J. Plasma Fusion Res. SERIES, Vol.7 (2006) 262-264

Electron Transport Parameters in Pure C_5F_8 and C_5F_8-Ar Mixtures

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(Received: 4 October 2004 / Accepted: 17 March 2005)

Abstract

The drift velocity and the longitudinal diffusion coefficient of electrons in pure C_5F_8 and the 0.5 % C_5F_8-Ar mixture were measured by using the double-shutter drift tube in the range of E/N over 50 – 4000 Td in pure C_5F_8 and 1 – 100 Td in the 0.5 % C_5F_8-Ar mixture.

Keywords:

electron drift velocity, longitudinal diffusion coefficient, C_5F_8, C_5F_8-Ar mixture, octafluorocycropenten

1. Introduction

Octafluorocycropenten (C_5F_8) is expected as one of the potential plasma sources which can meet the demands of the future ULSI manufacturing in two ways: higher etching selectivity of SiO_2 to Si_3N_4 [1] and higher deposition rate of fluorocarbon film on Si and Si_3N_4 surfaces [2]. The molecule has shorter atmospheric lifetime (one year) than other perfluorocarbon molecules (CF_4, for example, has 50,000 years) and is expected far more friendly to the global environment than other popular etching gases. It, however, is rather recently industry manufactured and its electron collision cross section data and the related electron transport data are scarce.

In order to determine a set of electron collision cross section set of the C_5F_8 molecule, we need as many electron transport parameters as possible. In particular, the transport parameters in dilute C_5F_8-Ar mixtures are important for deriving the vibrational excitation cross sections of the molecule. And by using the vibrational cross section so derived and analyzing the experimental transport parameters in pure C_5F_8 gas the elastic momentum transfer cross section can be determined.

We measured electron transport parameters, the electron drift velocity (W) and the product of the gas number density and the longitudinal diffusion coefficient (ND_L) in pure C_5F_8 and 0.5 % C_5F_8-Ar mixtures.

2. Experimental set-up

Measurements were carried out by using the double shutter electron drift tube, which is shown in Fig. 1, and the details of the apparatus have been discussed by Nakamura [3]. The drift distance is variable (1 – 10 cm) and a differential method can be used to derive W and ND_L from the arrival time spectra (ATSs) of electrons obtained at several drift distances. By this differential method we can exclude otherwise inevitable end-effects from the measurements.

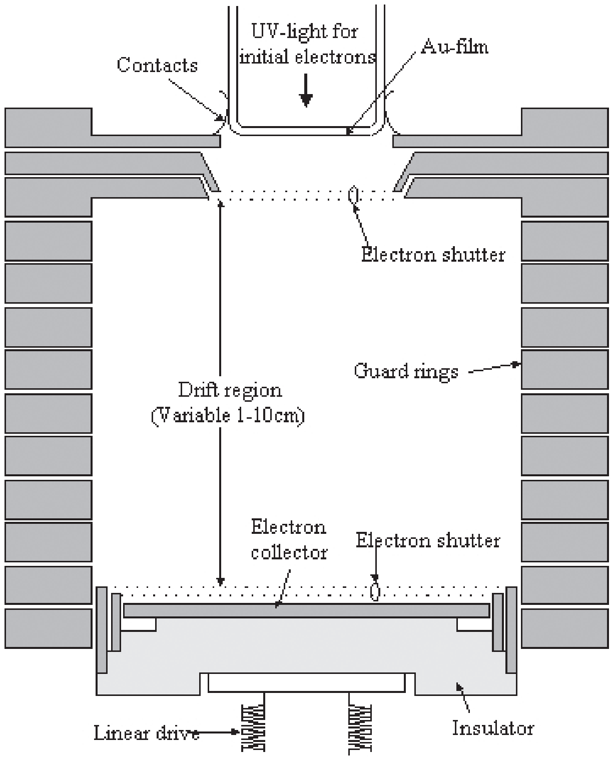

Fig. 1 A schematic diagram of the double-shutter drift tube.

The background pressure was less than 1×10^{-5} Pa. The gas pressure was measured by a digital manometer. The purity of C_5F_8 was 99.99 %, and the 5 % C_5F_8-Ar mixture was prepared by mixing the C_5F_8 gas and Ar gas of 99.9999 % purity. All experiments were carried out at room temperature (297 – 299 K).

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Measurements were carried out over the E/N (where E is the applied electric field and N the gas number density and 10^{-17} Vcm^2 = 1 Td) range from 50 to 4000 Td in pure C_5F_8 and from 1 to 100 Td in C_5F_8-Ar mixtures.

