Experimental Observations of Vertical Clouds In a Boundary-Controlled Dusty Plasma Environment

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Introduction:

Phenomenologically, there appears to be some correlation between the behavior of negatively charged monodisperse dust particles immersed in a capacitively coupled plasma and a diverse number of unaffiliated research areas examining such things as metallic glasses, coulomb explosions and DNA molecular dynamics. Under appropriate boundary conditions, charged dust particle systems (i.e., complex plasmas) are proving a reasonable analog for examination of the physics behind these systems. The strong dependence on the boundary conditions in each of these cases has created increased interest in establishing the plasma parameters required for producing user-controlled boundary conditions. In this work, the potential field inside an Indium Tin Oxide (ITO) coated glass box, placed on the lower powered electrode of a GEC rf Reference Cell, was mapped employing a Langmuir-type probe. Dust particles with a mixture of sizes placed inside the box were employed to examine vertical hexatic structures (see Fig 1). The underlying physics linking the box potential fields and the dust structures formed will be explored.

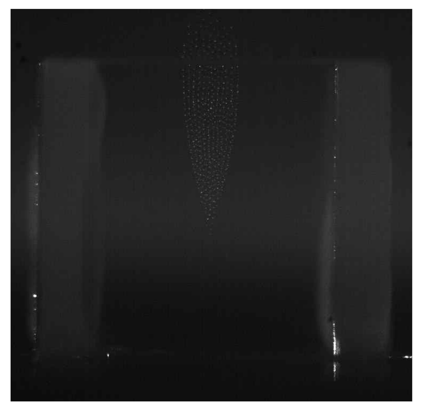

Figure 1. A vertical hexatic dust cloud inside a 12.7 x 12.7 x 12.7 mm glass box (Ar plasma).

Experimental Setup:

- GEC rf Reference Cell
- Pressure: 210 mTorr (28 Pa.)
- Power: Max to 1 Watt
- NB: -11 V
- 12 mm ×10.5 mm (height × width) Glass box
- ½" ITO box
- 8.89 & 6.5 µm MF dust
- High Speed cameras

