Two-Color Mie-Scattering Images of Uncorrelated and Correlated Trapped Dust in Low-Frequency Helium Discharges

B. N. Ganguly, P. D. Haaland, P. Bletzinger, and A. Garscadden

***Abstract*—Simultaneous two-color Mie scattering images from the particle size dependent self-assembled trapped dust particles in a low-frequency helium discharge have been measured. The dynamics of the dust ensemble during the discharge switch-off suggests that the long range order in a correlated dust phase can reduce the ion–ion and the electron–ion recombination rates on dust surface by several orders of magnitudes compared to the ambipolar or to free diffusion rates.**

***Index Terms*—Glow discharge, laser light scattering, self-assembled complex.**

WE REPORT measurements of the self-assembling of dust particles by their size distribution using simultaneous near real-time two-color Mie scattering in a 2 torr pure helium, 15 to 20 KHz voltage excitation frequency, discharge operated with graphite electrodes. A 3-cm i.d. and 1-cm-wide cylindrical spherical graphite is used as the outer electrode and a 1-cm diameter graphite is used as the center electrode which are mounted in a 5-cm diameter glass tube (shown in Fig. 1). In this discharge configuration, the dust particles are transported by ion drag force to an equilibrium position just outside the interelectrode volume and they are trapped by the edge radial electric field. This condition leads to a minimal perturbation of the discharge electrical characteristics as the dust particle density grows. In pure helium discharge with graphite electrodes, the particle growth is primarily by ion accretion of sputtered carbon cluster ions. Ion accretion usually favors particle growth with a narrow size distribution [1]. This characteristic of the discharge permits us to follow the time evolution of trapped particles by their size distributions and also the transition of the particles from uncorrelated phase to a phase with long range correlation. A krypton ion laser output of 647.1 nm and an argon ion laser output 514.5 nm are combined using a broadband half silvered mirror so that each beam is propagating parallel to each other but spatially displaced to permit chopping by the alternate blades using a mechanical chopper. A beam expander combination lens is used for both beams to illuminate a spatially overlapping wide discharge volume. A color video camera is used at 90° angle to detect the Mie-scattered light from both laser beams at alternate video frame. A video frame grabber board is used for data transfer to a computer. Since the Mie-scattering efficiency [2] scales as $(d/\lambda)^6$ where d is the particle diameter and λ is the scattered light wavelength, at a fixed scattering angle, the smaller particles will preferentially scatter 514.5 nm, whereas the larger particles will scatter 647.1 nm. This arrangement permits imaging of self-assembled dust particle growth in both uncorrelated and correlated phases. Figs. 1 and 2 show the images of the trapped dust particles at the edge of the plasma after run time of several minutes. Note that the larger particles (red scattered light) are assembled closer to the electrodes as compared to the smaller particles. In addition, the smaller particles are trapped and distributed over a larger volume compared to the heavier particles. The spatial variation of scattering intensities of both 647.1 and 514.5 nm show the dust densities are concentrated on or near the axis of symmetry with respect to the electrodes. Under this discharge operating condition, there is no measurable amount of dust particle trapped in the interelectrode volume due to the relatively strong radial electric field variation which permits transport of the negatively charged particles to the boundary walls.

After a run time of tens of minutes, the Mie-scattering intensities of both laser beams undergo a transformation from diffuse distributed light scattering to crisp objects with very well delineated boundaries, corresponding to the formation of highly correlated dust ensemble. Figs. 1 and 2, along with the blowup insets, show the Mie-scattering images of both scattered lights. These dust ensembles are located near the axis and correspond to the previous locations of highest dust densities, in the uncorrelated phase, which implies the presence of a very small radial electric field gradient. In addition, the dust particles of same size are self-organized to form correlated ensembles.

Besides the characteristics of highly delineated boundaries, these dust ensembles exhibit very different dynamic behavior compared to the uncorrelated dust particles. The transport properties of these correlated dust differ significantly from the uncorrelated phase during the discharge switch off. The uncorrelated dust particles undergo Coulomb explosion with the dispersal of the particles in all directions including against gravity. Whereas, the dust ensembles in the correlated phase retain their crisp boundaries for several video frames ($>$0.1 s) and their motion is determined primarily by the balance between the Stokes force and the gravitational force. This persistence suggests that in such dust ensembles, the strongly correlated [3] ion–ion, and

