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Dust structures in cryogenic dc discharge: Some suggestions for future research

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Abstract. In this work, the cryogenic dusty plasma, which is represented by a mixture of two dust components with different structural and dynamical properties, was experimentally investigated. Experiments were conducted in dc glow discharge at temperatures 10 and 77 K using CeO_2 micron powder as a dust. In dust structures obtained one of the components consists of dust particles with chain-like ordering (dust chains) and another component consists of fast-moving particles orbiting horizontally through the first component ("crazy" particles). Dust particle velocity distribution functions were obtained. The possible reasons of two-component dust structure formation were discussed.

1. Introduction

A dusty plasma is an ionized gas containing charged micron particles of condensed matter [1–3]. Gas discharges at decreased temperature of atoms have many features that may occur in experiments with dusty plasma. For example, at the cryogenic temperatures of the discharge tube walls strong anisotropy of ion velocity distribution function takes place, which in turn can cause considerable change of dusty plasma structure properties [4–6]. In this work dust structures which are two-component dust mixture were considered in the cryogenic dusty plasma experiments.

2. The experiment

The experiments were conducted with dc glow discharge generated in vertical glass tube with inner diameter of 15 mm placed inside optical helium cryostat (figure 1a). The discharge was generated in helium at pressure of about 0.1 Torr and at discharge current of about 0.1 mA (figure 1b). CeO_2 polydisperse particles of about 3–5 μm in size (figure 1c) were injected in plasma from the container positioned above the stratified discharge positive column. Levitation of dust particles in the field of gravity was carried out by means of a double electric layer created in the bottom part of discharge tube using additional glass tube with a narrowing of 0.1 cm in diameter ("capillary"). Observations were conducted in the first striation over the "capillary". In order to illuminate and register dust structures at cryogenic temperatures the cryostat was supplied with flat round windows of 3 cm in diameter. Diode-pumped solid-state laser with the wavelength 532 nm was used. The scattered laser light from particles was registered by means of high speed CCD video camera with 100 fps rate.


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The two-component dust structure obtained at about 10 K is shown in figure 2a. In the dust cloud observed one of the components consists of stationary dust particles with chain-like ordering (dust chains). The second one consists of fast-moving particles diffusing through the first component. Such particles orbit the dust chains mainly on horizontal trajectories.

At 77 K from video frames received dust particle velocity distributions were obtained. As it is shown on figure 3 Maxwell's function well approximates the maximum of horizontal distribution. On the contrary, the values in horizontal distribution "wings" fall several times slowly.

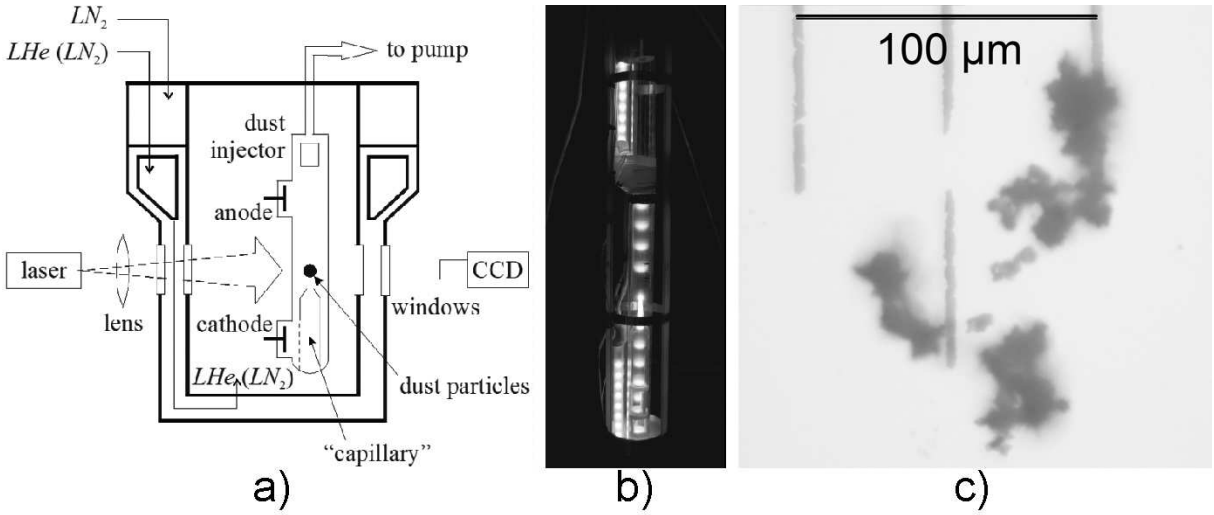

Figure 1. a) Schematic of the cryogenic experimental setup, b) side view of the stratified dc discharge, c) microscopic view of CeO_2 particles.

We can assume that such distribution function is a result of superposition of distribution functions of two particle groups observed, where the central part of function corresponds to dust chains, and the behavior of "tails" caused by orbiting particles. Now to find orbiting particle velocity distribution function we can carry out the following procedure: we can subtract Maxwell function, which approximates distribution central part, from full distribution. The values received lie on required distributions: left values – on the left part of distribution of the particles with negative velocities (moving to the left), right values – on the right part of distribution of the particles with positive velocities (moving to the right). Distributions received have almost identical view and are symmetrically positioned about zero with maxima of about 4–5 mm/s. It was obtained that the kinetic temperature of the orbiting particles exceeds temperature of particles in chains approximately by 1.5 times.