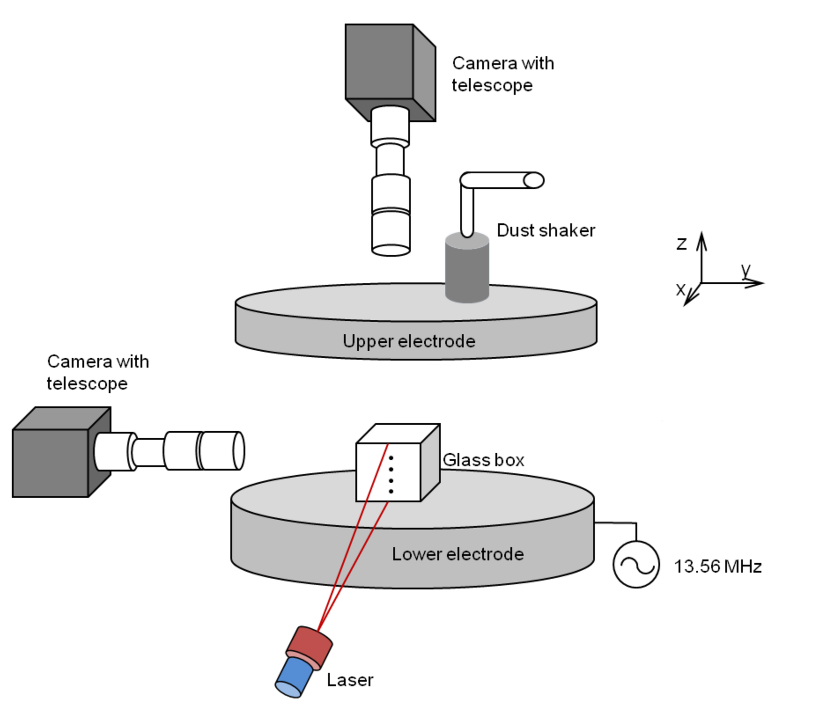

Figure 2. GEC reference cell set up, inter-electrode space is of 1.9 mm

The structures observed were obtained by setting the system to maximum power. This produces an easily observable plasma ball inside the glass box where particles can be trapped. Once power is reduced, a diminished plasma ball (glow) inside the glass box may be observed and typical dust acoustic waves are formed. A sudden transition (threshold) at which a dust-dust repulsion type interaction is observed was found. Depending on particle size and different particle ratios, particle behavior ranges from dropping to the lower electrode to the formation of the crystal-like structures shown in the following section.

Vertical Crystals

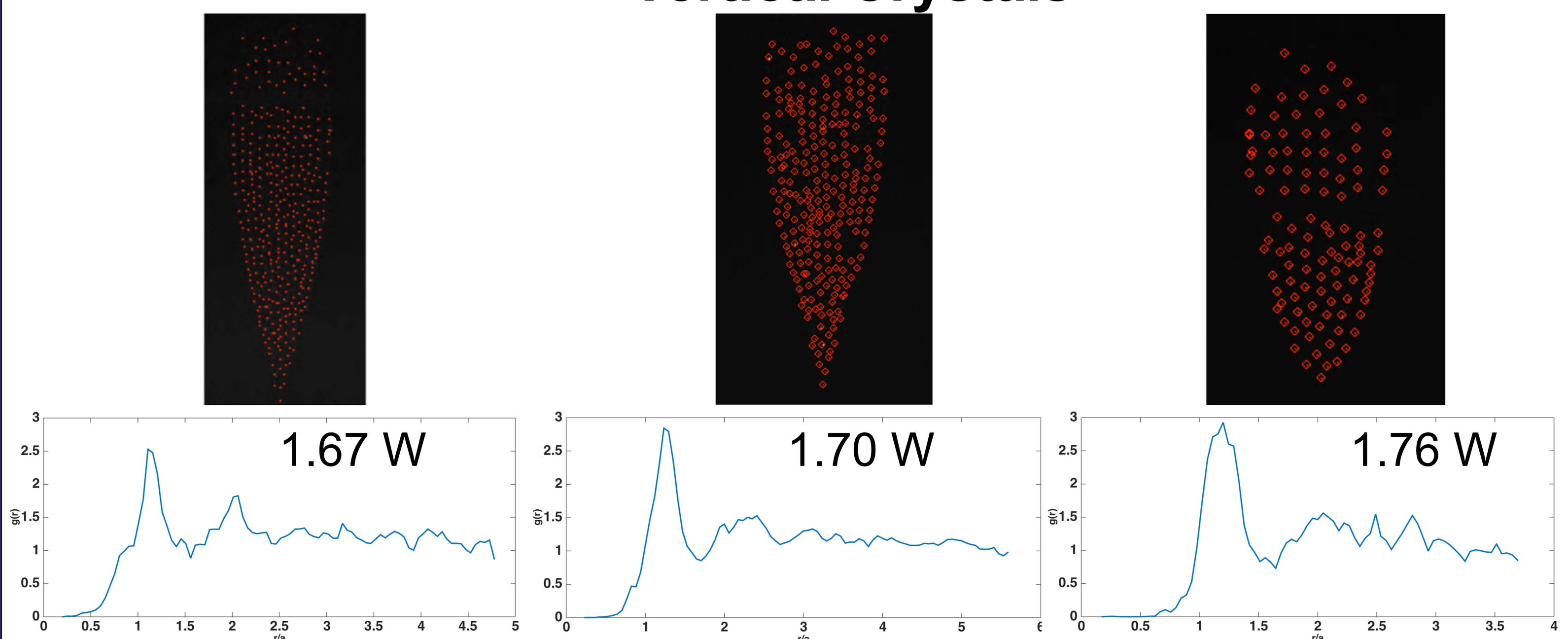

Figure. 3 Vertical Crystal structures of a combination of 8.89 & 6.5 µm MF dust. Hexatic & square structures can be observed as well as typical crystal defects.

