Electron swarm parameters of SF_6 under time varying electric fields

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ABSTRACT

The electron swarm parameters in gases are necessary for the simulations of plasma processes. The sulfur hexafluoride (SF_6) has enormous applications suitability, because of its excellent dielectric properties, it is a gas used extensively as an insulating gas in various electric devices. Consequently, we must dedicate a significant attention to studying the physical properties of this gas. An investigation has brought into effect on the electron swarms parameters in SF_6 gas in time varying electric fields using a Monte Carlo simulation. Swarm parameters as a function of instantaneous E/N (E is the electric field and N the gas number density of background gas molecules) for different dE/dt are determined.

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1. INTRODUCTION

The plasma technologies are present in many industries and a continually augmentations into various fields of activity. Plasmas are used in many different applications like nanotechnologies, plasma processing, bio-technologies, and biomedical applications [1-7]. The sulfur hexafluoride (SF_6) has a large cross section for attaching the electrons and averts the initiation and evolution of the electrical discharges under an applied electrical field. With a high dielectric strength, the Sulfur hexafluoride is used in many applications, as an insulating in high voltage transmission and distribution equipment. Consequently, the SF_6 gas is utilized in miniaturization of the high voltage devices, and the instruments of electric transmission and distribution. Electronegative gases are frequently utilized, like insulators in high-voltage devices and equipments, in plasma-material processing and in the technological processes utilizing plasma. To understand the phenomena in plasma and ionized gases, we need to have an exact electron swarm parameter for various electronegative gases. Therefore, considerable attention has been consecrated to studying the physical properties of this gas [6-10].

In the development of plasma technologies, the modelling of processes in plasma has an important role. The simulation is significant and useful in the search for the optimal conditions in the plasma technology. The swarm parameters are of importance in the modelling of electrical discharges and plasmas, and have an important role in the simulation of the dynamics of charged particles in electrical discharges and plasma. The simulation in the electrical discharges and plasma permits a description of both transport of charged particles and kinetic in the plasma, for the supervising and control of the apparatuses with plasma.

The Monte Carlo technique is the better method for having an excellent description of the particle's kinetics in the electrical discharges and plasma. This method of simulation simulates the realistic physical processes in electrical discharges and plasma and describes the temporal and spatial evolutions of particles [11-13]. The swarm parameters of the charged particles used for the electrical discharge and plasma applications are deduced theoretically and experimentally under the static electric fields. The transport coefficients or the swarm parameters are determined as a function of E/N the effective electric field (E electric field and N number density) in the steady state (static electric). However, the electric field is time varying in the plasma processes, in this work we will study the swarm parameters in the dynamic state. The purpose of this work is to search the electron swarm parameters in sulfur hexafluoride. We have studied the comportment of electrons in time varying electric fields by a Monte Carlo method and have examined the difference between the dynamic and static cases. Swarm parameters are determined as a function of E/N for different rates of increase of the electric field.

2. SIMULATION MODEL AND METHOD

The Monte Carlo method allows having a complete description of the charged particles kinetics. Monte Carlo technique follows the spatial and temporal evolution of the charged particles and simulates the real physical processes. The simulation of the transport of charged particles in an electric field with the Monte Carlo method is presented. The problem in this method is to follow the trajectories of the charged particles between collisions and recognize the nature of the collisions of the particles with the background gas. In this study we consider only the collisions of the electrons with the molecules of the background gas, and neglect the electron-electron collisions. In order to obtain a sufficient precision a high number of electrons are followed, and the transport parameters are obtained after the electron swarms are reached the hydrodynamics conditions. In the present Monte Carlo simulation, an electric field is applied to the gas gap as a linearly increasing function of time.

$$\frac{E}{N} = a.t \qquad (1)$$

Where $\frac{E}{N}$ is in Td and the time t in nanosecond, a is a constant.

With a cosine distribution and a mean energy of 0.1 eV the initial electrons are injected in the gap at t=0 and r=0. For to not influence the running of the simulation of the swarm parameters in the times the energy is low enough, and we have not considered the interactions with the electrodes. With the equations of motion, the new positions and energies of the electrons are calculated. Under the action of the electric force the electrons move in the time steps dt. By comparison with a computer-generated random number, the probability of collision and the nature of collision are determined [13]. The cross sections of all possible processes are utilized and isotropic scattering processes are assumed [13]. In the calculations we utilize a background gas of SF_6 molecules with a number density of $N=3.56.10^{22}$ m^{-3} in a spherical coordinate system. A unit of 1 Td = 10^{-21} V. m^2 is used to avoid large negative powers of 10. The cross section set of SF_6 employed is that of Hayes et al, [14], Peach [15, 16] and Itoh et al. [17].

