NO production in the COST Reference Microplasma Jet and a dielectric barrier discharge measured by means of Laser Induced Fluorescence (LIF)

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Abstract: Non-equilibrium atmospheric-pressure plasmas, such as the COST Reference Microplasma Jet (COST-Jet) or dielectric barrier discharges are beneficial for various applications due to their chemical and physical properties [1, 2]. Since nitric oxide (NO) is a chemically active species, which plays a vital role in various biological processes, the generation of nitric oxide (NO) in atmospheric plasmas is of growing interest [3, 4]. The NO densities are measured via LIF for different plasma and gas parameters in the COST-Jet.

Keywords: atmospheric pressure plasma jet, COST-Jet, NO, Laser-induced fluorescence spectroscopy.

1. Introduction

Atmospheric pressure plasmas, such as Microplasma jets and dielectric barrier discharges can be used for a wide range of applications, such as biomedical applications or etching processes. However, the sources for plasma jets, especially parameter correlations, were poorly characterized and results from different jet-devices were only hardly comparable. In this context a robust stable micro RF reference atmospheric pressure plasma jet (µAPPJ) was developed with a high degree of reproducibility. This reference jet is referred to as the COST-Jet [5].

The gas temperature in those discharges remains cold, i.e. near room temperature, while the electrons can be effectively heated to several thousand Kelvin (T_e is typically in the range of a few eV). This strong- non-equilibrium character of the discharge allows the treatment of temperature sensitive surfaces while the hot electrons cause a complex high temperature chemistry. This leads to all kind of dissociation products, such as N, O and OH representing some of the high reactive species. In addition, secondary reactive products are formed due to several processes, as for example O_3 and NO. Those species typically have a longer lifetime and are therefore likely candidates to interact with the treated sample. While at larger concentrations NO was found to be extremely harmful to the human body, at lower concentrations the molecule triggers many important biological processes as intercellular messenger and diffuses rapidly through most tissues which makes it an important component for tissue and wound treatments [6].

In this work we present time averaged NO ground state density distributions measured in the effluent of the COST-Jet and a dielectric barrier discharge by means of Laser Induced Fluorescence (LIF).

2. Methods

2.1. The COST-Jet

The COST Reference Microplasma Jet (COST-Jet) is supposed to serve as a reference for atmospheric pressure plasma applications. The device consists of two main components namely the housing and the head of the Jet. The head consists of the gas tube which is attached to two 30mm long plane parallel configured electrodes with a 1mm discharge gap. Here one electrode is grounded while the other is RF driven. The electrodes are stacked between two quartz panes in order to get optical access to the discharge itself down to the UV spectrum. The housing clamps down the head, includes the electrical connections, and miniaturized voltage and current probes.

As a carrier gas usually, a noble gas is used (i.e. 1slm of He) to which little amount of reactive gas components (up to 2% of e.g. N_2 or O_2) can be added.

Fig. 1. Picture of the COST-Jet.

2.2 Dielectric barrier discharge

The DBD is mounted inside a vacuum vessel to ensure stable conditions for the calibration of the LIF signal as well as to offer the possibility to vary the gas atmosphere in which the discharge is ignited, as presented in figure 1.

To adjust the flow of the feed gas and the pressure inside the vessel, mass flow controllers and a rotary vane pump are used. The driven electrode consists of a copper electrode which is covered with a dielectric barrier made of Al_2O_3. The applied frequency can be adjusted between 75 Hz and 4 kHz and the maximum amplitude of the voltage pulse can be varied between 6 kV_{pp} and 30 kV_{pp}. The discharge gap between the driven and the grounded electrode was set to 1 mm for all LIF measurements. The discharge is ignited in various gas admixtures of molecular nitrogen (N_2) and molecular oxygen (O_2).

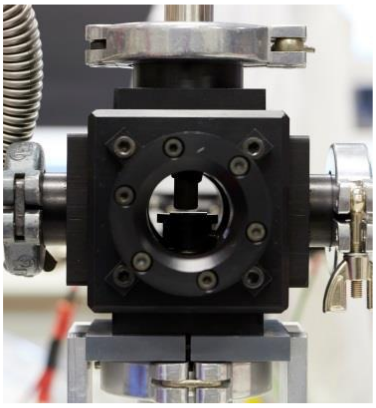

Fig. 2. Picture of the DBD mounted inside a vessel.

