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Dust Cloud Dynamics In Complex Plasma Afterglow

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Introduction

In plasma afterglow, the external electromagnetic fields which maintain the discharge are absent or insufficient to sustain the glow. So, the plasma decays, which means that the electrons and ions are lost over a relatively short timescale (milliseconds). However, it has been shown that in complex plasma afterglow, the particles do not lose all carried charge but keep small residual charges for a long time (seconds) [1,2]. Consequently, the motion of the dust cloud must be affected by the discharging process and residual charges, due to electrostatic forces. Experimental observations of dust cloud dynamics in a RF discharge afterglow are presented. Image analysis is used to extract information from videos taken of the plasma. Estimations of the mean confining electric field have been made for different experimental conditions using a model for the contraction of the dust cloud. The dynamics of the void in complex plasma afterglow has been investigated.

Experiment

Experimental observations of different complex plasma afterglow conditions in a RF discharge have been made. Experiments were performed in the PKE-Nefedov chamber, which has two parallel electrodes separated by 3cm. The dust particles were grown in argon plasma, from the sputtering of a polymer layer deposited on the electrodes. The mean radius of the dust particles in these experiments is ~200nm. The dust particles were illuminated by a thin sheet of laser light, and a high speed camera was used to record the light scattered by them. An interference filter was placed in front of the camera to select the frequency of the laser light. Four different afterglow conditions were studied, which had different pressures and bias voltages applied to the electrodes.

For each condition, two distinct types of dynamic behavior of the dust cloud were viewed when the discharge was switched off: a contraction of the dust cloud, which occurs over a short timescale of tens of milliseconds, followed by a fall of the dust cloud due to gravity, which occurs over a longer timescale of seconds.

Confining Electric Field Estimation

The videos were converted into image sequences, and image analysis was used to extract quantitative information about the dynamics of the dust cloud in complex plasma afterglow. It is assumed that the intensity of scattered light I is proportional to the number density of dust particles n_d. When the discharge is turned off, an initial decrease in intensity is observed which is due to reduction in plasma light, and then the intensity increases sharply (see Fig. 1). This is due to the contraction of the dust cloud. The contraction of the dust cloud is thought to be caused by the electrostatic force of the confining electric field on the charged dust particles.

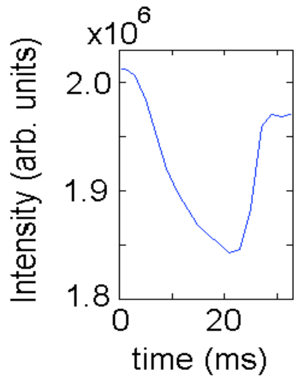


Figure 1. Scattered light intensity in afterglow, for P=1.6mbar.

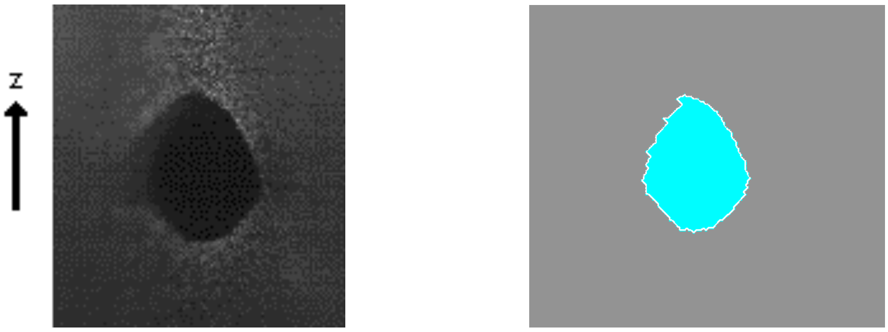
From the dynamics of the dust cloud, an estimation of the mean confining electric field has been made. It is assumed that the dust cloud is spherical, and that it contracts due to the confining electric field. Over the timescale of the contraction, gravity will have a small effect in comparison to the electric field, so its contribution has been neglected in the calculations. The forces acting on the dust particles are then the electrostatic force and the neutral drag force due to collisions with unionized argon. Since $I \alpha n_d$, changes in intensity can be related to changes in the number density of dust particles, and hence changes in the dust cloud radius. Also, changes in the dust cloud radius are related to the magnitude of the confining electric field and the time of contraction, which can be determined from the video. In the early afterglow, the dust particles have a mean charge of ~ 10e [2], so then these values can be substituted to find the electric field for different conditions.

