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Plasma decays in dusty afterglow

L. Couëdel[1,2], A. Mezeghrane[2], B. W. James[1], M. Mikikian[2], A. A. Samarian[1],
M. Cavarroc[2], Y. Tessier[2] and L. Boufendi[2]

[1] *School of Physics A28, The University of Sydney, NSW 2006, Australia*

[2] *GREMI (Groupe de Recherches sur l'Énergétique des Milieux Ionisés), CNRS/Université d'Orléans , 14 rue d'Issoudun, Orléans Cedex 2, France*

Abstract

Measurements of electron density decay in the afterglow of dust-free and dusty plasmas have been performed. It has been shown that the presence of dust particles enhances the electron loss rate. Preliminary measurements on an argon line decay showed that dust particles quiken the line decay.

Introduction

Recently the decharging of dust particles in complex plasma afterglow raises interest as well as the dust particle residual charge [1, 2]. Indeed it has been observed that dust particles do keep residual electric charges when the power of a RF discharge is turned off. Moreover, negatively charged, neutral and positively charged dust particles have been observed in the late afterglow of the RF discharge [2]. It has also been measured in pulsed argon-acetylene dusty discharge that the electron density decay during afterglow phases shows an unexpected behaviour: the electron starts to increase when the RF-power is switched off before decreasing exponentially [3, 4]. This anomalous behaviour was attributed to the charging-decharging of the dust particle. Consequently, any complementary measurements on plasma decay is helpful in order to understand the dusty plasma afterglow physics. In this paper, measurements on the electron density decay in dusty and dust-free plasmas are reported. We also report estimation on argon line decay and preliminary spectroscopic measurements on dusty plasma afterglow

Electron density decay

A RF discharge is ignited in a grounded 13 cm diameter cylindrical box. The interelectrode space is 3.3cm. The system is embedded in a vacuum chamber. The powered electrode is linked to a RF generator with 13.56 MHz frequency. This electrode is showerhead type in order to obtain an homogeneous gas distribution in the plasma region.

Electron density measurements are performed using the microwave resonant cavity technique. Two antennas are fixed face to face in the bottom of the plasma box.The first antenna is linked

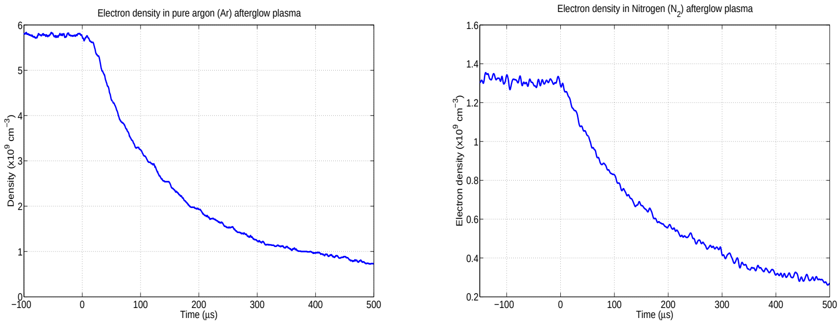

Figure 1: Electron density decay in dust-free plasma afterglow. Left: argon. Right: Nitrogen

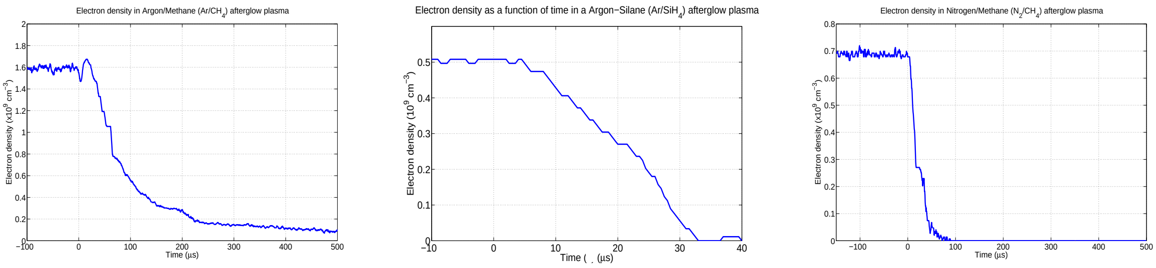

Figure 2: Electron density decay in dusty plasma afterglow. Left: A_r/Ch_4. Middle: Ar/SiH_4, Right: N_2/CH_4

to a microwave generator which frequency varies between 100 kHz and 4 GHz. The second antenna measures the signal. When looking for the resonance modes with and without plasma, one can obtain the electron density [5]. Measurements of the electron density in afterglow plasma are performed in two kinds of dust-free plasmas: plasma of molecular gas (N_2) and plasma of monoatomic gas (Ar).

For pure argon plasma, the Ar flow rate is 41.8 $sccm$. The operating pressure is 1.1 $mbar$ and the RF power is $P_W = 20\ W$. In order to reconstruct the resonance curves, the plasma was pulsed with $t_{on} = 10\ s$ and $t_{off} = 30\ s$. For pure nitrogen plasma, the N_2 flow is rate 43.5 $sccm$. The operating pressure is 0.9 $mbar$ and the RF power is $P_W = 40\ W$. The plasma was pulsed with $t_{on} = 10\ s$ and $t_{off} = 30\ s$.

As it can be seen in Figs. 1, the electron density decreases faster for a nitrogen afterglow plasma ($\tau_d \sim 150\ \mu s$) than for an argon afterglow plasma ($\tau_d \sim 200\ \mu s$).This is due to the fact that for a molecular gas plasma, losses of charged species are in volume while in a monoatomic gas plasma, losses are in surface (i.e. diffusion and recombination onto the walls of the reactor).

