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Excitation of Nonlinear Dust Acoustic Waves in a Glow Discharge Plasma

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Wave phenomena in the dust component of the dusty plasma are at present of great interest for investigators [1]. Micronsized dust grains are very heavy compared to electrons and ions and when immersed into a low temperature plasma they acquire a great charge of 10^3 - 10^5 electrons. The charge on dust grains is not fixed, since it is connected self-consistently with the conditions in surrounding plasma. For this reason new wave modes must appear in dusty plasmas. In the present work for the excitation of waves a gas dynamic impact is used.

The experimental setup is similar to that used in [2]. The stratified glow discharge with cold electrodes was created in a vertically maintained glass tube of the 36 mm diameter (see Fig. 1). The upper electrode was the anode placed in a lateral nib. The lower electrode was the hollow cylindrical cathode. The electrodes were separated by 26 cm. In some experiments a grid was inserted into the tube 7 cm above the upper cut of the cathode. The grid was kept under the floating potential.

Current of 0.1-1 mA could be driven through this system at neon gas pressure of about 0.3 torr. MF dust grains 1.03 μm diameter were held in a container with the grid bottom above the anode nib. After shaking the container the particles rained down and levitated in the striations. All the observations were conducted in the lowest striation, where an ordered dusty plasma structure was formed. To illuminate the particles a light sheet from a 50 mW laser diode was used. The scattered light was observed by a fast CCD camera at a frame rate of 300 fps.

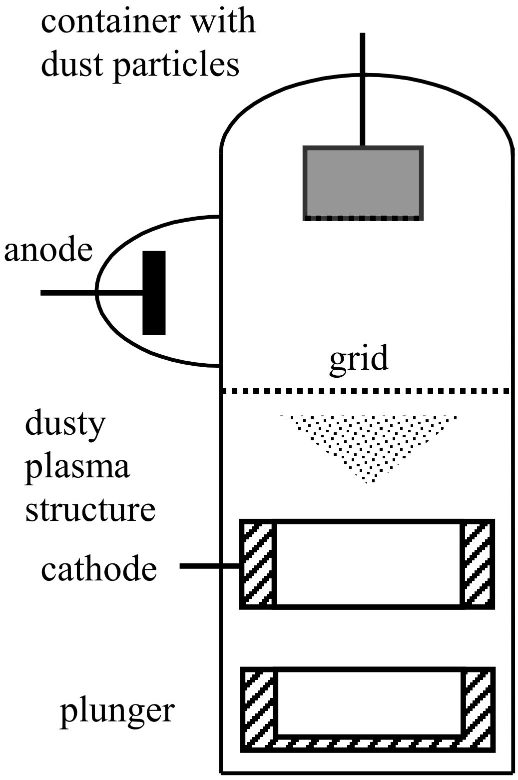

Fig.1. Experimental setup

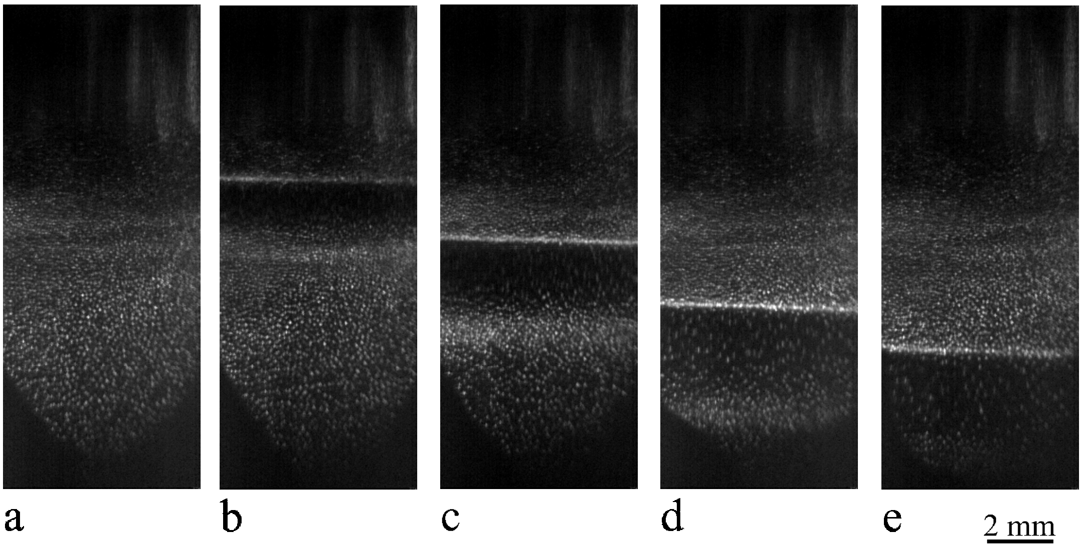

Fig.2. Sequence of videoimages presenting the disturbance produced by the gas-dynamic impact, *a* represents the initial structure, time interval between the frames *b-e* 83 ms.

For the excitation of the waves a plunger was set below the cathode. The plunger was manually moved with the help of a magnet at a speed of about 30-40 cm/s through the 4-5 cm space, creating a gas flow with the duration of about 0.1 s, which displaced the dust grains with respect to the striation. First experiments were conducted without the grid. When the plunger was moved downward the dusty plasma structure was first slowly moving downward. During the time of 33 ms it was displaced for about 500 μm. The structure becomes unstable at this position. It moves rapidly upward and several loops of dust density propagating downward appear inside it. At the end of the process the waves are damped and the structure as a whole returns to its initial position. The characteristic length and frequency of the wave are 1.3 mm and 86 Hz respectively. The properties of these waves are very similar to the properties of the self-excited waves obtained in [3, 4].