3. RESULTS AND ANALYSIS

For the modelling and simulation of the plasma and electrical discharges, it is fundamental to know the electron transports parameters, diffusion coefficients, ionization and attachment coefficients, and other reaction coefficients in gases. The drift velocity of electrons moving into the space stressed by an electric field is one of the most important characteristics of an ionized gas (electrical discharges and plasma). The electron drift velocity is required for modelling and simulation of the electrical discharges and plasma, this drift velocity gives the average of the movement of the electrons under the influence of an electric field. Swarm parameters as a function of the reduced electric field E/N are determined in this work.

In the electric power industry for transmission and distribution of electrical energy the systems with gas insulated are widely used. In this study we consider the case of swarm parameters in an electronegative gas (SF_6), and the Monte Carlo technique is used. This kinetic method utilized for the electrical discharges and ionized gases estimating the percentage of a species of charged particles, after collisions the loss and gains in the energies terminate in others categories. The Monte Carlo method allows us to follow a large number of charged particles. The computing time in this method depends on the number of the charged particles in the gap and the number of collisions occurring among the charged particles between the electrodes. In an electronegative gas the seed electrons can disappear by the attachment processes and stop the simulation in the low E/N conditions.

With adequate relations we calculate the swarm parameters in the space and time for the charged particles, and the determination of transport coefficients. The drift velocity is shown in Figure 1 as a function of E/N for various dE/dt. We observe on the curves a peak which develops at low E/N region and this peak displace and increase to larger E/N for larger dE/dt. as shown in Figure 2 This phenomenon is observed in the dynamic electric field condition and is never found in steady state dc field conditions as shown in Figure 3 [18-24]. This peak reflects the influence of the dynamic electric field on the electron movements and the elastic collision processes, is not due to the processes of inelastic collision. We observe fluctuations in the swarm parameters due to the nature of the electric field. In the low reduced electric field, the electrons after electronic excitation collision, and few vibrational excitation collisions disappear due to the attachment processes. In the low reduced electric field, the electrons emitted in the initial direction, with initial energy of 0.1 eV, after a few collisions, the electrons lose their initial anisotropic angular distribution and the initial direction of velocity is rapidly changed.

The electron means energies as a function of E/N are plotted in Figure 4. For lower dE/dt we observe fluctuations to larger E/N, these fluctuations decrease and displace to larger dE/dt. as shown in Figure 5. The curves should coincide in the case where the electrons respond instantaneously to the variation of the electric fields. The electrons mean energy as a function of E/N under the steady state dc electric field conditions is presented in the Figure 6. The values were calculated by the Monte Carlo method [17-19]. The electrons mean energy for different dE/dt tends to the mean energy under static electric field for larger E/N. As anticipate, the fluctuations are more pronounced in the electron drift velocity, which is a statistical mean only of the component of the velocity along the z axis, the electron mean energy value is an average of the three components of the velocity, along x, y and z axes. For the same number of collisions, the electron mean energy is more precise than the electron drift velocity.

In the Figure 7 and Figure 8 we have the electron energies distributions at E/N=200Td for E_{20} and E_{80} conditions. As shown in Figure 7 the anisotropic parts of the distribution are quite small for *a*=20 but in inverse; the distribution for *a*=80 with the anisotropic parts is much greater than with isotropic part alone. At the same energies the curves of the Maxwellian distribution are traced by the dot and the full lines. This involves that the low E/N peak results from the acceleration of electron during the interval between collisions, in the low energy region where the direction of the electrons is easily changeable by the electric field.

The swarm parameters of electrons, chiefly the longitudinal diffusion coefficient, are important and indispensable to simulate the plasma processing and electrical discharges in gases. One of the purposes of this study is to stipulate the diffusion coefficients as a function of E/N. The longitudinal and transverse diffusion coefficients, ND_L and ND_T are shown in Figure 9 and Figure 10. The longitudinal and transverse diffusion coefficients for E/N at less than 200 Td have conventional dependence on E/N. The gradient of longitudinal and transverse component of diffusion coefficient for E/N declines rapidly at 200 Td. This is due that the electron ionization coefficient has a wide effect on the longitudinal diffusion coefficient and a less effect on the transverse diffusion coefficient. For E/N less than 100 Td the longitudinal diffusion coefficient and the transverse diffusion coefficient decreases rapidly, this effect is due to the large vibrational collision and attachment proportions.

