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Measurements in Fine Particle (Dusty, Complex) Plasmas and Experiments on the International Space Station in a Joint Russian/German Scientific Project
微粒子プラズマの計測と国際宇宙ステーション実験

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The research project of fine particle (dusty, complex) plasmas is going on with cooperation for the PK-3 plus flight module between scientific teams of Germany and Russia on the International Space Station (ISS). Several Japanese scientists have joined to the project for investigating a physical phenomenon of critical point in the plasmas. For further experiments among the scientists, uniformity of plasma comes to be a project to obtain uniform and large dust clouds. The activity has been started with measurements in plasmas, which aims to develop well-controlled "multi-purpose-plasmas" used for basic experiments and processing in Japanese Experiment Module "KIBO" on the ISS. Measuring plasmas and developing an apparatus are being advanced with learning succession of the PK-3 plus flight module for constructing an apparatus of multi-purpose small payload rack in the KIBO.

1. Introduction

The science team "*Development of a Plasma Module for Multi-purpose Small Payload Rack*" authorized by the Japan Space Exploration Agency (JAXA) was motivated in the experiments on the international space station (ISS) of dusty (complex) plasmas, which had been going on with collaboration between Max-Planck-Institute for Extraterrestrial Physics (MPE, Germany) and Joint Institute for High Temperature (JIHT, Russia) for several years.

Plasmas including dust particles (typically, micrometer sized), so called complex plasmas, have attracted much interest of scientists for a few ten years. The dust particles are charged by fluxes of electron and ion in the plasmas. The charge of dust particles can be on the order of a few thousands of elementary charge in typical laboratory plasmas. The charged dust particles are regarded as a strongly-coupled Coulomb system. In the system, one can observe many physical phenomena found in solid or liquid state, such as crystallization, phase transition, wave propagation, and so on, at kinetic level.

Complex plasma experiments have been done in microgravity conditions with apparatuses boarding on parabolic flight, sounding rockets, and the international space station for recent years. Several physical phenomena, e.g., wave propagation and so on, reported by MPE and JIHT in the experiments on the ISS. The utility for complex plasmas on the ISS was replaced a new apparatus denoted by PK-3 plus set in the Russian module at the end of 2005.

Several scientists in Japan have joined to the mission of PK-3 plus for demonstrating a critical phenomenon in complex plasmas predicted by a Totsuji theory [1] since July 2009. The data analyses are going on under the scientific agreement between the Japanese scientists and JIHT with support from JAXA. The theory requires high density of plasmas to approach the critical point. Based on results of diagnostics in PK-3 plus, high power and pressure conditions were employed to obtain the high-density regime. With increasing power and pressure, dust particle free region, so called void, appeared at the center of plasmas and expanded. The void formation had come to be known well in experiments under microgravity with the previous apparatus of PK-3, PKE-Nefedov. It seemed that the void resulted in non-uniformity of plasmas enhanced with increasing plasma density. The void-less, homogeneous, system would be necessary to demonstrate physical phenomena as well as the critical in complex plasmas. Furthermore it is also expected to be useful for plasma process in the future space activity. Mixture of massive matters and plasmas not accomplished under gravity would develop something new as functionalized materials. As crystals come from epitaxial growth on surface under gravity, bulk crystals may be formed with suspending in bulk plasmas activated by abundant radical and energetic electron under microgravity.

The aim of the science team is understanding the plasmas related to behaviors of dust particles, and consequently obtaining well-controllable plasmas

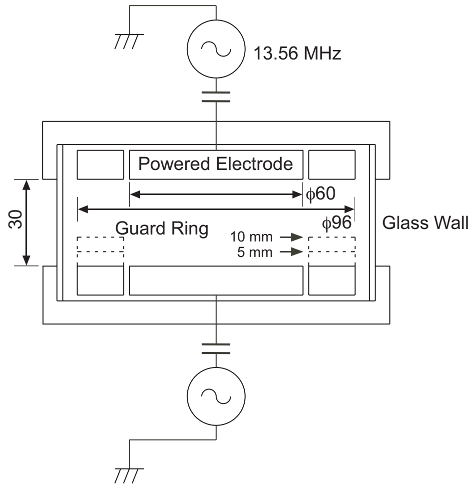

Fig. 1 Schematic of PK-3 chamber.

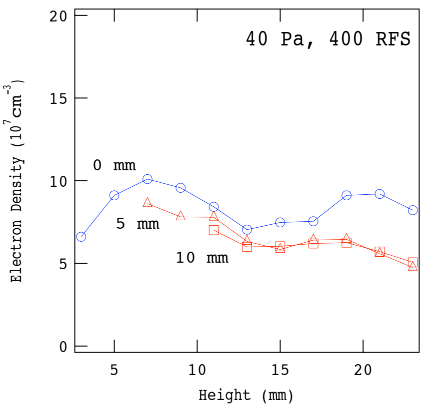

Fig. 2 Spatial distributions of electron density with and without the modification of guard ring at the bottom side.

and developing its source of multi-purpose small payload rack on KIBO for complex plasmas and plasma processing in the future.

In the preliminary researches, a diagnostics of electron density with frequency shift probe for the PK-3 plus has been developed [2]. The diagnostics clearly showed an aspect of plasma production in the configuration of electrodes and grounded guard rings. It is thought that the gentle density gradient of electron spatial distribution is preferable for homogeneous dust particle system. At the first step, dynamics of plasmas in PK-3 plus should be understood well, especially, production of space charges, diffusion, and loss processes.

2. Activities of the Science Team

Figure 1 shows schematic of PK-3 plus modified in the original apparatus [3]. The two parallel plate electrodes of 60 mm in diameter were located at top and bottom of the chamber, which were driven by 13.56-MHz rf voltages with phase difference of π rad. The electrodes were surrounded the grounded guard rings. Assuming that spatial distributions of space charges (electron and ion) are strongly affected by diffusion to the chamber wall, modification of guard ring is thought to be effective to change the spatial distributions of the space charges (Sato's idea). The electron density was measured with modifying the guard ring at the bottom. The top surface of guard ring was raised 5 or 10 mm from the powered electrode.

Figure 2 shows the spatial distribution of electron density measured by the frequency shift probe in a plasma at 40 Pa of Ar and 400 mW of power. When the surface of guard ring was raised up form the original, the electron density at the bottom side relatively increased. The electrons diffusing to be lost at the glass wall were reduced by the raised guard ring.

With the guard ring of which surface is raised 5 mm from the powered electrode level, the dust particles moved to the region of electron density being relatively higher around the bottom. Then the edge of dust particle cloud near the glass wall was made be sharp at a few mm high from the surface of guard ring, compared with the ambiguous edge for the original guard ring. This may be resulted in changing the potential structure of the plasma, and the mechanism should be necessary to be investigated in the future.

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