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Structure and Motions of Heteromorphic Fine Particles in an HF Discharge Plasma
異径微粒子含有高周波プラズマ内の微粒子構造と運動観察

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Motions and structures of heteromorphic fine particles in an HF discharge plasma are studied experimentally. Ci_3N_4 particles with diameter of about 8 um are used, which make a stable 3D lattice-like structure. The particles in the structure is vibrating and they often has a planet-like orbit. The 3D structure is recorded by a microscopic camera, and the 3D image is reproduced by a computer. When short hemps are used as particles, they do planet-like motions and spinning motions with vertical axis. The mechanism of these attractive motions are now under investigation.

1. Introduction

Related with complex systems, fine-particle plasmas have much attention to scientists and engineers [1-4]. Already, studies of Coulomb crystals, wave phenomena, structures under microgravity have been done. Here, we are studying about heteromororpheric or multi-species particles in a plasma by using a high-frequency (HF) Ar plasma, and analyzing the motions and structures of charged particles.

2. Experimental

Schematic and photograph of the developed plasma machine "*FP-1*" are shown in Figs. 1 & 2. In a stainless steel chamber (150 mmφ, 150 mmh), a 100 mmφ disk electrode and a 80 mmφ metal ring are set. In this experiment, HF argon discharge is produced at 10~13 Pa by applying HF voltage (f= 100 kHz) of about 270~290 V_{rms} to the lower electrode with respect to the upper grounded mesh electrode. Typical plasma parameters are T_e~ 3 eV, n_e~ 1.6×10^{15} m^{-3} and plasma potential of V_s~ 10 V.

A metal ring is added on the lower electrode to confine fine-particles. The cloud diffuses under the upper electrode. The particles used are silicon nitride Si_3N_4, which has diameter of $d \simeq 8$ µm and dispersion of 0.4 um. They are injected from a dust dropper. A digital microscope camera (SELMIC LWD100, working distance of 100 mm, magnification of 70 – 900, and resolution of 1.75 um) and a CCD video camera are used to investigate the particle behaviors. Under a condition of discharge voltage V_d= 280 V_{rm}, discharge current I_d= 0.2 A_{rm} and pressure

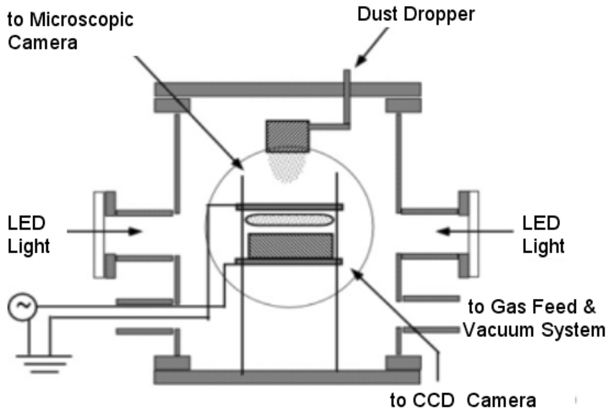

Fig. 1 Schematic of the experimental set up.

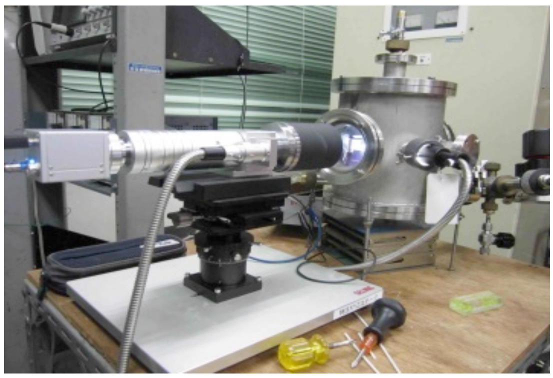

Fig. 2 A photograph of the equipment.

