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Experimental study of waves and instabilities in cryogenic dc discharge dusty plasmas

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The wave processes in dusty plasmas are widely investigated nowadays from both theoretical and experimental point of view. Main attention is concentrated on linear waves and instabilities in weakly coupled dusty plasmas, which are directly connected with the effect of dust component. Thus, dust acoustic waves and instabilities leading to self-excitation of travelling waves were observed in DC and RF gas discharges [1-4]. Some studies address investigations of vortex motion in dusty plasmas [5-6]. Such regular self-excited motions of particles appeared due to variation of discharge parameters such as discharge current (power) and bulk gas pressure. This paper present the experimental observations of the self-oscillations (waves and instabilities) arisen under the cooling the discharge down to cryogenic temperatures.

The experiment was carried out on the cryogenic setup designed in [7]. In the setup dc discharge is cooled inside standard double Dewar system. The device for discharge generation is cylindrical glass tube with cold electrodes (upper one is anode). Monodisperse polystyrene (PS) particles with diameter 5.44 μm were used for dust structure investigations. Particles were dropped from the container with grid at bottom and positioned above the anode. For particle illuminations a diode laser beam (λ = 532 nm) via optical fibre was introduced into the Dewars. The observations were performed through windows, arranged throughout the height of the Dewars. For recording of scattered light from the particles CCD video camera was used at frame rate of 25 fps.The discharge current was about 0.45-0.50 mA. Initially discharge tube was filled by *He* gas up to the pressure of about 5 Torr. The tube was cut off from the pump (vacuum system) before cooling, so the neutral gas density during the experiment remained constant. The outer Dewar was used as a thermal guard and was filled by liquid nitrogen. The inner Dewar was cooling by liquid helium vapors and we were able to vary and control the temperature inside the Dewar in the range of 80 K > T > 10 K.

At ~80 K structure consisted of is at least an order of magnitude denser ($n_p \sim 10^5$ cm^{-3}) than structure at room temperature and filled the striation throughout the entire cross section of the tube.

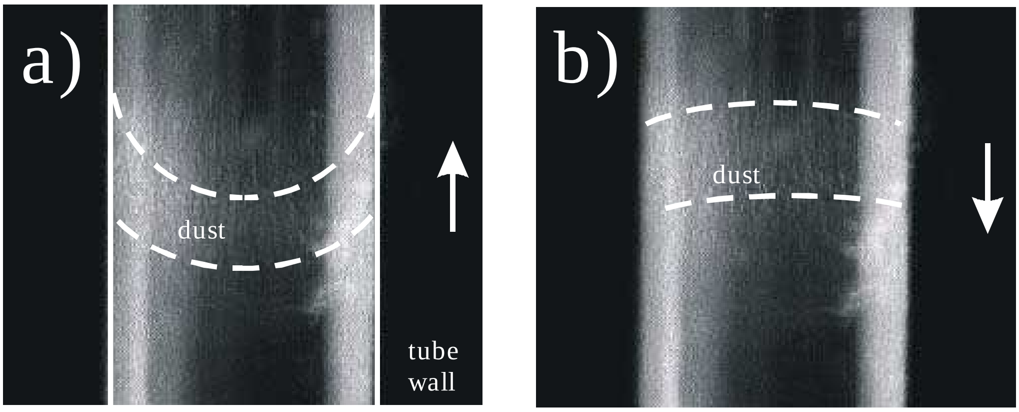

Fig.1. Dust cloud self-oscillation at 77 K. Arrows show the direction of dust movement. Dotted lines are boundaries of dust. The frequency of oscillation is about 9 Hz.

Observations show that dust particles at ~80 K move with greater velocities than the particles at 300 K at the same discharge currents and neutral gas densities. Besides, phenomenon of excitation of joint axial (vertical) self-oscillations of the striation and dust in it was observed. When current was increased up to 0.9 mA the “striation-dust” system was considerable flatted and oscillated similar to boundary-fixed membrane with frequency of about 9 Hz and 5 mm amplitude on the discharge axis (see Fig.1). When the temperature is decreased the threshold current of dust self-oscillation excitation is also decreased. The dependence of the current threshold on the discharge temperature is shown on the following Fig.2.

