Experimental Investigation of Phase Transition and Phase Co-Existence of a DC Glow Discharge Complex Plasma

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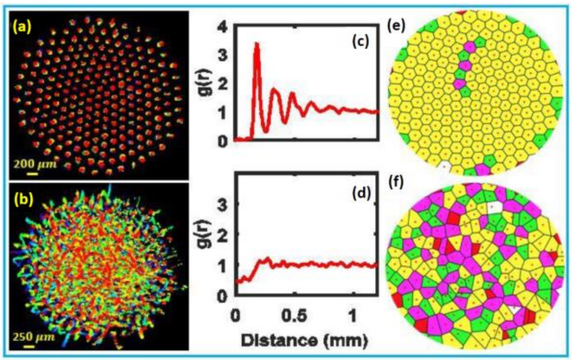
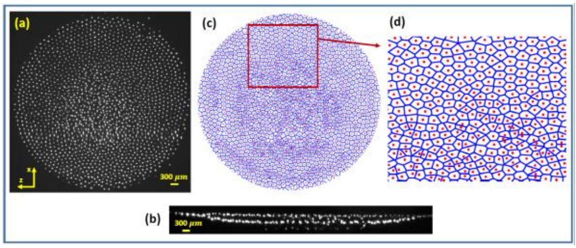
The study of two-dimensional crystals, particularly the nature of their melting transition and phase coexistence nature, has long been a subject of theoretical and experimental interest and also the source of some controversy. A complex plasma serves as a versatile model system for studying two-dimensional and three-dimensional structures. It consists of highly charged micron (or sub-micron) sized dust grains embedded in a conventional plasma. Most of the laboratory investigations on complex plasma crystals have been carried out so far in RF-produced plasmas, and their formation in a DC glow discharge plasma remains experimentally challenging. We made an attempt to produce complex plasma crystals in a DC glow discharge plasma system using the Dusty Plasma Experimental (DPEx) device with a unique asymmetric electrode configuration. Complex plasma crystal is produced in the DPEx device using mono-dispersive MF particles in the DC glow discharge Argon plasma environment [1,2]. A host of diagnostic tools such as the Voronoi diagram, Delaunay Triangulation, pair correlation function, orientational order parameter, dynamic entropy, and Langevin dynamics is employed to characterize the complex plasma crystals over a range of discharge conditions.

After the formation of DC plasma crystal, a systematic experiment is carried out to understand the nature of the phase transition over a range of neutral gas pressures. The crystal is found to melt completely with a negligible reduction of neutral gas pressure after it reaches a threshold value [3] and the nature of the melting or formation process is established as a first-order phase transition. The mechanism of sudden melting is identified as the ion wakes induced Schweigert instability. In another set of experiments carried out in different discharge conditions with a bigger plasma crystal, surprisingly, instead of complete melting, a crystal-fluid coexistence state is observed when the neutral gas pressure is reduced gradually. The co-existence of two phases is found to be in a non-equilibrium in which a hot fluid lies at the center surrounded by a cold crystal. Further reduction in neutral gas pressure results in the complete transformation of phase co-existing states to a cold fluid state. Our experimental findings will be of interest in a wide range of inter-disciplinary fields, where researchers are exploring two-dimensional structures, their phase behavior, and non-equilibrium characteristics.



(a), (b) Overlapped position coordinates of dust particles for consecutive 50 frames. (c), (d) Correlation functions and (e), (f) Voronoi diagrams corresponds to (a) and (b), respectively. Fig. a), (c) and (e) correspond to P=6.9 Pa whereas Fig (b), (d) and (f) are correspond to P=6.7 Pa.



(a) Top and (b) side view of the phase coexisting complex plasma system. (c) Corresponding Voronoi Diagram of Fig (a). (d) Zoomed view of phase coexisting boundary region.

List of related published papers (option)

[1] M. G. Hariprasad, P. Bandyopadhyay, Garima Arora, and A. Sen, 'Experimental observation of a dusty plasma crystal in the cathode sheath of a DC glow discharge plasma', Physics of Plasmas 25, 123704 (2018).

[2] M. G. Hariprasad, P. Bandyopadhyay, Garima Arora, and A. Sen, 'Experimental investigation of test particle induced micro-structural changes in a finite two-dimensional complex plasma crystal', Physics of Plasmas 26, 103701 (2019).

[3] M. G. Hariprasad, P. Bandyopadhyay, Garima Arora, and A. Sen, 'Experimental observation of a first-order phase transition in a complex plasma monolayer crystal', Phys. Rev. E 101, 043209.

Note: Abstract should be in (full) double-columned one page.