Measurement and simulation of Ar and He metastable density profiles in radio-frequency micro-plasma jets

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Space resolved concentrations of helium He* ($^3S_1$) and argon Ar* ($^3P_2$) metastable atoms in an atmospheric pressure radio frequency micro-plasma jet are measured using tunable diode laser absorption spectroscopy. The spatial profile of metastable atoms in the volume between the electrodes is deduced for various electrode gap distances. Density profiles reveal the sheath structure and reflect the plasma excitation distributions, as well as the dominance of the α-mode discharge.
In order to analyze the experimentally observed profiles of the metastable atoms a 2D numerical simulation was set up. Applying an appropriate He/Ar chemical model the correlation between the profiles of the metastables and the underlying excitation mechanisms is deduced.

Introduction

We apply tunable diode laser absorption spectroscopy (TDLAS) to record the spectral profiles of two argon and helium absorption lines, deducing He* ($^3S_1$) and Ar* ($^3P_2$) metastable densities for various discharge conditions. Since rare gases like helium and argon are typically used as carrier gases for micro-plasmas, the lowest metastable states of these atoms are analyzed, since they represent one of the main energy carriers in these discharges.
The measurements and simulations are made for an atmospheric pressure micro-plasma jet, a capacitively coupled, non-thermal glow-discharge plasma at high pressures. The jet features a 1 x *g* x 40 mm^3 discharge volume between two metal electrodes driven at 13.56 MHz (*g* = variable electrode gap distance). A more detailed description is given in reference [1].

Measurements

The spatial profile of metastable atoms as well as absolute densities in the discharge depend strongly on the distance of the two electrodes. Fig. 1 gives three density profiles of the metastable distribution between the electrodes for Ar* ($^3P_2$).

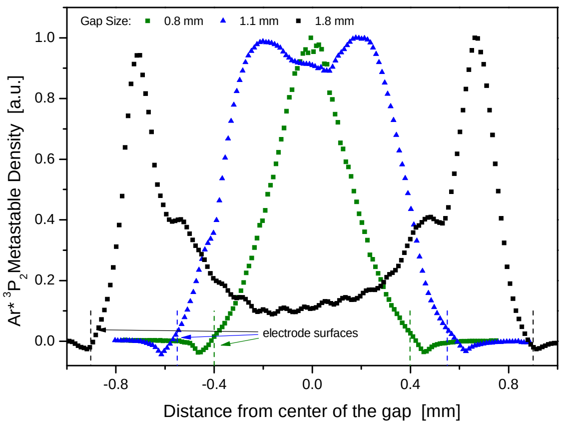

Fig. 1. Ar* ($^3P_2$) metastable density profiles between the electrodes for 1.8 mm, 1.1 mm and 0.8 mm electrode distance.

For electrode distances that are large compared to the sheath thickness, the spatially resolved measurements reveal the highest metastable densities in a short distance from the surface of the electrodes, and low densities in the center. However, shrinking the gap size substantially changes the profile by merging the sheath structures, and leading to highest productions rates in the center of the gap. A detailed description of further TDLAS studies done for this discharge is given in reference [2].

Simulation

By means of the hybrid model nonPDPSIM we perform a 2D numerical simulation of the micro-plasmajet [3]. The unstructured numerical grid consists of triangular elements. On this grid transport equations for all charged and neutral species are integrated as a function of time. The system of equation is closed by Poisson's equation, which is also integrated in time, followed by an implicit update of the electron temperature by solving the electron energy equation. To account for a non-Maxwellian distribution of the electron energy the zero-dimensional Boltzmann's equation is solved at times and transport and rate coefficients are updated during the simulation. Adapted Navier-Stokes equations are solved to obtain the fluid averaged advective velocity.
We apply a He/Ar chemical model to the code considering the dominant species. By varying the electrode gap distance we obtain similar profiles of the metastables as observed experimentally.

Results

By analyzing the number density and spatial distribution of the metastable atoms both, experimentally and by means of the dynamical simulation, we reproduce the underlying excitation mechanisms.

Acknowledgements

This project is supported by DFG (German Research Foundation) within the framework of the Research Group FOR1123.

References

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