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Voids in Dust Clouds Suspended in the Plasma Sheath

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Abstract. Voids in dusty plasma are a new phenomenon, which is still not understood. In this work we have studied experimentally for first time voids in the sheath of a radio-frequency (RF) dusty plasma. Injecting big dust particles into the plasma, we form a dust cloud in the sheath. The behaviour of the cloud as a function of RF power and gas pressure is investigated using video imaging. Both dependencies show a threshold for the void formation. This threshold is characterised by a sudden decrease in the inter-particle distance, while in the non-void mode the distance increases with power and pressure. We have performed Langmuir probe measurements of the floating potential in the bulk plasma close to the sheath in order to estimate the form of the potential well trapping the dust grains.

INTRODUCTION

The interest in dusty plasmas arose fifteen years ago with the development of semiconductor manufacturing, as dust contamination was proved to be harmful for the semiconductor devices. To be able to control a process we need to understand it in detail. For this we need a lot of fundamental knowledge.

In 1996, Praburam and Goree first observed a new phenomenon which they called "great void" [1]. In their work, the void was observed in the bulk plasma as the dust particles were nanometrer sized and were grown by sputtering graphite electrodes. This work was continued by Samsonov and Goree [2]. In 1999, voids were again observed [3]. In this experiment, the dust particles were micrometre sized, but, due to the microgravity conditions, the cloud was again in the bulk plasma.

There are several attempts at finding theoretical explanation of the void formation [4, 5, 6, 7, 8].

EXPERIMENTAL PROCEDURE

Here, we describe the experimental set-up designed for this work. The argon pressures are in the range of 0.06–0.21 mbar. In the bottom of the vessel, an electrode is powered at 13.56 Mhz. The power is in the range of 3 to 60 W. We have injected spherical melamine formaldehyde(MF) particles with diameter of 9.8 mm in the plasma. The electrode is designed with a special form to create a trap for the particles — in the centre there is a circular groove 3 cm in diameter and 3 mm deep. To illuminate the particles, we

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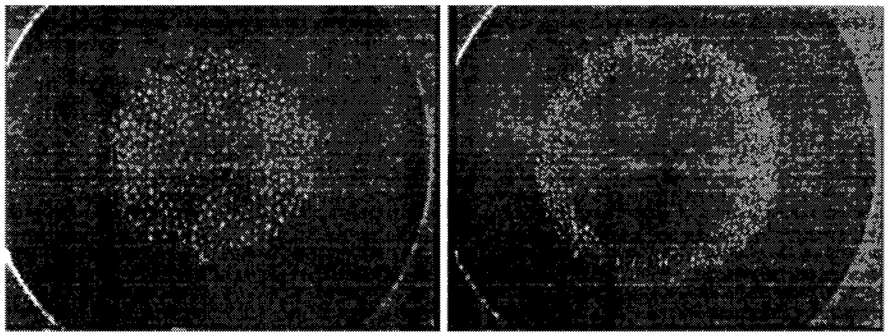

FIGURE 1. Images of the dust cloud at pressure 0.11 mbar at low and high power. The illuminated ring around the cloud is the edge of the groove in the electrode. At high power we can see in the centre a dust free region — void.

have used a horizontal laser light sheet. The particles are large enough to be imaged separately. The imaging is performed by a video camera positioned above the reactor. A Langmuir probe has been used to measure the floating potential of the discharge.

EXPERIMENTAL RESULTS AND DISCUSSION

In the argon plasma the dust particles become negatively charged. This keeps them apart. On the other hand, the trap doesn't allow them to spread into the whole vessel. The particles form a cloud positioned above the centre of the groove in the electrode.

Figure la shows the particle cloud. The cloud has a diameter of approximately 1 cm. By changing the conditions of the plasma, we have been able to reach a situation, in which a dust free region(void) has been formed in the centre of the cloud(Fig. 1b). We have made a series of measurements at constant pressure and varying power, and, at constant power and varying pressure. Typical graphs are shown in figures 2 and 3.

In the case of 0.11 mbar pressure the cloud has been uniformly dense up to 25 W. Above 25 W a void forms in the centre of the cloud. If we compare the area of the cloud at different powers, we see that, after forming the void, this area decreases(Fig. 2b). Figure 2 gives the impression that the void shrinks and the cloud surface increases above power of 40 W. The reason for this is the very strong glow of the plasma at high powers. This decreases the contrast of the picture, which, in turn, results in less precise measurements. The decrease of the cloud area after void formation in the centre may be due to decrease in the inter-particle distance or to shift of the particles in vertical direction.

