PROBE DIAGNOSTICS OF LOW PRESSURE DISCHARGES IN CF_4 AND CF_4-O_2 MIXTURES

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ABSTRACT

We have determined the dependence of the reduced electric field strength E/p in the positive column of dc discharges on the reduced pressure p r in slowly flowing CF_4 and on the oxygen content in CF_4-O_2 mixtures. Double probe measurements were used to obtain values of energy and concentration of electrons in these plasmas. The role of the negative ions in the plasma is discussed with the aid of the behaviour of the electric field strength when sharp negative current pulses take place.

1. INTRODUCTION

At present only very few informations exist concerning the energy (mean value and distribution function) and the concentration of electrons in discharges through gases used in plasma etching. The reduced electric field strength E/p is an important parameter of the plasma and is related to the energy of electrons. Therefore at first we measured E/p in the positive column of dc discharges in O_2, CF_4, CF_4-O_2, Cl_2 and CCl_4.

2. EXPERIMENTAL

All the investigations were made in glass tubes with the radius r = 2,5 cm. As usual the axial potential difference was measured by means of electrostatic cylindrical probes. But we used double probes (Pt) for determining the mean energy and concentration of electrons. Their current-voltage characteristic was recorded point by point. The probes had the diameter of 0,35 mm and length of 4 mm. All the probes were placed along the axis of the discharge tube. Some single probe characteristics were measured in O_2 and CF_4 plasmas. In contrast to the O_2 plasma the semilogarithmic plot of the electronic portion of the current to probe versus probe voltage (negativ to the space potential!) is a straight line in the CF_4 plasma. Therefore we analysed our double probe measurements in CF_4 and CF_4-O_2 mixtures too under the assumption of a Maxwellian electron energy distribution function. The electron temperatur $U_e = \frac{kT_e}{e_0}$ in Volt was obtained using the formula stated in /1/. The concentration of electrons was determined from the ion saturation current to the double probe by means of the technique established in /2/ which is based on the Laframboise probe theory. The evaluation was done according to the experimental extension of this theory given in /3/.

3. RESULTS AND DISCUSSION

Typical E/p - p r curves are shown in Fig.1 and 2. With the exception of O_2 plasma we observed the phenomenon of the contraction of the positive column at pressures lower than one torr. The tendency to contraction of the plasma was found to be increasing with the sequence of the (CF_4-O_2), CF_4 Cl_2 and CCl_4 plasmas corresponding the increasing of E/p. We also measured E/p in O_2, CF_4 and CF_4-O_2 rf discharges in a planar reactor and it was interesting to find the same relation between E/p in CF_4 and O_2 rf plasma (27,14 MHz) as in dc plasmas.

It is known that the concentration of F exhibits an maximum value as a function of the O_2 content in the CF_4-O_2 plasma /4/. In connection with these observations the behaviour of the electric field and the electron energy is interesting in the CF_4-O_2 plasma. In Fig.3 one can see that the electric field strength do not show appreciable variation with the oxygen addition to CF_4 up to 80% O_2. This could be an indication that the oxygen additions does not alter the electron energy. In fact, this suggestion is confirmed by a comparative consideration of the values for the electron energy in CF_4- and CF_4-O_2-plasmas, respectively, listed in table 2. It is noted that these results of our probe diagnostic are in agreement with the spectroscopic investigations in CF_4-O_2 rf plasmas in /5/.

In comparison with the O_2-plasma the large values of E/p and U_e in CF_4 and CF_4-O_2-plasmas, respectively, are apparent.* They are probably due to the fast loss processes of electrons by formation of negative ions.

Main production processes of the negative ions are

$$CF_4 + e \longrightarrow CF_3 + F^-$$

$$CF_4 + e \longrightarrow CF_3^- + F$$

with the threshold energies 4,2 eV and 4,8 eV, respectively /6/. The role of the negative ions in the plasma is dependent on the kind of their loss mechanism. We distinguish two types of reactions:

1. Loss of negative ions by associative detachment, for example,

$$F^- + CF_3 \longrightarrow CF_4 + e$$

$$CF_3^- + F \longrightarrow CF_4 + e$$

As a result electrons are formed, e.g. in the particles balance of electron the loss by attachment is compensated.

2. Loss of negative ions by ion recombination,

$$F^- + CF_3^+ \longrightarrow CF_4$$

$$CF_3^- + CF_3^+ \longrightarrow C_2F_6$$

In this case the formations of negative ions involves an increase of both E/p and U_e.