Hexatic-type crystals (Fig. 3) formed inside a ½" glass box (in the vertical direction), where the particle-plasma interaction is different from that seen for typical horizontal crystal structure.

The assumed linearly changing vertical component of the electric field, the ion wake interaction and the glass box boundary add to the already present Yukawa particle-particle interaction.

Qualitatively, the resulting pair correlation functions [1] (Fig 3) are comparable to those for horizontal structures having gamma values ranging from 50 to 60 [2].

Mapping Results

CASPER's S-100 nano-manipulator allows for direct measurement of the potential inside aglass box. This provides a profile of the potential well, which can be used for electric field component calculation. Figure 4a & 4b show the top and side view of the setup respectively.

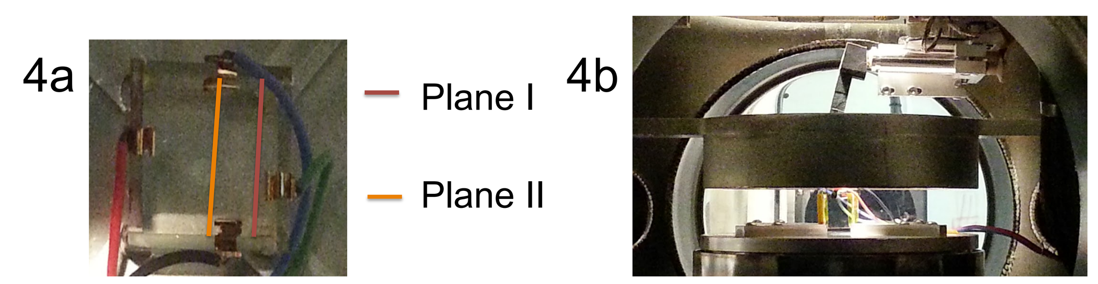

Figure 4. a) Top view of the ITO glass box b) Side view of mapping setup, S-100 probe and leads can be observed.

Mapping results for plane II potential well show two clear regions, intersecting at appoimately 6 mm. The calculated electric field in the horizontal component does not show a clear force direction preference; however, the vertical component shows a strong split at about 7 mm.

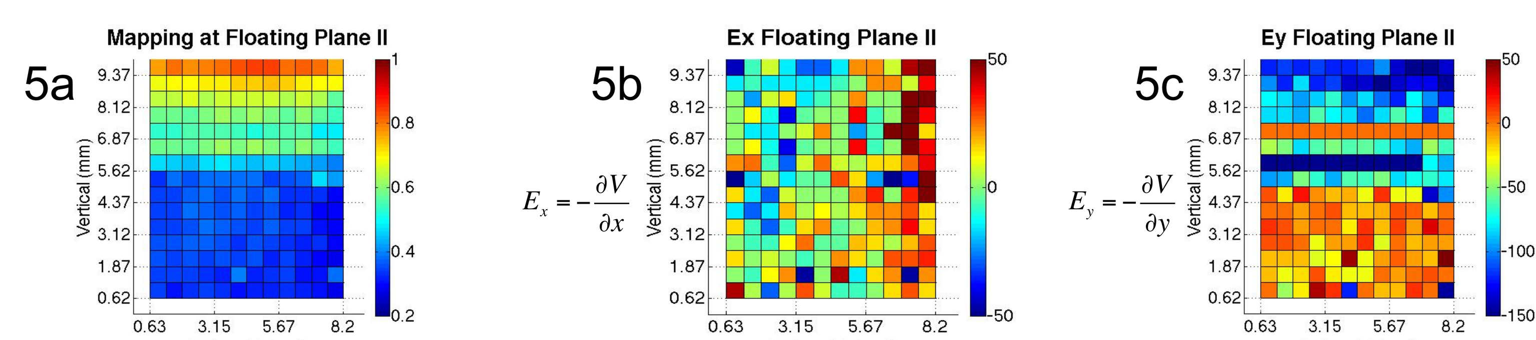

Figure 5. a) S-100 potential well mapping results, b) Calculated electric field horizontal component, c) Calculated electric field in the vertical component

The above was investigated further using only 6.5 µm MF dust as microprobes and the ½" glass box.

