ states by O atoms, resulting in NO formation, i.e. reaction $N_2^* + O \rightarrow NO + N$. The rate coefficient for $N_2(A^3\Sigma_u^+)$ is $k[A^3\Sigma] = 7\cdot10^{-12}$ cm^3/s, while the rates for other electronic states were taken the same as the rate of quenching of $N_2(C^3\Pi_u)$ state, $k=3\cdot10^{-10}$ cm^3/s. The "baseline" version of the model, which includes NO formation only by quenching of triplet states of N_2, resulted in significant under prediction of NO number density and N atom decay rate, which occurs by the reaction $NO + N \rightarrow N_2 + O$. The present results suggest that quenching of excited electronic states of N_2 by O atoms occurs primarily via a reactive channel, which is also the dominant mechanism of NO formation in ns pulse afterglow plasmas. Measured $N_2(X, v=0\text{-}4)$ populations at the present conditions are fairly low, such that NO formation in reactions of vibrationally excited nitrogen molecules, such as $N_2(X\,^1\Sigma_g^+, v>12) + O \rightarrow NO + N$, is unlikely.

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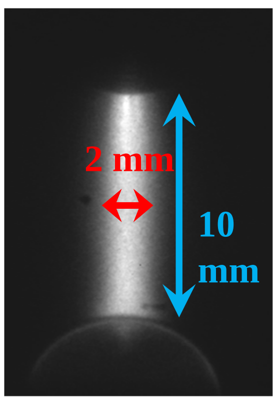
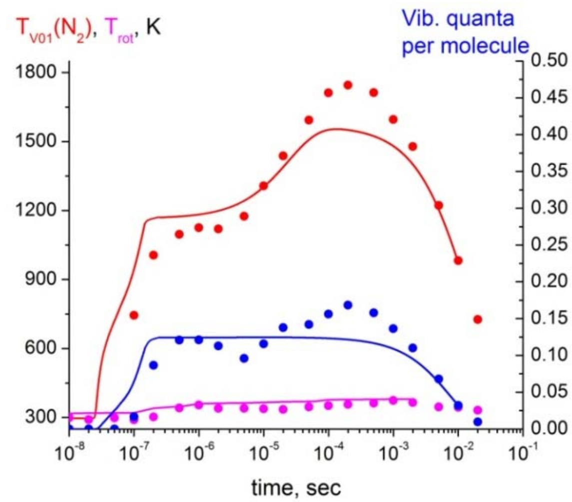
NO FORMATION IN LOW-TEMPERATURE, NSEC PULSE AFTERGLOW PLASMA

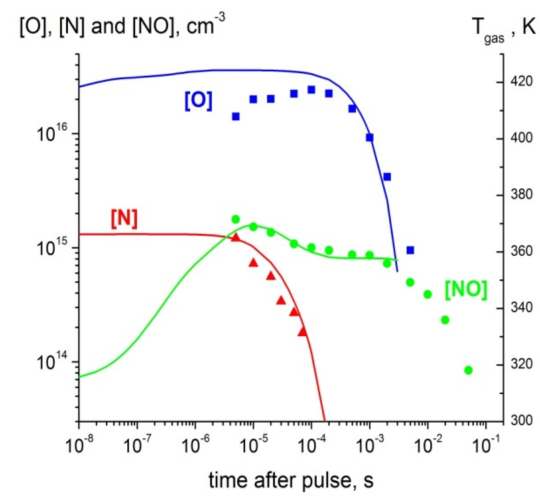
- Optical diagnostics including psec Coherent Anti-Stokes Raman Spectroscopy, Single- and Two-Photon Absorption Laser Induced Fluorescence are used to measure excited states dynamics in nsec pulse plasmas in N_2 and air.
- Quenching of N_2 excited electronic states appears to occur primarily via a reactive channel, $N_2^* + O \rightarrow NO + N$, a dominant mechanism of NO formation
- Measured $N_2(X,v=0\text{-}4)$ populations at these conditions are fairly low, kinetic modeling: $N_2\ (X\ ^1\Sigma_g^+, v) + O \rightarrow NO + N$ channel appears unlikely



- Nsec pulse discharge plasma, air at 100 torr



- Gas temperature and N_2 vibrational temperature



- [N], [O], [NO]

PLSC_0513 ***HIGHLIGHT***

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Effects of Anomalous Electron Cross-Field Transport on Electron and Ion Velocity Distribution Functions in a Low Pressure Magnetized Plasma

Y. Raitses[(a)],Y. Shi[(a)], I. D. Kaganovich[(a)], V. M. Donnelly[(b)], V. Godyak[(c)], A. Smolyakov[(d)]

(a) Princeton Plasma Physics Laboratory, Princeton, NJ (yraitses@pppl.gov)
(b) University of Houston, Houston, TX (vmdonnel@central.uh.edu)
(c) University of Michigan, Ann Arbor, MI (egodyak@comcast.net)
(d) University of Saskatchewan, Canada (andrei.smolyakov@usask.ca)

The formation of electron and ion kinetic properties and their effect on the electric field distribution in magnetized plasmas are governed by complex particle and heat transport phenomena. For example, the application of a magnetic field in a low pressure plasma can cause a spatial separation of cold and hot electron groups. This magnetic filter effect is not well understood and is the subject of our studies. In this work, we investigate electron and ion velocity distribution functions in a low pressure plasma discharge with crossed electric and magnetic field [1]. Previous experimental studies showed that the increase of the magnetic field leads to a more uniform profile of the electron temperature across the magnetic field. (See Fig. 1.) This surprising result indicates the importance of anomalous electron transport that causes mixing of hot and cold electrons.[1] High-speed imaging revealed a coherent rotating structure with frequency of a few kHz, as shown in Fig. 2.[1,2]. Theory describing this rotating structure and resulting anomalous transport has been developed and points to ionization and electrostatic instabilities as their possible cause.[3-5] Recent kinetic simulations predicted the effect of coherent rotating structures on ion velocity distribution functions. Laser-Induced-Florescence measurements are currently being conducted to validate these predictions.

