Controlling the density of plasma species in Ar/CF_4 Radiofrequency Capacitively Coupled Plasma Discharges

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KEYWORDS

Ar/CF_4 discharge, plasma species, RF-CCPs.

SHORT SUMMARY

In this manuscript, a fluid model is utilized to calculate the density of plasma species assuming geometrically symmetric Ar/CF₄ Radiofrequency Capacitively Coupled Plasmas. The harmonics of the driven potential can control the concentration of plasma species. When the plasma is derived with the fundamental frequency, Ohmic heating allows electrons to be heated symmetrically. Higher harmonics give rise to an electrical asymmetry and electrons heating asymmetry between the powered and grounded sheaths. The electron temperature depends on the driven harmonics; it adjusts gain and loss rates and plasma species densities.

EXTENDED ABSTRACT

The Ar/CF4 plasmas are indispensable for semiconductor and microelectronics industries. They are a current topic for plasma simulation tools [1]. Tailoring the waveforms of the driven potential has been frequently used to optimize the ion energy distribution and the ion angular distribution in Radiofrequency Capacitively Coupled Plasmas (RF-CCPs) [2, 3, 4]. Here, we would like to infer the consequences of tailoring the driven potential on the plasma species density. In this contribution, we simulate Ar/CF4 discharges assuming a geometrically symmetric discharge with two planar electrodes separated by 5 cm and a bulk density of 1015m-3. The gas pressure is 200 mTorr. The gas composition consists of 90% for Ar and 10% for CF_4. The mass, momentum, and energy continuity equations according to drift-diffusion approximation are considered as [5, 6]:

$$\frac{\partial n_{e,i,n}}{\partial t} + \vec{\nabla}.\vec{\Gamma}_{e,i,m} = G_{e,i,m} - L_{e,i,m}, \quad (1)$$

$$\vec{\Gamma}_{e,i,m} = \text{sign}(q_{e,i,n}) n_{e,i,m}\, \mu_{e,i,m} \vec{E} - D_{e,i,m} \vec{\nabla}\, n_{e,i,m} \quad (2)$$

$$\frac{\partial n_e T_e}{\partial t} = -\vec{\nabla}.\left(\frac{5}{3} T_e \vec{\Gamma}_e - \frac{5}{3} n_e D_e \vec{\nabla} T_e\right) - e\vec{\Gamma}_e . \vec{E} - n_e n_G K_{loss}, \quad (3)$$

$$T_i = T_m = 0.026\ eV. \quad (4)$$

Here $n_{e,i,m}$ is the density of electrons, ions, and neutral species, respectively. n_G is the background gas density. $\vec{\Gamma}_{e,i,m}$ is the particles flux. G and L are gain and losses terms. $\mu_{e,i,m}$ and $D_{e,i,m}$ are the species mobility and diffusion constants. $\text{sign}(q_{e,i,n})$ is the sign of the species charge. $\vec{E}$ is the electric field. $T_{e,i,m}$ is the species temperature in energy units. There are different reaction rates in the literature. Here, we employed published reaction rates that are considered in [5, 6]. The mobility and diffusion constants are assumed as given by [7, 8, 9]. Bolsig+ 2019 [10, 11] is used to estimate rates of excitation and ionization and the energy loss coefficient (k_{loss}) that are not given explicitly in [5].

The plasma is generated assuming consecutive harmonics, the driven potential is given as

$$V(t) = \sum_{k=1}^{N} V_0 \cos(2\pi k f_0 t), \quad (5)$$

where V_0 is the amplitude. The peak-to-peak amplitude is $2V_0$ = 400 Volt. f_0 is the fundamental frequency and equals 13.56 MHz. The simulation

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has been carried out employing different harmonics, in equation 5, N=1,2,3, and 4.

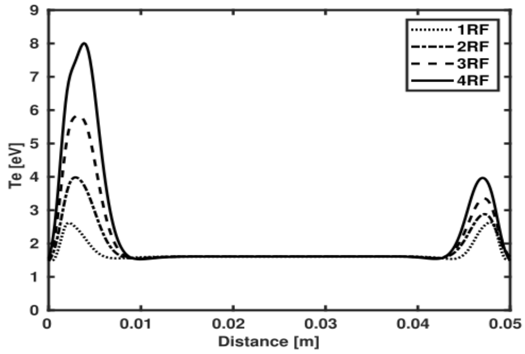

Figure1: The electron temperature when the plasma is generated via different harmonics. 1RF, 2RF, 3RF, and 4RF labeled the cases when N in equation 5 is 1,2,3, and 4, respectively.

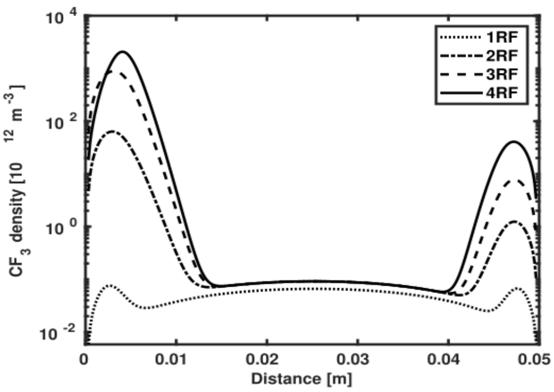

Figure 2: The density of CF_3 when the plasma is derived with different harmonics.

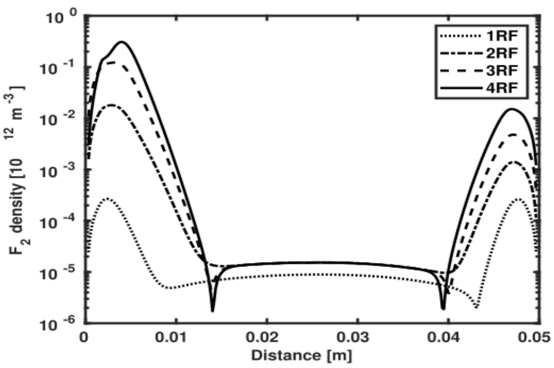

Figure 3: The density of F_2 when the plasma is derived with different harmonics.

The temperature between two electrodes is given in Figure 1. The fundamental frequency produces symmetric discharge. Therefore, electrons are heated the same way in both sheaths [8]. As seen in Figures 2 and 3, the density of different species produced by the fundamental frequency is symmetric. By adding more harmonics, an electrical asymmetry between the two sheaths arises. The electric field and the electrons flux within the powered sheath increase more than that within the grounded sheath. Consequently, Ohmic heating and the electron temperature are asymmetric. Ohmic heating enhances by increasing the applied potential due to the increment of the sheath electric field and electrons flux. Therefore, the driven harmonics could be used to adjust the density of plasma species as shown in Figures 2 and 3. Qualitatively similar behavior has been observed theoretically and experimentally for another gas mixture in RF CCPs jet [12]. It is worth reporting that not all species are sensitive to generated electrical asymmetry. A comparison with experimental results should be done in future studies.

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