Formation and recombination of a fully ionized plasma by nanosecond discharges in ambient conditions

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Résumé

Nanosecond Repetitively Pulse (NRP) discharges in pin-to-pin configurations are classified in three regimes: corona, glow and spark [1]. These three regimes are weakly ionized (< 1 %) and out of equilibrium. It was however shown [2],[3] that nanosecond discharges can be fully ionized. The formation of the corona, glow and spark regimes are well known [1], but the formation of a fully ionized plasma by a nanosecond pulse is still partly understood. In this presentation, we will describe the steps of formation of the fully ionized discharge in a 2-mm gap and the recombination of the electrons. The imaging of the discharge was performed from 50 to 1000 mbar with a sub-nanosecond iCCD gates. The following steps of the thermal spark formation has been seen (time stamps in brackets are representative of atmospheric pressure):

1. A homogeneous plasma channel is first formed between the electrodes.
2. A filament is formed at the cathode (5.25 ns), and then at the anode (6.25 ns).
3. The filaments propagate toward each other. Typical speed is 2×10^4 m/s at the anode and 4×10^5 m/s at the cathode.
4. At 10.25 ns, a fully ionized channel connects the two electrodes.

Optical Emission Spectroscopy of the discharge was performed and we used Stark broadening of the N$^+$, O$^+$ and H$_\alpha$ lines for electron number density measurements. A typical fit of the N$^+$ and O$^+$ lines is shown in Fig 1. a). These measurements were spatially resolved in the interelectrode gap. We show that: (i) the filaments are fully ionized and (ii) the electron number density is homogeneous along the filaments. In consequence, the plasma is homogeneously fully-ionized by the end of the pulse. These measurements are extended in Fig 1 b) with Stark broadening of H$_\alpha$. The excitation electron temperature, T_e, was also measured using the relative ratio of the observed lines of N$^+$. We artificially added 10% to the electronic temperature of the best fits in Fig. 1 b) to estimate the relative error in the measurement of T_e. Using these temperatures, we could run a 0D model of the afterglow kinetics. We show electron-N$^+$ recombination of electrons is responsible for the electron number density decay. However, ionization of N(^{2}D) by electrons has to be taken into account to reproduce the experimental results. It is shown in Fig. 1 b) that better agreement is achieved in the first 40 ns with a model including ionization than with only 3-body recombination.

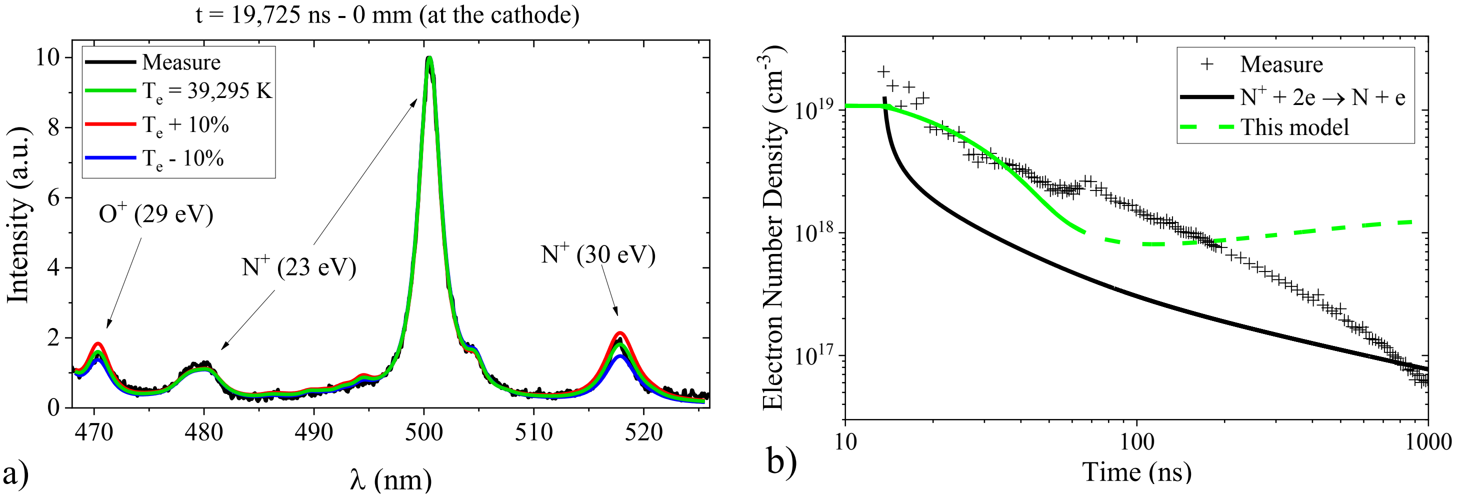

Figure 1. a) Typical fit (in green) of the N$^+$ and O$^+$ emission (black). Continuum emission was subtracted (assumed to be linear). We obtained $n_e = 1.4\times10^{19}$ cm-3 and T_e = 39.2895 K with the best fit. Two other simulations (in red and blue) show the error in T_e is less than 10%. b) Measured decay of the electron number density (crosses) compared with electron-ion recombination only (black solid line) and the 0D model of this abstract (green).

Références

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