A similar series of measurements have been performed under constant power and varying gas pressure. Atypical graph(at 10 W) is shown on Fig. 3a. In this case, the cloud goes from a circular shape to an annular one at 0.1 mbar. The measurement has been performed in the range of 0.06 to 0.21 mbar, when the cloud has appeared as a ring of single particles. As it has been in the case of power dependence, we can see that up to the

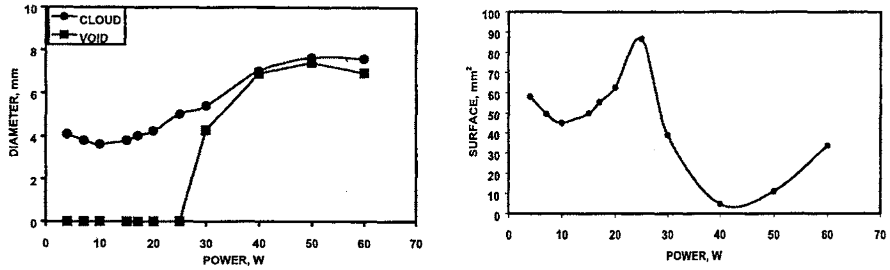

FIGURE 2. (a) Cloud and void diameter as a function of the RF power. The pressure is O.11 mbar. At this pressure the void appears at 25W. (b) Surface of the mono-layer cloud as a function of the RF power.

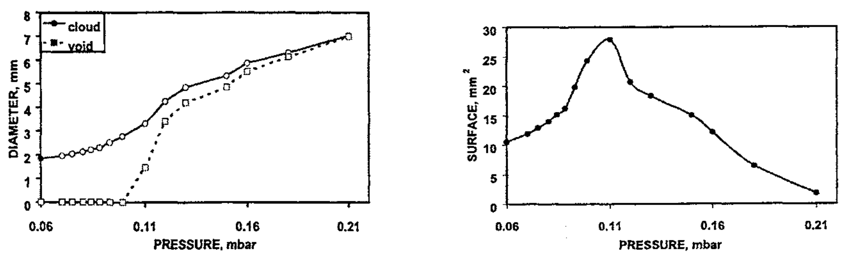

FIGURE 3. Cloud and void diameter as a function of the gas pressure. The power is lO W. At this power the void appears at 0.1mbar. (b) Area of the mono-layer cloud as function of the gas pressure. After the void is formed the cloud area decreases.

threshold the area of the cloud increases and after the formation of the void it decreases. To try to establish the reason for the area change, we have estimated the volume taken by a single particle. As the measurement is based on 2D images and the laser light sheet is thicker than the diameter of the particles, it is not possible to fully consider the vertical movement of the particles. However, as there is no change in the number of particles in the cloud, the estimation has showed that the inter-particle distance is the basis of the change in the cloud area.

We aim to understand the phenomenon of voids in dust clouds on the basis of the dynamics of dusty plasmas. The main forces acting on a dust grain in the plasma are electrostatic, ion drag, neutral drag, thermophoretic and gravitational. The particles levitate in the plasma in a position where the gravitational force is in equilibrium with the vertical component of the electrostatic force.

The ion drag force is due to the momentum transfer from the ions to the dust particles. The ions move in the electrostatic field and transfer momentum to the dust particles in the opposite direction to the electrostatic force.

To find out if the horizontal component of the electrostatic force is directed inwards or outwards, we need additional information. For this reason we have performed Langmuir probe measurements. As the probe measurements are not relevant in the sheath, we have measured the floating potential directly above the sheath. The results are shown in figure 4. For technical reasons, the measurements were performed at a fixed level

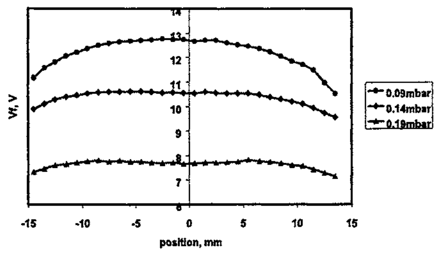

FIGURE 4. Floating potential measured at 1.5 cm above the electrode at different pressures. The measurements are performed above the groove in the electrode. Position 0 corresponds to its centre.

above the electrode. As the sheath thickness changes in response to the changing plasma parameters, our measurements are not at a constant distance from the dust cloud. By increasing the pressure, we decrease the sheath thickness and the particles also move a little lower. In this case, the measurement of the floating potential is closer to the plasma bulk and it should be less sensitive to changes in the sheath profile. We see that as the pressure increases the profile flattens and at high pressures there is even a slight drop in the centre. This drop, even though it's within the measurement error and therefore it's not reliable, already gives an idea of one possible reason for the void formation.

CONCLUSIONS

We have reported the results of laboratory observations of voids in a RF dusty plasma. The formation of voids has been investigated for the first time as a result of increased pressure or RF power. To discover whether the electrostatic or the ion drag force is responsible for this behaviour of the dust cloud, we have performed Langmuir probe measurements of the floating potential. The precision of the measurements is not enough for definitive conclusions. To obtain clear evidence that the form of the potential is causing the annular form of the cloud at higher pressures or powers, we need additional measurement techniques.

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