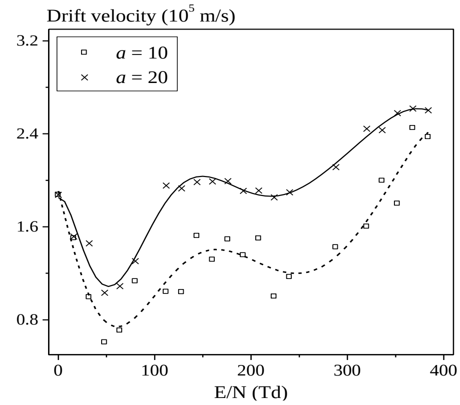

Figure 1. Electron means drift velocity as a function of reduced electric field for *a*=10 and *a*=20

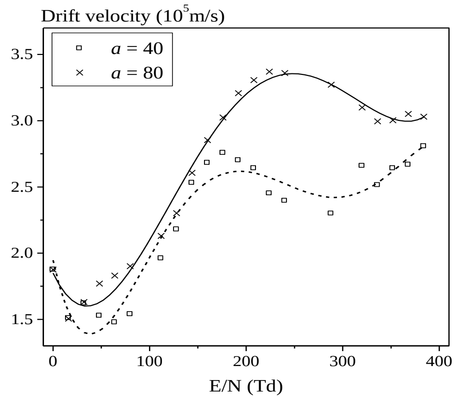

Figure 2. Electron means drift velocity as a function of reduced electric field for *a*=40 and *a*=80

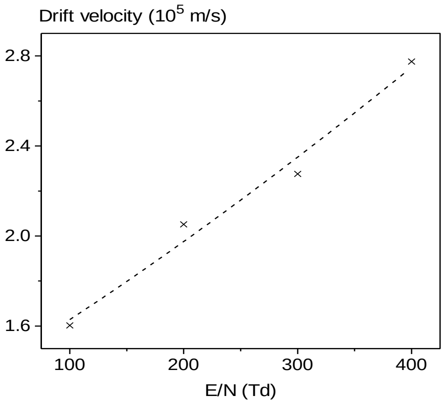

Figure 3. Electron means drift velocity for static electric field

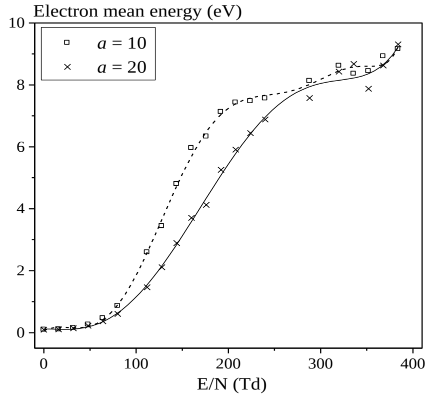

Figure 4. Electron means energy as a function of reduced electric field for *a*=10 and *a*=20

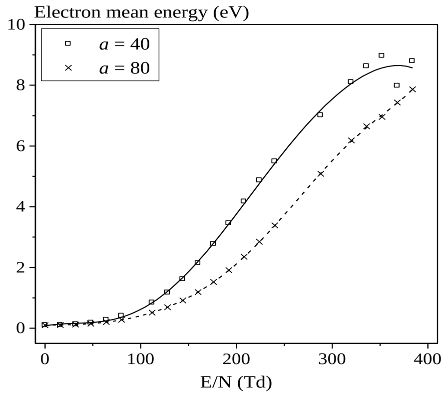

Figure 5. Electron means energy as a function of reduced electric field for *a*=40 and *a*=80