Difference in particle behavior in the dust cloud described above allows us to divide particles into two subsystems, which, thus, form the two-component mix with behavior similar to binary systems in colloids or chemical compositions. Formation of such binary-like dust systems is probably caused by both distinctive features of cryogenic discharges and the difference in particle form in subsystems. We assume that one component can consist of particles of approximately symmetric forms, another – from strongly asymmetric particles such as elongated dust "rods" (figure 2b). The assumption based on the results of the experimental investigations of dc discharge dusty plasma at room temperature where ordered chain-like dust structures formed of nylon cylindrical grains were obtained [7].

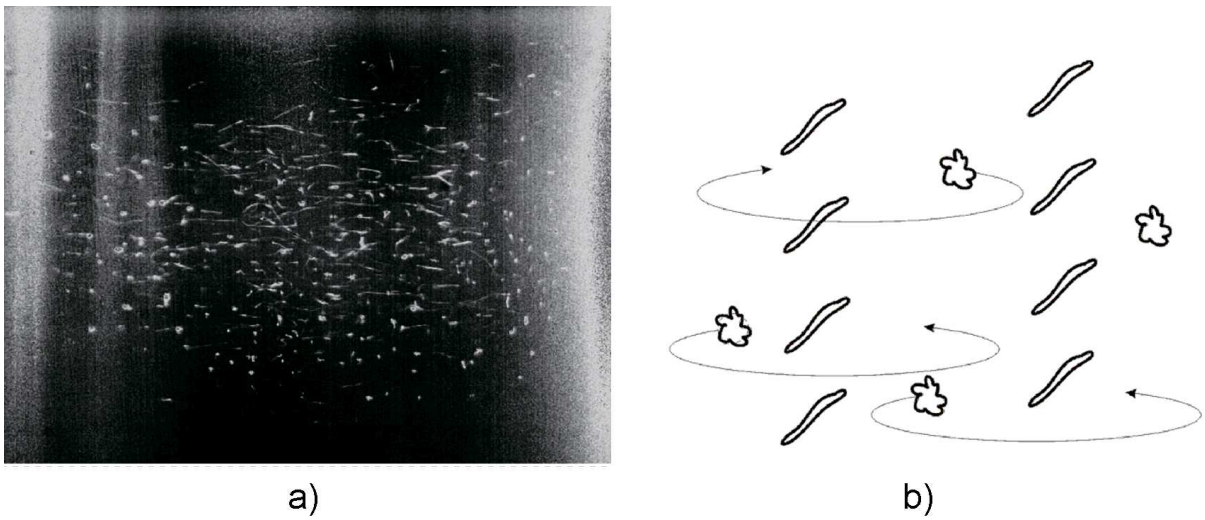

Figure 2. a) Side view of the two-component dust structure in dc discharge striation at about 10 K, b) differences between particles in components.

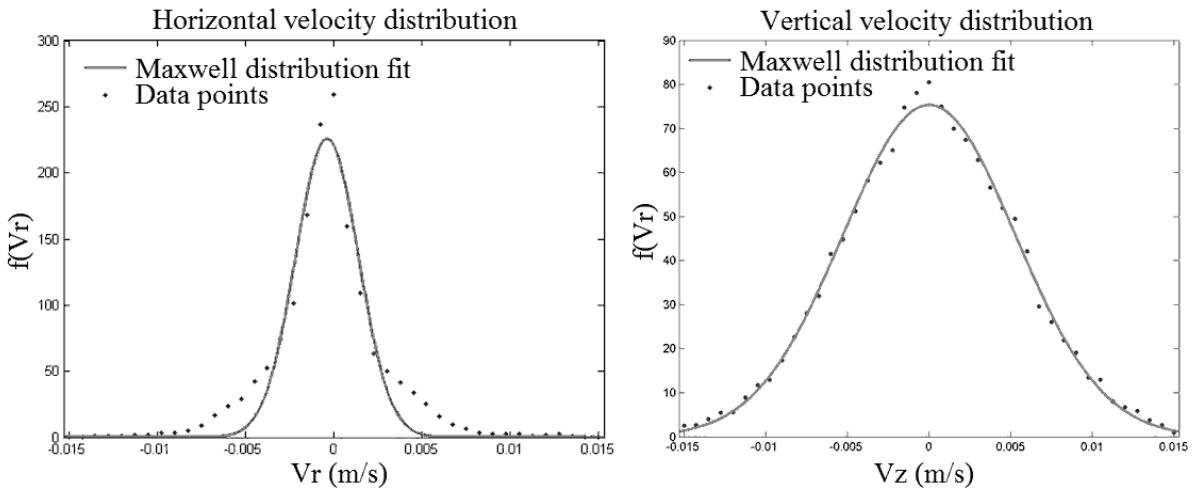

Figure 3. Horizontal and vertical dust particle velocity distribution functions for two-component dust structure obtained at 77 K (dots corresponds to the experimental data and solid line corresponds to the Maxwell fit).

3. Conclusion

The phenomenon of relatively fast-moving "crazy" particle was observed in a number of laboratory and microgravity experiments [8, 9]. Recently, "crazy" particles were distinctly observed in the experiments with dc discharge in gas mixtures [10], where orbiting particles can achieve kinetic energies up to thousands eV. In this paper, we propose that the nature of binary-like dust structure formation is determined by both deformation of ion distribution function due to temperature decrease and difference in particle form in components. However, this is left for future work.

Acknowledgments
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