3. Results and discussion

3.1 Arrival time spectrum

We used the double-shutter (four-gauze) drift tube, whose electron drift distance was variable from 1 to 10 cm. The electron arrival time spectra (ATSs) were observed at several drift distances, and the drift velocity and the longitudinal diffusion coefficient were determined from the positional variations of the mean arrival time and the characteristic width of the ATSs. From this the hydrodynamic equilibrium of the parameters were confirmed. Three typical examples of the ATS observed in pure C_5F_8 are shown in Fig. 2. Rapid attenuation of the ATS at E/N = 600 Td indicates strong electron attachment and the lower the E/N, the stronger the attenuation was. The electron attachment of the C_5F_8 molecule sets the lower limit of our measurement in the gas and also in the mixture.

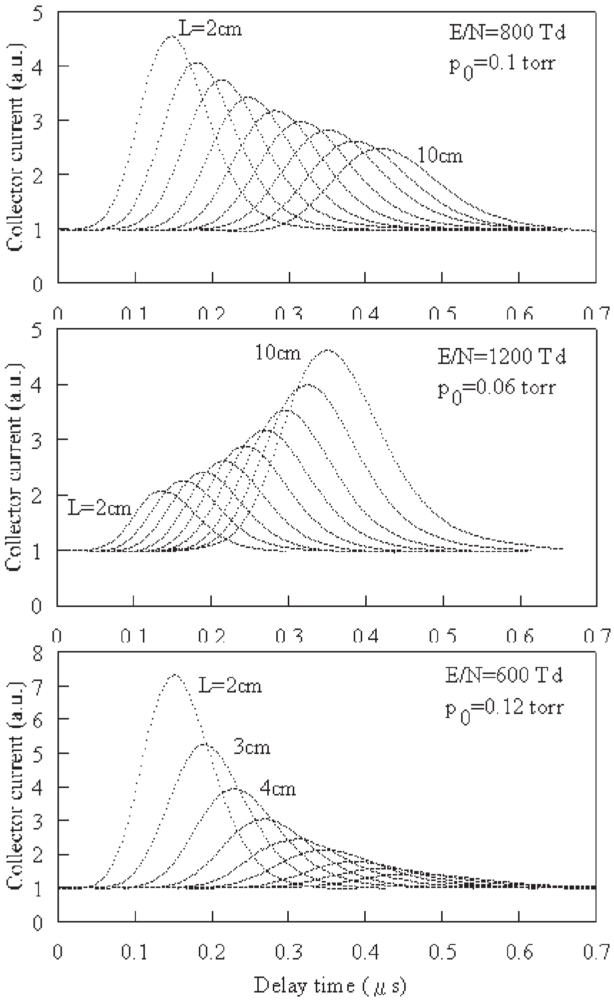

Fig. 2 Typical examples of the arrival time spectra (ATSs) of electrons in pure C_5F_8. Normal ATSs are shown in (a). Electron ionization and attachment is seen in (b) and (c), respectively.

3.2 Electron swarm parameters in pure C_5F_8

The present results of the electron drift velocity W and the product of the gas number density and the longitudinal diffusion coefficient ND_L are shown in Figs. 3 and 4. They are compared with those in c-C_4F_8 [4] and also with the only available drift velocity [5].

The present W had a broad minimum at E/N = 200 – 300 Td. The total electron cross section of C_5F_8 over the electron energy range of 5 – 100 eV is about 50 % larger than c-C_4F_8 which also has a cyclic structure but with a single C-C bond [6]. The present drift velocity, however, was higher than that in pure c-C_4F_8, and the latter increased rather monotonously with increasing E/N [4]. The present ND_L, on the other hand, increased monotonously with increasing E/N and was fairly close to that in c-C_4F_8.

3.3 Electron swarm parameters in the 0.5 % C_5F_8-Ar mixture

The present W and ND_L in the 0.5 % C_5F_8-Ar mixture is shown in Figs. 5 and 6, which are compared

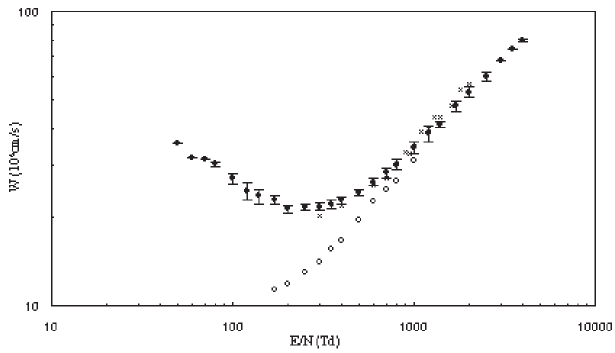

Fig. 3 The drift velocity W as a function of E/N in pure C_5F_8: ●, present result in pure C_5F_8; ×, Yoshida *et al.* [5]; ○, c-C_4F_8 by Yamaji *et al.* [4].

