Electron Interactions with Plasma Processing Gases: CF_4, CHF_3, C_2F_6, and C_3F_8

Loucas G. Christophorou and James K. Olthoff
National Institute of Standards and Technology
Gaithersburg, Maryland, USA 20899

INTRODUCTION

To assess the behavior of gases in their uses in manufacturing semiconductor devices and other applications, and to promote the modeling of these processes, it is necessary to have accurate information on the fundamental interactions of low energy (< 100 eV) electrons with process gases. In support of this effort, we have undertaken the assessment and evaluation of the available information on cross sections and rate coefficients for collisional interactions of electrons with three groups of gases: those used in etching, deposition, or cleaning (e.g., CF_4, CHF_3, C_2F_6, C_3F_8, NF_3, Cl_2, and HBr), those used as buffer gases (e.g., Ar, He), and those that are present in practical systems as impurities (e.g., O_2, N_2, H_2O). In this paper we summarize our assessed data on cross sections and rate coefficients for the fully or partially fluorinated molecules CF_4, CHF_3, C_2F_6, and C_3F_8. Two distinct features of the interactions of slow electrons with the perfluoroalkane molecules are their large cross sections for *direct* vibrational excitation at low energies and the dissociation of all their electronic states into charged and/or neutral fragments. We also indicate specific electron-interaction data needs for these gases. In this regard, knowledge is lacking on two important basic processes, namely, dissociation into neutral fragments by electron impact and electron interactions with vibrationally and electronically excited species. In addition, with the sole exception of the electron-impact ionization of radicals from CF_4, there are no data on the interactions of slow electrons with the radicals of these plasma processing gases.

PROCEDURE

In order to provide cross section and transport data that are as complete, consistent, and reliable as possible, we have determined "recommended" and "suggested" values for each type of cross section and coefficient for which data exist. These values are derived from fits to the most reliable data that are currently available. The reliability of each set of data is determined from the following criteria: (i) data are published in peer reviewed literature; (ii) no evidence of unaddressed errors; (iii) data are absolute determinations; (iv) multiple data sets are consistent with one another over ranges of overlap within combined stated uncertainties; and (v) in regions where both experimentally and theoretically derived data exist, the experimental data are preferred. If any of these criteria cannot be met, then the best available data are used to designate a "suggested" cross section or coefficient. Figure 1 shows an example of how a recommended cross section is extracted from multiple sets of experimental and theoretical data.

The recommended cross section data and coefficients for the plasma processing gases studied are available on the World Wide Web at *http://www.eeel.nist.gov/811/refdata*. These data sets are continually updated as new data are published in the literature.

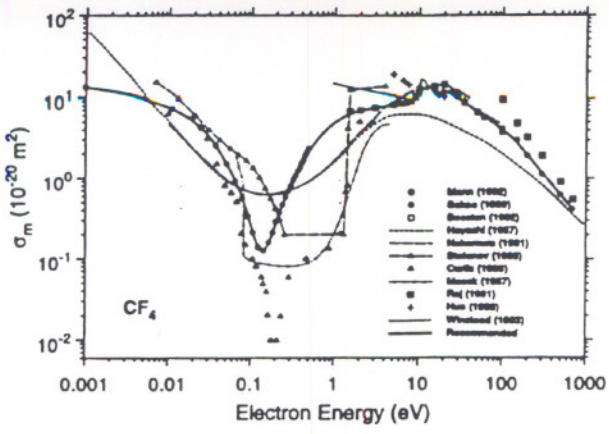

FIG. 1 Momentum transfer cross sections for CF_4 as a function of electron energy [1]. The heavy solid line is the recommended cross section derived from the available experimental data. The references listed in the legend may be fully identified by referring to the list of references in Ref. 1.

REFERENCE DATA

Carbon Tetrafluoride (CF_4) – The data on electron-scattering cross sections and attachment, ionization, and transport coefficients are reasonably complete for CF_4 [1]. Figure 2 shows the independently assessed cross sections. Their sum agrees rather well with the recommended total electron-scattering cross section based on assessed measurements. Relatively minor data needs remain. These include the experimental determination of direct and indirect vibrational excitation, and investigation of the apparent discrepancy between the measured cross section for dissociation into neutrals and other related cross sections (recent measurements indicate that the data presented here for dissociation into neutrals are much smaller than the true values).

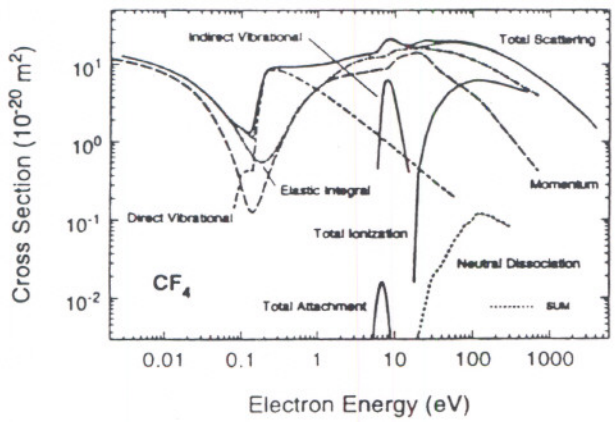

FIG. 2. Electron-interaction cross sections for CF_4 (Ref. 1).

