ELECTRON ENERGY DISTRIBUTION IN DC Argon/Cl_2 DISCHARGE

M. Roberto

Departamento de Física, Instituto Tecnológico de Aeronáutica,
Centro Técnico Aeroespacial, S. José dos Campos - S. Paulo- Brazil
marisar@fis.ita.cta.br

Abstract

A study of the electron energy distribution function in a DC discharge in the mixture of argon and Cl_2 is presented, using the numerical code Kinema-Elendif. Mixtures of reactive gases with rare gases are used for thin-film etching and deposition in microelectronic device fabrication. Thus, it is important to understand the plasma chemistry of gas mixtures and the discharge influence in the deposition processes. This code is used to calculate the electron energy distribution function for a pure argon discharge and argon/chlorine mixtures. Elastic and inelastic processes, such as, excitation to argon metastables and ground state argon ionization, are considered for the argon. Collisional processes, such as, molecular chlorine ionization, atomic chlorine ionization, dissociative attachment of chlorine, among others, are considered for the chlorine. A comparison is made between a pure plasma and one with small quantities of Cl_2. The effect of the pressure and the parameter E/N is also verified. It is noted that a small quantity of Cl_2 affects the electron energy distribution function.

1. Introduction

Electrical discharges using mixtures of reactive with rare gases have been a subject of great interest, because of their application in film etching and deposition in microelectronic device fabrication [1,2]. Several industrial applications can be made using low-temperature plasmas such as the production of integrated circuits that involves deposition and etching [3]. However, the plasma chemistry of gas mixtures is not well understood[4,5,6]. A numerical method was developed to study the electrical discharges in plasmas with argon/chlorine mixtures, which solves the spatially homogeneous Boltzmann equation, to find the specie densities as a function of pressure for input values of power density [4]. It was showed that a small quantity of chlorine affects the discharge.

The objective of this work is to investigate the modifications in the electron energy distribution function in a plasma with argon and chlorine, using the numerical code called Kinema-Elendif, developed by Morgan and Penetrant [7]. A DC discharge is considered.

2. Theoretical model

The Kinema-Elendif code calculates the temporal evolution of the particle densities in a plasma. The part of the code called Elendif calculates the electron energy distribution function (EEDF), using the two-term spherical harmonic expansion. The transport coefficients, rate coefficients and energy balance were obtained by solving the spatially homogeneous Boltzmann equation

$$\frac{\partial f}{\partial t} + \frac{e\overrightarrow{E}}{m} \cdot \overrightarrow{\nabla}_v f = \left(\frac{\delta f}{\delta t}\right),$$

where f is the electron velocity distribution function, e is the electron charge, E is the electric field and m is the electron mass. The term on the right hand side of the equation is the collision integral, which accounts for electron energy transferred in elastic and inelastic collisions.In a DC discharge the electron velocity distribution function depends on the parameter E/N, the ratio of the local electric field E to the local total particle density in the discharge N (which is, to a good approximation, equal to the neutral particle density) and the plasma composition.

The collisional processes considered are in the following:

- Molecular chlorine ionization: $Cl_2 + e^- \longrightarrow Cl_2^+ + 2e^-$
- Atomic chlorine ionization: $Cl + e^- \longrightarrow Cl^+ + 2e^-$
- Dissociative attachment of chlorine: $Cl_2 + e^- \longrightarrow Cl^- + Cl$
- Dissociation of chlorine: $Cl_2 + e^- \longrightarrow 2Cl + e^-$
- Excitation to atomic chlorine : $Cl + e^- \longrightarrow Cl^* + e^-$
- Electronic excitation to molecular chlorine: $Cl_2 + e^- \longrightarrow Cl_2^* + e^-$
- Excitation to argon metastables: $Ar + e^- \longrightarrow Ar^* + e^-$
- Ground-State argon ionization: $Ar + e^- \longrightarrow Ar^+ + 2e^-$

It is assumed that the electrons have a Maxwell-Boltzmann energy distribution at a initial temperature T_e=1.0 eV.

3. Numerical results and discussion

The input parameters are the pressure, the parameter E/N, which is a measure of the the energy imparted to a charged particle by the electric field over the distance of one mean free path, the initial electron temperature T_e and the cross-sections. The Figures 1 and 2 show the electron energy distribution function (EEDF) for pure argon and for mixtures with 95%Ar/5%Cl_2 and for 80%Ar/20%Cl_2, for pressure=1 torr, E/N=27 Td and 120 Td, respectively. It can be noted that plasmas with pure argon have EEDF with a longer tail. A small quantity of chlorine modifies this function because chlorine has several vibration and excitation levels with threshold energies well below 10 eV (the lowest excitation level for argon is at 11.5eV). These processes result in a displacement of the tail of the EEDF. As E/N increases the EEDF becomes broader due to the electron energy increase. The pressure has very little influence in the EEDF, since in the interval of the pressure considered (0.3-1.0 torr) one has very little variation between the rupture voltage with the parameter pressurexdistance between the electrodes [8].

