# ELECTRICAL CHARACTERISTICS AND RATES OF INELASTIC PROCESSES IN THE POSITIVE COLUMN (PC) OF THE GLOW DISCHARGE (GD) IN FLUORINE MIXTERES WITH He,Ne,Ar,Kr.

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ABSTRACT

The electron temperature $T_e$, the reduced electric field strength E/N, the electron concentration $n_e$, the gas temperature Tg, as well as the dissociation rates of fluorine were investigated as a function of discharge current, pressure and composition of the mixture. The change of the mixture partial composition was found to cause the change of the physical parameters of plasma, the mechanism and the rates of the inelastic processes.

## 1. INTRODUCTION

A non-equilibrium plasma in the mixtures of fluorine with inert gases has recently found practical application as a medium for a synthesis of fluorine compounds with noble gases as well as in connection with the development of economical lasers in which the inverse population of eximers of $ЭT^*$ type is used, where Э is the noble gas atom. It is assumed that the initial stage of processes for obtaining compounds of noble gas with fluorine is the process (1):

$$F_2 + e \rightleftarrows \begin{matrix} F^- + F^+ \\ F^- + F \\ F + F \end{matrix} \qquad (1)$$

However, the substantiated conclusions on the mechanism of dissociation are lack.
The present paper deals with the investigations of the reduced strength of electric field, temperatures of electrons and heavy particles, rates of $F_2$ dissociation and electron concentrations as well as the calculations of dissociation rate coefficient (1) and level rate coefficients of processes (2.1),(2.2) and (2.3)

$1.F_2+e \rightarrow F^-+F$ (2.1); $2.F_2+e \rightarrow F^++F^-+e$ (2.2); $3.F_2+e \rightarrow F_2^*+e \rightarrow F+F+e$ (2.3)

## 2. EXPERIMENTAL

The work was carried out at the change in pressure of the mixtures from 1 to 5 torr in the discharge current 0.5-40mA, and in the partial fluorine composition from 0 to 100%. The experimental installation and the procedure of determining the physical parameters of the fluorine plasma were described previously (1,2). The electron temperature $T_e$ was determined from two- and one-probe characteristics. The dissociation rate was mea-

sured by the method of selective absorption of fluorine radicals. In the investigation use was made of fluorine 99.5%, containing impurities of $N_2$, $O_2$, HF. Spectrally pure noble gases were used.

## 3. RESULTS

Fig. 1-2 present examples of the dependence of electron temperatures, the rate of the diffusion destruction of charges on the wall probe and the reduced electric field strength on the percent composition of mixtures at various currents and pressures. The $T_e$, E/P values increase slightly with the decrease in current and pressure. The increase in the electron temperature and the reduced strength of electric field with the increase of fluorine molecules concentration is connected with the availability of the additional process of electron destruction in the process (2.1), the decrease in time of their life and concentration (see Fig.3.2). As the portion of $F_2$ in the mixture grows, the mechanism of charge destruction changes. Indeed, the increase in the percent composition of inert gas (see Fig.2.5) results in the significant growth of the rate of diffusion destruction of charges. Estimations of the rate of direct ionization processes were made:

$1.F_2+e\rightarrow F_2^++2e$ (3.1); $2.F_2+e\rightarrow F^-+F^++e$ (3.2); $3.Ne+e\rightarrow Ne^++2e$ (3.3)

in the case (3.1) and (3.2) in the assumption of the Maxwell electron energy distribution (2) and the approximation of the total cross-section of ionization by Fabrikant function (3) according to the expressions:

$$\Gamma_+ = kNn_e \quad (4.1), \quad k=\eta\sigma_{max}Te^{1/2}\frac{2b-1}{b}\left(2+b\frac{Ui}{Te}\right)\exp\left[-\frac{Ui}{Te}\right] \quad (4.2)$$

where $b=1+Te(Umax-Ui)$, $\eta$ is the constant, Umax is the electron energy corresponding to the maximum cross-section $\sigma_{max}$ of the process, $T_e$ is the electron temperature, Ui is the threshold value of excitation potential. For 100% Ne composition in the calculation use was made of experimental distribution functions studied by the second harmonic method, and the expression for k in (4.1) in the form : $k=\int_u\sigma(U)F(U)\sqrt{U}\,dU$ (5)
The concentration of electrons was determined according to expressions: $n_e=\frac{UiS}{eV_e}$ (6.1) and $n_e=\int_0^\infty f(\varepsilon)d\varepsilon$ (6.2)
The scatter in $n_e$ values did not exceed 20%. The estimates have shown that ionization rates for the processes 3.1, 3.2 and 3.3 are equal to $2.6\ 10^{16}$, $1.5\ 10^{15}$ and $2.5\ 10^{12}$ $cm^{-3}\ sec^{-1}$, respectively. The calculation and the data in Fig.2 permit to conclude that in the pure $F_2$ the charges are destroyed in the volume. As the portion of inert gas in the mixture increases, the mechanism of charge destruction approaches the ambipolar one.
Fig.(3.1-3.5) show the data on measurement of the dissociation rate of fluorine molecule depending on the gas composition. From the given data it is seen that the dissociation rate decreases with the decrease in F2 concentration in mixtures and with the decrease in the discharge current (Fig.3.1,3.5), which is in agreement with the conclusions on dissociation of molecules under the effect of an electron impact (1).
To calculate level coefficients of dissociation rates $k_{2.1}$, $k_{2.2}$

