

多目的実験ラック利用を目指したプラズマ発生装置の開発（RT2011 報告）

高橋和生 [1]，佐藤徳芳 [2]，渡辺征夫 [3]，林康明 [1]，足立聡 [4], Hubertus M. Thomas[5], U. Konopka[5], Gregor E. Morfill[5], Tanja Hagl[5], V. I. Molotkov[6], V. Fortov[6], A. Lipaev[6]

[1] 京都工芸繊維大学, [2] 東北大学名誉教授, [3] 九州大学名誉教授, [4] 宇宙航空研究開発機構宇宙科学研究所, [5]Max-Planck-Institut für extraterrestrische Physik, [5]Joint Institute for High Temperatures, Russian Academy of Science

Development of a Plasma Module for Multi-purpose Small Payload Rack (Report on Activities of the Research Team in 2011)

Kazuo Takahashi[1,], Noriyoshi Sato[2], Yukio Watanabe[3], Yasuaki Hayashi[1], Satoshi Adachi[4], Hubertus M. Thomas[5], Gregor E. Morfill[5], Tanja Hagl[5], V. I. Molotkov[6], V. Fortov[6], A. Lipaev[6]*

[1]Kyoto Institute of Technology, [2]Prof. Emeritus Tohoku University, [3]Prof. Emeritus Kyushu University, [4]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [5]Max-Planck-Institute for Extraterrestrial Physics, [6]Joint Institute for High Temperatures, Russian Academy of Science

[1]Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan

[*]E-Mail: takahash@kit.jp

Abstract: The dusty (complex or fine particle) plasma research for observing critical phenomena is going on with cooperation of the PK-3 plus flight module between scientific teams of Germany and Russia. In the project, uniformity of plasma comes to be a project to obtain uniform and large dust cloud. Generally, plasmas have many possibilities for material synthesis as well as for dusty plasmas. The team aims to develop well-controlled “multi-purpose-plasmas” for multi-purpose small payload rack with learning succession of the PK-3 plus flight module and achievements of Japanese plasma processing society. The diagnostics of plasmas has been tried with a microwave resonator (so-called, frequency shift or hairpin probe) for electron density measurement in PK-3 plus chamber. In 2011, the results of the measurement were examined by using another method of double probe. The optical emissions were observed for developing methods of diagnostics in the plasmas including the dust particles, which were disturbed by using the probes.

Key words; plasma, complex plasma, fine particle plasma, dusty plasma, multi-purpose small payload rack, Japanese Experiment Module “KIBO”

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1. Introduction

This research team was motivated in the experiments on the international space station (ISS) of dusty (complex or fine particle) plasmas, which had been going on with collaboration between Max-Planck-Institute for Extraterrestrial Physics (MPE, Germany) and Joint Institute for High Temperatures (JIHT, Russia) for several years.

Plasmas including dust particles (typically, micrometer sized), so-called complex plasmas, have attracted considerable scientific interest in recent decades. The dust particles are charged by fluxes of electron and ion in the plasmas. The charge of dust particles can be in 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.[1)]

Several scientists in Japan have joined to the mission of PK-3 plus for demonstrating a critical phenomenon in complex plasmas predicted by Totsuji since July 2009.[2)] The data analyses are going on under the scientific agreement between the Japanese scientists and JIHT with support from Japan Aerospace Exploration Agency (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 plus, 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 and developing its source of multi-purpose small payload rack on the Japanese Experiment Module (JEM) “KIBO” for complex plasmas and plasma processing in the future.

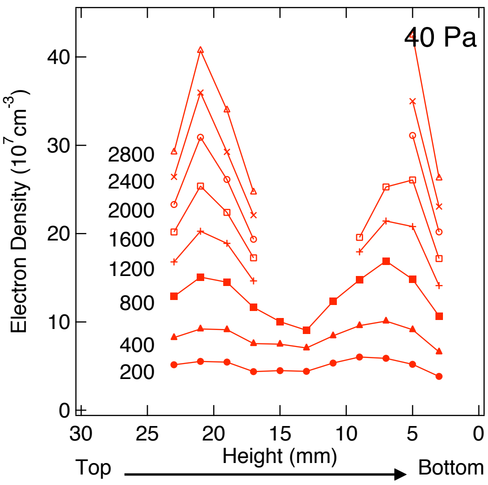

Fig. 1. The Spatial distribution profiles of electron density between top and bottom electrodes at 40 Pa measured with changing the rf set point from 200 to 2800 RFS.