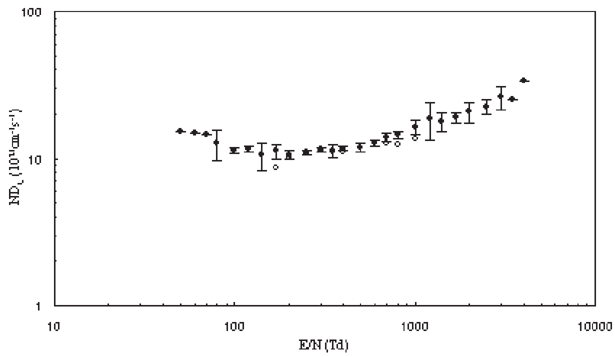

Fig. 4 The product of the gas number density and the longitudinal diffusion coefficient ND_L as a function of E/N in pure C_5F_8. The symbols are the same as in Fig. 3.

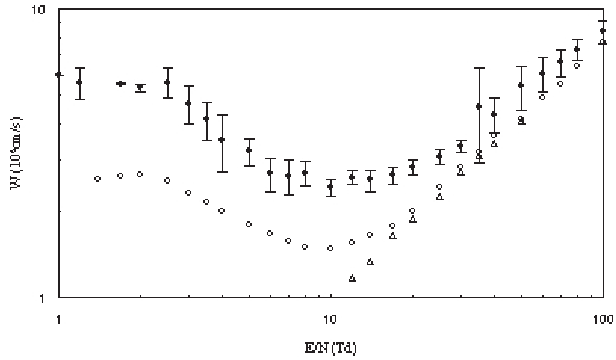

Fig. 5 The drift velocity W as a function of E/N in the 0.5 % C_5F_8-Ar mixture: ●, the present result in the mixture; ○, the 0.5 % c-C_4F_8-Ar mixture by Yamaji *et al.* [4]; △, pure Ar [3].

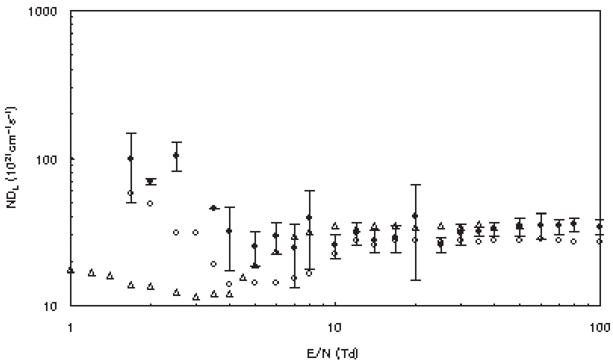

Fig. 6 The product of the gas number density and the longitudinal diffusion coefficient ND_L as a function of E/N in the 0.5 % C_5F_8-Ar mixture. The symbols are the same as in Fig. 5.

with those drift velocity in pure Ar [3] and in the 0.5 % c-C_4F_8 mixture [4]. The measured values in the mixture are nearly equal to these in pure Ar at a higher E/N range, but in the lower E/N range they are much higher than in pure Ar. The tendency is similar to the c-C_4F_8-Ar mixture but is much stronger. The strong electron attachment of the C_5F_8 molecule was again a serious nuisance to accurate measurements of transport parameters in this dilute mixture, we may need to continue measurements of ND_L in lower E/N region.

4. Conclusions

The drift velocity and the longitudinal diffusion coefficient of electrons in pure C_5F_8 and the 0.5 % C_5F_8-Ar mixture were measured by using the double-shutter drift tube in the range of E/N over 50 – 4000 Td in pure C_5F_8 and 1 – 100 Td in the 0.5 % C_5F_8-Ar mixture.

In pure C_5F_8, the electron drift velocity showed clear minimum at unusually high $E/N \sim 200$ Td. Together with the nearly constant ND_L in pure C_5F_8, the electron transport parameters in pure C_5F_8 showed markedly different E/N dependence from those in pure c-C_4F_8.

We may need further measurements in the 0.5 % C_5F_8-Ar mixture and in other mixtures with different C_5F_8 mixing ratios.

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