DIAGNOSTICS AND MODELING OF STREAMER INDUCED EMISSION IN PULSED POSITIVE CORONA DISCHARGE

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1 Abstract

Time and space resolved multichannel emission spectroscopy has been applied to study the emission induced by pulsed positive primary streamers in coaxial geometry generated in high purity nitrogen at atmospheric pressure.

Experimental results obtained confirm three distinctive phases : a) discharge phase in which the streamer emission is predominantly controlled by electron impact exitation of ground state species, b) post-discharge phase in which the emission is controlled by $N_2(A^3\Sigma^+_u)$ metastable species via pooling and resonant energy transfer processes, and c) intermediate phase in which emission due to relaxing EEDF is superimposed with increasing contribution of $N_2(A^3\Sigma^+_u)$ induced emission.

Considering relevant excitation, quenching and radiative processes, new diagnostic approaches for experimental measurements are proposed for atmospheric pressure pulsed positive corona discharges.

2 Introduction

Application of fast high-voltage pulses to symmetric electrode systems (point-plane, wire-plane or wire-cylinder) induce highly non-homogeneous electric field and results in generation of multiple plasma channels providing the discharge device is filled with the gas at sufficiently high pressure. When the point or wire electrode is charged positively then induced plasma channels (positive streamers) propagate from point/wire anode to the plane or cylinder cathode and the discharge itself is then called positive corona discharge. Basically, the single positive streamer event is an ionization wave which propagates against the direction of electron drift with typical velocity 10^7-10^8 cm/s, plasma channel of the streamer has a radius is ~ 10^{-1}-10^{-2} cm and contains ~ 10^{14} electrons per cm^3.

The main difficulty with interpretation of atmospheric pressure streamer induced emission is given by poor experimental information on the electron energy distribution function (EEDF) and ground state vibrational distributions (VDF) of diatomic species that is caused by space and time scales of pulsed streamers. Basic space and time scales of streamers are conditioned by processes occurring in a high selfconsistent electric field at the streamer head. It is usually assumed that in the streamer head the electron energy distribution function is in equilibrium with local electric field and streamer propagates in the pre-ionized space that is created by photoionizing radiation coming from high field streamer regions. During the streamer propagation emission driven both by streamer head (high energy) and streamer body (low energy) electrons can be observed. The electron impact excitation and ionization, collisional transfers, recombination or chemical processes result in the electronic excitation of neutral and ionized species. Electronically excited species produce radiation in the UV-VIS range that can

be used for diagnostic purposes. For example emission of electronic states efficiently pumped through direct ionization and excitation of ground state neutral species by electron impact can provide sensitive probe for spectroscopic measurement of streamer electron's average energy. In air or nitrogen-like gases most of such spectroscopic studies has focused on the emission of $N_2(C^3\Pi_u \rightarrow B^3\Pi_g)$ and $N_2^+(B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+)$ systems. The intensity ratio of (0,0) bands of these two systems has been often used to this purpose assuming Maxwellian and Druyvesteyn electron energy distribution functions.

The main goal of our work is to determine streamer parameters in our experimental device. The first step is to detect streamer induced emission observable in atmospheric pressure nitrogen with NO or O_2 traces. The modeling of synthetic spectra and recalculation of most important rate constants for the electronic excitation of N_2 and NO by electrons is the next step. Last step is then the development of diagnostics procedures based on simplified model of streamer induced emission

3 Experiment

Experimental corona device consists of Ag coated Cu central wire anode (2r = 0.75 mm) and grounded stainless steel cylinder (2R=56 mm) [1,2] . Pulsed HV power supply with maximum ratings 100 kV/1kA/ 7 ns rise time/ ~ 100 ns fall time delivers up to 2 J/pulse with up to 10Hz repetition rate at atmospheric pressure into the discharge volume ~ 1500 cm^3. For present measurements the corona discharge was operated with 2 Hz repetition frequency with fixed flow (4000 sccm) of high purity nitrogen (99.999) at fixed pressure (760 Torr) controlled by pressure gauge. Emission coming out along the symmetry axis of the discharge was monitored through quartz optics by ISA JobinYvon and Chromex spectrometric systems.