Crystal Formation Process (Splitting)

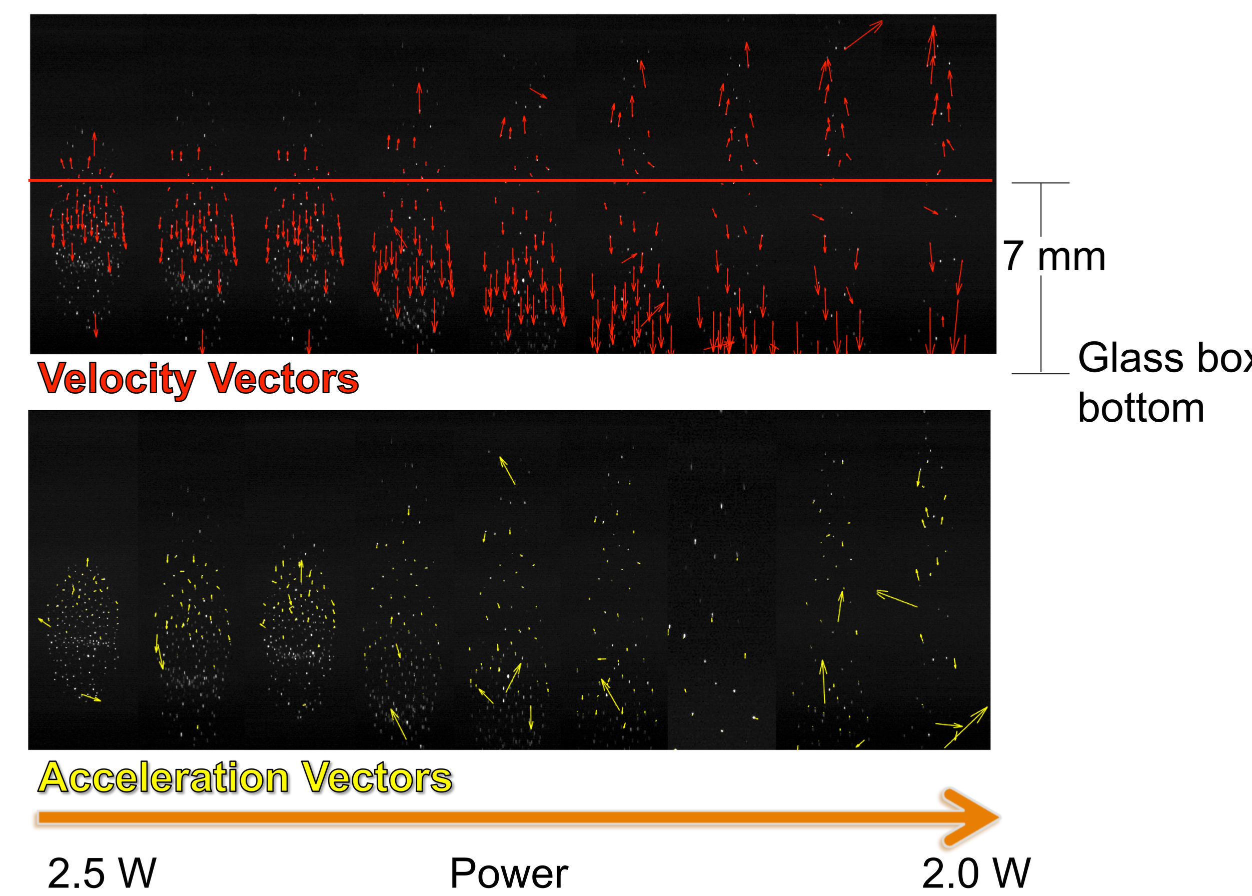

Figure 6. Splitting process for vertical crystal formation. All 9 nine frames represent a total time of 9 milliseconds. The glass box height is 12.7 mm with the splitting process occurring at 7 mm

As the system power is reduced, particle velocity vectors (shown in red) demonstrate the location where splitting occurs, while the acceleration vectors (shown in yellow) show an average constant acceleration profile until the particles reach both ends of the box. (See Fig. 6.)