and $k_{2,3}$ according to expression (4.2) use was made of literature data. Calculations of the rate coefficient $k=\sum \alpha_i k_i$ were performed with the use of experimental values $\Gamma_{diff}, n_e$ (Fig.3) according to the expression (4.1).The results of the calculation show that with an accuracy to coefficient 2 in the pure $F_2$ and mixtures the dissociation is accomplished mainly due to the dissociative ionization reaction (2.2). The process of dissociative attachment to fluorine molecules (2.1) gives the contribution $\sim 3\%$ in the pure $F_2$. Only at very strong dilutions the contribution of the process (2.1) becomes comparable with the dissociative ionization contribution. The calculation of $k_{2,3}$ from the expression (4.2) (see Table) shows that in

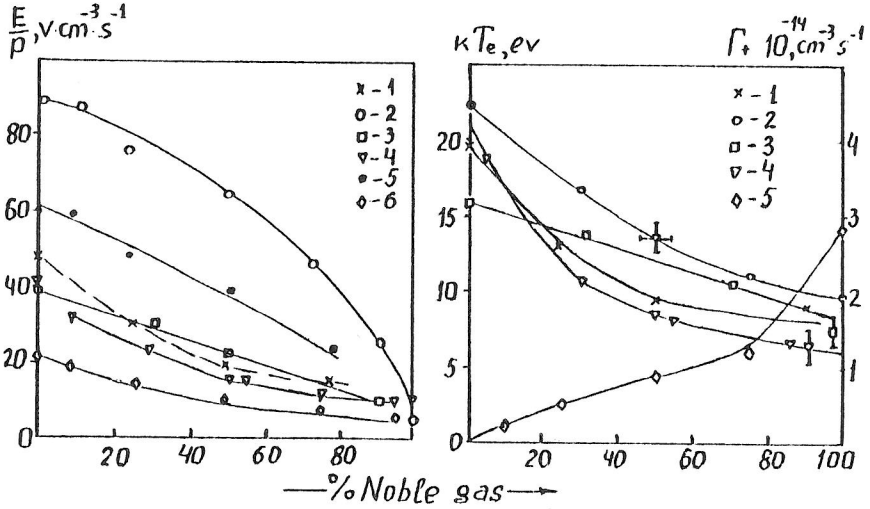


Fig.1




Fig.2

Fig.1. The dependence of E/P on the plasma composition. 1.(Ar+$F_2$), P=1torr, I=10mA. 2.(Ne+$F_2$), P=1torr, I=0.5mA. 3.(He+$F_2$), P= 3torr, I=3mA. 4.(Kr+$F_2$), P= 3torr, I=3mA. 5.(Ne+$F_2$), P=3torr I=0.5mA. 6. (Kr+$F_2$), P=3torr, I=30mA.

Fig.2. The dependence of temperature of electrons (1-4) and the rate of diffusion destruction of charges (5) on the plasma composition. 1.(Kr+$F_2$), P=3torr, I=30mA. 2.(Ne+$F_2$), P=1torr, I= =1mA. 3.(He+$F_2$), P=3torr, I=3mA. 4.(Kr+$F_2$), P=3torr, I=3mA. 5.(Ne+$F_2$), P=1torr, I=1mA.

conditions of the glow discharge at the realizable fields the role of the dissociation process through excitation of the vibrational levels can be essential only in gases containing $< 10\%$ of noble gases.
The decrease in the effective life-time of $F_2$ molecule ($\tau_{eff}$) and the negligible change in energy yield of atoms ($W_{at}$) the change of concentration of fluorine molecule in mixtures almost by the order of 2 (see Table) is connected, on the one hand, with the increase of contribution of the energetically

profitable process of dissociative attachment and, on the other hand, with the changes in physical parameters of the plasma. With the decrease of $F_2$ concentration in the mixture the rate of dissociative attachment decreases and, correspondingly, the concentration of negative ions decreases. This results in the chan-

