

Electron Transport, Ionization, and Attachment Coefficients in C_2F_4 and C_2F_4/Ar mixtures

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In the use of perfluorocyclobutane ($c-C_4F_8$) as a plasma processing gas for silicon dioxide etching, perfluoroethylene (C_2F_4) is produced as a by-product of electron and photon impact on $c-C_4F_8$, and also as a product of thermal decomposition of $c-C_4F_8$. Consequently, dissociative processes can make C_2F_4 a significant gas constituent. Measurements of electron transport, ionization, and attachment coefficients are reported in this paper for pure C_2F_4 gas and for mixtures of C_2F_4 with Ar. The experimental work described in this paper has been conducted at the National Institute of Standards and Technology (NIST) and at the Universidad Nacional Autónoma de México (UNAM). The independent measurements at the two laboratories complement and cross check each other. The experimental method employed both at NIST and at UNAM is the pulsed Townsend technique,¹ and full descriptions of the apparatuses and analysis used can be found in the literature.^{2,3}

Figure 1(a) shows the $w(E/N)$ for 100% C_2F_4 measured at NIST (closed points) and at UNAM (open points). The agreement between the measurements made independently at the two laboratories is good and the data complement each other in terms of the E/N range covered. The solid line in Fig. 1(a) is a least squares fit to the available data. Figure 1(b) shows $w(E/N)$ values for mixtures of C_2F_4 with Ar at relative C_2F_4 concentrations of 0.1%, 0.5%, 1%, 5%, and 10% (NIST measurements, closed points) and at 0.025%, 0.05%, 0.1%, 0.5%, 1% and 5% (UNAM measurements, open points). Again the agreement between the two independent measurements is good. Also shown in Fig. 1(b) are $w(E/N)$ data for 100% Ar for comparison.⁴ The lines in Fig. 1(b)

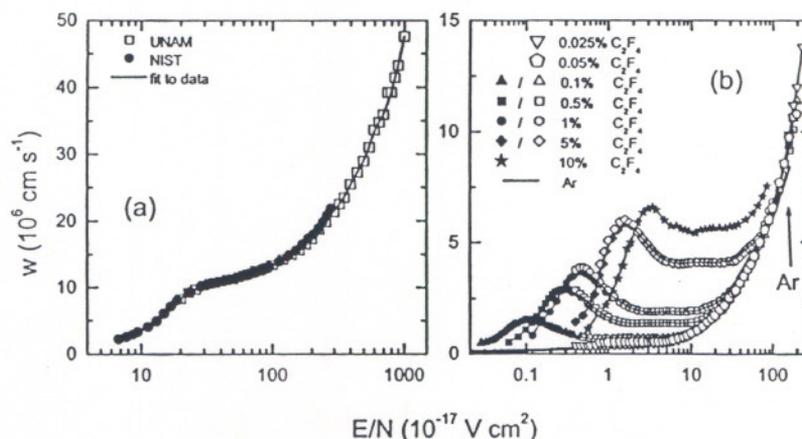


Figure 1. Electron drift velocity, $w(E/N)$, for (a) 100% C_2F_4 and (b) in mixtures of C_2F_4 with Ar at concentrations (by number density) of: 0.025%, 0.05%, 0.1%, 0.5%, 1%, 5%, and 10%. For comparison, the $w(E/N)$ for pure Ar are also plotted in the figure. The solid points are measurements made at NIST and the open points are measurements made at UNAM. The solid lines through the data for each mixture are least squares fits to all the data.

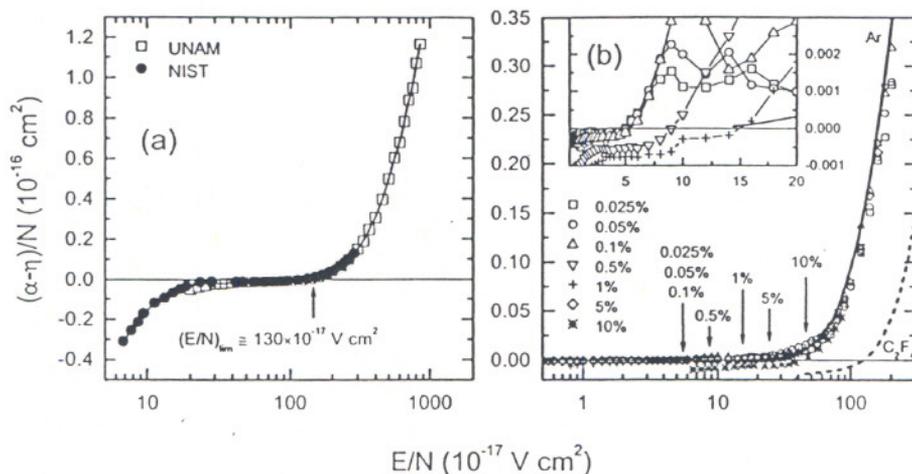


Figure 2. Density-reduced effective ionization coefficient $(\alpha-\eta)/N$, as a function of E/N for (a) pure C_2F_4 and (b) for C_2F_4/Ar gas mixtures: *, measurements at NIST; all other measurements were taken at UNAM. The vertical arrows shown in the figure give the location of the $(E/N)_{lim}$. The inset shows $(\alpha-\eta)/N$ on an expanded linear E/N scale. For comparison α/N for pure Ar is also shown in the figure (solid line).

for each mixture represent a least square average of all data for that mixture.

It is interesting to observe the distinct regions of negative differential conductivity exhibited by the data in Fig. 1(b). A maximum in the drift velocity would indicate a minimum in the magnitude of the overall electron scattering cross section in a certain electron energy range. If the drift velocity maxima result from electrons being scattered by C_2F_4 into the energy region where the electron scattering cross section of Ar has a minimum (~ 0.23 eV),⁵ the values of $(E/N)_{max}$ would represent the E/N value at which the average electron energy in the corresponding mixture is ~ 0.23 eV. As the percentage of C_2F_4 in Ar is increased, because C_2F_4 is more efficient in slowing down the electrons than Ar, the value of E/N for which the energy of the electrons lies in the region of the cross section minimum increases. This explains why $(E/N)_{max}$ shifts to higher E/N values as the percentage of C_2F_4 in the mixture is increased.

Figure 2(a) shows the measured values of the density-reduced effective ionization coefficient $(\alpha-\eta)/N$ as a function of E/N for 100% C_2F_4 . The solid line shown in Fig. 2(a) is a least squares fit to the measured data. The data in Fig. 2(a) show that the limiting value, $(E/N)_{lim}$, of E/N [value of E/N at which $(\alpha-\eta)/N \rightarrow 0$] for this gas is $\sim 130 \times 10^{-17}$ V cm². This value is shown in Fig. 2(a) by the vertical arrow. The negative values of $(\alpha-\eta)/N$ at lower E/N can be attributed to attachment to C_2F_4 or perhaps to a strongly attaching impurity (see Ref. 6). Figure 2(b) shows measurements of $(\alpha-\eta)/N$ for C_2F_4/Ar gas mixtures, where N is taken to be the total gas number density of the mixture. Also shown in Fig. 2(b) for comparison are the values of $(\alpha-\eta)/N$ for 100% C_2F_4 (- - -) and the value of α/N for pure Ar (—) taken from the literature.⁷

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