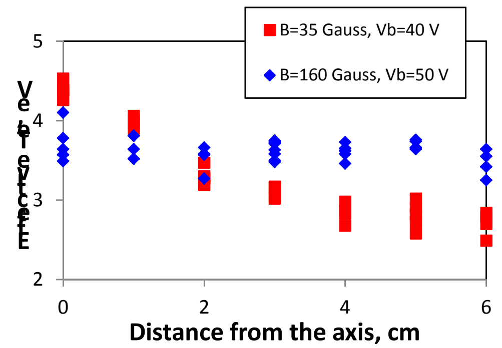

Figure 1 – Effect of the magnetic field on the electron temperature distribution across the magnetic field.

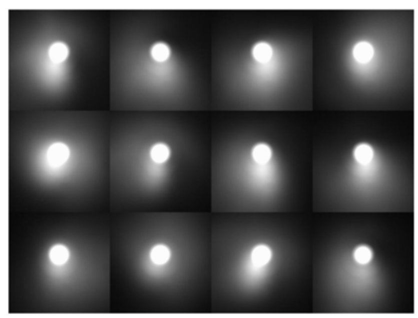

Figure 2 – Coherent rotating structure measured in E×B configuration of the magnetized discharge.

References

[1] Y. Raitses, Rotating spoke in E × B discharges, Invited talk at 2012 GEC Conf. Austin, TX.
[2] C. Ellison, Y. Raitses and N. J. Fisch, Phys. Plasmas **19**, 013503 (2012).
[3] C. Ellison, K. Matyash, J. Parker, Y. Raitses, N. J. Fisch, Phys. Plasmas **20**, 014701 (2013).
[4] W. Frias, A. I. Smolyakov, I. D. Kaganovich, and Y. Raitses, Phys. Plasmas **19**, 072112 (2012).
[5] W. Frias, A. I. Smolyakov, I. D. Kaganovich, and Y. Raitses, "Long wavelength gradient drift instability in Hall plasma devices. Part II: Applications," submitted to Phys. Plasmas (2013).

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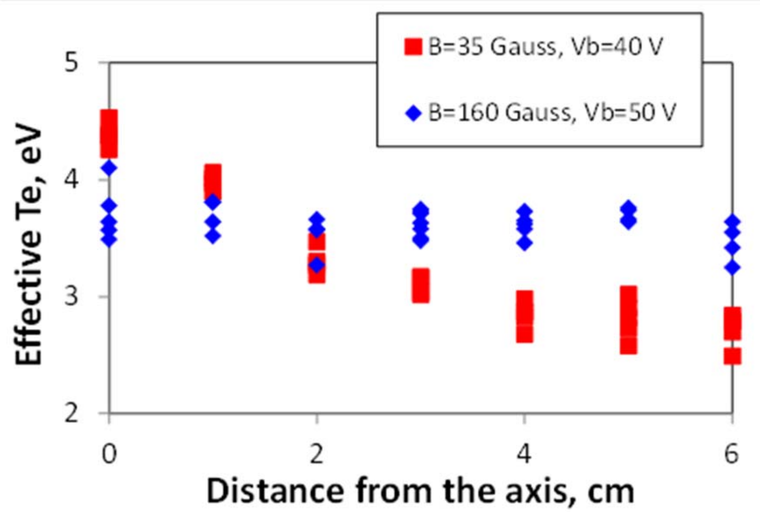
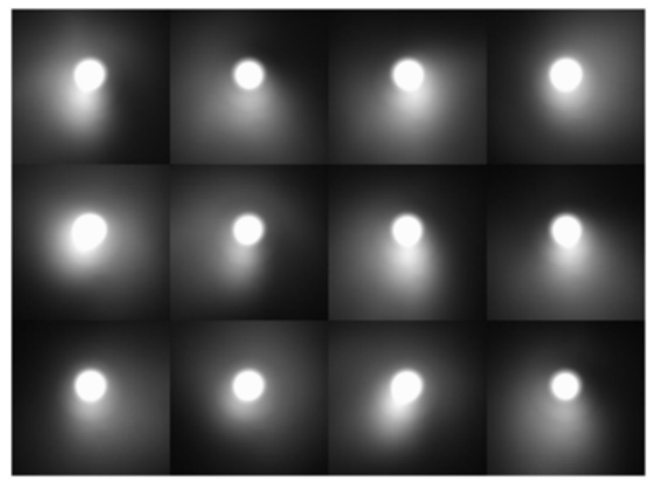
ANOMALOUS ELECTRON TRANSPORT IN LOW PRESSURE PLASMA WITH MAGNETIC FILTER

- **Application of the magnetic field in a low pressure plasma can cause a spatial separation of cold and hot electron groups – so-called magnetic filter effect.**
- **Measurements of EEDF in DC-RF magnetized discharge revealed that at pressures below 1 mtorr, anomalously large electron transport causes mixing of hot and cold electrons.**
- **High-speed imaging and probe measurements revealed a few kHz coherent rotating structure, which is responsible for anomalous electron transport.**



- **Electron temperature from EEDF measurements across B-field**



- **Rotating plasma structure responsible for anomalous cross-field transport**

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