IL NUOVO CIMENTO VOL. 17 D, N. 3 Marzo 1995

Influence of SF_6 on HF Laser Plasma Parameters (*).

M. G. BAEVA [1](**) and P. A. ATANASOV [2]

[1] *Department of Physics, Techn. University - Varna 9010, Bulgaria*
[2] *Institute of Electronics, Bulgarian Academy of Science*
Tsarigradsko shosse 72, Sofia 1784, Bulgaria

(ricevuto il 20 Ottobre 1994; approvato il 23 Dicembre 1994)

Summary. — This paper presents the results of calculations of electron drift velocity, mean energy and ionization, and attachment coefficients in $SF_6 : C_3H_8 : He$ mixtures performed according to the multiterm Boltzmann-equation analysis. The parameters for wide variation of gas mixture composition and E/N values are obtained. The results presented may be useful in studying the HF laser action, analysis of the gas discharge, and research, development and modelling of this type of lasers.

PACS 51.50 – Electrical phenomena in gases.

1. – Introduction.

Gas mixtures $SF_6 : C_3H_8 : He$ are of great interest now due to their usage in HF chemical lasers—high-power radiation sources in 2.5–3.5 μm range having a large number of recent applications [1-6].

The vibrationally excited HF* molecules responsible for HF laser operation are produced by the following reactions in an electric discharge:

$$SF_6 + e^- \to SF_5 + F + e^- ,$$

$$F + C_3H_8 \to C_3H_7 + HF^* .$$

That is the reason of investigating mixtures containing SF_6, C_3H_8 and He, and the influence of SF_6 on plasma parameters. The results presented for these mixtures are probably the first to be published in literature.

(*) The authors of this paper have agreed to not receive the proofs for correction.
(**) Present address: Inst. für Hochleistungsstahltechnik, Technische Universität, Wien, Arsenal Obj. 207, Franz Grill Strasse 1/390, 1030 Wien, Austria.

2. – Cross-sections.

The mixtures under consideration contain three kinds of gases—SF_6, C_3H_8 and He. In order to obtain plasma parameters, the cross-section data for the elementary processes with electrons should be available.

The SF_6 molecule has «sophisticated» shapes of electron collision cross-sections [7,8].

The elastic momentum transfer cross-section is $2.7 \cdot 10^{-13}$ cm^2 at an electron energy of 0 eV and decreases to $8 \cdot 10^{-16}$ cm^2 at 1 eV. Then it increases to $17.6 \cdot 10^{-16}$ cm^2 for an energy of 7.6 eV, it changes slightly remaining of order $16 \cdot 10^{-16}$ V$\cdot$cm^2 in the range 8–25 eV and tends to decrease monotonically to 0 for an electron energy of 1000 eV.

The cross-section for the inelastic process of attachment has the most specific behaviour. It has a value of $3 \cdot 10^{-13}$ cm^2 at 0 eV which decreases to a magnitude of order 10^{-14} cm^2 at 0.08 eV. In 0.1–3 eV region a rapid fall to 0 is observed. Beyond this point the cross-section has values of order 10^{-18} V$\cdot$cm^2 and it is 0 at an electron energy of 16 eV.

The vibrational excitation with a threshold of 0.096 eV has values of cross-section larger than the elastic momentum transfer one in the 0.5–2.5 eV range. The other processes for the SF_6 molecules taken into account are vibrational excitation (0.065 eV), electronic excitation (9.8; 13.3 eV) and ionization (15.7 eV).

The elastic momentum transfer cross-section for C_3H_8 molecules has a minimum occurring at an energy 0.11 eV but it remains higher than the cross-sections of the inelastic processes in the energy region 0.001–1000 eV. The inelastic processes included in our calculations are as follows: vibrational excitation (0.093 eV; 0.358 eV), electronic excitation (6.8 eV; 9.1 eV), ionization (11.14 eV), attachment (6 eV).

Helium is a well-known gas and we will not discuss here the behaviour of its collision cross-section.

All cross-section data used in the present investigation are from [7,8].

