Letter to the Editor

CALCULATION OF THE ELECTRON ENERGY DISTRIBUTION FUNCTION IN SF_6 WITH AN ADMIXTURE OF "ACTINOMETER" GASES[1)]

ВЫЧИСЛЕНИЕ ФУНКЦИИ РАСПРЕДЕЛЕНИЯ ЭНЕРГИИ ЭЛЕКТРОНОВ В SF_6 С ДОБАВЛЕНИЕМ »АКТИНОМЕТРИЧЕСКИХ« ГАЗОВ

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The electron distribution function is studied in SF_6 and $SF_6 + O_2$ discharges of small amounts of Ar, He and N_2 as "actinometer" gases to obtain the respective excitation frequencies for the particle diagnostics by the emission spectroscopy method. For this purpose the Boltzmann equation is solved. Tracing the densities of O and F atoms argon is proved to be the best suitable actinometer gas of them causing only a small distortion of the results up to 10% of its continents.

Knowledge of the concentrations of different neutral particles or radicals, especially of their time changes during plasma processing are desirable for a better understanding of the mechanism and also monitoring of the plasma chemical processes. A very suitable method for the diagnosis of the reactive plasma became particularly the emission spectroscopy since there is no need for a direct contact with the plasma there. Because of a correlation between the emission intensity and the etching rate proved by Harshberger et al. [1] in the $CF_4 + O_2$ plasma of variable oxygen contents, emission spectroscopic analysis was used to monitor the etching processes. Another method utilizing emission spectroscopy was reported by Coburn and Chen [2] for the determination of the relative reactive particle density by measuring its emission intensity and that of a noble gas which is added in a small amount to the plasma. It is based on an assumption that the energies of excited states of noble gas atoms and of the reactive species of interest are close to each other so that the emission issuing from those states may have a similar dependence on plasma parameters. The same technique, in principle, called as the "actinometric technique" has been independently developed and used by d'Agostino et al. [3—5] and in other laboratories [6—8] also for other mixtures.

If the excitation by direct electron impact prevails and the radiative decay is very rapid with respect to the collisional quenching, the intensity of emitted photons can be written as

$$I_x \sim N_e N_x \sqrt{\frac{2e_0}{m}} \int_{u_x}^{\infty} Q_x(U) U f(U) \mathrm{d}U = N_x \eta_x .$$

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In this relation N_e, N_x are the densities of electrons and molecules or atoms in the ground state, e_0 and m denote the charge and mass of electrons, $f(U)$ is the electron distribution function (EDF) at an electron energy U; $Q_x(U)$ are the cross sections with threshold energy U_x; η_x denotes the excitation efficiency. Combining the emission intensities of excited noble gas atoms (I_A) and reactive species of interest (I_x) we obtain the relation

$$N_x = KN_A \frac{I_x}{I_A}$$

where $K = Z_A/Z_x$.

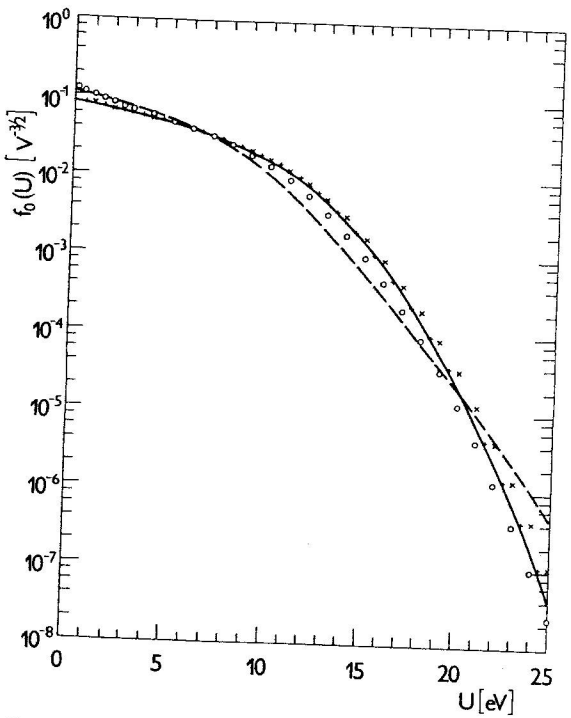

Fig. 1. Electron distribution function for $E/N = 1 \times 10^{-15}$ V cm^2 in $SF_6 + 10\%$ Ar(+), $SF_6 + 10\%$ He (×) and $SF_6 + 10\%$ N_2 (o); full line indicates the EDF in pure SF_6, dashed line in pure O_2.