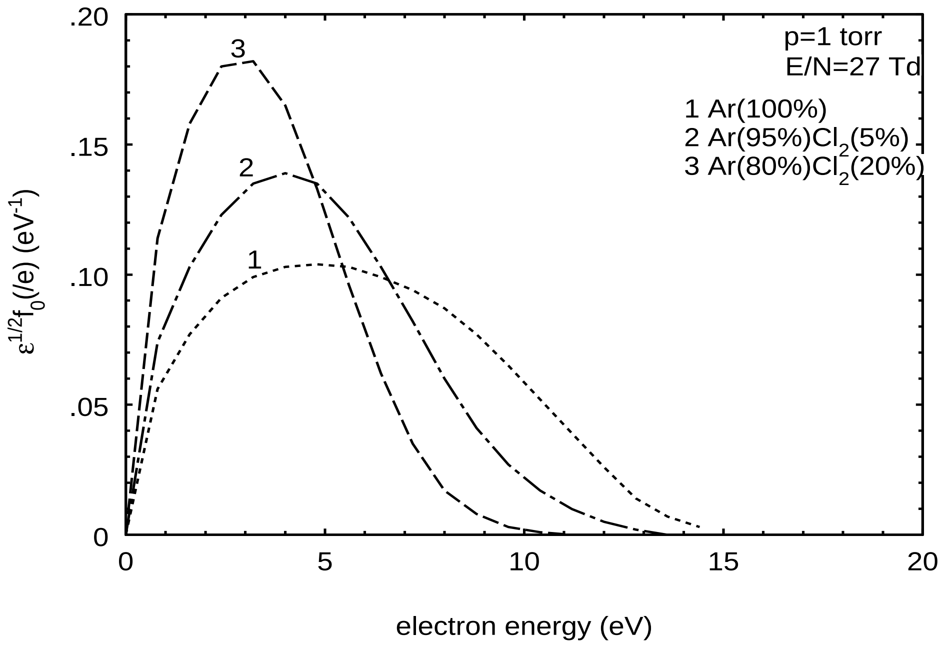

Figure 1. Electron energy distribution function for pure argon, 95%Ar/5%Cl2 and 80%Ar,20%Cl2, for pressure=1 torr and E/N=27 Td.

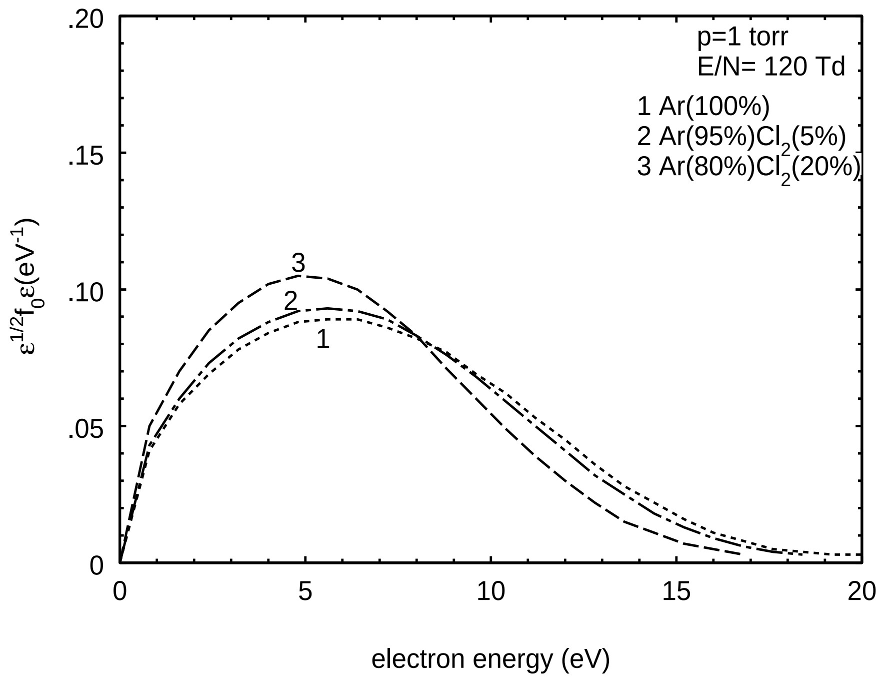

Figure 2. Electron energy distribution function for pure argon, 95%Ar/5%Cl2 and 80%Ar/20%Cl2, for pressure= 1 torr and E/N=120Td.

4. Conclusions

Using the Elendif code, it was possible to investigate the behaviour of the electron energy distribution function in a plasma with a mixture of argon and chlorine. The code was used to compare a pure argon discharge, a 5%Cl_2/95%Ar and a 20%Cl_2/80%Ar mixture. The EEDF was calculated, fixed E/N parameter and the pressure. It was showed that the EEDF has a shorter tail for the mixture. The model presented here did not include all reactions that appear in the mixture Ar/Cl_2. Some reactions were not included due to the low value of the reaction coefficients. In despite of these simplifications, it was possible to verify the influence of the addition of an electronegative gas to a noble gas discharge.

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