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DUST CHARGE IN COMPLEX PLASMA AFTERGLOW

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Abstract

In this talk, we report the first experiment in which the distribution of residual charges on dust grains after the decay of a dusty plasma was measured. The experiment was performed in the PKE-Nefedov reactor where the dust particles were physically grown in the plasma. A temperature gradient was introduced in the chamber to create an upward thermophoretic force to balance gravity. The residual charges were determined from an analysis of dust oscillations, which were excited by applying a sinusoidal bias to the bottom electrode. It was found the coexistence of positively and negatively charged dust as well as and non-charged dust for more than one minute after the discharge was switched off. The residual charges for 200 nm radius particles have been measured for two different pressures. The experimental data were compared with the predictions of a simple theoretical model that describes residual charge evolution in discharge afterglow.

Introduction

Dusty or complex plasmas are partially ionized gas composed of neutral species, ions, electrons, and charged dust particles [1,2]. In laboratory experiments, these particles can be either injected or grown directly in the plasma. Injected dust particles are usually micron-size particles. Due to their mass, they are confined near the bottom electrode where the electric force counterbalances gravity. The microgravity condition is necessary to study dust clouds of micrometer-size particles filling the whole plasma chamber. In the laboratory, dense clouds of submicron particles light enough to completely fill the gap between the electrodes can be obtained using reactive gases such as silane or using a target sputtered with ions from plasma. Dust-particle charge is a key parameter in complex plasma. It determines the interaction between a dust particle and electrons, ions, its neighboring dust particles, and electric field. The determination of the dust-particle charge is thus one of the basic problems in any complex plasma experiments. Knowledge of dust charge will allow us to understand the basic properties of dusty plasma, particle dynamics in dust clouds, and methods to manipulate the particles. Thus one of the main dusty plasma challenges is to understand the dust charging in a wide range of experimental conditions, which simulates industrial and space plasmas.

There are many publications reporting on the investigation of dust charging in discharge plasma; see [1-4] and references therein. However there are only a few papers devoted to dust charging, or decharging to be more specific, in the discharge afterglow. So any new experimental evidence of residual dust charges in afterglow plasma will lead to a better understanding in the decharging of complex plasma. Indeed the value and nature of residual charges after plasma extinction is of great importance. The dust-particle charge in afterglow plasma could induce a problem in future single-electron devices where a residual charge attached on deposited nanocrystals would be the origin of dysfunction. It could make easier industrial plasma processing reactor decontamination thanks to the use of specially designed electric fields. The residual charges on dust particles in fusion reactors (such as ITER) also can make the cleaning process much easier. In this paper, we report first detailed experiment on the residual charge measurement of dust particles after the decay of a dusty plasma. A coexistence of positively and negatively charged dust particles as well as non-charged ones was found for more than 1 min after the discharge was switched off. The residual charges for 200-nm-radius particles have been measured for two different pressures.

Experiment

Set up and procedure

The experiment was performed in the PKE-Nefedov reactor designed for microgravity experiments, see Fig. 1. It consists of 4-cm-diam parallel electrodes separated by 3 cm. The injected power varies in the range 0–4 W. Dust particles are grown in an argon plasma 0.2–2 mbar from a sputtered polymer layer deposited on the electrodes and coming from previously injected dust particles. When the plasma is off the top electrode was cooled. The temperature gradients which occurred produced the upward thermophoretic force balanced the gravity. To study particle charges, a sinusoidal voltage produced by a function generator with amplitude ± 30 V and frequency of 1 Hz was applied to the bottom electrode.

The induced low-frequency sinusoidal electric field generated dust oscillations if they kept a residual electric charge. A thin laser sheet perpendicular to the electrodes illuminates dust particles and the scattered light is recorded at 90° with standard charge coupled device CCD cameras with 25 images per second. Video signals were transferred to a computer

via a frame-grabber card with 8-bit gray scale and 560x700 pixel resolution. In order to avoid edge effect, a field of view over $8.53 \times 5.50 \text{ mm}^2$ restrained to the center of the chamber was used for residual charge measurement. By superimposition of video frames particle trajectories have been obtained. The coordinates of the particles were measured in each third frame. The amplitude of the oscillations was figured out from the measured particle positions. Absolute values for the oscillation amplitude were obtained by scaling the picture pixels to the known size of the field of view.