2. Electron density measurement with frequency shift probe

In the preliminary researches, diagnostics with a frequency shift (hairpin) probe was developed to measure electron density and to take spatial distribution profiles of electron density for the PK-3 plus.[3)] Figure 1 shows spatial distribution profiles of electron density between top and bottom electrodes in Ar plasmas at 40 Pa measured with changing the rf set point from 200 to 2800 RFS. Two peaks are found in the profiles of electron density at a distance of 8 mm from each electrode. The plasmas were highly excited near the electrodes. The electrons diffuse to side walls and are lost there. This electron diffusion process results in a dip in electron density in the profiles at mid-plane of electrodes.

3. Activities in 2011

The electron density in the PK-3 plus configuration was calculated with PIC/MCC simulations in MPE.[4)] Figures 2 show the spatial distribution profiles of electron density in Ne plasmas essentially not different from Ar. The upper is the distribution in pristine plasma. The lower corresponds to that in the plasma, where an antenna for frequency shift probe measurement is placed at the center. The antenna decreases electron sinking on the surface and affects on the spatial distribution of electron density. The antenna comparably large to scale of plasmas seems not to be appropriate for measurement of electron density.

Hindering loss of electron on equipment for diagnostic, traditional double probe was employed, which does not take electrons and ions as currents in measurement electrical circuit.

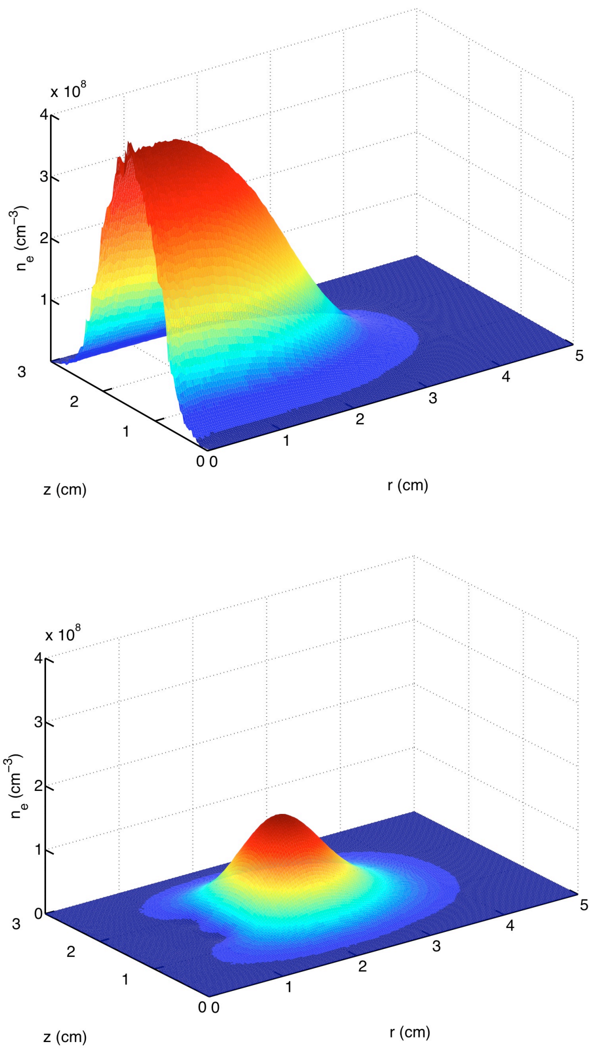

Fig. 2. The Spatial distribution profiles of electron density in Ne plasmas calculated in PIC/MCC simulations. The upper and lower are for pristine plasma and that holding the antenna at the center, respectively.