The peculiarity of the cross-sections set for SF_6, especially the high intensity of the inelastic collision processes, requires multiterm Boltzmann-equation analysis for plasma characteristics calculation. The results presented are obtained by Galerkin's method using *B*-splines as basis functions. This technique was offered by Pitchford *et al.* [9] and it has been used by many authors.

3. – Results.

E/N values for which the calculations have been made are in a wide region and correspond to the values used in a real HF laser [6].

3·1. *Ionization and attachment rate coefficients.* – Calculated values of the ionization and attachment rate coefficients, K_i and K_a, for three different mixtures are shown in fig. 1 and 2. Also, K_i and K_a values calculated for $E/N = 1 \cdot 10^{-15}$ V$\cdot$cm^2 are plotted in fig. 3 as a function of SF_6 flow rate.

An increasing of SF_6 quantity in the mixture decreases the ionization coefficient due to the strong electronegativity of SF_6 molecules.

Using the results for K_i and K_a the effective ionization coefficient $(K_i - K_a)$ and the limiting field to gas number density ratio $(E/N)^*$ at which $K_i - K_a = 0$ can be

—SF_6, C_3H_8 and
or the elementary

ion cross-sections

^{2} at an electron
it increases to
maining of order
nically to 0 for an

the most specific
magnitude of
observed. Beyond
s 0 at an electron

s of cross-section
range. The other
ational excitation
V).
s has a minimum
ss-sections of the
elastic processes
093 eV; 0.358 eV),
(6 eV).
behaviour of its

n [7, 8].
high intensity of
ation analysis for
ed by Galerkin's
Pitchford *et*

wide region and

l values of the
fferent mixtures
$= 1 \cdot 10^{-15}$ V·cm^2

ation coefficient

t $(K_i - K_a)$ and
$- K_a = 0$ can be

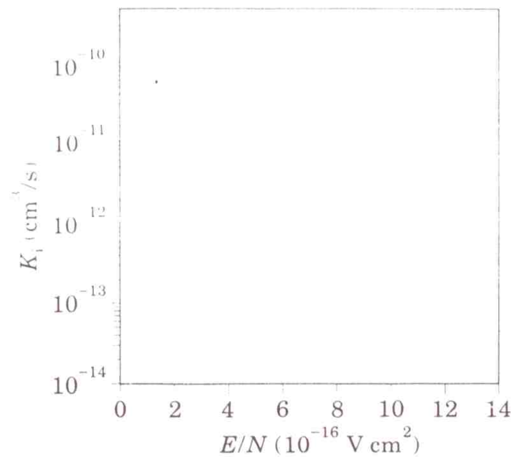

Fig. 1.

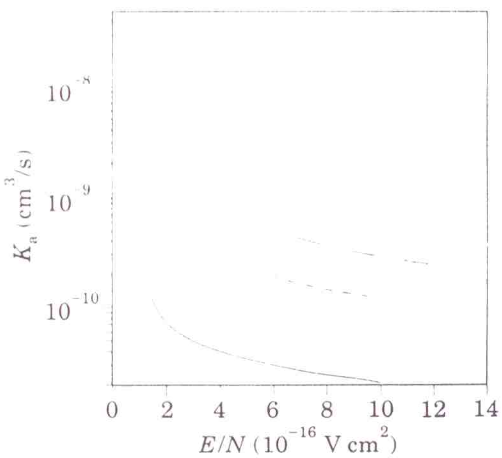

Fig. 2.

Fig. 1. – The ionization rate coefficient K_i *vs.* the reduced electric field E/N for mixtures $SF_6 : C_3H_8 : He = 0.2 : 0.07 : 7$ l/min (——), $1 : 0.07 : 7$ l/min (– – –), $2 : 0.07 : 7$ l/min (—–—).

Fig. 2. – The attachment rate coefficient K_a *vs.* the reduced electric field E/N for mixtures $SF_6 : C_3H_8 : He = 0.2 : 0.07 : 7$ l/min (——), $1 : 0.07 : 7$ l/min (– – –), $2 : 0.07 : 7$ l/min (—–—).

