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Dust Particles Growth and Behavior under Microgravity Conditions

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Abstract. This paper presents the first observations on dust particles growth and behavior under microgravity conditions obtained in the PKE-Nefedov chamber by a French-German-Russian program. Growth kinetics, spatial distribution and dynamics of grown particles have been investigated. Some of the results are discussed and compared with on ground experiments.

INTRODUCTION

Microgravity conditions are required to avoid gravity perturbations, revealing the real interactions between dust particles and pure plasma effects. In early 2001, experiments concerning the study of clouds of injected microparticles have been performed on board the International Space Station (ISS) by the Institute for High Energy Densities (IHED) of Russian Academy of Sciences and the Max-Planck-Institute for Extraterrestrial Physics (MPE). The Research Group on Energetics of Ionized Gases (GREMI) joined IHED and MPE for an extended program on dust particles growth. These new experiments have been performed on board the ISS in late october 2001 by a French-Russian cosmonauts team.

DESCRIPTION OF THE EXPERIMENTS

The PKE-Nefedov experimental setup [1] consists in a radiofrequency discharge where an argon plasma is created in push-pull excitation mode. Polymer particles (melamine formaldehyde ~3.4 and ~6.9 μm) can be injected in the plasma and illuminated by a thin laser sheet perpendicular to the electrodes. The scattered light is observed at 90° by two CCD cameras with different magnification. The system laser-camera can be moved horizontally to scan the entire cloud and obtain tridimensional information on the cloud structure. The behavior and the organization of these clouds have been investigated either on ground or in microgravity by MPE (structure, dust-free region called "void" in the center of the discharge).

Growth procedure

On Earth, the injected dust particles fall down on the electrode after an experiment. This layer of deposited matter is sputtered to generate a new dust particles population. In the PKE-Nefedov chamber, this growth has been obtained in GREMI laboratory at high pressure (~1 mbar) and low power (~1 W) with a typical appearance time (on screen) around 2 to 3 min. After this growing step with monodisperse particles, a constant process of sputtering and growth leads to particles of various sizes (between 0.2 and 0.8 μm in diameter as shown by scanning electron microscopy). This size dispersion can be also achieved by working for few minutes at higher power. New dust particles are grown from the previous grown dust cloud. This situation leads to successive generations of dust particles as shown in figure 1a. The X-ray fluorescence analysis reveals that these particles are principally constituted of carbon (no more nitrogen as in melamine formaldehyde). Due to their submicron size, gravity is not the predominant force and they can be trapped in the whole volume of the plasma even on Earth. The "void" and large crystalline regions have been observed (figure 1). We can also notice vortex-like regions near the electrode edge.

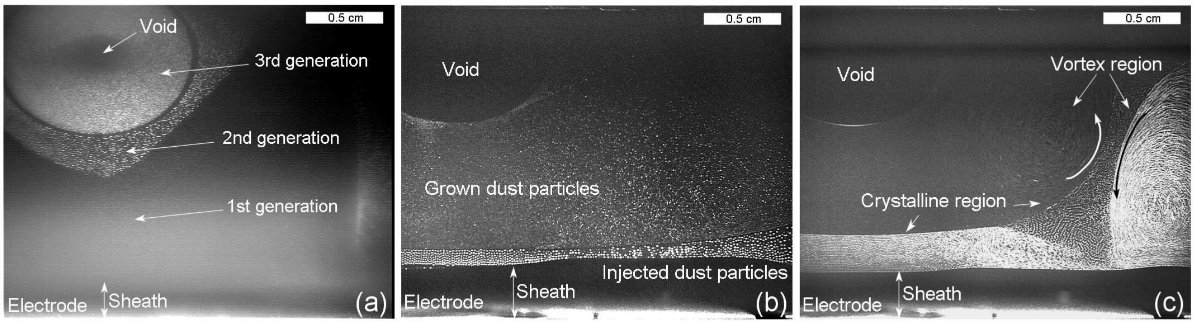

FIGURE 1. *Dust clouds on ground : a) multiple generations, b) grown and injected particles (3.4 μm), c) crystalline and vortex-like regions of various sizes grown particles (15 images superimposed)*

Microgravity experiments preparation

One of the unknown parameter for the on board experiments is the quantity of matter deposited inside the reactor from previous experiments: injected particles do not fall down on the electrode when the plasma is turned off. On ground we have observed a direct correlation between the size of the grown particles and their density. Their size will remain very small while their density is very large. Another requirement for this experiment is to obtain a rather low base pressure. Our laboratory experiments have shown that the growth can be inhibited if the base pressure before an experimental run is not low enough (10^{-3} Pa), that is to say if the argon plasma is not pure (presence of O_2 or/and N_2). This aspect (also reported in Ref.