A qualitative verification of the nature of negative ion loss mechanism is possible with the aid of analysing the transient behaviour of the plasma /7/. The figures 4,5 show examples of oscillographic records of the voltage between two probes, when current decreases abruptly. As to be seen the electric field strength decreases nearly at the same time and then it increases slowly with the time in contrast to the E-behaviour in the O_2 plasma. Consequently, negative ion loss by ion recombination cannot be neglected in both CF_4 and CF_4-O_2 plasmas.

* see tables 1,2

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I (mA)	Probe 1		Probe 2	
	U_e (V)	$n(10^{15} m^{-3})$	U_e (V)	$n(10^{15} m^{-3})$
10	8,1	0,8	7,5	1,3
20	-	-	7,2	2,8
30	8,5	3,3	7,2	3,9
40	-	-	5,8	6,1
60	10,4	6,2	6,2	12,0

Table 1 : Temperature U_e and density n of electrons in CF_4-dc discharges at a pressure of 0,3 Torr
Probe 1 was placed at the gas feeding point whereas probe 2 was placed approximately in the middle of the discharge tube 13 cm downstream of probe 1.
Apparent due to the different degrees of conversion of the gas in the discharge the values of U_e and n differ at the two probe points at the same values of current and pressure.

$\%O_2$	0	20	30	40	100
U_e	7,6	7,9	7,1	8,1	(2,6)

Table 2 : Electrontemperature in dc discharges in CF_4-O_2 - mixtures; U_e measured by means of probe 2.
In table 2 the value of U_e at x = 100% is included in parentheses because the characteristics in this case were analysed under the assumption of a Maxwellian electron energy distribution function too although this function in pure oxygen should be rather Dryvesteynian.

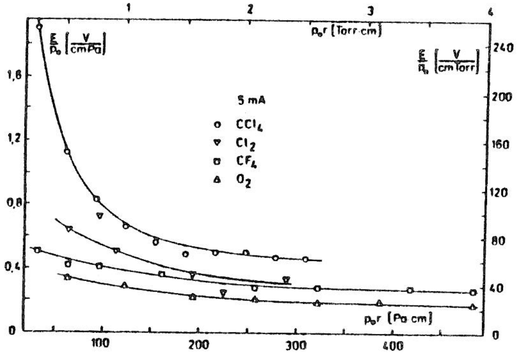

Fig. 1

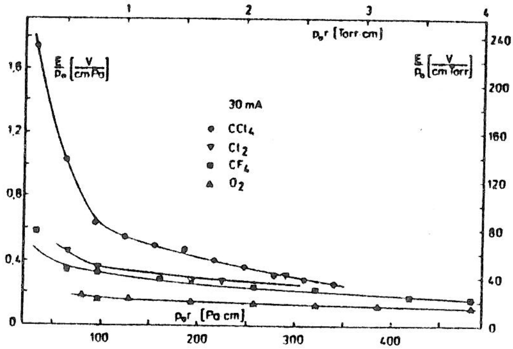

Fig. 2

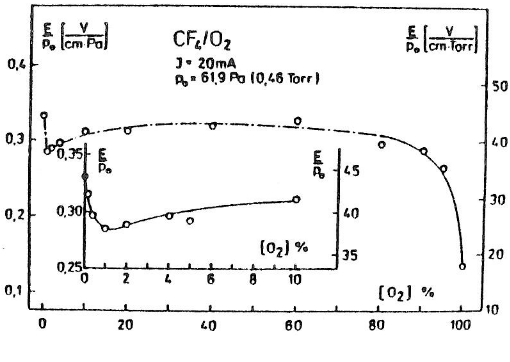

Fig. 3

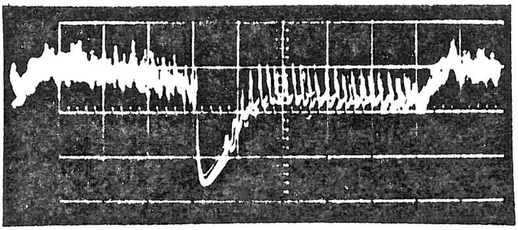

Fig.4
CF_4
p = 0,5 torr
i_o = 40 mA, i = 3 mA

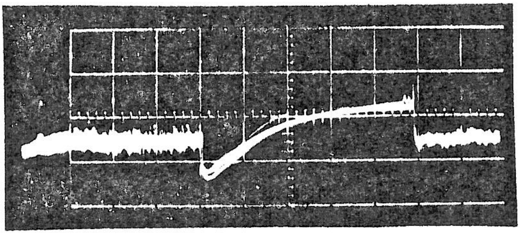

Fig.5
CF_4 - 80% O_2
p = 0,5 torr
i_o = 40 mA, i = 5 mA