§ 25. Molecular Dynamics Analyses on Strongly Coupled Dusty Plasmas

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Coulomb crystal formed by solid particles in dusty plasmas has attracted much interest of plasma scientists since it was discovered in laboratories. In the crystal, such structures as body-centered cubic (bcc), face-centered cubic (fcc) and simple hexagonal appear, depending on the charge state of the particle and the plasma conditions. Especially, the simple hexagonal structure should be focused an attention on. In the structure, the particles form hexagonal lattices in a horizontal plane. The lattices stack in the direction perpendicular to the plane without alternation, i.e., the particles line up in a straight line in the vertical direction. The formation of the vertical alignment implies presence of some attractive forces, since it is difficult to understand that the alignment can be formed only by Coulomb repulsive force between negatively charged particles. Hayashi *et al.* found the structural transition from bcc or fcc to simple hexagonal induced by the growth of the particles in a plasma for chemical vapor deposition (CVD)[1]. In the plasma, the attractive forces come to act on the large-sized particles charged by more than a few thousand electrons. The origins of the attractive forces were suggested in several papers. One theory proposed that the forces can be caused by wake potential in ion flow. Besides, it may be possible to act the forces on the particles because of the dipole moment induced by the deformation of the sheath around the particles. In the present study, we try to understand the interaction between particles and ion, and the potential formation around the particle in experiments with optical emission spectroscopy.

In our experiments, dusty plasmas were generated on a planar electrode in a vacuum chamber. The electrode was connected to an rf (13.56 MHz) power supply. For the discharge, nitrogen (N_2) and argon (Ar) were introduced into the chamber through mass flow controllers. The flow rates of N_2 and Ar were set at 3.5 and 5 sccm, respectively. For injection of acrylic regin particles of 5 μm into the plasmas, a dust dropper was located above the electrode. The particles were trapped by a metal ring on the electrode during discharge on. When pressure and rf power were maintained at 200 mTorr and 0.034 W/cm^2, respectively, the behavior of particles and the spatial distribution of optical emission from the plasmas were observed. In the observation, the particles were illuminated by a semiconductor laser, and a charge-coupled device (CCD) camera was employed to detect the scattering light from the particles and the optical emission.

Figure 1 (a) shows the spatial distribution of emission of light from the plasmas, indicating that the particles were trapped around the plasma-sheath boundary at the height between 4 and 6 mm from the electrode. The particles lined up in straight lines perpendicular to the electrode. The structure implied that the particles formed simple hexagonal structure, and that attractive force acted between the particles in the direction parallel to the line. Then emission of light from an ion specie of N_2^+ was observed with an interference filter passing through first negative system band of the ion at 391 nm (Fig. 1 (b)). It can be expected in the figure that the density of the ion around the particle was comparable to that around bulk region. Although one should have been required to analyze the density distribution of the ion in the a few micrometer scale in order to understand the potential structure around the particle, the present CCD camera system could not achieve such high performance measurements in resolution and sensitivity.

Further experimental and theoretical studies are still hoped to be done for analyses of the particle interaction in dusty plasmas. We will continue to study optical emission spectroscopy in the dusty plasmas, employing a CCD with an image intensifier unit (ICCD).

Reference

1) Hayashi, Y. et al. : Jpn. J. Appl. Phys. **36** (1997) 4976.

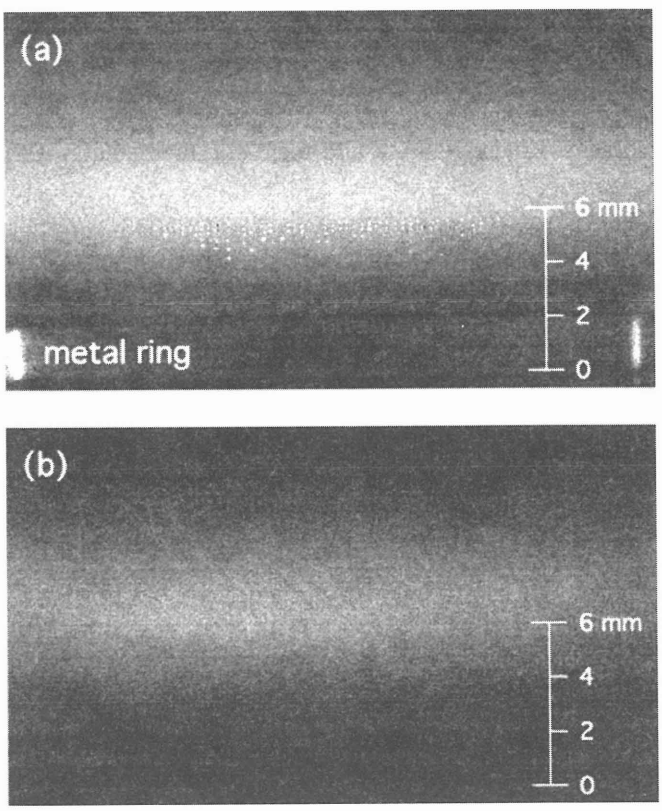

Fig. 1. The spatial distributions of emission of light from the plasma obtained by CCD camera. The intensity of the light was expressed by gray scale, the highest corresponding to white color. The scale bar shows height from the electrode. (a) emission of light from the plasmas and scattering light from the patticles, and (b) emission of light at 391 nm from N_2^+ ions.