2.3. LIF

A tuneable dye laser (Radiant Dyes Laser GmbH, Germany) with Coumarin 47 is used which is pumped by the third harmonic of a Nd-YAG laser at $\lambda_{3\omega}$ = 355 nm (InnoLas Laser GmbH, Germany). A BBO crystal is used to frequency double the light of the dye laser (λ_{dye} ~ 226 nm). The laser energy is monitored with a GaP photodiode detector which measures the pulse energy of each laser pulse. To collect the fluorescence light a gated photomultiplier (R928, Hamamatsu Photonics, Japan) is used. The photomultiplier is mounted perpendicular to the laser beam and the light is focused onto the entrance slit with a quartz lens. The measured LIF signals are corrected for variations in laser energy and dye efficiency and are directly proportional to the ground state density via

$$N_F^{tot} = \frac{A_{21}}{A_{21} + Q_2} N_L g(\Delta\nu) \sigma L n_0$$

Here N_F^{tot} and N_L are the total amount of fluorescence and excitation photons respectively, A_{21} is the Einstein coefficient, Q_2 the quenching rate, σ the excitation cross section, $g(\Delta\nu)$the spectral line shape of the excitation, L the length of the interaction volume and n_0 the ground state density of the species of interest. The influence of quenching in the effluent is discussed.

3. Results

3.1. NO in the COST-Jet

The NO distribution was measured in the effluent region of the COST-Jet for different plasma and gas parameters. The absolute densities and the distribution are explained by plasma chemical reactions. One example is shown in figure 2. Here, the NO density in the effluent, depending on the gas admixture, is measured showing a maximum production for a N_2/O_2 admixture that is close to synthetic air. Here the reaction with secondary products such as O_3, the electronegativity of the plasma and the modulation of the EEDF must be taken into account.

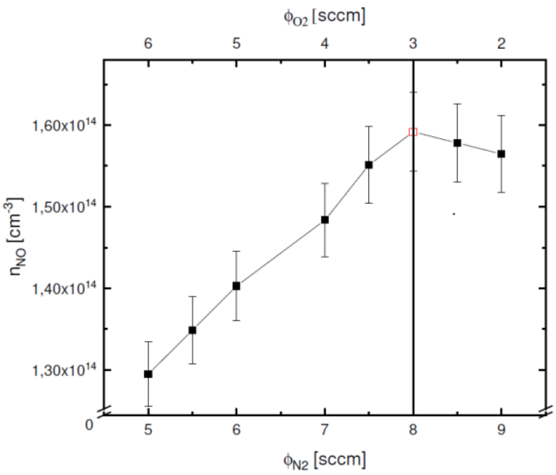

Fig. 3. NO density measured as a function of the gas admixture in the effluent region of the COST-Jet [7].

3.2. NO in the DBD

The NO density within the plasma volume of the DBD was determined for various parameter sets. The NO density generated in the volume of the DBD as a function of the gas mixture is presented in figure 2. The NO density shows a dependence on the N2/O2 ratio. With increasing oxygen admixture, the NO density increases at first until it starts to decrease after the oxygen admixture exceeds 30 %.

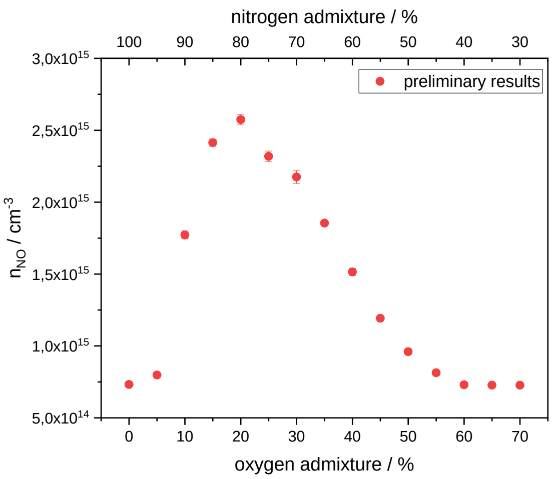

Fig. 4. NO density measured as a function of the gas admixture within the plasma volume of the DBD.

4. References

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5. Acknowledgements

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