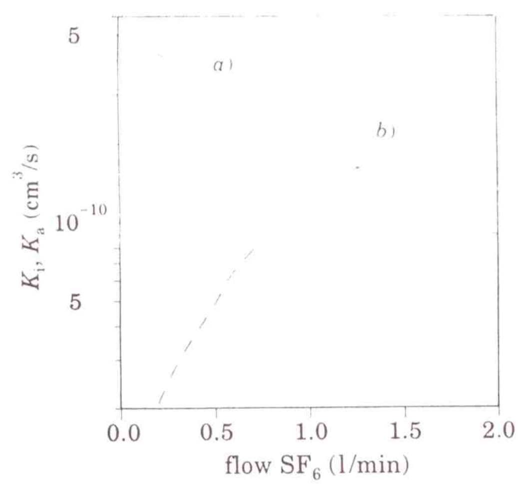

Fig. 3.

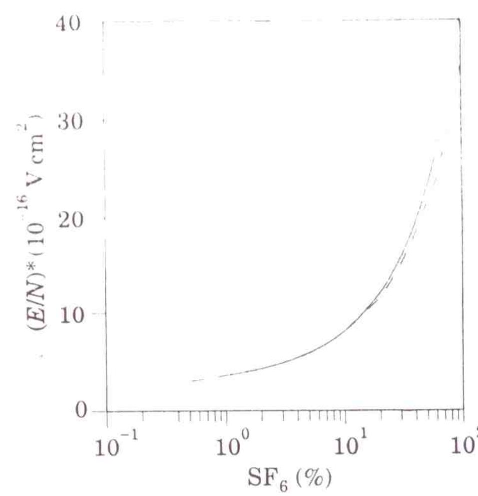

Fig. 4.

Fig. 3. – The ionization (*a*)) and attachment (*b*)) rate coefficients as a function of SF_6 flow rate at $E/N = 1 \cdot 10^{-15}$ V·cm^2.

Fig. 4. – The limiting reduced field $(E/N)^*$ *vs.* the SF_6 concentration for mixtures SF_6 : He: —— present calculation, – – – Kleine *et al.* [10].

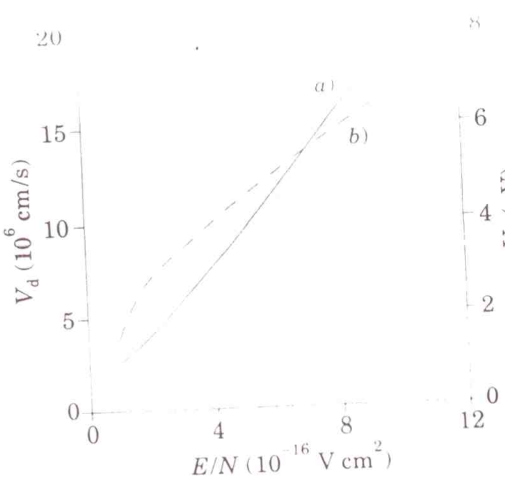

Fig. 5.

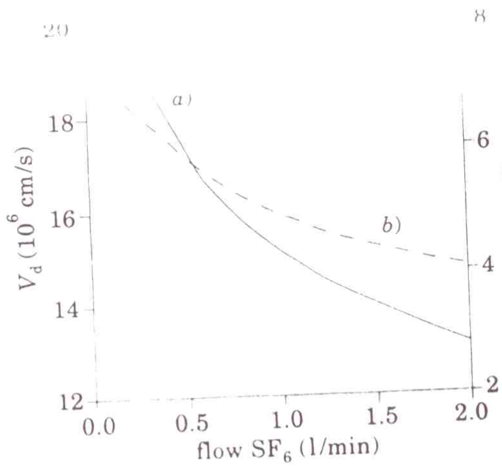

Fig. 6.