Conclusions

Based on the acceleration traces of a representative set of particles (see Fig. 7a & Fig 7b), the forces observed in the upper region of the box (defined as the region above 7 mm) compared to the forces in the lower region are different as expected. The acceleration magnitude of the upper region particles remains constant until particles reach the top of the box; however, the lower region particle acceleration profile shows a slow negative slope. In addition, particle acceleration magnitudes are different.

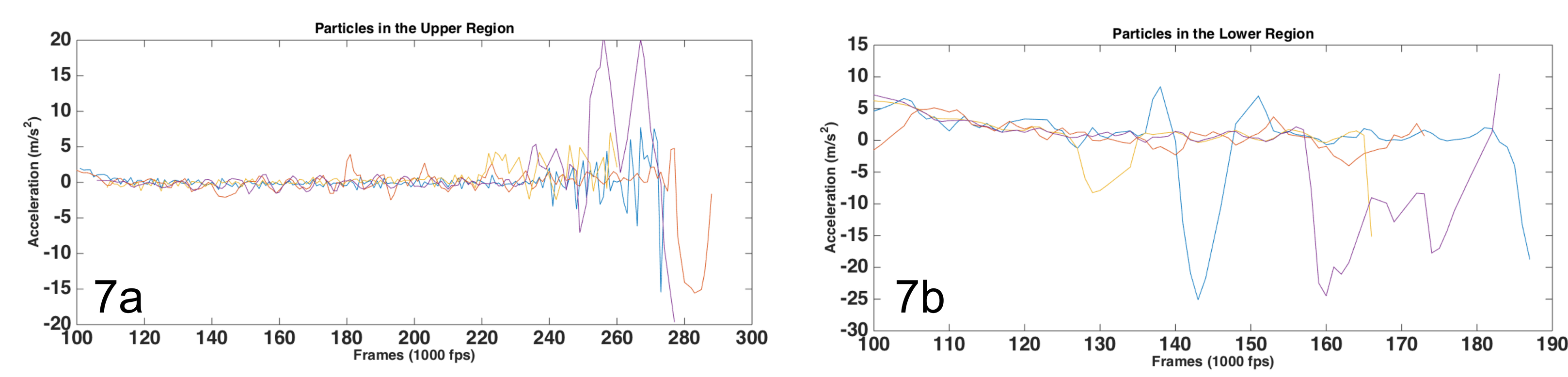

Figure 7. a) Acceleration traces for four representative particle trajectories immediately after the splitting process, b) Acceleration traces for four particle trajectories immediately after the splitting process

The splitting process observed may be produced by a sudden formation of a vertical wall sheath extension in the horizontal plane, producing two distinct regions in the box where the upper region encounters the ion wake and the lower region does not. However, as the rf power is reduced both particle screening length and charge increase [3], producing particle-particle repulsion. Further investigation is required to determine the primary contributing factor for the process observed.

[1] Quinn, R. A., et al. "Structural analysis of a Coulomb lattice in a dusty plasma." *Physical Review E* 53.3 (1996): R2049.
[2] Liu, Songfen, et al. "The structure of a two-dimensional magnetic dusty plasma." *Journal of Physics A: Mathematical and General* 38.13 (2005): 3057.
[3] Kong, Jie, et al. "Interaction force in a vertical dust chain inside a glass box." *Physical Review E* 90.1 (2014): 013107.