Electron Kinetics in a Collision-Dominated SiH₄ rf Plasma including Self-Consistent rf Field Strength Calculation

R. Winkler,¹ M. Capitelli,² C. Gorse,² and J. Wilhelm¹

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The electron kinetics of a collision-dominated rf plasma in silane has been studied by solving the nonstationary electron Boltzmann equation. Ionization and attachment processes and the spatially averaged electron loss to the plasma wall by ambipolar diffusion have been included in the kinetic approach. This makes it possible to calculate, in addition to the time-resolved energy distribution, the self-consistent rf field amplitude which is necessary for the maintenance of the steady-state rf discharge. The impact of the rf field frequency, of the density ratio of negative ions to electrons, and of superelastic (second kind) collisions with excited silane molecules was studied. In particular, large rf field amplitudes of about 100 V cm⁻¹ Torr⁻¹ result, connected with large modulations of the energy distribution for field frequencies in the megahertz region.

KEY WORDS: Electron kinetics, rf discharge; SiH₄; rf field strength; modulation of nₑ and Tₑ.

1. INTRODUCTION

In plasma technology, collision-dominated rf plasmas are widely used, especially for plasma etching and deposition. In such rf plasma devices the working gas is often electronegative in nature. Then attachment of electrons can represent the main part of the total loss of electrons in the plasma volume. When a significant attachment occurs, modelling of the electron kinetics in the rf plasma requires including electron loss and production terms and thus the electron particle balance in the kinetic equation of the electrons.

If such an attachment is present at low electron energies in a special working gas, generally a large mean attachment frequency (due to averaging over the low energy part of the electron energy distribution) results, and

¹ Zentralinstitut für Elektronenphysik, IT Greifswald, GDR.
² Dipartimento di Chimica, Università di Bari, Bari, Italy, and Centro di Studio per la Chimica de Plasmi del CNR, Bari, Italy.
the loss of electrons from the plasma is dominated by attachment. Then, the electron particle balance is determined mainly by the volume, and the loss by attachment must be equal to the production by ionization, on the average, over one rf cycle for maintenance of a steady-state rf plasma. A typical example for such a situation is an rf plasma in SF$_6$ which has a very intense attachment process at very small electron energies. The electron kinetics of the collision-dominated bulk region of this plasma has been recently dealt with.$^{(1,2)}$ There, by solving the adequate nonstationary electron Boltzmann equation, the periodic behavior of the electron density, of the energy distribution, and of relevant macroscopic quantities of the electrons have been determined together with the rf field amplitude needed to maintain the bulk plasma. As a consequence of this large attachment in SF$_6$, very large rf field amplitudes of about 160 V cm$^{-1}$ Torr$^{-1}$ at field frequencies in the megahertz region have been obtained, and the energy distribution and relevant macroscopic quantities show large modulation even at high field frequencies of about 100 MHz.

However, there are also other working gases of interest for plasma technology which possess much smaller attachment cross sections and/or the attachment processes have relatively large energy thresholds. Then considerably smaller mean attachment frequencies (due to averaging over small cross sections and/or over the region of higher electron energies in the energy distribution) are to be expected and the electron particle loss by attachment can become comparable with or even smaller than the particle loss to the walls, which enclose the rf plasma. In this case, the electron particle balance is no longer only determined by the volume, and the electron loss to the walls has to be included in an appropriate approximation in order to model in a self-consistent way the electron particle balance in the kinetic equation of the electrons.

The present paper is devoted to the investigation of the self-consistent electron kinetics in a silane rf plasma, which is typical of such a situation and is also of great interest technologically, namely the deposition of amorphous silicon. First results concerning this problem have already been reported.$^3$ Furthermore, the electron kinetics in rf plasmas of SiH$_4$ and SiH$_4$–H$_2$ mixtures without inclusion of electron particle balance and thus without a self-consistent treatment of the rf field amplitude has recently been studied.$^{(4,5)}$

2. THEORETICAL BASIS

The starting point is the nonstationary Boltzmann equation

$$\frac{\partial}{\partial t} F - \frac{e_0}{m} E \cdot \frac{\partial}{\partial v} F = C_{\text{el}} + \sum_k C_k^{\text{p}} + \sum_i C_i^{\text{t}} + \sum_m C_m^{\text{a}} - \frac{1}{\tau} F$$  \hspace{1cm} (1)