Diagnostics of atmospheric plasmas and plasmas on liquid
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1. Introduction

Cold atmospheric plasma jets (CAPJ) are widely investigated for their application potential in the emerging field of plasma medicine [1]. The diagnostics of CAPJ is challenging as the plasma interacts with both the ambient air and the target biological tissue. As biological tissue is usually covered with a liquid layer, the study of reactive oxygen and nitrogen species (RONS) that are generated in the liquid is of supreme importance for understanding biological response to plasma treatment.

Here, investigations on a CAPJ featuring guided streamers (also termed plasma bullets) operating with helium (He) or argon (Ar) at a frequency of ∼ 1MHz are presented. The surrounding gas of the CAPJ is controlled using a shielding gas device, which allows for creating a defined gas curtain around the plume of the jet. As shielding gas a mixture of oxygen O_2 and nitrogen N_2 is used at various compositions. RONS in liquids can either originate from the plasma plume interacting with the shielding gas or water vapor and subsequently be transported to the liquid, be generated in secondary reactions in the liquid phase or be generated by radiation impinging on the liquid surface.

2. Gas Phase Diagnostics and Modelling

2.1 Dynamics of guided streamers

The dynamics of the guided streamers is investigated by phase resolved optical emission spectroscopy and 2D plasma hydrodynamics modeling[2]. It was found that the propagation of guided streamers is significantly affected by the electronegativity of the shielding gas: In attaching gases electrons attach to O_2 forming negative ions. The resulting charge density assumes a role similar to the dielectric walls in surface ionization waves observed in CAPJ traveling along tubes. The effect on He metastable generation is shown by laser atom absorption spectroscopy (LAAS) measurements[3].

2.2 Plasma chemistry

The RONS produced in the plasma plume of the CAPJ are investigated by combining LAAS on metastable Ar (Ar^*), Fourier transform infrared (FTIR) spectroscopy in the far-field of the jet and zero-dimensional kinetic modeling. The model resolves the fast sub-μs excitation and ionization processes as well as the slower gas phase reactions. The RONS O_3, $NO_2^{\bullet}$, N_2O_5, HNO_3, N_2O and H_2O_2 are detected via FTIR spectroscopy and agree well with the densities predicted by the model[4].

3. Diagnostics of plasma-treated liquids

It is observed that the gas-phase $^{\bullet}OH$ densities expected from kinetic modeling correlate with the H_2O_2 densities measured in plasma-treated liquids by a commonly used colorimetric assay as shown in Fig. 1. The hydrogen peroxide, as an example for reactive oxygen species relevant for mammalian systems, detected in the liquids can arise from different origins. One source will be the directly in the gas phase formed H_2O_2, which can be increased by raising the working gas humidity and be dissolved in the solution. Also CAPJ's vacuum ultraviolet (VUV) radiation will contribute to hydrogen peroxide concentration since VUV will dissociate water molecules to form hydroxyl radicals $^{\bullet}OH$, which fast recombine to hydrogen peroxide. Beside $^{\bullet}OH$ other oxygen radicals such as superoxide anion are detected by spin trapping enhanced electron paramagnetic resonance (EPR) spectroscopy in plasma treated liquids.

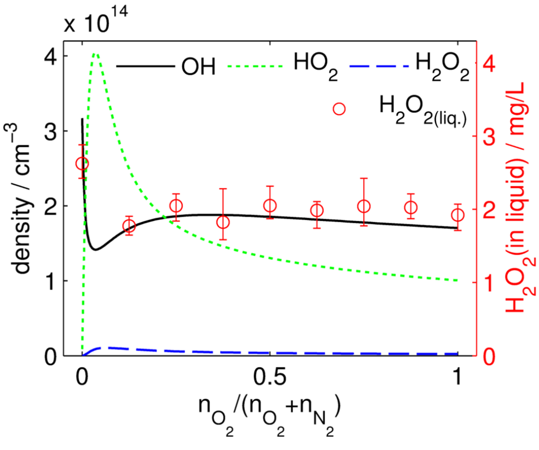

Fig. 1: H_2O_2 *concentration measured in plasma-treated liquid and densities of* OH, HO_2 *and* H_2O_2 *obtained from a kinetic model for shielding gas compositions ranging from pure* N_2 *to pure* O_2.

References

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