acta phys. slov. 41 (1991), No. 5,6

INVESTIGATION OF SOME ELECTRICAL PROPERTIES IN 400 kHz Ar AND N_2 RF DISCHARGES[1]

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A self bias potential and resistive component of plasma impedance in a 400 kHz RF discharge was measured in a planar reactor for various electrode area ratios (from 1:1 to 1:6). Measurements were performed in an N_2 and Ar discharge at the pressure of $p = 120$ and 240 Pa. The presented results show the influence of the current density on the plasma sheath impedance and the resulting self bias potential, respectively.

I. INTRODUCTION

Planar RF discharges have become standard in a wide variety of processes, especially for anisotropic etching, which is the result of a gasification reaction controlled in some way by bombardment of a directed species.

Hence, it is very important to know the potential distribution between the sheaths in the planar reactor, in order to assume the energy of ions impacting on the etching surface. The purpose of this paper is to demonstrate the importance of current density on the plasma sheath impedance, to show how the self-bias potential depends on the applied voltage, the type of gas and pressure.

From these results it is evident that the models of capacitive RF discharges must take into account different parts of the RF discharge formation with different processes in plasma sheaths and different normal current density.

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[1] Contribution presented at the 8th Symposium on Elementary Processes and Chemical Reactions in Low Temperature Plasma, STARÁ LESNÁ, May 28-June 1, 1990

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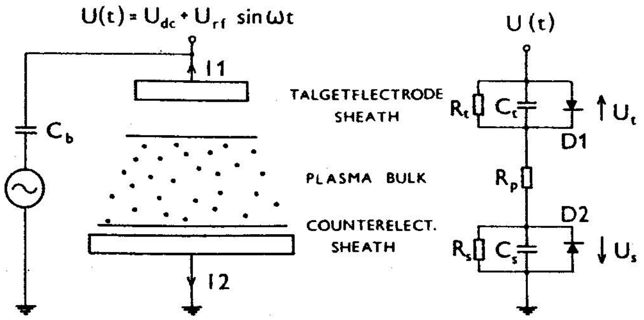

Fig. 1. Equivalent circuit of RF discharge in planar reactor.

II. EQUIVALENT CIRCUIT OF PLANAR PLASMA REACTOR

The scheme of the equivalent circuit is shown in Fig. 1. The external blocking capacitor C_b insulates the electrodes electrically, so the net charge flow to both electrodes must be zero [1, 2].

$$\int_0^{2\pi} I_1 d\omega t = \int_0^{2\pi} I_2 d\omega t. \tag{1}$$

The second requirement is continuity of the current, so

$$I_1 = -I_2. \tag{2}$$

For different areas of the two electrodes, the relations (1), (2) can be satisfied simultaneously only if

$$U_s - U_t = U_{rf} \sin\omega t + U_{dc}, \tag{3}$$

where U_s, U_t are the voltages across the substrate and the target plasma sheath, respectively; U_{dc} is the negative bias on the smaller (target) electrode and is usually called the self-bias potential; U_{rf} is the amplitude of the applied voltage.

The self-bias potential consists of two average voltages which develop on the sheaths, so

$$U_{dc} = \bar{U}_s - \bar{U}_t. \tag{4}$$

Thus, if we measure U_{dc} versus U_{rf}, we can estimate how the applied voltage is distributed between the sheaths (we assume that the impendance of the plasma bulk is negligible).

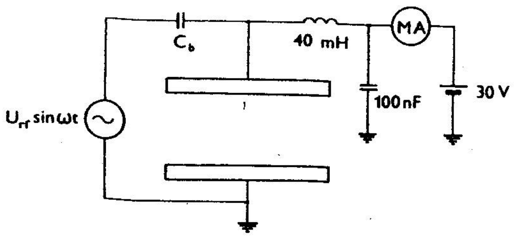

Fig. 1a. Measuring of plasma sheath resistance, gap length $d = 1.5$ cm.