Because of parametric dependence of the EDF on E/N and the composition of the mixture, the coefficient K is generally not constant but varies with these parameters and also is affected by the shape of the excitation cross section.

Here attention is paid to the dependence of this coefficient on the electron distribution function. The EDF is obtained from the Boltzmann equation [9], which is parametric in E/N and in the composition of the mixture. The dependence of the EDF on the composition of the mixture $SF_6 + Ar$, He, N_2 and $SF_6 + O_2 + Ar$, He, N_2 is investigated. In the calculations we used the cross section for electron collisions with O_2, SF_6, N_2 molecules and He atoms from [9, 10, 11]. Modified values from [12] were used for

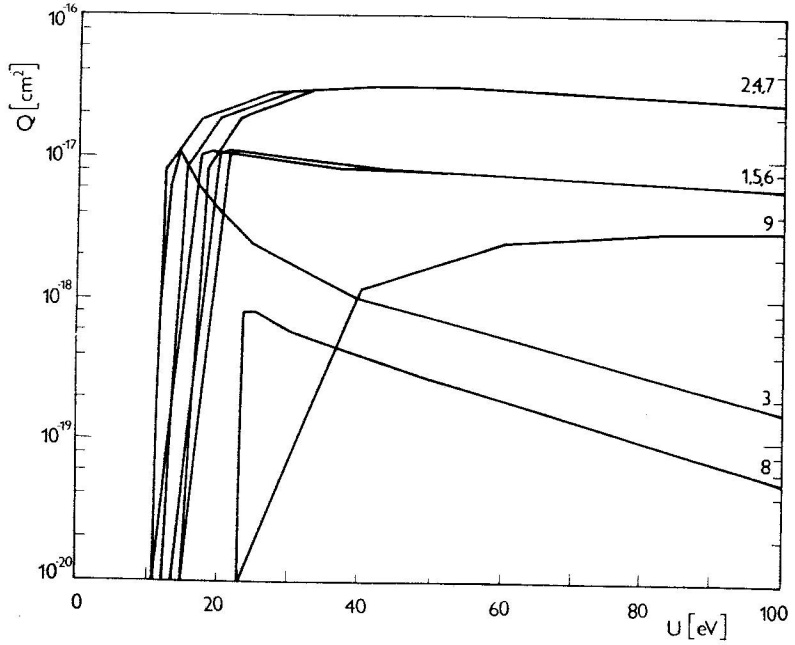

Fig. 2. Excitation cross sections for transitions listed in Tab. 1.

argon atoms; these were fitted to experimentally measured electron mobility and the Townsend ionization coefficient. Illustration of the changes of the calculated EDF in SF_6 with 10% Ar, He and N_2 with respect to the EDF in pure SF_6 and in pure oxygen is shown in Fig. 1 (E/N is equal to 1×10^{-15} V cm^2). There is only a slight change of the EDF if 10% of argon is added (compared with the EDF in pure SF_6) while the admixture of the same amount of He or N_2 either enriches the EDF with energetic electrons or the EDF is depleted of them. Similar results were obtained in the $SF_6 + O_2$ mixture if Ar, He or N_2 were added to the discharge plasma. The EDF in the $SF_6 + O_2$ mixtures without actinometer gas admixtures for different oxygen contents were presented in [13].

Table 1

Num.	Gas	U_{th} [eV]	Q	Z_i	λ [nm]	Transition
1	O	10.73	≡Ar (5)	E–11	777.5	$3p^5P—3s^5S$
2	O	10.73	≡Ar (4)	E–10	777.5	$3p^5P—3s^5S$
3	N_2	11.00	[14]	E–11	337.1	(0,0) SPS
4	Ar	11.83	[17]	E–11		4s′ (1/2)
5	Ar	13.47	[16]	E–11	750.3	4p′(1/2)—4s′ (1/2)
6	F	14.74	≡Ar (5)	E–12	703.7	$3p^2P—3s^2P$
7	F	14.74	≡Ar (4)	E–12	703.7	$3p^2P—3s^2P$
8	He	23.00	[9, 15]	E–16	388.8	$3p^3P—2s^3S$
9	He	23.06	[14]	E–17	501.6	$3p^1P—2s^1S$