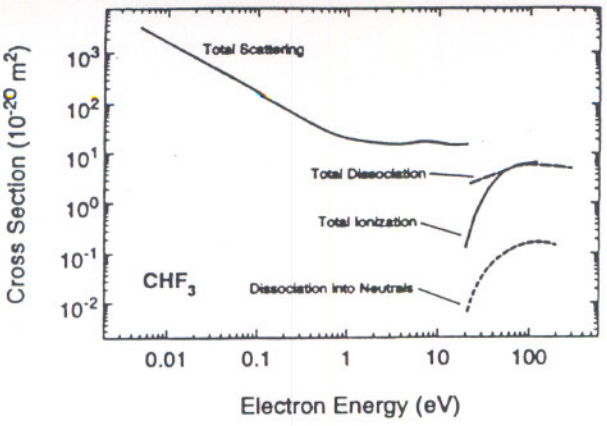

FIG. 3. Electron-interaction cross sections for CHF_3 (Ref. 2).

Trifluoromethane (CHF_3) – Figure 3 shows the meager electron-scattering cross section data for this important plasma processing gas [2]. With the possible exception of the data for total dissociation and total ionization, the rest of the data in Fig. 3 are approximate. Basic measurements and calculations are needed for virtually all elastic and inelastic electron scattering processes, including momentum transfer, vibrational excitation, elastic scattering, differential scattering, and electron transport, attachment and ionization coefficients. Confirmation is required of the measured cross sections for total electron scattering and for total ionization. Resolution is also needed of the discrepancy between the measured cross section for dissociation into neutrals and other related cross section data.

Perfluoroethane (C_2F_6) – Figure 4 shows the cross sections for C_2F_6 [3]. Some of the data are still preliminary (e.g., the cross section for momentum transfer at low energies). Only the cross sections for dissociative attachment and total dissociation are recommended. Cross section data are

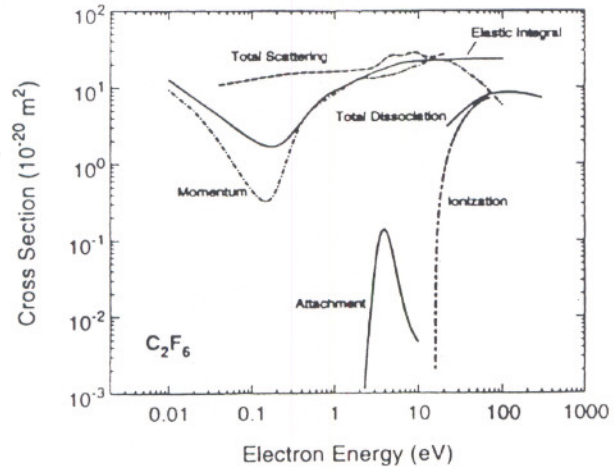

FIG. 4. Electron-interaction cross sections for C_2F_6 (Ref. 3).

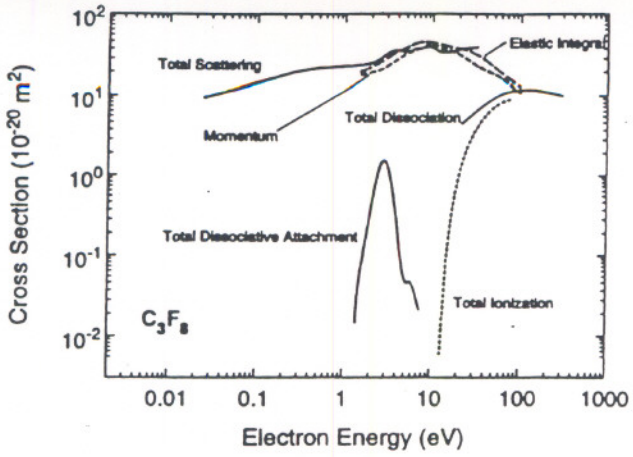

FIG. 5. Electron-interaction cross sections for C_3F_8 (Ref. 4).

needed, especially for dissociation into neutrals, and vibrational and electronic excitation. Additional data are needed for momentum transfer, elastic integral, total ionization, and total scattering cross sections. There exist reasonably accurate data on attachment, ionization and transport coefficients, although more measurements are desirable at high *E/N*.

Perfluoropropane (C_3F_8) – Figure 5 shows the presently available electron-scattering cross sections for this molecule [4]. The total electron scattering cross section data are recent measurements by Sanabia et al. [5], the total ionization and dissociative attachment (T = 300 K) cross sections are assessments based on the published experimental data in literature, and the total dissociation cross section are the measurements of Winters and Inokuti [6]. The momentum transfer and elastic integral cross sections are the unpublished data of Tanaka and co-workers [7], which are estimates derived from differential scattering cross section measurements. No direct measurements of these cross sections are presently available. While these preliminary values exceed the measured total scattering cross section near 10 eV, they are not incompatible within the combined estimated uncertainties. No measurements exist of electron impact dissociation into neutral fragments and vibrational and electronic excitation. Much work is needed for virtually all cross sections and the electron transport coefficients for this molecule.

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