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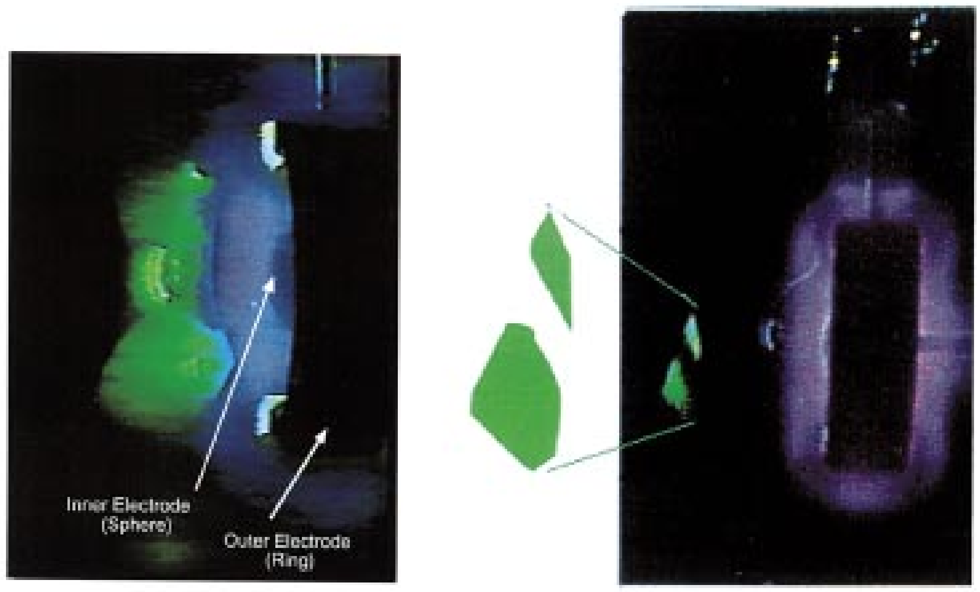

Fig. 1. Mie-scattering image from uncorrelated (left) and correlated (right) dust using a 514.5-nm laser beam.

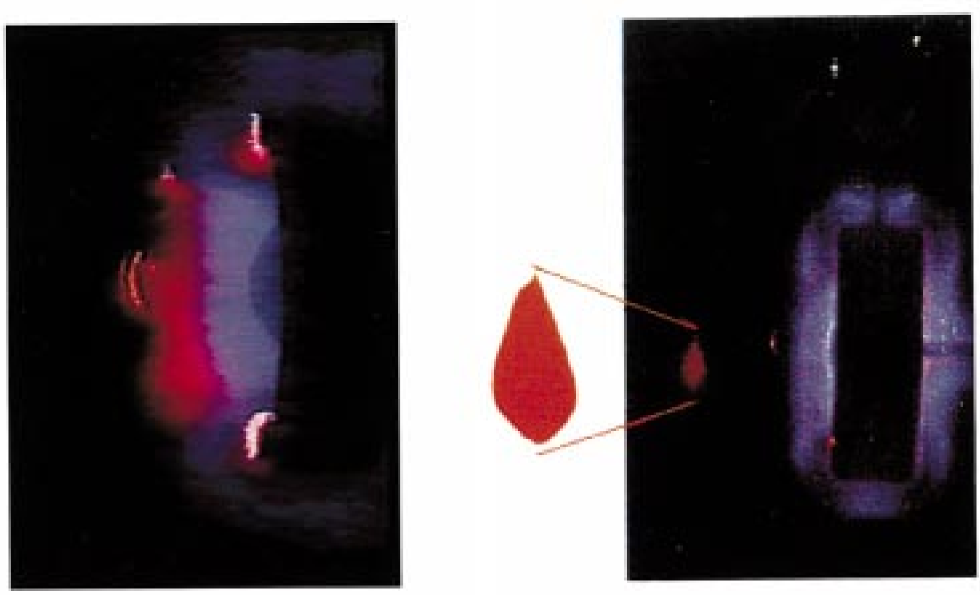

Fig. 2. Mie-scattering image from uncorrelated (left) and correlated (right) dust using a 647.1-nm laser beam.

electron–ion motions lead to a several orders of magnitude reduction in the ion–ion and electron–ion recombination rates on dust particles compared to the ambipolar or to free diffusion rates.

REFERENCES

[1] P. Haaland, A. Garscadden, and B. Ganguly, "Ionic and neutral growth of dust in plasmas," *Appl. Phys. Lett.*, vol. 69, pp. 904–906, 1996.

[2] H. C. van de Hulst, *Light Scattering by Small Particles*. New York: Dover, 1981, p. 144.

[3] V. N. Tsytovich, U. de Angeles, R. Bingham, and D. Resendes, "Long-range correlations in dusty plasmas," *Phys. Plasmas*, vol. 4, pp. 3882–3894, 1997.