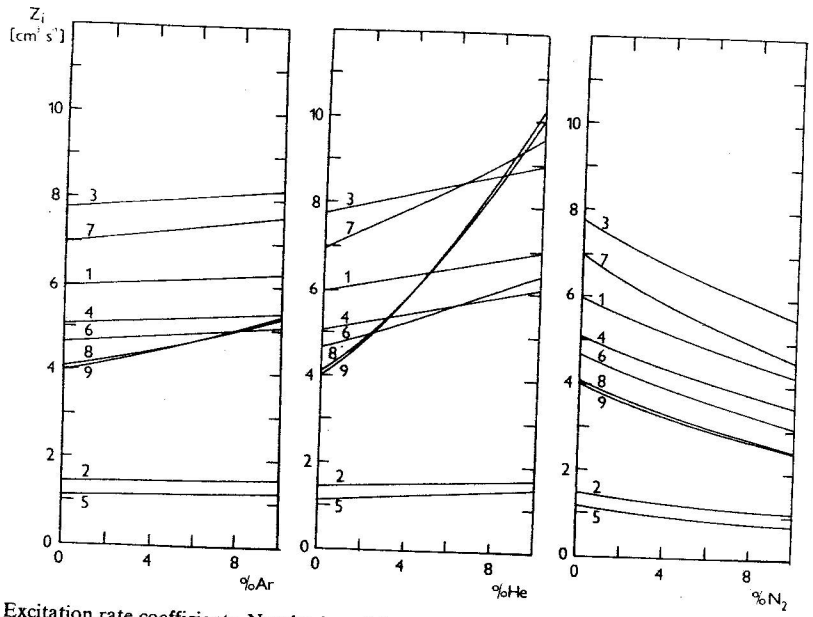

Fig. 3. Excitation rate coefficients. Numbering of the curves according to Tab. 1. Each of the curves has a different order of magnitude on the vertical scale — see Tab. 1.

To discuss the coefficient K the rate coefficients (Z_i[cm^3 s^{-1}]) for the transitions listed in Tab. 1 were calculated with the use of this EDF and with cross sections from Fig. 2 in dependence on the composition of the mixture. The results for the three mixtures $SF_6 + Ar$, $SF_6 + He$, and $SF_6 + N_2$ are depicted in Fig. 3. In the absence of some cross section data these were replaced by argonlike curves. For this reason the plots in Fig. 3 give only qualitative information on the effect of actinometer gases. In

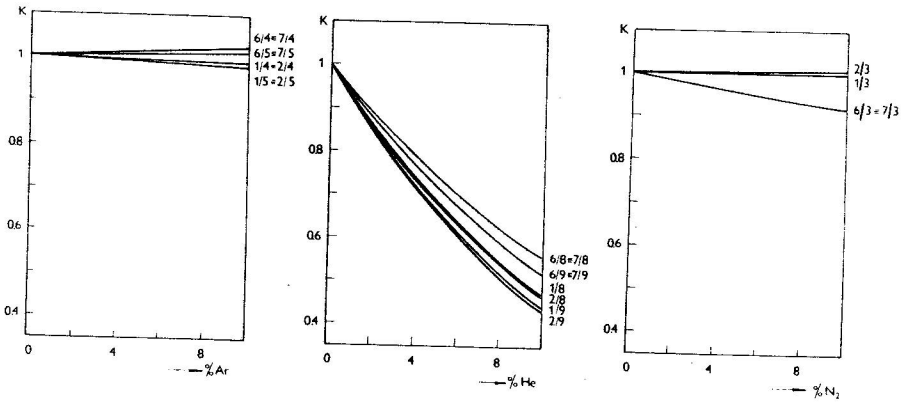

Fig. 4. Coefficient K for different combinations of the excitation curve in Fig. 3 as indicated by the symbolic fraction at each curve.

Fig. 4 the coefficient K is deduced for the case of tracing atomic oxygen and fluorine if Ar, He or N_2 is added to the reactive plasma. It illustrates the subsequent effect of changes of the EDF upon the coefficient K which results from the dependence of the EDF on the kind and amount of the actinometer gas. Among the gases considered here and given the composition of the etching mixture, it is apparently argon which suits best as an actinometer gas. It is evident that the choice of the actinometer gas should be carefully considered with regard to the tested particles. The calculation of the coefficient K in the case of available cross section data for the electron transitions of interest could moderate the strict requirements on the actinometer gases.

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