Influence of thin film on the electrical properties of pulsed plasmas

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Abstract: Dynamics of ion densities in pulsed complex plasmas have been previously studied by the analysis of the floating voltage on the electrodes. In the plasmas that contain highly reactive gas such as acetylene, a thin film of hydrocarbons deposits on electrodes and walls of the reactors. The dust particles produced by acetylene polymerization can also be included in the thin film. The growth of thin film on the electrodes influences the measured floating voltages and particle densities. Simultaneous measurements of electron density by microwave interferometer and floating electrode voltage have been performed. The floating voltage decreases when the thickness of the thin film grows, since the positive ions current to the electrode is smaller. Still, the change of floating electrode voltage increases, as well as the discharging time of the capacitance of LC filters. The electron density decay time in the plasma afterglow follows the change of capacitance discharging time in the same manner. In this work the impact of the thickness of the thin film on the diffusion of electrons and positive ions is discussed.

Keywords: plasma density, dusty plasmas, electrical characteristics

1. Introduction

The electrical characteristics of a radio-frequency discharge have been studied by many authors. In these investigations, different models were developed in order to establish the relationship between the electrical characteristics and physical properties of the discharges. These models enabled monitoring of the physical properties (such as ion energies and fluxes, electron temperatures and densities) by electric measurements.

Non-invasive methods for measurement of different physical parameters are particularly important in the case of reactive and dusty plasmas. High reactivity of the constituent gases in such plasmas leads to thin film deposition on the surfaces in the chamber, thus changing the conditions in the discharge.

We examined the influence of the presence of a thin film on the physical and electrical properties of pulsed plasmas. Experimental results show an increase of the electron density and a decrease of the floating electrode voltage with the thickness of the film, whether it has incorporated dust particles or not.

2. Setup and course of the experiment

a) *Experimental setup*

The measurements were performed in a low – pressure capacitively coupled discharge driven symmetrically by RF frequency at 13.56 MHz. The discharge was produced between two parallel stainless-steel electrodes with 30 cm in diameter and 7 cm distance. The signal from the RF generator was square-wave modulated with a frequency of 100 Hz and 50 % duty cycle. The RF input power, measured by a directional power meter placed between RF generator and the matching box, was 20 W, with low reflected power (less than 0.2 W). The total gas pressure was constant at 0.1 mbar for flow rates of 8 sccm for argon and 0.5 sccm for acetylene. Hydro-carbonaceous nano-sized dust particles were grown

in the process of plasma polymerization from the acetylene monomer.

Electron densities were measured by the means of a super-heterodyne microwave interferometer (MWI) with working frequency of 26.5 GHz and 1μs time resolution. It yields the line-of-sight averaged electron density. The details of the experimental setup can be found in [1].

b) *Course of the experiment*

The chamber was previously cleaned by sputtering the electrodes by oxygen plasma. The first measurement was done in pure argon plasma in the clean chamber. The deposition of the thin film on the electrodes and the walls of the chamber began by adding acetylene to the discharge. After several minutes of thin film deposition, acetylene was removed from the discharge gas. The measurement was done after approx. 1 minute (corresponding to the residence time of acetylene) in pure argon plasma with a thin film layer on the electrode. Further measurements were done by repeating the same procedure, increasing with each new cycle the thickness of the deposited film.

The formation of the dust particles was avoided by the "proper" pulsing of the RF generator signal [2]. By pulsing the signal with low frequencies (100 Hz) the nucleation and coagulation of the clusters and radicals is prevented, hence the formation of dust particles.

In the measurements with dust embedded in the thin film, the pulsing frequency is increased to 800 Hz for 3 minutes intervals, enabling the growth of dust particles. Afterwards was the frequency set to 100 Hz, acetylene evacuated and discharge shut down. In this way the particles that fell on the electrode were incorporated in the thin film and their influence was examined.

3. Measurements and results

Some authors report that no significant difference in the sheaths and plasma occurs when a dielectric coating is on the metallic surface of the electrode [3]. In the present measurements, we have seen that this difference exists for the measured floating voltage and electron density, when the thin hydrocarbon film is gradually deposited on the metallic electrodes.