Experimental results obtained confirm three distinctive phases : a) discharge phase in which the streamer emission is predominantly controlled by electron impact exitation of ground state species,

$$N_2(X) + e \rightarrow N_2^* + e \quad (1)$$

b) post-discharge phase in which the emission is controlled by $N_2(A^3\Sigma^+_u)$ metastable species via pooling and resonant energy transfer processes,

$$N_2(A) + N_2(A) \rightarrow N_2^* + N_2(X) \quad (2)$$

$$N_2(A) + AB \rightarrow AB^* + N_2(X) \quad (3)$$

and c) intermediate phase in which emission due to relaxing EEDF is superimposed with increasing contribution of $N_2(A^3\Sigma^+_u)$ induced emission.

During the discharge phase most intensive is the emission of N_2 2.PG system followed with 4.PG system (Fig.1) and 1.NG system of N_2^+. During post discharge phase we have observed [2,3] that the intensity of nitrogen second positive system $N_2(C^3\Pi_u \rightarrow B^3\Pi_g)$ emission varies quadratically with the intensity of the NO-$\gamma(A^2\Sigma^+ \rightarrow X^2\Pi)$ system (Fig.2). Such dependence evidences $N_2(A^3\Sigma^+_u)$ metastables as precursors of post discharge emission. Futher investigations of time resolved emissions have discovered efficient formation of $N_2(B^3\Pi_g$, $C^3\Pi_u$, $C''^5\Pi$, $C'^3\Pi_u)$ states. The observation of Herman infrared $N_2(C''^5\Pi_u \rightarrow A'^5\Sigma_u^+)$ system that can be populated exclusively by $N_2(A^3\Sigma_u^+)$ energy pooling during post discharge phase is an independent confirmation of the former scheme.

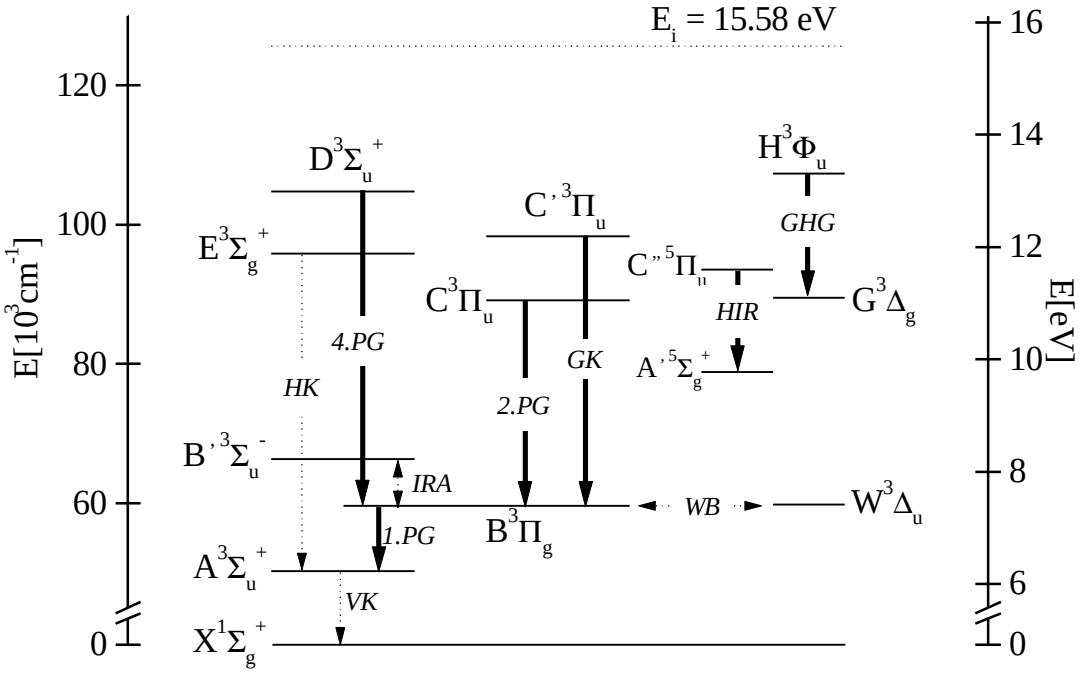

Fig.1 : Partial energy level diagram and radiative transitions for N_2 molecule. (*VK* = Vegard-Kaplan system, *IRA* = Infrared Afterglow system, *WB* = Wu-Benesch system, *HK* = Herman-Kaplan system, *GK* = Goldstein-Kaplan system, *HIR* = Herman Infrared system, *GHG* = Gaydon-Herman Green system). Bold arrows indicate transitions observed in high purity nitrogen corona discharge.

