Electron-anion separation in electronegative rf microdischarges

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Several types of double-layer structures have been reported previously in the literature and the stratification of negatively charged species in electronegative discharges is a well known phenomena. Here we report on the evolution of a different type of double layer structure found in electronegative microplasmas. In these microdischarges, the electron ensemble oscillates between the electrodes forming sheaths that are larger than half the discharge gap. As the electrons oscillate, they move across and beyond a central electronegative core formed by anions. As a result of their different motion, electrons and anions are completely separated and regions of positive space charge form between the oscillating electron ensemble and the central electronegative discharge.

1. Introduction

Low temperature atmospheric pressure microplasmas have received growing interest in recent years for their potential use in many technological applications, such as displays, radiation sources, analytical systems, material processing and biomedical applications [1-4]. In biomedical applications helium is typically used as a buffer gas due to its excellent thermal properties, and reactive oxygen species (ROS) are often sought to trigger biological responses. ROS can be produced in the plasma for example, by introducing oxygen or water in the feed gas. Even if water is not deliberately introduced in the discharge, traces of water are expected in most biological applications due to open-air operation and treatment of moist biological material.

Motivated by the need to better understand the dynamics and chemistry of water containing discharges, we have performed computer simulations of He+H_2O microplasmas that reveal complex spatio-temporal profiles. In this paper, we report on the evolution of the He/H_2O microdischarge as the inter-electrode spacing is decreased and the electronegativity is increased. It is found that in electronegative rf microdischarges a state is reached where the anions and the electrons become completely separated and areas of positive space charge develop between the oscillating electron ensemble and an electronegative central core [5]. While the data presented in this paper corresponds to a He/H_2O admixture, we have observed similar behaviour in other electronegative discharges such as He/O_2.

2. Computational Model

The computational results that are presented in this paper have all been obtained using a conventional one dimensional fluid model. This solves the continuity equation for each species considered in the model, the electron energy equation and Poisson's equation for the electric field. Due to the large collisionality of the plasma, the charged particles inertia is neglected and the drift-diffusion approximation is used to determine their mean velocity. Previously, this model has been shown to reproduce the main characteristics of atmospheric pressure electropositive rf microdischarges sustained between two parallel plate electrodes [6].

For this study we consider a model with 31 species and 80 reactions. These are chosen from reference [7], where more than 500 reactions were

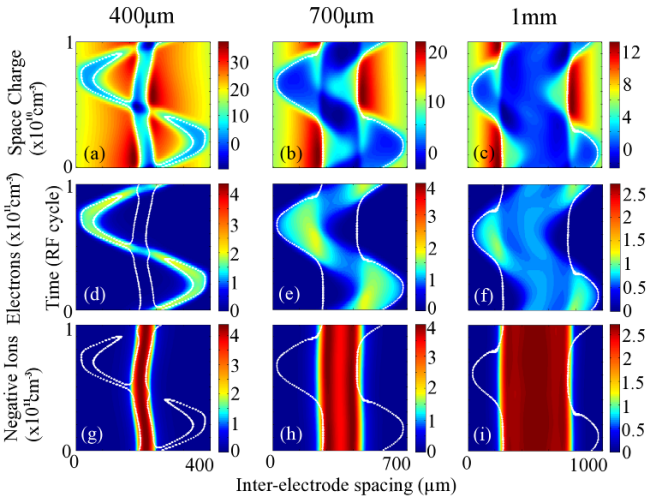

Fig 1: Evolution of electron-anion separation as gap size is reduced for a 3000ppm He+H_2O discharge. Electron and ion density plots are normalized for each gap size to enable visual comparison of the two species.

screened to identify the dominant chemical processes in He/H_2O plasmas. In this study we fix the rf driving frequency to 13.56MHz and apply an input power of 1W/cm^2. The inter-electrode spacing is varied from 1mm to 400µm, and the H_2O concentration is swept between 300ppm and 3000ppm.