The electrical circuit used for measuring the floating electrode voltages V_f is presented in figure 1. The floating voltage was measured by the external *LC* filters [4]. Each electrode was coupled to the capacitor *C* of the *LC* filter through a large inductance, passing the slowly changing DC component V_f of the electrode voltage. The change of electrode floating voltage in the plasma afterglow can be approximately expressed as:

$$V_f = V_{f0} + \Delta V_f \, (1 - \exp(-(t - t_0)/\tau)).$$

V_{f0} is the electrode floating potential at the end of plasma-on phase, ΔV_f is the amplitude of the voltage change during the afterglow, $\tau = R_{eq}\, C$ is the discharge time constant of the capacitor *C* and R_{eq} equivalent resistance for discharging the *C*. The time t_0 denotes the beginning of the afterglow phase.

We assume that by measuring ΔV_f we are actually measuring the number of ions deposited on the walls in the plasma afterglow.

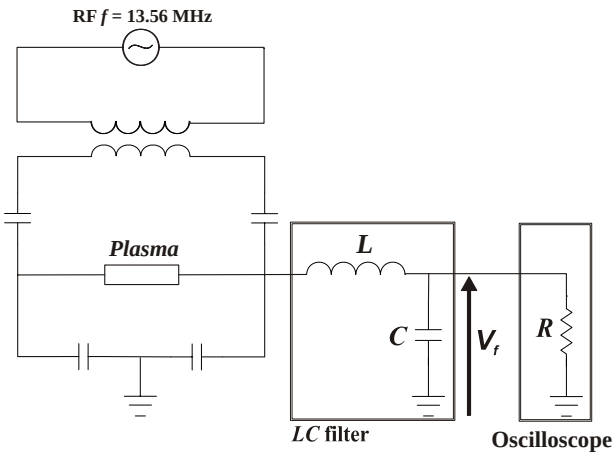

Figure 1. *The equivalent electrical circuit – L = 400 μH, C = 0.47 μF, R = 1 MΩ*

The electron and ion fluxes to each electrode are not equal and the net dc current flowing in the external circuit is blocked by the series connected blocking capacitor. The charged capacitor gains the net dc potential across it. In the case of symmetrically driven CCP, the same dc potential is built up on the both electrodes, since the same net dc current is

flowing from the discharge to the external circuit. In figure 2 is shown the change of the measured V_{f0} as the thickness of the deposited film grows. It can be seen that the DC voltage of the electrode -$|V_{f0}|$ is decreasing, indicating that the net current flowing into the external circuit is also decreasing.

The presence of the thin film can be modeled by a series parallel-plate capacitor at each electrode

$$C_f = \varepsilon_0 \varepsilon_r \frac{A}{d_f}.$$

Here A is the surface on the electrode coated with the film and d_f is the thickness of the film. As the thin film grows, its capacitance is decreasing from the initial infinite value (for the clean electrodes) to some finite value determined by the thickness of the film. The increased impedance of the film layer reduced the dc net current flowing to the external circuit, lowering the charging of the blocking capacitor, i.e. dc voltages.

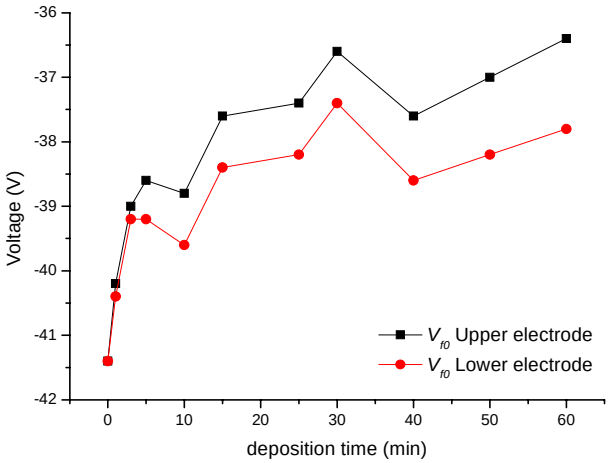

Figure 2. *Electrode floating voltage V_{f0} decreases as the thickness of the film on the electrodes grows.*

The line of sight averaged measurements of electron density for the different deposition times of the thin film are shown in figure 3. It can be seen that in both power-on and afterglow phase of the pulsed discharges the measured electron density is the smallest for the clean metal electrodes. As the thin film deposits and its thickness grows, the maximum of electron density in the power-on phase is increasing in the first 10 minutes of the film deposition and after that it keeps the constant value. In the plasma afterglow, the decay of the electrons is slower when the deposited film is thicker.