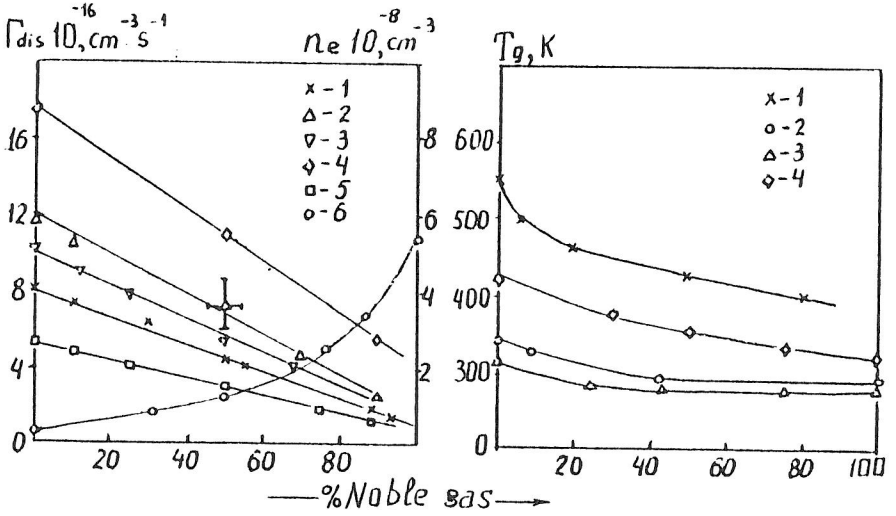


Fig.3 Fig.4

Fig.3. The dependence of dissociation rate of fluorine molecules (1-5) and concentration of electrons (6) on the plasma composition. 1.($Kr+F_2$), P=3torr, I=3mA. 2.($Ne+F_2$), P=1torr, I=30mA. 3.($He+F_2$), P=3torr, I=5mA. 4.($Kr+F_2$), P=3torr, I=20mA. 5.($Ar+F_2$) P=1torr, I=20mA. 6. $n_e$,($Kr+F_2$), P=3torr, I=3mA.

Fig.4. The relation of heavy particles temperature of the plasma with the plasma partial composition. 1.($Kr+F_2$), P=4torr, I=2 mA.2.($Ar+F_2$), P=1torr, I=5mA. 3.($Ne+F_2$), P=3torr, I=0.5mA. 4.($He+F_2$), P=3torr, I=3mA.

ge of character of charge destruction, the growth of concentration of ions, the decrease of E/N, temperature of electrons, the deformation of electron energy distribution function. The change of electron component gives rise, in its turn, to the change in the mechanism of dissociation of molecules.

Table. The rate constants of the inelastic processes and electric parameters of the PCGD plasma in the mixture ($Kr+F_2$) ( P=3torr, $I_{disch.}$=3mA).

| Parameter | % $F_2$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 100 | 90 | 70 | 50 | 45 | 25 | 12.5 | 10 | 5 |
| $N_F$ $10^{-16}$,$cm^{-3}$ | 8.0 | 7.2 | 5,7 | 4.1 | 3.7 | 2.1 | 1.1 | 0.9 | 0.5 |
| $k_1$ $10^8$,$cm^{+3}s^{-1}$ | 0.1 | 0.12 | 0.13 | 0.2 | 0.2 | 0.22 | 0.25 | 0.26 | 0.35 |
| $k_2$ $10^8$,$cm^{+3}s^{-1}$ | 1.6 | 1.5 | 1.0 | 0.7 | 0.65 | 0.4 | 0.3 | 0.27 | 0.25 |
| $k_3$ $10^8$,$cm^{+3}s^{-1}$ | 0.034 | - | - | 0.12 | - | 0.175 | - | - | 0.27 |
| k $10^8$,$cm^{+3}s^{-1}$ | 3.0 | 2.6 | 1.4 | 0.9 | 0.75 | 0.55 | 0.57 | 0.6 | 0.8 |
| E/N $10^{16}$,v $cm^2$ | 15 | 13 | 9.2 | 7.0 | 6.3 | 5.4 | 4.6 | 4.2 | 4.2 |
| $V_{dr}$ $10^{-5}$,m $s^{-1}$ | 52 | 34 | 15 | 9 | 8 | 4.6 | 3.3 | 3.0 | 2.6 |
| $\tau_{ef}=N_{F_2}/\Gamma_{dis}$,s | 1.0 | 1.0 | 0.9 | 0.9 | 0.85 | 0.6 | 0.5 | 0.45 | 0.3 |
| $W=\Gamma_{dis}/W_{sp}$ $10^2$, at $eV^{-1}$ | 6.0 | 6.0 | 7.0 | 6.4 | - | 6.6 | - | 4.6 | 4.0 |

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