Dynamics of radio-frequency driven microplasmas

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1. Introduction

Non-equilibrium atmospheric pressure plasmas, in particular microplasma devices, have tremendous application potential. Radio-frequency driven atmospheric pressure plasma jets (APPJ) can provide high radical concentrations at low gas temperatures, e.g. for modification of sensitive surfaces in biomedicine \(^1\). The plasma dynamics is a complex multi-scale problem with pronounced electron dynamics within the radio-frequency cycle governing plasma ionization and initiating non-equilibrium plasma chemistry. Of particular interest are power coupling and energy transport processes from the plasma core region into the chemically reactive effluent region which is targeted for technological exploitations.

2. Plasma design

Investigations of the plasma dynamics are carried out in the so-called \(\mu\)-APPJ. The \(\mu\)-APPJ is an especially designed microscale version of the APPJ providing excellent access for optical diagnostics, in particular to the core plasma. Details of the plasma design and various results can be found in references \(^2\), \(^3\), and \(^4\).

3. Employed techniques

Diagnostics of atmospheric pressure plasmas are extremely challenging due to small confining structures and the collision dominated high pressure environment demanding exceptionally high spatial and temporal resolution down to microns and pico-seconds. The most promising approach is active combination of advanced optical techniques and numerical simulations. Employed techniques include: classical optical emission spectroscopy (OES), phase resolved OES (PROES), laser spectroscopy, finite-element numerical simulations, and optical techniques based on coupling with numerical simulations.

4. Selected results

Plasma ionization and sustainment are governed by electrons energized through the dynamics of the plasma boundary sheath. Excellent agreement between PROES measurements and numerical simulations reveals mode transitions between different ionization mechanisms during sheath expansion, sheath collapse, and electron acceleration in the high voltage sheath region.

Under certain conditions the operation in a He/O\(_2\) gas mixture indicates an electronegative character. Fig. 1 illustrates possible consequences in a space and time resolved contour plot of the electron density. Maximum density is observed in close vicinity of the electrodes during sheath collapse where quasi neutrality cannot be satisfied through negative ions confined to the time averaged plasma bulk region.

The determination of absolute atomic oxygen densities is of particular interest for the dynamics of plasma chemistry, energy transport mechanisms, and technological applications. A variety of advanced optical and numerical techniques show very good agreement for absolute values and spatial profiles along the plasma channel towards the effluent region.

Fig. 1: Dynamics of the electron density in an electronegative radio-frequency driven atmospheric pressure microplasma jet.

Acknowledgement

The numerical simulations have been generously supported by Y Sakiyama and DB Graves from the University California Berkeley. We would also like to greatly acknowledge very helpful discussions with F Iza and MG Kong from Loughborough University.

References