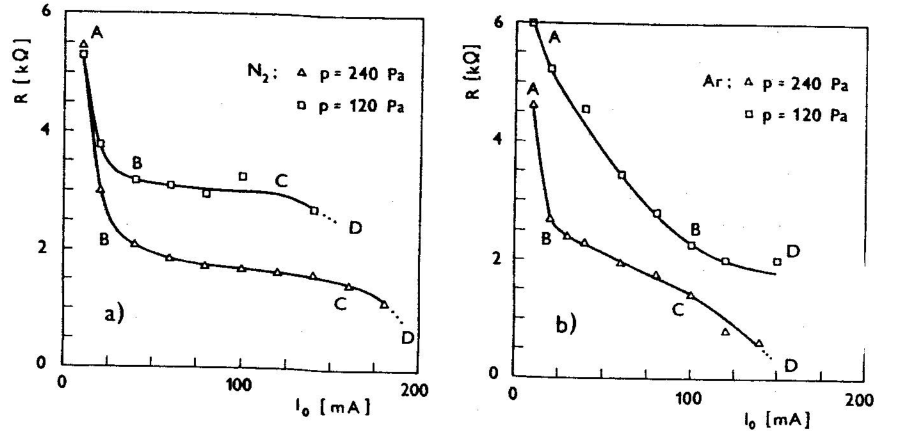

Fig. 2a, 2b. Resistive component of plasma sheaths impedance as a function of the current flowing through the reactor.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Our experiments were performed in the reactor with computer controlled measuring and the data acquisition system described earlier [3, 4], which was adapted for 400 kHz. The current through the reactor was measured by the Rogowski coil with an auxiliary coil, which excluded the capacitive current due to the parasitic capacity of the reactor.

The DC resistance of the plasma sheaths impedance was measured by applying a small DC voltage parallel to the RF source (Fig. 1a) and we measured the DC current through the reactor, thus resistance is $V_{dc}/i_{dc}(V_{dc} = 30$ V).

The results of measuring the resistive component of the plasma sheath impedance versus the amplitude of the current flowing through the reactor are shown in Fig. 2. These measurements were performed in the planar reactor with copper electrodes, their area was $A_t = A_s = 380$ cm^2. The shape of the characteristics can be explained as follows :

If the discharge is operating within the region AB, the glow covers only a part of the electrode surface, and this part increases or decreases in the area apparently in proportion to the flowing current. So the resistance changes very fast. Further, at the point B, where the whole surface of electrodes is covered by the glow, the voltage across the sheaths begins to rise with the current and thus the changes of resistance are slow (part BC). It appears from this that the current density tends to be constant, like in the DC glow discharge.

As the current is further increased (part CD), conductivity rises and at the point D a secondary breakdown occurs [5]. This strong increase of current conductivity with the secondary breakdown can be explained by secondary electrons emitted by electrodes under ion bombardment (γ electrons) and electron multiplication through the sheaths [6, 7, 8].

These two regimes (α ,γ - before and after the secondary breakdown, respectively), differ in the sustaining mechanism. For a frequency of the applied voltage much higher than the ion plasma frequency ω_i and much lower than the electron plasma frequency ω_e in the α regime the dominant electron-energy gain mechanism is related to the sheath expansion, which imparts periodically some energy to the plasma electrons, while in the γ regime the electrons emitted by the electrodes and the electron multiplication through the sheaths are responsible for the electron-energy deposition [6, 8].

In our case, for $\omega_i >> \omega$ (we estimate that the plasma density is about 10^{10} cm^{-3}[7, 8], so $\omega_i \cong 3$ MHz), the electrons issuing from the electrodes and the sheaths have a dominant role also in the α regime [7].

This explanation is in agreement with the self-bias measurements in the planar reactor with nonequal electrode surfaces - Fig. 3.

For example in Ar, 240 Pa, for the area ratio A_t/A_s=1/2 and a low applied voltage magnitude the self-bias potential is very low. The glow covers only a part of the electrode areas A_t, A_s and thus the average voltages developed across the sheaths are quite equal. That is why U_{dc}, which resulted from equation (4), is very low (see Fig. 3a, part AB). With the increasing input power the smaller electrode is completely covered by the glow, but not the larger one. In this part (part BC), the voltage developed across the sheath St is increasing, but the voltage across Ss remains constant, so U_{dc} rises. With a further increase of the applied voltage the current through St is increasing, and the voltage $\bar{U}_t$ tends to be constant [5]. On the other hand the voltage $\bar{U}_s$ is rising, because now the glow covers all the electrode area A_s. As a result of this U_{dc} is decreasing to the breakdown - point D.