3. Results and Discussion

Double-layer type structures have been reported previously in a variety of low-temperature electronegative plasma systems [8-12]. When electronegative discharges are confined in a single cavity (as the case considered here), three different regimes are typically observed [8-10]. At low electronegativity (α), the discharge stratifies into an electronegative core with electropositive edges. As α increases, the electropositive edges slowly disappear, and at even larger α, the discharge centre flattens. Here we report on a different structure that is observed in atmospheric pressure electronegative discharges as the discharge gap is reduced and that results in the complete separation of electrons and anions.

As the gap size is reduced, the width of the quasi-neutral bulk plasma begins to decrease and the sheaths progressively occupy more of the gap between the electrodes (see fig. 1(a-c) where the spatio-temporal evolution of the space charge is shown for discharges held in 400, 700 and 1000µm gaps). It has been shown that in electropositive discharges the quasi-neutral bulk plasma is no longer stationary and it oscillates between the electrodes following the motion of the electron ensemble [6, 13, 14]. Similar electron behaviour is found in electronegative discharges (see fig. 1(d-f)). On the other hand, negative ions remain confined to the centre of the discharge and due to their large inertia their spatial oscillation is negligible (see fig. 1(g-i)).

The stratification of electrons and anions in the 1mm discharge is clearly visible when comparing figures 1(f) and 1(i). Anions are confined to the centre of the discharge and electrons form wings at either side of the electronegative core. This is similar to structures observed in low-pressure electronegative discharges. An additional structure forms, however, when at the input power and driving frequency considered in this study, the gap is reduced below 600µm. Then, the electron oscillation becomes larger than half the gap size and the electron ensemble is found to move across and beyond the central electronegative core (fig. 1(d)). This results in the space charge distribution becoming strongly non-monotonous with "islands" of high positive space charge forming between the oscillating electron ensemble and the electronegative core fig. 1(a).

Fig. 1 shows the evolution of the anion and electron separation as a function of the inter-electrode spacing for a fixed H_2O concentration of 3000ppm. The evolution for a fixed gap size (400µm) as a function of the H_2O concentration is shown in Fig. 2. As said previously, when the gap is reduced the quasi-neutral bulk region oscillates between the electrodes, and when the discharge is electronegative the negative ions are confined to the centre of the discharge. When the electronegativity is low, fig. 2(a,d,g), the negative ion density is too low to affect the space charge significantly (fig. 2(a)). However, as the concentration is increased (fig. 2(b,e,f)) the negative ions begin to play a more important role. The central electronegative region becomes wider and the anion density becomes comparable to the electron density. Further increase of the H_2O concentration, results in the formation of a central electronegative core (fig. 2(c,f,i)).

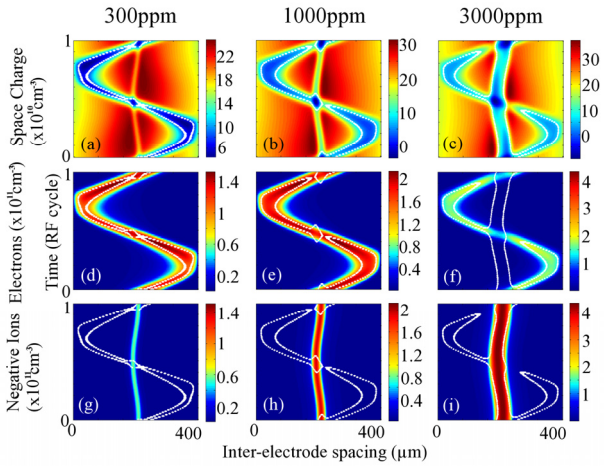

Fig 2: Evolution of electron-anion separation as the H_2O concentration increases for a He+H_2O discharge in a 400µm gap. Electron and ion density plots are normalized to enable visual comparison of the two species.

4. Conclusions

It has been shown in this paper that in rf electronegative microdischarges operation in small gaps results in the separation of electrons and anions and the formation of "islands" of positive space charge between the oscillating electron ensemble and the stationary electronegative core. These appear when the oscillation of the electron ensemble becomes greater than half the discharge gap and the

electronegativity is sufficiently high to form an electronegative bulk.

5. References

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