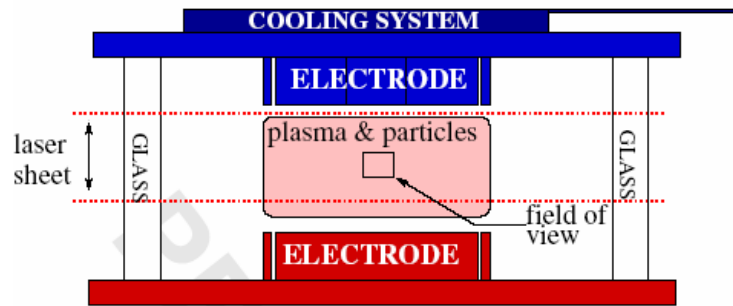


Figure 1 Experimental set-up

The residual charge measurements have been performed by the following routine. First the chamber was pumped down to lowest possible pressure (base pressure 2×10^{-6} mbar) and the cooling system was turned on. After this, argon was injected up to the operating pressure, the discharge was started, and particles were grown, forming familiar structures such as a void. Then, the discharge was switched off and the bottom electrode was biased by sinusoidal voltage.

Results

Figure 2a presents a superimposition of images taken after discharge had been switched off. There are two different types of motion observable. Dust particles drift upwards, downwards, and to the side due to existing temperature gradients and they oscillate due to electrostatic force [5]. It is obvious that the thermophoretic force acts on any dust particle in the chamber, while the electrostatic force acts only if particles have charge in afterglow. Thus the presence of oscillating particles see Fig. 2 clearly indicates that dust particles do have residual charges after the discharge has been switched off. Dust particles oscillating in opposite phases as well as nonoscillating dust grains have been observed, indicating that negatively charged, positively charged, and noncharged dust particles coexist after plasma extinction. These images give us a clear track of the dust oscillations, so dust grain trajectories can be reconstructed see Fig. 2b.

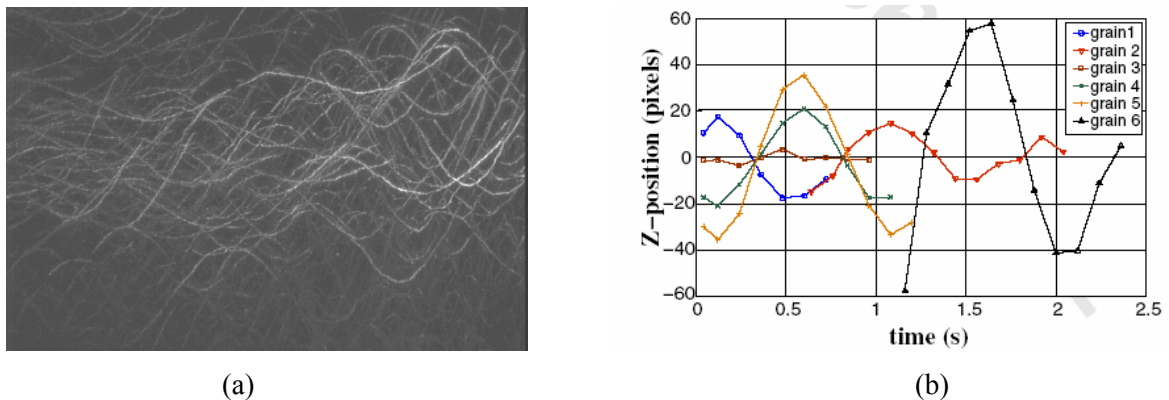
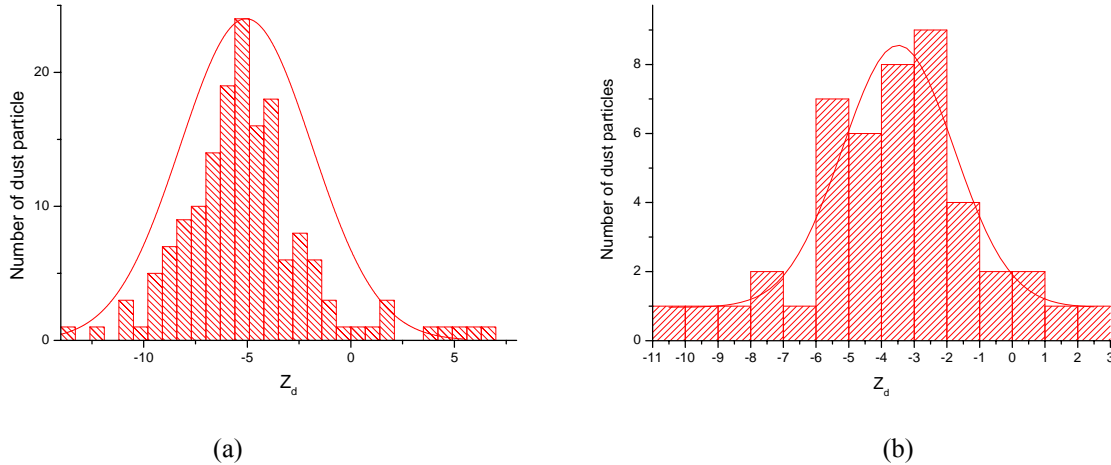


Fig.2. (a) Superimposition of video frames 10 s after plasma extinction. Dust-particle oscillations can clearly be seen. The temperature gradient has a slight horizontal component. Therefore, oscillations are in the two-dimensional laser plane. (b) Oscillation of six dust grains 10 s after plasma extinction. Nonoscillating dust grains and opposite phase oscillations are observed.