It was found that the estimated electric field is stronger for each of the higher pressure conditions (P=1.6mbar, biased and unbiased) than for the lower pressure (0.8mbar) condition.

Including the effect of the neutral drag force in calculations gives an electric field which is an order of magnitude higher than if it is neglected. This is because a larger inward force is required to oppose the friction force from collisions with neutrals, which acts outwards.

Void Dynamics in Afterglow

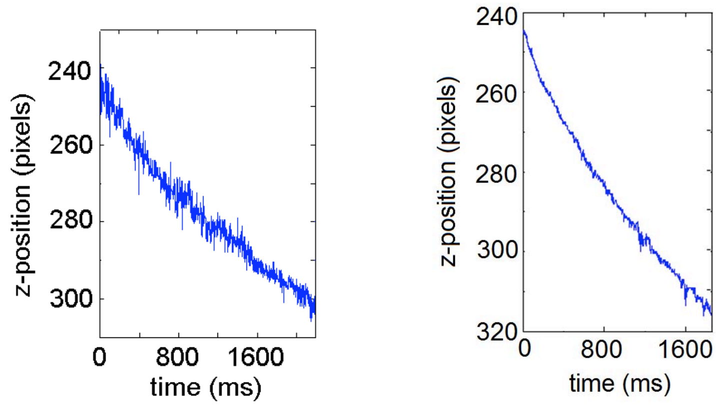
The dynamics of the dust void have also been studied. The dust void forms in a running discharge from the balance of an outward ion drag force and inward electrostatic force [3]. When the discharge is turned off, the ion drag force decreases, however the dust void is seen to maintain its sharp boundaries for a long time in the plasma afterglow. This permits taking contours of the void in each image, from which the evolution of the dust void in afterglow can be quantified (Fig. 2).



(a) (b)

Figure 2. (a) Dust void for P=0.8 mbar (b) Contour of the dust void.

The dust void was observed to fall steadily in the afterglow due to gravity. The z-position of the dust void centre has been graphed against time for the four different discharge conditions (Fig. 3).



(a) (b)

Figure 3. Z-position of dust void for (a) P=1.6 mbar and (b) P=0.8 mbar.

From these graphs, the dust void falls with approximately a constant velocity. The dust void in the lower pressure condition falls at a higher velocity than the higher pressure condition. This is due to the dust particles having a higher velocity as a result of a smaller neutral drag force.

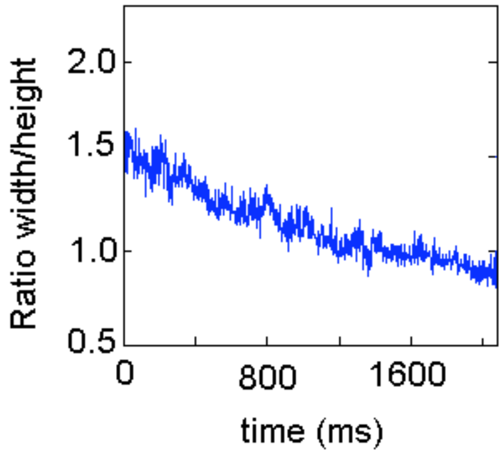


Figure 4. Ratio of the width to the height of the dust void, for a pressure P=1.6 mbar.

The dust void was also seen to maintain a constant width after the discharge had been switched off. In a running discharge, the void contour has approximately an elliptical shape. During evolution of the dust void for each condition, the ratio of the void's width to its height decreases, indicating that the void gradually becomes smaller in the vertical direction (Fig. 4). This may be due to the dust particles having different sizes at top and bottom of the void.

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