The energies of ions leaving the plasma were simultaneously measured by the plasma process monitor. It was determined that the plasma potential increased with the deposition time about the same voltage as the measured floating voltage. The plasma potential was then increased with the respect to the (grounded) walls, disabling the electrons to escape from the plasma in the radial direction due to higher potential barrier. The electron losses became smaller, leading to the higher decay time of electron density in the plasma afterglow in the case of dielectric-coated electrodes (see figure 4).

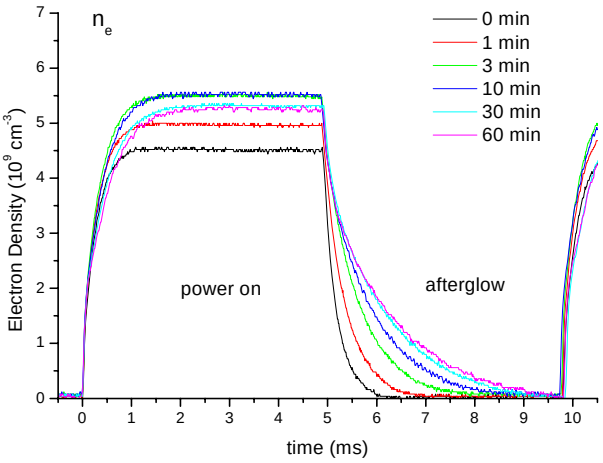

Figure 3. *Changes of the electron density and the decay time in the pulsed pure argon plasma with the deposition time of the thin film*

With the larger deposited film, the decay time becomes larger indicating the slower electron losses. In the plasma afterglow, due to quasi-neutrality, the decay times of ions should be the same as the decay times of electrons. Figure 4 shows also the discharge times of the voltage ΔV_f of the capacitors C on the both electrodes. It can be seen that the decay times of n_e are behaving in the same way as the discharge times of the capacitor. Since we assumed that the most of the ions diffuse to the electrode in the plasma afterglow, due to smaller distance to the electrode compared with the discharge radius, this is regarded as a confirmation for the assumption that the electrode is discharging due to ion flux in the plasma afterglow and that ΔV_f is proportional to the total ion flux.

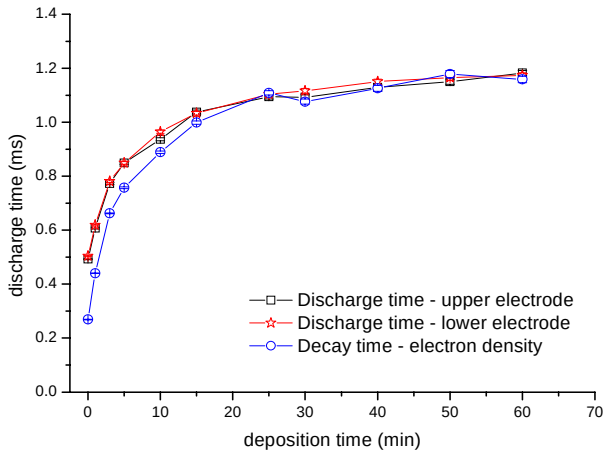

Figure 4. *Discharge times of the capacitors in the LC filter in the plasma afterglow have similar behavior as the decay time of electron density measured independently by MWI*

A similar behavior of the floating electrode voltages and electron densities is observed when the dust particles are embedded in the deposited thin film. In this case, the decay times of n_e are higher than for the same deposition period of acetylene film without particles, which is also valid for the discharge times of the capacitors on the *LC* filter. This may be due to larger surface of the dust particles, hence increased total effective surface of the dielectric coating. Other factors that can influence the different loss rates in the dusty plasma afterglow, such as electron temperature distribution and its non-uniformity in the discharge chamber, will be a subject of the further analysis.

4. Summary and outlook

The measurements showed that the influence of dielectric coating in the discharge chamber on the plasma physical and electrical properties should not be neglected. Its effect is especially important for plasma transport properties in the afterglow phase of the pulsed discharges, since the loss terms differ. The quantitative analysis of these plasma parameters and their incorporation in the electrical model allows a better understanding of the reactive plasma processes. Further measurements of the thickness of the deposited film and the chemical characterization of it can give more insight into conductive properties of different materials and their influence on electron and ion losses in the plasma afterglow phase.

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