Topic number: 10

Negative ions and double layer formation in He/O_2 cold atmospheric pressure plasmas

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Cold radio-frequency (RF) driven atmospheric pressure plasma jets in He with a small molecular admixture of O_2 can produce large number densities of reactive oxygen species, such as atomic oxygen [1, 2]. The gas temperature of the plasma is close to room temperature and has therefore a high application potential for sensitive surface treatments, e.g. in bio-medicine.

Numerical simulations are used to gain further understanding of the dynamic plasma chemistry within the atmospheric pressure plasma. The used one-dimensional fluid model, with semi-kinetic treatment of electrons, across the discharge gap of the plasma has been benchmarked by phase resolved optical emission spectroscopy measurements [3, 4]. The governing equations are mass- and momentum conservation of the considered species as well as the electron energy conservation. In total 16 species (ground state atoms and molecules, excited species, electrons, negative and positive ions) and 116 reactions among them are accounted for. The transport coefficients for electrons and chemical reaction rates involving electrons are calculated in advance using the Boltzmann solver BOLSIG+ [5] and stored in look-up tables as a function of mean electron energy.

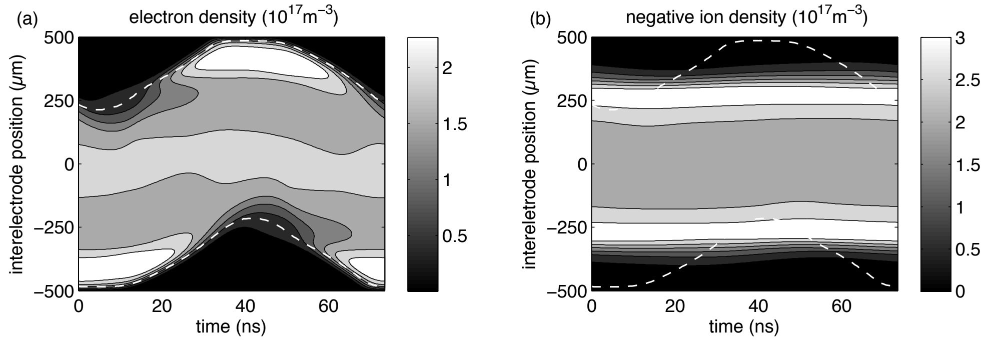

Fig. 1: Dynamics of the electron density (a) and the negative ion density (b) in an electronegative radio-frequency driven atmospheric pressure microplasma jet within one RF-cycle.

The simulations reveal that the sheath and electron dynamics are significantly influenced by comparatively high densities of negative ions. The time and space resolved electron density as well as the total negative ion density (sum of O^-,O_2^- and O_3^-) at an input power of 1.13 W are shown in fig. 1 on a linear greyscale for one RF cycle. Here, light colours indicate high and dark colours low densities, respectively. The white dashed line indicates the boundary between the bulk plasma and the plasma sheaths, which is determined assuming an equivalent sharp electron step [6]. The negative ions can not respond to the rapidly changing RF electric field, due to their comparatively high inertia and are confined to the time averaged plasma bulk region (fig. 1 (b)). This has consequences for the spatio-temporal behaviour of the electrons shown in fig. 1 (a). Maximum density is observed in close vicinity of the electrodes during sheath collapse and not in the center of the plasmas as for electro-positve plasmas. The electro-negativity in the center is in the order of one as can be drawn from fig. 1. Here, the quasi-neutrality condition of a plasma is fulfilled by both, electrons and negative ions. During times of sheath collapse this condition has to be fulfilled by electrons exclusively, since the ions are confined to the time averaged plasma bulk region, which results in the maxima close to the electrodes.

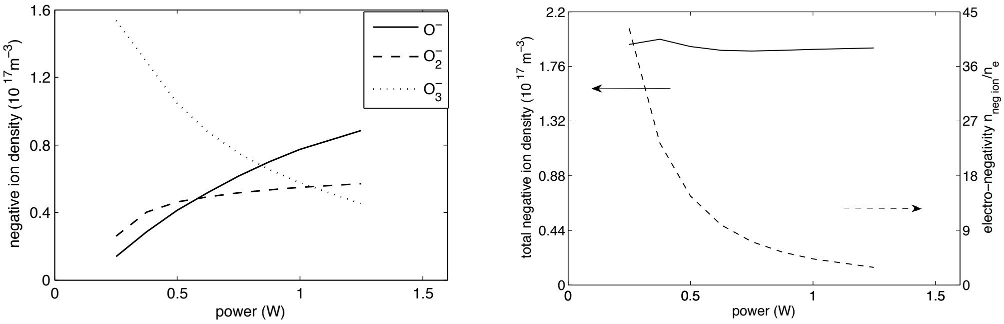

Fig. 2: Time and space averaged densities of the considered negative ions (a) as well as the time and space averaged total negative ion density and electro-negativity (b) for different input powers.

It can be seen that the dominant negative ion changes with power as plotted in fig. 2 (a). Here, the space and time averaged densities of each considered negative ion is shown for different input powers. At low powers the dominant negative is O_3^-, with increasing power the atomic oxygen density increases along with a decrease in the ozone density. Therefore, O^- is the dominant negative ion for high power operation. Furthermore, the time and space averaged total negative ion density stays almost constant for different input powers as shown in fig. 2 (b). The electron density increases with power, which leads to a decrease of the electro-negativity, defined as the ratio of total negative ion density and electron density, illustrated in fig. 2 (b).

Furthermore, the formation of transient double layers in the vicinity of the plasma boundary sheath is observed in those electro-negative plasmas at atmospheric pressure. It can be shown that these double layers contribute significantly to ionization and excitation processes within the plasma.

Reference

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