Measurement of ion fluxes in plasmas with nanoparticles

B. Sikimić, I. Stefanović(*), and J. Winter

[1] *Institute for Experimental Physics II, Ruhr-Universität Bochum, 44801 Bochum, Germany*
(*) ilija.stefanovic@rub.de

The novel method for measuring the ion fluxes to the electrodes in pulsed radio frequency CCP plasma has been developed. The methode has been used in pure argon and argon with nanoparticles immersed. In the pure argon plasma the ion fluxes increse linearly with the discharge power. With the nanoparticles inside the ion fluxes saturate for powers larger than 40 W. The observed flux saturation is related to the nanoparticle dynamics and the ratio of the plasma volume to surface losses.

Diagnostics of reactive plasmas is an important issue for proper characterisation of laboratory and industrial plasma sources. The quality of thin film deposition or etching in radio frequency discharges depends strongly on ion density and flux. However, to determine their values is not an easy task. Due to the thin film deposition, the validity of Langmuir probe measurements is always an open question and their results even more complicated to explain than in the noble gas plasma. There are different methodes developed to measure ion flux and ion power losses in radio frequency discharges [1]. The capacitively coupled planar probe has been designed to measure ion flux even when its surface is coated with insulating material from the plasma itself [2]. Still, both methodes include some perturbation in the discharge and this should be taken into account properly [1, 2].

Pulsed RF plasma has been used to control the formation of nanoparticles in argon diluted acetylene RF plasma [3, 4]. The decay of reactive species (like Ar* metastables and electrons) in the plasma afterglow, during the power off time, has been used to deduce the basic properties of reactive plasmas with the nanoparticles [3]. Here, we report on novel diagnostics technique for measuring ion fluxes in reactive plasma discharges based on time dependance of electrode self-bias voltage in the discharge afterglow.

The experimental set-up has been described elsewhere [3]. The signal from the RF generator was square-wave modulated with a frequency of 100 Hz and 50 % duty cycle. The electrode self-bias was measured by using *LC*- filter [5]. 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. Fig. 1 presents th typical electrode self-bias waveform during the plasma-on phase and the plasma afterglow with the definitions of the measured waveform parameters.

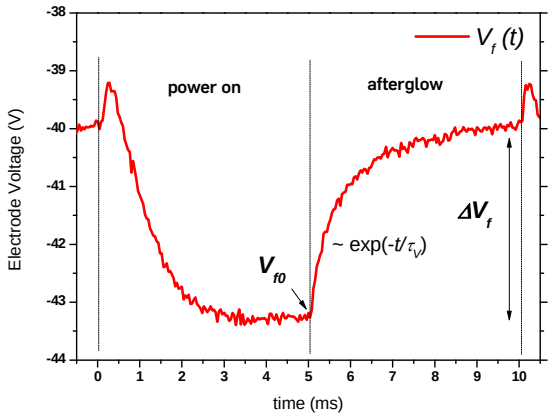

Fig. 1: Time dependant electrode self-bias voltage V_f. ΔV_f is the amplitude and τ_v the time constant of the voltage decay in the afterglow [5].

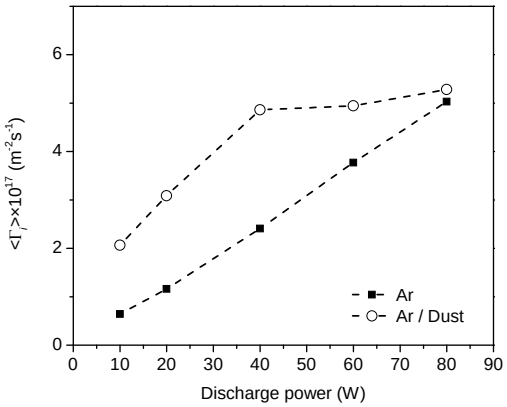

Fig. 2: Time averaged ion flux to the electrodes upon discharge power: solid squares – pure argon, open circles – argon with hydrocarbon-nanoparticles. Gas pressure was p = 10 Pa.

It has been show (see our other contribution Sikimić, Denysenko, Stefanović, Winter) that in the plasma afterglow the averaged ion flux $< \Gamma_i >$ can be calculated from the measured self-bias voltage waveform as

$$< \Gamma_i >= \int_{\tau_T}^{\tau_V} \Gamma_i dt /(\tau_V - \tau_T) = \frac{C\Delta V_f (\exp(-\tau_T / \tau_V) - \exp(-1))}{eA(\tau_V - \tau_T)} . \quad (1)$$

Here $\tau_T << \tau_V$ is the characteristic decay time of electron temperature in the afterglow. So the ion averaged ion flux can be calculated from

$$< \Gamma_i >= 0.63 \frac{C\Delta V_f}{eA\tau_V} . \quad (2)$$

In the formula (2), is the electrode surface area and *e* is the elementary charge.

The ion fluxes towards electrodes are measured by using above described method and presented on Fig. 2 in dependance of discharge power. In pure argon plasma, the ion flux increase with the increasing power linearly in the same way as the electron density [6]. With the nanoparticles inside, ion flux increases linearly and saturate for the powers larger then 40 W. The Ar* metastable density follows the same dependance [6]. However, with nanoparticles inside, the electron density increases linearly to the maximal power indicated [6].

The ion flux saturation with the power could possibly be connected with the nanoparticle dynamics in plasma bulk. The light scattering measurements show the zones with larger ~~and~~ and smaller nanoparticle density, with decreasing density from the discharge center to the electrode sheaths [7]. The particle density gradient is the result of the balance of different forces. In this experiment the most important are the ion drag and the electrostatic force that balance the particle position in plasma. With the increasing power the ion drag force becomes larger pushing the particles to the electrodes and "diluting" the plasma bulk from nanoparticles. The results of global model for dusty plasmas [8] show that the plasma energy balance depends on the ratio of volume loss to surface loss processes. With decreasing volume processes (recombination on nanoparticles) the electron temperature decreases [8]. So, the following scenario for ion flux saturation with increasing power can be proposed: with the increasing discharge power the ion density increases pushing the nanoparticles to the electrodes. Due to the decrease of particle density in the plasma bulk, the plasma volume losses decrease and so the plasma temperature necessary for sustaining the plasma. The decrease of plasma temperature leads to the decrease of Bohm velocity and to saturation of ion flux, as well as metastable density[6].

This work was supported by DFG Project WI 1700/3-1, Research Department "Plasmas with Complex Interactions" and Research School of Ruhr Universität Bochum.

References

[1] V. A. Godyak, R. B. Piejak and B.M. Alexandrovich *J.Appl. Phys.***69** (1990) 3455.
[2] N. St. Braithwaite, j. P. Booth and G. Cunge *Plasma Sources Sci. Technol.* **5** (1996) 677
[3] I. Stefanović, N. Sadeghi, J. Winter *J. Phys. D: Appl. Phys.* **43** (2010) 152003
[4] I. Stefanović, J. Berndt, D. Marić *et al. Phys. Rev. E* **74** 026406
[5] B. Sikimić, I. Stefanović, I. Denysenko, J. Winter 20th ISPC, 24-29 July 2011, Philadelphia, USA, CPP06
[6] I. Stefanović, B. Sikimić, N. Sadeghi and J.Winter, unpublished
[7] B. Sikimić, A. Aschinger, I. Stefanović and J. Winter, unpublished
[8] V. Land and W. J. Goedheer *NJP* **9** (2007) 246