Study of the reactivity of a microplasma

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IR Tuneable Diode Laser Absorption Spectroscopy (TDLAS) and UV broad band absorption spectroscopy measurements are used to detect, O_3, NO and NO_2 produced by a microplasma made of a micro-hollow cathode geometry. The gas flows through the microplasma; an additional plasma plume may be ignited on the microplasma anode region. The current density in the microplasma is about 3 orders of magnitude higher than in the plume. It is shown that O_3, NO and NO_2 densities scale as a function of the specific energy (J/l). The effect of the plume ignition is to lower the production of these species.

1. Experimental set-up

The microplasma is generated in a microhollow cathode (MHC) configuration made of a hole drilled through a metal/dielectric/metal sandwich [1]. One of the electrodes acts as the cathode (K) and the other as the anode (A1). The hole diameter is 200 µm. A MHC operates in three different regimes depending on the plasma current: abnormal, self-pulsing and normal regime. The self-pulsing regime is achieved in the range of 1-100 kHz, in argon, helium, nitrogen and oxygen. The self pulsing current is related to a fast plasma expansion on the cathode backside. The pulse frequency is controlled by the microplasma device capacitance, the gas breakdown voltage, and the average discharge current [2,3]. The reactor used is separated in 2 rooms by the MHC as shown on the figure 1. Thus, the gas is forced to flow through the microhole and the quantity of treated gas is well known. When a second electrode (A2) is added, a large volume of plasma plume may be generated between A1 and A2, at a low electric field (1-50Td depending upon the gas) [4].

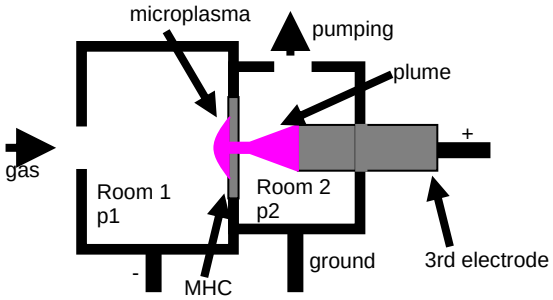

Fig. 1: experimental set-up

The pressure in the room 1 ranges from 70 to 130 Torr and in the room 2 from 16 to 70 Torr. The microplasma is created in the microhole separating the room 1 and 2; the plume in ignited the room 2. Different measurements are performed on the microplasma and on the plume in Air. UV absorption spectroscopy allows investigating the O_3 concentration. Tuneable diode laser absorption spectroscopy is performed with the TOBI system. TOBI allows to measure simultaneously NO and NO_2 in the plume [5]. All the measurements are made in the room 2.

2. Results

2.1. NO

The figure 2 shows the evolution of the NO concentration with the averaged current in the microplasma. The laser line is 1906.140 cm^{-1}. The experimental points for the lower currents are in the self-pulsing regime and the other in the normal regime. When plotted as a function of the specific energy, no difference appears between continuous plasma and the self-pulsing regime for the NO production.

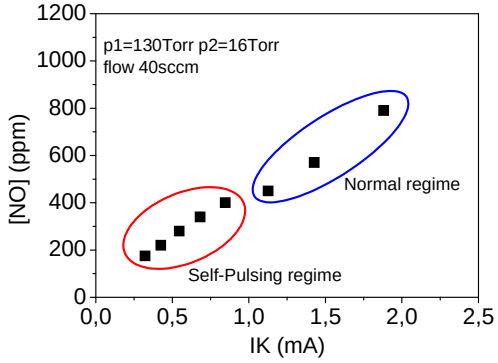

Fig. 3: evolution of NO concentration with the averaged current (p1 = 130 Torr; p2 = 16 Torr; 40 sccm)

The figure 3 shows that the NO concentration is independent of the pressure in the room 1.

Measurements varying the pressure in the room 2 show that the NO concentration is independent of the pressure in the room 2.

