Electron Transport, Ionization, and Attachment Coefficients in C$_2$F$_4$ and C$_2$F$_4$/Ar mixtures

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In the use of perfluorocyclobutane (c-C$_4$F$_8$) as a plasma processing gas for silicon dioxide etching, perfluoroethylene (C$_2$F$_4$) is produced as a by-product of electron and photon impact on c-C$_4$F$_8$, and also as a product of thermal decomposition of c-C$_4$F$_8$. Consequently, dissociative processes can make C$_2$F$_4$ a significant gas constituent. Measurements of electron transport, ionization, and attachment coefficients are reported in this paper for pure C$_2$F$_4$ gas and for mixtures of C$_2$F$_4$ 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 Autonoma de Mexico (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, and full descriptions of the apparatuses and analysis used can be found in the literature.

Figure 1(a) shows the $w(E/N)$ for 100% C$_2$F$_4$ 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$_2$F$_4$ with Ar at relative C$_2$F$_4$ 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. The lines in Fig. 1(b)
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 C₂F₄ into the energy region where the electron scattering cross section of Ar has a minimum (~0.23 eV), the values of \((E/N)_{\text{max}}\) would represent the \(E/N\) value at which the average electron energy in the corresponding mixture is ~0.23 eV. As the percentage of C₂F₄ in Ar is increased, because C₂F₄ 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 \((E/N)_{\text{max}}\) shifts to higher \(E/N\) values as the percentage of C₂F₄ 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% C₂F₄. 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, \((E/N)_{\text{lim}}\), of \(E/N\) at which \((\alpha-\eta)/N \rightarrow 0\) for this gas is \(-130 \times 10^{-17} \text{ V cm}^2\). 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 C₂F₄ or perhaps to a strongly attaching impurity (see Ref. 6). Figure 2(b) shows measurements of \((\alpha-\eta)/N\) for C₂F₄/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% C₂F₄ (---) and the value of \(\alpha/N\) for pure Ar (---) taken from the literature.