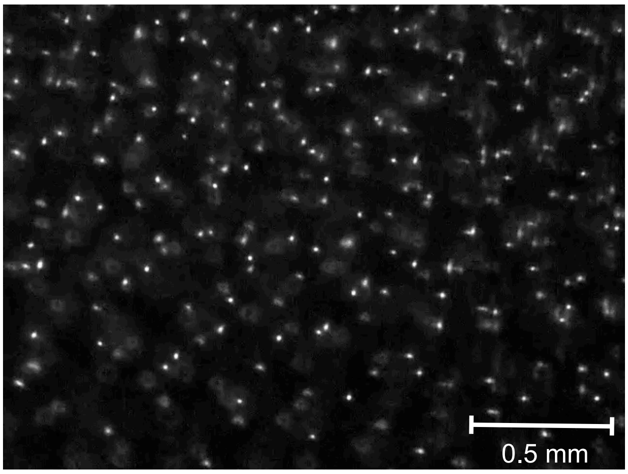

Fig. 3 Lattice-like 3D structure of Si_3N_4 in the HF Plasma (side view). V_{RF} = 280 V_{rms}, I_{RF} = 0.2 A_{rms}, f = 100 kHz, p(Ar) = 13 Pa.

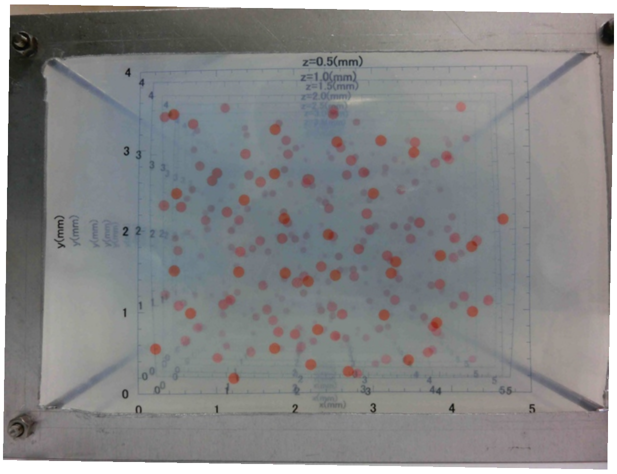

Fig. 4 The 3D image (side view) of the particle structure in the plasma, which is measured by the microscopic camera and colored by a computer.

p(Ar)= 13 Pa, a disk-shaped cloud is generated. Lattice-like 3D structure is observed like Fig. 3 (side view). The each particle motion and the particle-group motions are recorded by these cameras. The particles are almost static. However, as the particles has a size distribution, they do not make a crystal, but they make a 3D lattice-like structure, where each particle is vibrating around its position.

In order to record this 3D structure, characteristic of thin depth of focusing of the microscopic camera (about 0.5 mm) is utilized. The camera is moved horizontally to the plasma, and every 0.5 mm from the plasma, still frames are recorded. Then, the particle images are colored by a computer and reproduced in a 3D style, which is shown in Fig. 4 (side view). The 3D animation is also produced.

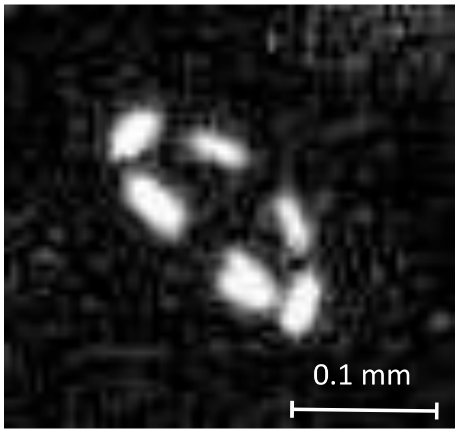

Fig. 5 An orbit of a SiC particle (side view). 10 images are superimposed. V_{RF}= 280 V_{rms}, I_{RF}= 0.2 A_{rms}, p(Ar)= 12 Pa.

Motion of each particle is recorded and its orbit is analyzed by a computer. By automatic-chasing, it is found that many particles have sinusoidal motions in horizontal and vertical directions, frequency of which is about 15 Hz. Figure 5 shows one of fascinating orbits of a particle (a SiC particle, d~ 8 um). The 10 images are superimposed and the orbit is reproduced, in which there is a planet-like revolution of the particle.

When we use short hemps as particles (average length of 0.73 mm, dispersion of 0.32 mm and diameter of 0.052 mm), many planet-like revolutions are observed. And, often we observe steady spin motions of hemp-particles with a vertical axis and a constant angular speed. The larger hemps do not spin. The smaller the hemps are, the higher rotation speeds they have. The mechanism of this spin motion is now under consideration with a model.

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