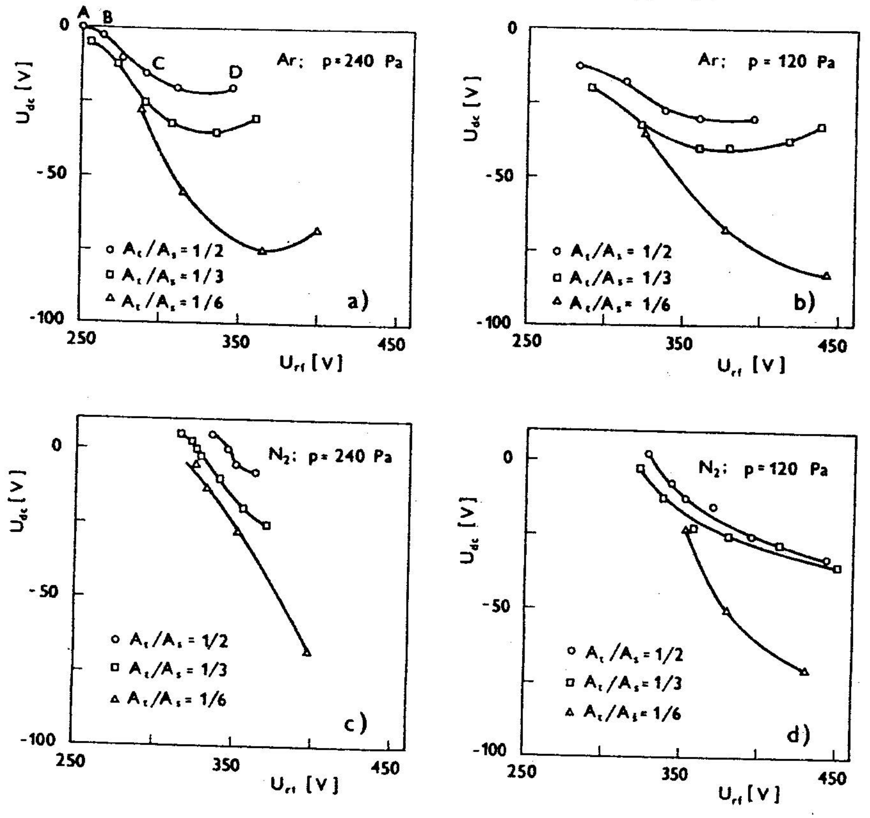

Fig. 3a, 3b, 3c, 3d. Self-bias potential versus amplitude of applied voltage for various electrode surface ratios.

For the area ratio A_t/A_s=1/6 the part AB of the characteristic is absent, because the glow covers the whole surface of the smaller electrode A_t even for the lowest ampitudes of the applied voltage. The breakdown for N_2 is not observed and it is in agreement with the fact that the breakdown voltage for N_2 (DC discharge), is much higher than for Ar [8].

IV. CONLUSION

From the presented experimental results and discussion it is evident that for a reliable theoretical model of a capacitive coupled RF discharge it is necessary to take into account the effect of normal current density j_n to account for the existence of two different regimes in the RF discharges.

ACKNOWLEDGEMENTS

The authors wish to thank Prof.Dr.P. Lukáč and Doc.Dr.V. Martišovitš for their advice and encouragement.

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Received October 18th, 1990
Accepted for Publication February 28th, 1991

ИССЛЕДОВАНИЕ НЕКОТОРЫХ ЭЛЕКТРИЧЕСКИХ СВОЙСТВ Ar И N_2 В ВЧ РАЗРЯДЕ ПРИ ЧАСТОТЕ 400 КГц

Приведены результаты измерения собственного потенциала и реальной части волного сопротивления Вч разряда с частотой 400 КГц в планарном реакторе при разных отношениях площади электродов (от 1:1 до 1:6). Измерения проводились в разряде N_2 и Ar при давлении 120 и 240 Па. Приведенные результаты показывают влияние плотности тока на волновое сопротивление экранировки плазмы и следовательно собственного потенциального порога.