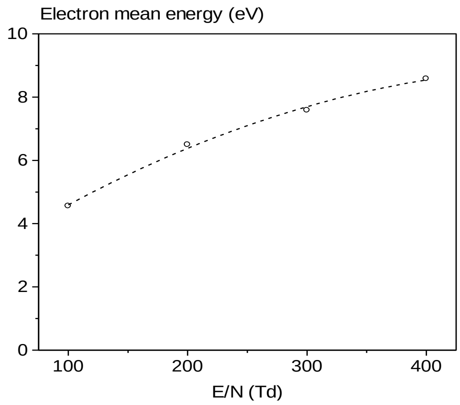

Figure 6. Electron means energy under the static electric field

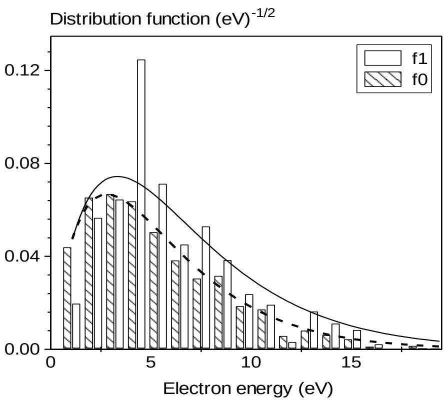

Figure 7. Electron energy distribution at E/N=200Td, for *a*=20. f0: isotopic part, f1: with anisotropic parts

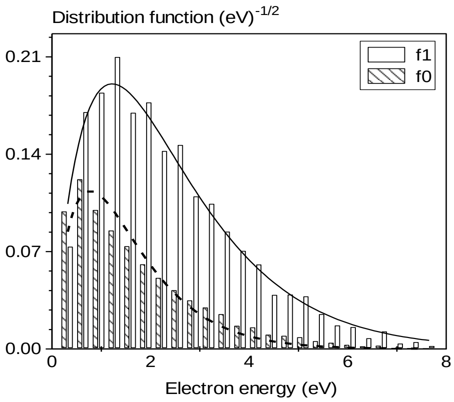

Figure 8. Electron energy distribution at E/N=200Td, for *a*=80. f0: isotopic part, f1: with anisotropic parts

The causes of the fluctuation of the transport coefficients for the low dE/dt are the non-equilibrium of the electron energy distribution and to the statistical scattering caused by the number of electrons which decreases rapidly due to attachment. To reduce the fluctuation and the scattering in the simulation a considerable number of electrons should be injected into the drift space in order to reduce the fluctuation. The Monte Carlo method is the preferred method to simulate the swarm parameters in gases.

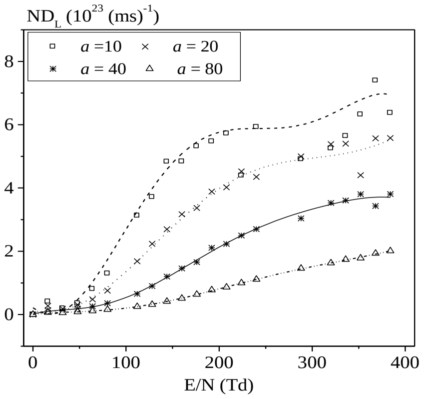

Figure 9. Longitudinal diffusion coefficient as a function of reduced electric field for all cases

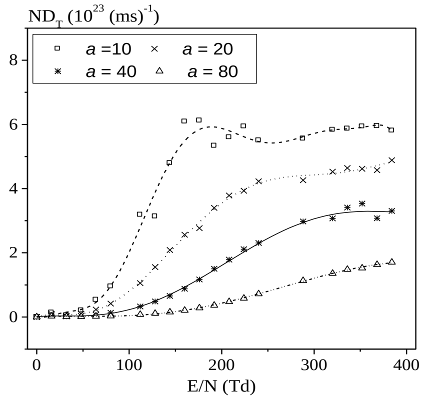

Figure 10. Transverse diffusion coefficient as a function of reduced electric field for all cases

4. CONCLUSION

We have examined the effect of time varying ramp electric fields on the electron swarm parameters using a Monte Carlo simulation. The importance of the SF_6 in the plasma processing, and in gaseous dielectrics have motivated us to study the swarm parameters in this gas. In the area of electrical discharge and plasma physics the Monte Carlo method as a simulation tool is important.

For different proportions of the electric field dE/dt, the electron swarm parameters were calculated as a function of reduced electric fields E/N. There is a significant difference in the electron swarm parameters between dynamic and static electric field condition. A peak in the electron drifts velocity takes place in the low E/N region for low dE/dt and progressively to move to the higher E/N as dE/dt increased. This characteristic found in the dynamic electric field condition is explained by change of the direction of electrons in the low energies by the electric field between collisions.

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