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Energy release and fast heating process in nanosecond repetitively pulsed discharges in air at atmospheric pressure

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Nanosecond repetitively pulsed discharges (NRPD) were generated using a pin to pin configuration between two steel electrodes (gap distance: 4 mm). The NRPD were produced at atmospheric pressure in preheated air or nitrogen at 1000 K by high voltage (6,3 kV) pulses of 10-ns duration applied at a repetition frequency of 10 kHz.

NRPDs have been widely used this last decade for different applications: plasma assisted combustion, aeronautic and aerodynamic flow control [1-2]. We are interested in the effect of NRPDs on combustion, namely on the mechanism of stabilization of lean premixed flames. It is well known [3] that one of the possibilities to reduce nitric oxides in flames consists in using lean premixed combustion systems. However, these systems tend to be unstable at low fuel equivalence rations. To solve these problems, it was shown [4] that one can stabilize lean premixed flames by a local addition of energy that produces a local increase in heat and active species concentrations. In light of the high effectiveness in lowering the flame exctinction limit for very low power requirements, NRPDs represent a very promising method in answer to this need.

The objective of our study is to determine the mechanism that leads to flame stabilization. Following the results obtained using the kinetic model [5] it was predicted that atomic oxygen, which is a key species in the combustion process, together with fast heat release, are produced through a two-step mechanism., which is the following:

$$N_2(X) + e \rightarrow N_2(A,B,C) + e \qquad (1)$$

$$N_2(A,B,C) + O_2 \rightarrow N_2(X) + 2O + heat \qquad (2)$$

According to this mechanism, the electronically excited molecular nitrogen formed by electron-impact excitation during the pulse dissociates molecular oxygen, thus generating atomic oxygen and heat, and therefore enhancing the oxidation of the fuel.

To validate this mechanism, we have performed time-resolved Optical Emission Spectroscopy (OES) to determine the density evolution of the excited nitrogen states $N_2(B)$ and $N_2(C)$ as well as Cavity Ring-Down Spectroscopy (CRDS) to evaluate the density of $N_2(A)$ [6]. We have also used time-resolved Two-photon Absorption Laser Induced Fluorescence (TALIF) to measure the evolution of ground state oxygen density [7].

Our interest was then to focus on the impact of the excited nitrogen densities on the heat release and the increase of the gas temperature.

Gas temperature (Tg) measurements have been performed. We first determined the rotational temperature by fitting the time-resolved N_2 (C-B) (0,2) band around 380 nm using SPECAIR [8]. Here we assume that the rotational temperature is equal to the translational temperature (Tg = Tr) because the rotational-translational energy transfer is known to be fast at atmospheric pressure. We compared this temperature profile to the one obtained by calculations that take into account the temperature increase due to the exothermic behaviour of the second reaction of the mechanism .In these calculations we also evaluate the contribution of each excited nitrogen state to the increase of the gas temperature. We obtain good agreement between the measurements, which show a very fast increase of Tg from 1500K to 2800K in 10ns, and the calculations. N_2(B) is shown to have the major contribution (about 85%) to this fast heating process

In parallel a study of the energy evolution of the system was performed. Electrical measurements were made of the energy deposited per pulse. Inform the measured conduction current and the voltage, we determined that the energy deposited in the system was about 0,6 mJ per pulse. Using the measured excited nitrogen state densities and the rates of the dissociative quenching reactions, calculations were made of the exothermic energy released by the two-step mechanism and of the energy channelled into molecular oxygen dissociation. These represent about 10 and 30 %, respectively, of the total energy deposited in the discharge.

Reference

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