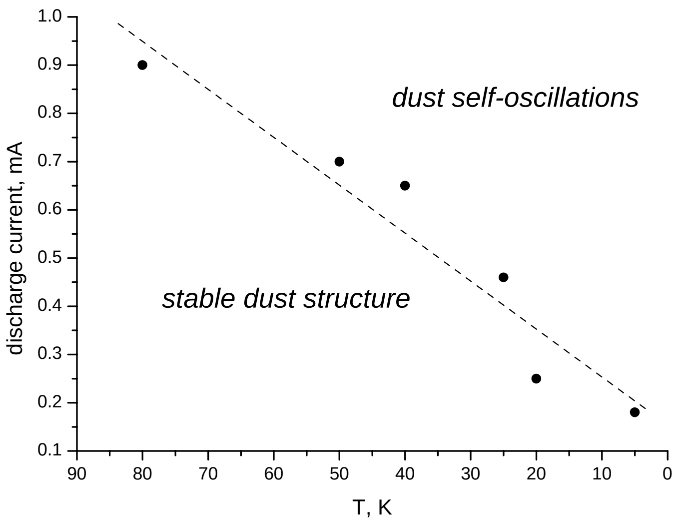

Fig.2. The diagram of striation-dust system stability at cryogenic temperatures.

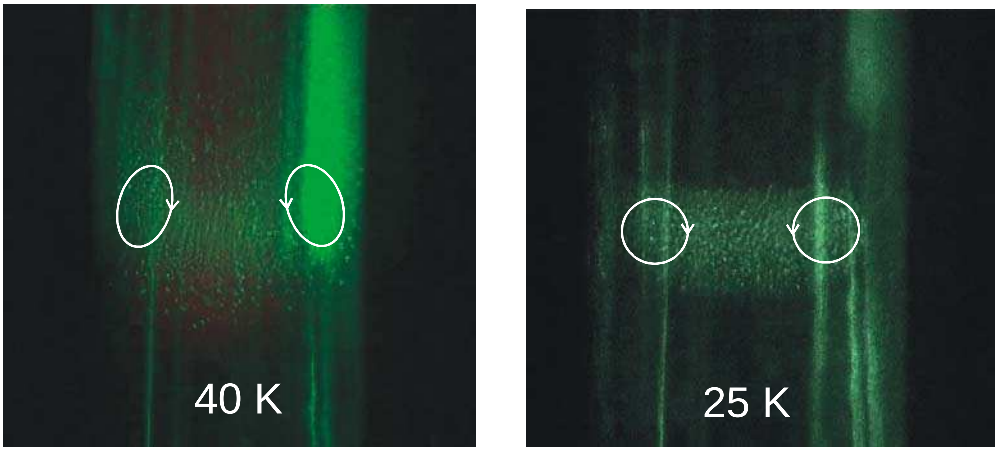

Fig.3. Dust vorticies at cryogenic temperatures. Discharge current at 40 K is 0.46 mA, at 25 K – 0.16 mA. The frequencies of rotations are about 0.3-0.5 Hz.

In addition, at the discharge currents close to threshold current dust vortices were observed at 40 K > T > 25 K. These vortices are rotations of dusty particles along the axis of cylindrical system (dusty vortices). The video images of vorticies observed at 40 K and 25 K are presented on the following Fig.3. The configuration and periods are rather similar to dust vortices at room temperature observed and studied in [5, 6]. Therefore, we can propose that formation of the cryogenic dust vortices can be described by analytical model [5]: in the presence of gravity a small charge gradient is an effective source of kinetic energy for the dusty vortex motion formation. The role of cryogenic temperatures in vortex formations is in providing a charge gradient by formation of dense dust structures consisting of great amount of particles. Such dust structures fill the striation throughout the entire tube cross section where the plasma parameters are varied sufficiently from center of the discharge to the periphery.

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