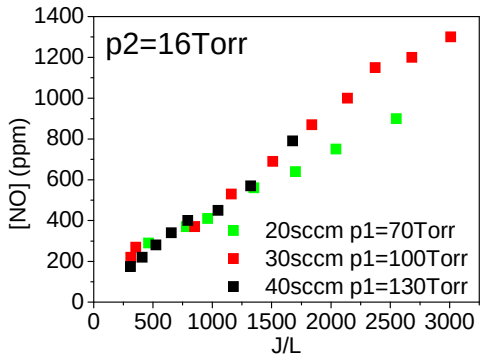

Fig. 3: influence of the pressure in the room 1 on the NO concentration (p2 = 16 Torr)

On the figure 4 the evolution of the NO concentration measured in the plume is compared to the concentration obtained in the microplasma in the same conditions. For the same current the NO concentration is lower in the plume. This result is independent of the distance between A1 and A2 when D is varying between 4 and 12 mm.

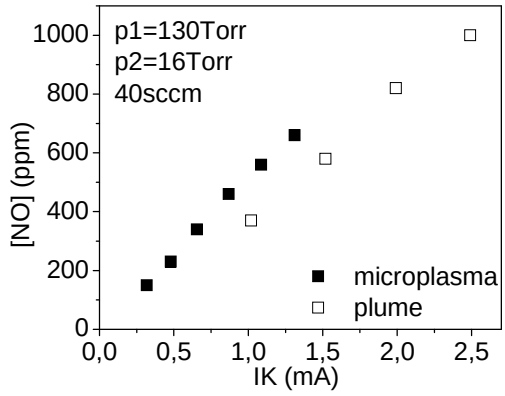

Fig. 4: variation of the NO concentration as a function of the cathode current in the 2 electrodes configuration (full squares) and in the 3 electrodes configuration (empty squares) (p1 = 130 Torr; p2 = 16 Torr; 40 sccm)

2.2. NO2 results

The figure 5 shows the evolution of the $_{NO2}$ concentration with the averaged current in the microplasma. The laser line is 1600.855 cm^{-1}. The $_{NO2}$ concentration increases for currents smaller than 0.5 mA and decreases for higher currents. The maximum is 95 ppm thus 3 times lower than the NO concentration for the same current.

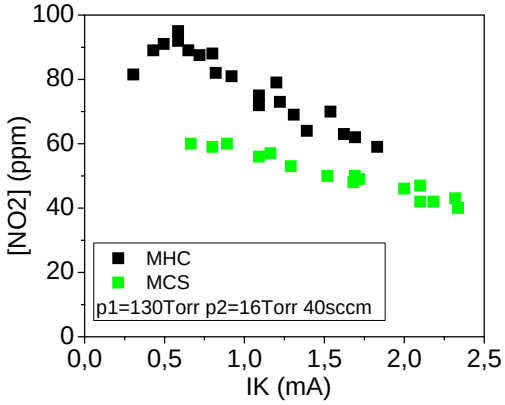

Fig. 5: variation of the NO2 concentration as a function of the cathode current in the 2 electrodes configuration (full squares) and in the 3 electrodes configuration (empty squares) (p1 = 130 Torr; p2 = 16 Torr; 40 sccm)

As for the NO concentration, the figure 6 shows that the NO_2 concentration is not influenced by the pressure in the room 2. Result is the same in the room 1.

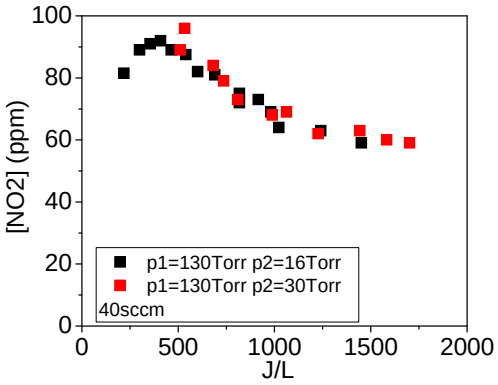

Fig. 6: influence of the pressure in the room 2 on the NO2 concentration (p1 = 130 Torr)

On the figure 5 the evolution of the NO_2 concentration measured in the plume is compared to the concentration obtained in the microplasma in the same conditions. As for NO, the NO_2 concentration in the plume is lower than in the microplasma for the same current. This result is independent of the distance between A1 and A2 when D is varying between 4 and 12 mm.