It is worth mentioning that in order to observe dust oscillations the discharge must be switched off abruptly. Interesting fact is that the residual charge on dust particles has a long relaxation time and does not depend on time when the excitation electric field was applied. Dust oscillations were observed for more than 1 min after plasma extinction and in both cases when the function generator was switched on during the discharge or a few seconds after the discharge is turned off. From the measurement of oscillation amplitude, the residual charge on a dust particle can be obtained:

$$Q_{d_{res}} = \frac{m_d b(w, Q_d, E_0(z_{mean})) w \sqrt{w^2 + \frac{4\gamma^2}{m_d^2}}}{E_0(z_{mean})} \quad (2)$$

where m_d is mass of dust, b is the amplitude of dust oscillation, E_0 is the value of the electric field, $w=2\pi f$ where f is the frequency imposed by the function generator and γ is the damping coefficient. The sign of the dust-particle charge is deduced from the phase of the dust-particle oscillation with respect to the excitation electric field. Oscillation amplitudes up to 1.1 mm have been measured depending on the operating pressure and charges from $-12e$ to $+5e$ are deduced where e is the elementary charge. It has been found that at high pressure dust particles keep a higher mean residual charge see Fig.3.



(a) (b)
Figure 3. Residual charge distribution for the different operational pressures (a) 1.2 mbar, (b) 0.4 mbar. Z_d is dust particle charge in units[e].

Discussion

The observation of neutral and positively charged particles in our experiments can be explained by the particle charge distribution. The charge distribution in a dust-particle ensemble is due to charge fluctuation on every individual dust particle. It has been shown [6,7] that the rms of stochastic charge fluctuations varies as $\delta(Q_d)^{1/2}$ where δ is a parameter depending on the plasma conditions and close to 0.5. Thus for mean charge around $-3e$ the charge distribution should lie mainly between $-1e$ and $-5e$. However, in our case we can expect a broader distribution, taking into account two reasons. First for small particles with a charge of about a few electrons the image force polarizability correction starts playing role; see [7]. And for electron temperature less than 0.1 eV charge fluctuation can be enhanced by a factor up to 3. That is a significantly broadened distribution, so dust particles can experience fluctuations to neutral and positive charges; see Fig. 3. Another reason for the broadened distribution could be the fact that charge distribution variance remains the same while the mean charge decreases. Indeed at the late afterglow the charge is not in equilibrium with the surrounding plasma, so the existing charge distribution should remain unchanged or changed slightly during the later stages. To elaborate on the true reason for the presence of residual charges of different sign we try to model the dust charging in afterglow plasma.

Numerical results

Calculation of residual dust charges in afterglow plasma were performed using a Cui-Goree model for calculating charge fluctuation [5] and time scales were computed using formulae from [6]. The ambipolar coefficient diffusion in the presence of dust particles has been taken as following:

$$D_{ad} = \left[\frac{(D_e \mu_i - D_i \mu_e) n_i}{\mu_i n_i - \mu_e n_e} \right] \cong D_i \frac{n_i}{n_e} \left(1 + \frac{T_i}{T_e} \right) \quad (3)$$

where D_e and D_i diffusion coefficients, μ_i and μ_e mobilities, T_e and T_i temperatures, n_i and n_e density of the electron and ions correspondently. Results taking into account the influence of dust particles on ambipolar diffusion in afterglow plasma are presented for two operating pressure (see Fig.4) These preliminary qualitative results show a strong

decrease of the mean particle charge with respect to the equilibrium charge under the running discharge conditions ($\sim 1000e$). The charge evolution has been calculated in the afterglow plasma until the freezing stage occurs [5]. Particle charge distributions (see Fig.4) show a broadening similar to the experimental results(see Fig.3). Nevertheless computed residual dust charges are too big compared to the experimentally observed (especially for the 0.4 mbar case). This discrepancy clearly indicates lacunas in the afterglow plasma model currently used. To improve it some additional phenomena such as electron release from dust particles [8] and/or increase of metastables density in complex plasma [9] have to be taking into account. The last one can be of great importance because it has been shown that metastables increase electron density in the very beginning of discharge afterglow [10]. This two phenomena can lead to a strong modification of dust residual charge.