Fig. 5. – The electron drift velocity V_d (*a*)) and mean energy U_r (*b*)) as a function of E/N for a mixture flow rate $SF_6 : C_3H_8 : He = 0.2 : 0.07 : 7$ l/min.

Fig. 6. – The electron drift velocity V_d (*a*)) and mean energy U_r (*b*)) as a function of SF_6 flow rate at $E/N = 1 \cdot 10^{-15}$ V·cm^2.

obtained. This quantity is needed to predict the breakdown field and the operating field in a self-sustained glow discharge.

In fig. 4 the calculated values of $(E/N)^*$ for mixtures SF_6 : He as a function of SF_6 concentration in comparison with those given in [10] are presented. The agreement with the values calculated in [10] proves to be very good.

3·2. *Electron drift velocity* V_d *and mean energy* U_r. – Figures 5 and 6 show the electron drift velocity V_d (curve *a*)) and mean energy U_r (curve *b*)) as a function of the reduced electric field E/N for the flow ratio of the $SF_6 : C_3H_8 : He$ mixture $0.2 : 0.07 : 7$ l/min at an overall atmospheric pressure and SF_6 flow rate for $E/N = 1 \cdot 10^{-15}$ V·cm^2, respectively.

The electron drift velocity V_d increases with the reduced electric-field E/N growth (fig. 5, curve *a*)) which corresponds to the higher electrical power stored in the discharge. An adding of SF_6 molecules in the mixture leads to a drift velocity decrease (fig. 6, curve *a*)). The reason is the much larger momentum transfer collision cross-section for SF_6 than the respective one for He and C_3H_8 molecules.

At low E/N values the mean energy increases faster than at high values (fig. 5, curve *b*)). The more the SF_6 molecules in the mixture, the lower the mean energy (fig. 6, curve *b*)) because the fraction of He molecules decreases. At high concentration of He the mean energy is higher as the electrons have smaller losses for vibrational levels excitation.

4. – Conclusion.

The results obtained demonstrate a strong influence of the SF_6 molecules quantity in the gas mixture upon the electron drift velocity, the mean energy, and ionization and attachment rate coefficients. Thus SF_6 molecules play an important role in the discharge plasma. These results may be useful for HF laser development and modelling.

In a real HF laser plasma some of the components disintegrate and HF molecules are formed. The decreasing of SF_6 and C_3H_8 molecules' concentration in the mixture is not taken into account in the present calculation. Data for the formed HF molecules' number may be obtained in case of a given laser system by using the output laser characteristics and the number of generated photons. This problem will be considered in a future work.

* * *

The authors wish to thank Prof. M. Hayashi for kindly supplying them with the cross-section data for the considered gases. This work is partially supported by the contract F-92 with the Ministry of Science and Education.

REFERENCES

[1] GROSS R. W. F. and BOTT J. F., *Handbook of Chemical Lasers* (Wiley, New York, N.Y.) 1976.
[2] HATCH C. B., *J. Phys. E*, **13** (1980) 589.
[3] GIBSON A. F., HATCH C. B., KIMMITT M. F., KOTHARI S. and SERAFETINIDES A. A., *J. Phys. C*, **10** (1977) 905.
[4] HECHT J., *The Laser Guidebook* (McGraw-Hill, New York, N.Y.) 1986.
[5] JONES C. R., BUCHWALD M. I., GUNDERSEN M. and BUSHNELL A. H., *Opt. Commun.*, **24** (1978) 27.
[6] SERAFETINIDES A. A., RICKWOOD K. R. and PAPADOPOULOS A. D., *Appl. Phys. B*, **52** (1991) 46.
[7] HAYASHI M., *Electron collision cross-sections*, in *Handbook of Plasma, Material Science* (Printed in Japan) Sept. 1992.
[8] HAYASHI M., private communication.
[9] PITCHFORD L. C., ONEIL S. V. and RUMBLE J. R. jr., *Phys. Rev. A*, **23** (1981) 294.
[10] KLINE L. E., DAVIES D. K., CHEN C. L. and CHANTRY P. J., *J. Appl. Phys.*, **50** (1979) 6789.