A new solitary wave was obtained in the experiments with the grid. The pressure was again adjusted to 0.3 torr and the discharge current was chosen in such a way that the lowest striation was formed exactly below the grid. This occurred at the current value of 0.1 mA. The dusty plasma structure was 4 mm separated from the grid. After moving the plunger downward the structure was again for some time streaming downward, then it stopped and began moving towards its initial equilibrium and when it returned to the stable position a disturbance propagating through it appeared (Fig. 2). We have determined the dust density distribution over the vertical axis *z* for each frame. In this way we obtained the profile of the density wave *n(z)*. Fig. 3 presents the schematic shape of this function. The disturbance

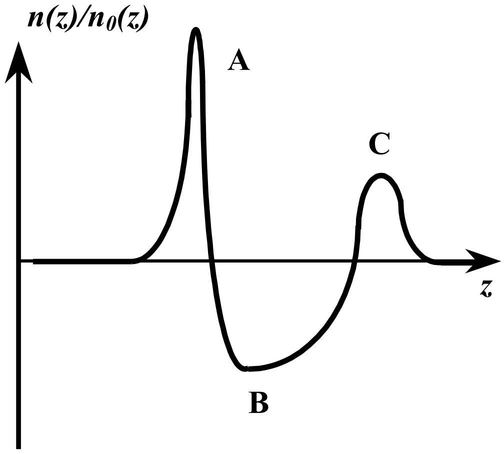

Fig.3. Qualitative density distribution in the wave. A, C – compression zones, B – the rarefaction.

consists of three parts: **A** is the first compression, **B** is the rarefaction and **C** is the second compression. The disturbance observed is nearly plane and therefore it can be treated in terms of only one spatial variable. The amplitudes (ratios of *n(z)* to the unperturbed density $n_0(z)$) for zones **A** and **C** reach the values of 1.6 and 1.3 respectively and 0.65 for the rarefaction. This means that the wave is strongly nonlinear.

The zone **C** is always running slightly faster than the zone **A**. The velocities of these zones respectively are 2.9 and 2.4 cm/s. The rarefaction however first moves together with the zone **C** and closer to the end of the process acquires the velocity of zone **A**. In the rarefaction the dust particles move upward with the velocity 10 – 15 cm/s.

Dust acoustic velocity is expressed as follows [1]:

$$ {}_{da} = \sqrt{\frac{Z_d^2 T_i}{m_d} \frac{n_d}{n_i}} \qquad (1) $$

where n_i, n_d are the ion and dust density, T_i is the ion temperature and Z_d, m_d are the dust grain charge and mass respectively. As it was already mentioned in [5] measurements of the local values of plasma parameters in standing striations are impossible with the known techniques. That is why we have to rely on the experimental data for the running striations. The charge on a dust grain determined by the extrapolation of an empiric dependence obtained in [5] is 400 - 750 e. The ion density was estimated to vary along the striation in the range of $4\cdot 10^7 - 10^8$ cm^{-3}. The dust density also slightly changes inside the initial dusty plasma structure around the average value of $3\cdot 10^4$ cm^{-3}. Thus C_{da} = 1.8 - 5.2 cm/s.

The conditions of our experiment are characterized by comparatively high neutral gas pressure and consequently great damping of the waves due to the neutral drag. If we use the *Epstein* formula for the neutral drag force which is applicable in our case (mean free path of Ne atoms at the pressure p = 0.3 torr is 170 μm and particle radius 0.5 μm), we can express the frictional damping rate as [4]

$$ \beta = \frac{4\sqrt{2\pi}}{3} \frac{pa^2}{m_d v_{th}} \qquad (2) $$

where a is the dust grain radius, m_d is the dust grain mass and v_{th} is the thermal speed of neon atoms. In our case $a = 0.5$ μm, $m_d = 7.5 \cdot 10^{-13}$ g, $v_{th} = 590$ cm/s and therefore $\beta = 75$ s^{-1}. The disturbance must be damped within 15 ms that is much smaller than the observed time of the wave propagation. It means that the wave should have an energy source other than the initial impulse. The dust acoustic instability, which is a typical phenomenon for the dc discharge striations could serve as such a source [4].

At higher values of the discharge current the dusty plasma structure levitated further from the grid, e.g. at the current of 1 mA it was formed 15 mm away from the grid. In this case the waves analogous to those obtained without the grid were generated by the plunger motion. Appearance of these waves could also be attributed to the dust acoustic instability. According to [4] the increment of the dust-acoustic instability is proportional to the longitudinal electric field in the discharge. The stable levitation of dust grains requires the increase of the electric field in the downward direction. It is known that such a gradient exists in striations. Therefore in this experiment the dust grains were displaced by the gas flow into the region with stronger electric field, where the excitation conditions could be satisfied.

It should be also noted that upward motion of a plunger and initial upward displacement of the dust grains did not lead to excitation of any wave. This is one more evidence of that the dust acoustic instability plays a significant role in this experiment.

Note that use of the neutral gas flows for affecting the dusty plasma structures is a novel feature. Since the flow speed is rather small it produces no significant influence on the background plasma and acts upon the dust particles only. It may give new experimental possibilities (e.g. low-frequency sound influences, discharge-independent dust levitation in the gas flow) and is especially appropriate for the direct current discharge, where the dust grains levitate at rather a high neutral gas pressure.

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