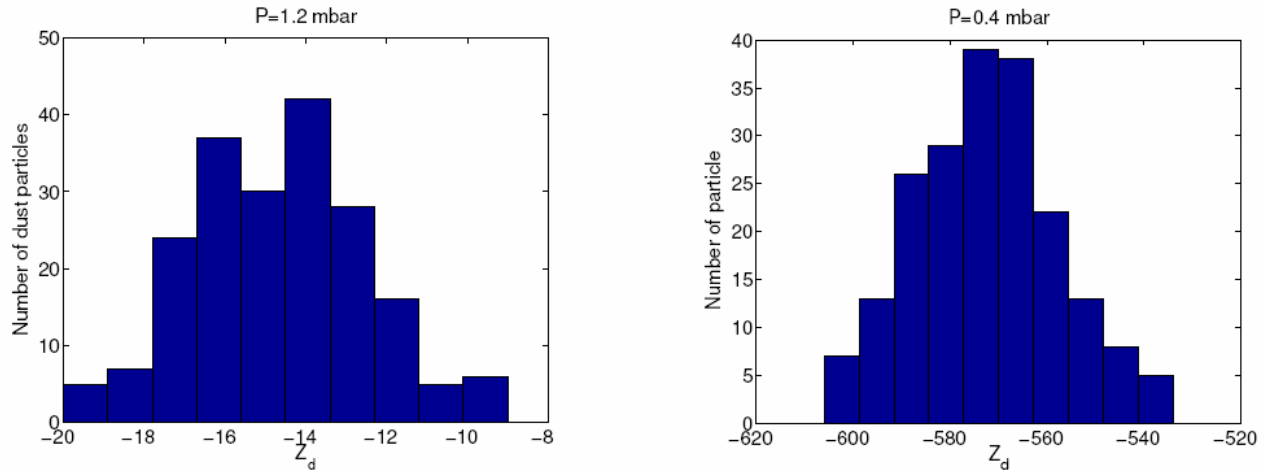


Figure 4. Simulated residual charge distributions for the different operational pressures; Z_d is dust particle charge in units[e].

Conclusions

Residual dust-particle charges have been measured in the late afterglow of a dusty plasma. Positive, negative, and noncharged dust particles have been detected. The mean residual charge for 200-nm-radius particles was measured. The particle charge is about $-5e$ at a pressure of 1.2 mbar and about $-3e$ at a pressure of 0.4 mbar. A model for the dusty plasma decay was exploited to explain the experimental data. The comparison experimental and numerical data showed that the dust residual charges can not be described by the models developed for the dust charging in a stable plasma. The considered model predicts a higher residual charge for lower pressure. In fact larger charges were measured for the higher pressure. So, to be able satisfactorily describing dust particle decharging in afterglow plasma one have to take into account various phenomena in decaying plasma such as: electron reheating, electron release, afterglow chemistry, etc. For example, a possible explanation of the higher charge for the higher pressure is an electron reheating in late afterglow from metastable atoms (see [6] and references therein).

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References

1. A.Bouchoule, *Dusty Plasmas: Physics, Chemistry and Technological Impacts in Plasma Processing* (Wiley, New York, 1999).
2. S. Vladimirov, K. Ostrikov, and A. Samarian, *Physics and Applications of Complex Plasmas* (Imperial Press, London, 2005).
3. E. B. Tomme, D. A. Law, B. M. Annaratone, and J. E. Allen, *Phys. Rev. Lett.* **85**, 2518 (2000).
4. C.Zafiu, A. Melzer, and A. Piel, *Phys. Rev. E* **63**, 066403 (2001).
5. L.Couedel, M. Mikikian, L. Boufendi, A. Samarian, *Physical Review E* **74**, 026403 (2006).
6. C.Cui and J. Goree, *IEEE Trans. Plasma Sci.* **22**, 151 (1994).
7. T. Matsoukas, M. Russell, and M. Smith, *J. Vac. Sci. Technol. A* **14**, 624 (1996).
8. I.Stefanovic, J. Berndt, D. Maric, *et al*, *Phys. Rev. E* **74**, 026406 (2006).
9. M. Mikikian, L. Boufendi, and A. Bouchoule, in 30th EPS Conf. on Contr. Fusion and Plasma Phys., (2003), **27A**, pp.3.1B.
- 10.L.Overger and Z.Klebar, *Plasma Sources Sci. Technol.*, **7**, 512(1998).