[2]) has been taken into account for the microgravity experiments and a turbomolecular pump has been installed on board replacing the direct vacuum connection to space previously used.

RESULTS AND DISCUSSION

Dust particles growth has been achieved on board the ISS. A huge amount of very small size particles has been observed. This situation which has been already obtained in the laboratory, is not the most common one and it is not clear if it is due to microgravity or to a high purity of the plasma and a lot of matter available. In these conditions the particles can not be individualized on images and then our study is focused on a global observation of the cloud. We can notice that a first interesting result is the presence of the void structure even with these small size particles.

Growth evidence

As shown in recent experiments performed in our laboratory in an argon-silane plasma [3], the dust particles growth can be followed through the evolution of the current harmonics amplitudes. Dust particles decrease the plasma electron conductivity through collisions or attachment, leading to a drop of the electron current reaching the electrodes. This effect has been observed during the on board experiments as shown on figure 2. We have plotted on the same figure the evolution of the video signal intensity recorded by the cameras (i.e. dust appearance) to show the direct correlation between these two quantities.

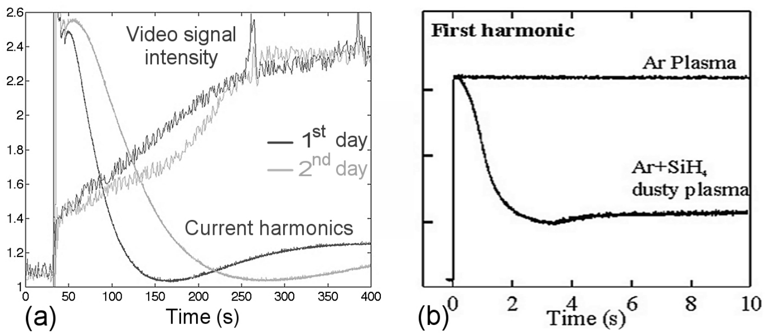

FIGURE 2. *Time evolution of the current harmonics, a) on board with video signals, b) in an Ar-SiH_4 plasma*

Dynamical behavior

As observed on ground, big vortex cells appear in the on board experiment showing that this behavior is not due to thermal convection as it could be supposed but caused by pure plasma effects and more precisely by the electric field near the electrodes edges. Another interesting dynamical behavior is the response of the cloud to a low frequency excitation applied on the electrodes. On figure 3b the cloud is constituted of grown particles and injected ones (3.4 µm, down right). We have recorded the position of the characteristic points labeled on the image in function of time for frequencies varying from 0.5 to 34 Hz (figure 3a for a frequency about 1 Hz). The points (P1,P2,P3) move in phase and then this movement propagates through the cloud of grown particles which is moving in phase at low frequency but with a phase shift at higher frequencies (figure 3c). This experiment could give information on dust acoustic wave propagation. A more precise investigation will be conducted on ground to see if microgravity plays a role in this phenomenon.

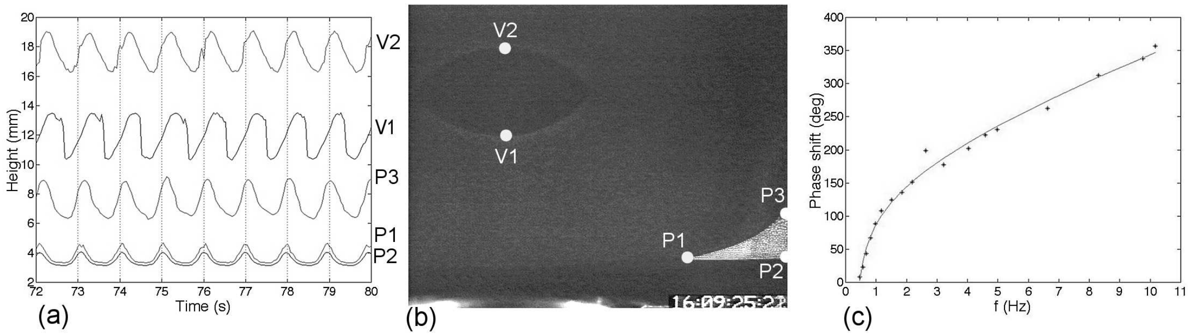

FIGURE 3. *Low frequency excitation of a cloud constituted of grown and 3.4 µm particles, a) time evolution of the height of the points labeled in b), c) measurements of the phase shift between V1 and P1*

CONCLUSION

This work opens interesting perspectives in the field of dust particles growth. Clouds of submicron particles of various sizes can be grown in the whole plasma volume. Furthermore, this experiment offers the opportunity to study experimentally the void region even on ground. However, microgravity is needed to avoid effects due to size segregation and to study dynamical effects.

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