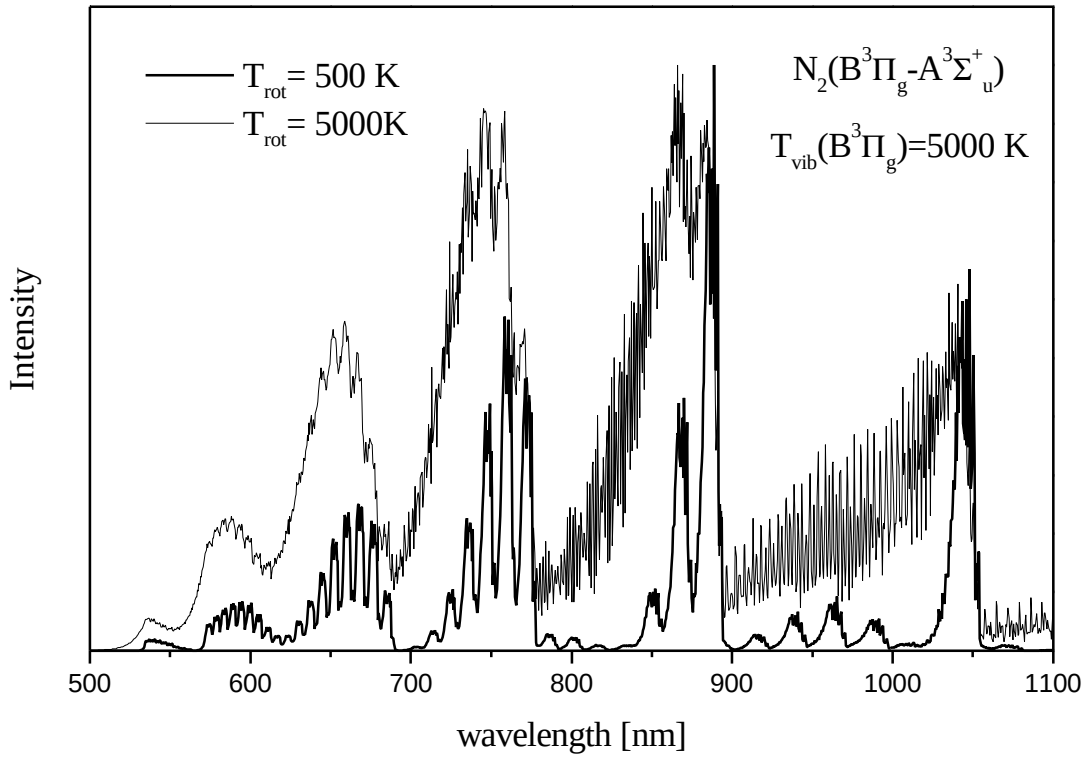

Fig.2 : Spectroscopic representation of Boltzmann vibrational distribution of $N_2(B^3\Pi_g)$ state.

4 Modeling

Analysis and interpretation of experimental spectra collected even with high with time and space resolution from multi-streamer device is difficult because of characteristic dimension and propagation velocity of individual streamers. The time that is necessary for passing the distance between anode and cathode is comparable with the interval for which electric field close to the anode allows generation of streamers. That is why streamers are generated with the incertitude of the order of nanoseconds rather than well synchronized in one unique streamer wave. This incertitude is the main reason why in multi streamer device the discrimination of streamer head and streamer channel emission by increasing time and space resolution is impossible. Emission sampled by ICCD or IRY detectors has always to be considered as a blend of emission induced by high energy streamer head and low energy streamer channel electrons, and the weight of these two contributions has to be considered carefully. For example in the analysis of $N_2(C^3\Pi_u,v)$ distributions during discharge period we assume that $C^3\Pi_u$ state it is mainly formed by electron impact from $N_2(X^1\Sigma_g^+,v)$ ground state. Then, in order to estimate the contribution of streamer head and streamer channel electrons, the critical issue is the knowledge of both ground state vibrational distribution VDF and electron energy distribution function EEDF (or at least mean electron energy) [3].

The modeling of synthetic spectra (Fig.2) of most intense bands together with recalculation of most important rate constants for the electronic excitation of N_2 and NO by electrons are basic assumptions for the improvement of old (estimation of average energy of free electrons) or development of new (concentration of $N_2(A^3\Sigma^+_u)$ metastables) diagnostics procedures.

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