To observe the influence of dust on electron losses during the post-discharge phase, electron density measurements are performed in three kinds of dusty plasmas.

For Ar/CH_4 plasma, an argon flow rate of 41.8 $sccm$ and a methane flow rate of 0.8 $sccm$ are

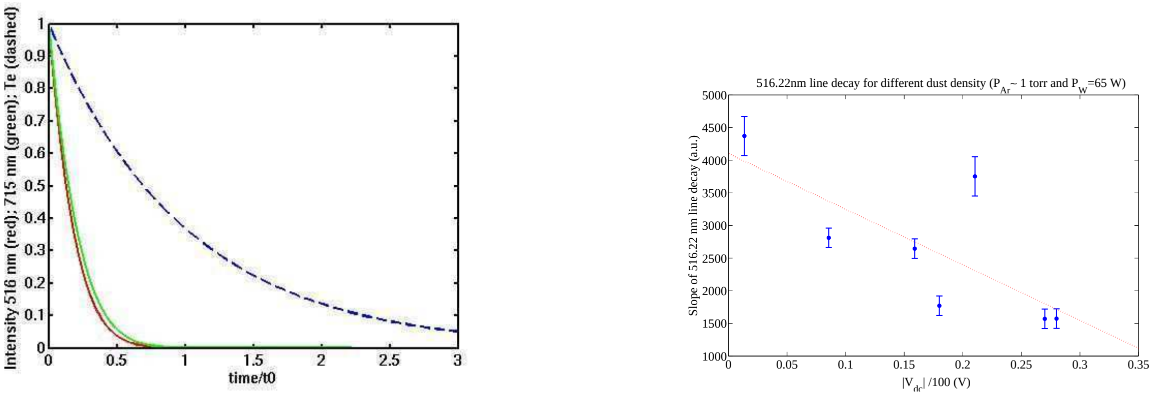

Figure 3: Left: Comparison of Argon line decay with electron temperature relaxation. Right: Slope of 516.22nm argon line decay as a function of the Self-bias V_dc in a dusty plasma

used. The operating pressure is 1.1 *mbar* and the RF power is $P_W = 20\ W$. The plasma was pulsed with $t_{on} = 40\ s$ and $t_{off} = 80\ s$. For Ar/SiH_4 plasma, an argon flow rate of 20 *sccm* and a silane flow rate of 1.2 *sccm* are used. The opperating pressure is 0.12 *mbar* and the RF power is $P_W = 10\ W$. The plasma was pulsed with $t_{on} = 2\ s$ and $t_{off} = 20\ s$. For N_2/CH_4 plasma, a nitrogen flow rate of 43.5 *sccm* and a methane flow rate of 1.3 *sccm* are used. The operating pressure is 0.9 *mbar* and the RF power is $P_W = 40\ W$. The plasma was pulsed with $t_{on} = 30\ s$ and $t_{off} = 60\ s$.

As it can be seen in Fig.2, the electron density decay time is shortened when dust particles are grown in the plasma. In both N_2/CH_4 plasma and Ar/SiH_4 plasma, the decay time is $\tau_D \sim 30\ \mu s$ which is more than five times smaller than for dust free plasma. The case of Ar/CH_4 plasma is more complicated, a small increase of the electron density is observed at the very beginning of the afterglow which tends to indicate that the decay process is dependent on the nature of dust particles. In every cases, the size of the grown dust particles has been mesured using SEM microscopy and was $r_d \sim 50 - 100\ nm$

Spectrocopy of dusty plasma afterglow

The argon line intensity depends on the plasma electron temperature. If the electron density is sufficiently low the population of excited states of atoms and ions is due to a balance between excitation from the ground state by electron collisions and radiative de-excitation. The corresponding simplified steady-state collisional radiative model describes what is referred to as corona equilibrium [6]. In order to simulate the spectral line emission from a decaying plasma an exponential decay of electron temperature has been assumed, from a value of Te_0 with an exponential time constant t_0: Using as an example $Te_0 = 3\ eV$ and $t_0 = 10\ \mu s$ the relative intensities of the two argon spectral lines 516.22 nm and 714.70 nm have been calculated. The intensities of both transitions fall much more rapidly than T_e (Fig.3). The excitation energy of the first excited state of neutral argon is 11.55 eV. This is the lower level for the 714.70 nm transition, while the 516.22 nm transition has a slightly higher lower level of 12.91 eV. Due to the higher excitation energy of the latter, its intensity falls faster than the other transition, but the difference is small. Although the ratio of these transitions varies with T_e, the rapid fall in intensities means that it is not a practical electron temperature diagnostic, except in the early stages of the decay.

Consequently, the decay of the 516.22 nm argon line has been measured in a capacitive RF discharge in which dust particles are grown by sputtering of polymer deposited on the powered electrode. In Fig.3, the slope of the decay as a function of the self-bias voltage of the powered electrode is presented. As the self bias is inversely proportionnal to the dust particle density, it can be seen that the more dust particles there are, the faster the decay is..

Conclusion

The presence of dust particles in a plasma modifies significantly the diffusion of electrons in plasma afterglow. Consequently the decharging process of dust particles must be influenced too. It has also been observed that the nature of dust particles influences the electron decay process observing an anomalous electron density increase in the very beginning of the afterglow in Ar/CH_4 plasma. Furthermore, the presence of dust particles in the plasma enhances the decay speed of the spectral line indicating that they could have an influence on electron temperature relaxation. These results are of great importance for the understanding of dusty plasma afterglow physics.

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