2.3. Comparisons

The evolution of the concentration of the different species NO and NO_2 are compared on

figure 7 in function of the injected power. The concentration of O_3 obtained in the same conditions in broad band emission spectroscopy is plotted too. The O_3 concentration decreases with the injected power whereas the NO concentration continuously increases. The NO_2 concentration firstly increases for values lower than 400 J/L and then decreases.

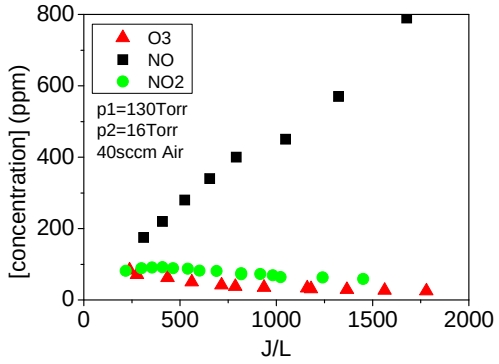

Fig. 7: evolution of O3 (red triangles), NO (black squares) and NO2 (green circles) concentration as a function of the injected power (p1 = 130 Torr; p2 = 16 Torr; 40 sccm)

The figure 8 compares results obtained in the microplasma and results obtained in a pulsed DC air discharge [6]. The discharge geometry is completely different. It is a pyrex tube of 50 cm length and 1.9 cm inner diameter. The discharge is pulsed: the pulse duration ranged from 20 µs to 3 ms, the repetition rate ranged from 50 to 1000 Hz. The peak current changes from 10 to 80 mA. The pressure is 3 Torr. And yet results are on the same curve.

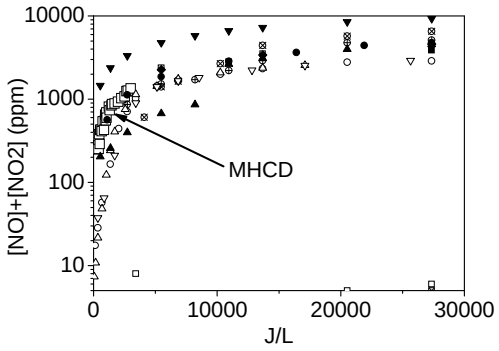

Fig. 8: comparison of the [NO]+[NO2] concentration for microplasma (70-130 Torr) and a pulsed DC discharge (2.7 Torr)

3. Modelling

In order to explain these results a simple 0D model has been created. It is separated in two parts where physical conditions are different. Firstly species are submitted to a air plasma during a time corresponding to the residence time of particles in a cylinder of 200µm diameter and 500µm deep. This part corresponds to the microplasma. Secondly, there are two different possibilities. The electronic density is set to zero and it corresponds to a post-discharge or the species moves in a bigger cylinder corresponding to the plume. In both part of the code, the reduced field, the temperature and the electronic density are deduced from measurements of absorption spectroscopy. Examples of the reduced field obtained in the plume for different currents and different distances between the MHC and the anode 2 in the same conditions of pressure than in figure 2 are shown on the figure 9.

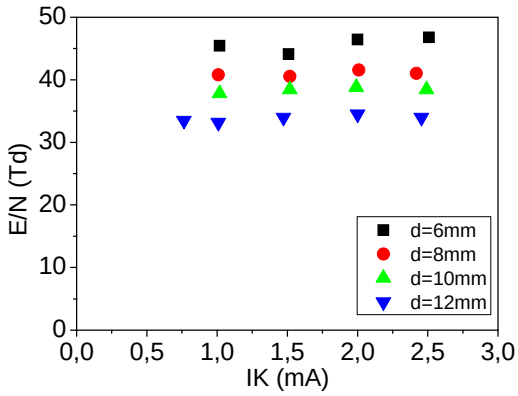

Fig. 9: evolution of the reduced field in function of the current for different distances between A1 and A2 (p1 = 130 Torr; p2 = 16 Torr; 40 sccm)

The reduced field is independent of the current and varies from 30 to 50 Td depending on the distance. The reactions considered in the model are taken from [7].

3. References

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