Ion density and electron temperature were measured with tips of 0.35 mm in diameter, 8 mm in length and separating 7 mm each other (Fig. 3). The ion density increased with increasing input rf power (rf set point, RFS). The distribution profile of electron density from sheath to mid-plane between electrodes became steep with the rf power. The electron temperature was not changed by the rf power. Peaks of electron temperature near the electrodes indicate that stochastic heating of electron contributes to ionize gases at sheath edges. Ions distribute from the sheath edges to the center. The spatial distribution profile of ion density around the center should be identical to that of electron density. This profile corresponds to that of pristine plasma derived from PIC/MCC simulations. The electron densities expected from the ion densities measured by double probe are higher than those by the frequency shift probe.

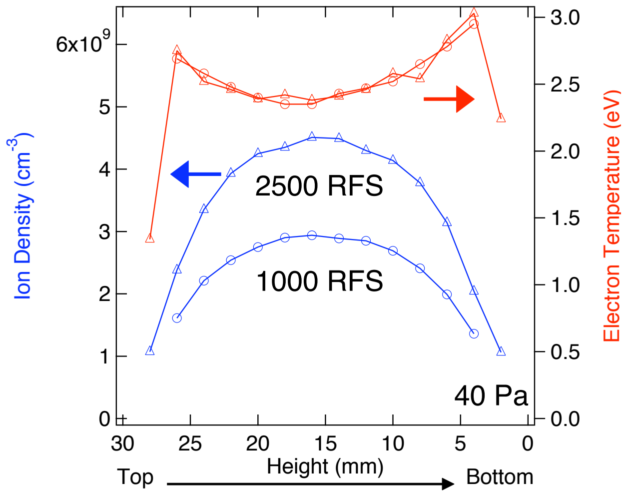

Fig. 3. The spatial distribution profiles of ion density and electron temperature measured by using double probe in Ar plasmas at 40 Pa with changing RFS of 1000 or 2500.

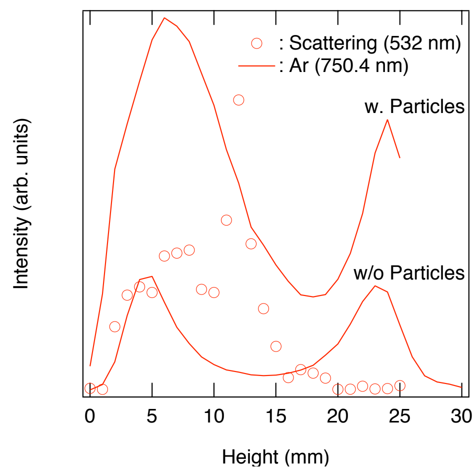

Fig. 4. Intensities of optical emissions from excited Ar atoms and scattering light from dust particles in Ar plasmas at 40 Pa and 400 RFS.

The optical emissions from excited Ar atoms at 750.4 nm were observed in Ar plasmas without and with dust particles in Fig. 4, plotted with intensities of scattering light from dust particles at 532 nm of illuminated laser. Without dust particles, Ar atoms were highly excited around sheath edges. The spatial distribution profile of optical emission from the excited Ar atoms is similar to that of electron temperature. Introducing dust particles, they were distributed near the bottom electrode, and the optical emission from the excited Ar atoms was enhanced. Thus the plasmas were modified by introducing the dust particles, which were expected to enhance electron density and/or temperature.

4. For further activities in 2012

The double probe seemed to be more appropriate for the measurement in PK-3 plus than the frequency shift probe. The spatial distribution profiles of ion density obtained by the double probe seemed to be reasonable compared with results of PIC/MCC simulations. The characteristics of PK-3 plus chamber, however, is not sure to be understood from the point of view of dynamics of charged particles, producing and diffusing of electrons and ions. Furthermore it is necessary for design of probe tips to be examined well in structure of tips collecting currents and forming sheath.

The chamber of new design modified from PK-3 plus and sophisticated for measurement may make a progress in understanding PK-3 plus, although analyzing PK-3 plus itself will be a standard tactics. Furthermore electron/ion density and temperature are required to be measured with interpretation of optical emissions, since these are difficult to be estimated without disturbing plasmas including dust particles.

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