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Spatial diffusion of charged dust particles in complex plasma in a vapor of liquid helium
極低温コンプレックスプラズマ中の熱泳動力による帯電微粒子拡散とその抑制

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Experimental study on non-equilibrium plasma is presented. A complex plasma in the vapor of liquid helium was produced by applying an rf voltage. The plasma is characterized by cold ions with as low as a few meV and hot electrons with a few eV. Dust particles were introduced into the rf plasma and spatial diffusion of charged dust particles under the thermophoretic force is studied in detail.

1. Introduction

A complex plasma in a vapor of liquid helium has been studied [1]. The plasma is characterized by a non-equilibrium state with $T_e >> T_i$, where T_e is a few eV and T_i is a few meV to 10 meV [2]. The collisional effects on charges of dust particles [3] and thremophoretic force on charged dust particles [2] were studied. Thermophoretic force is found to play a major role in the dynamics of dust particles in the presence of liquid helium. Thermophoretic force and gravitational force extract dust particles from the plasma through diffusion toward the surface of liquid helium. In this study, we measure neutral temperature to estimate ion temperature, and set a device with a ring electrode and mesh electrodes. Spatial diffusion of charged dust particles are observed in the plasma.

2. Experiment

Our experimental setup is described in Fig. 1. We produce an rf plasma in helium gas at three conditions, one at room temperature, one cooled by liquid nitrogen stored in the outer bottle and one in a vapor of liquid helium. Liquid helium is stored in the bottom of the bottle, and the vapor pressure is reduced to as low as 0.1 kPa to produce a stable plasma. A movable thermocouple measure the neutral temperature in the plasma. An rf plasma is produced between upper two mesh electrodes, where the top electrode is grounded and an rf power (13.56 MHz, 1~10W) is applied at the lower electrode. The plasma is diffused toward the lowest electrode. A ring electrode is set between the rf electrode and the lowest electrode, to make radial electrostatic potential produced by applied DC voltage V_r, from -80 to 80 V. Distance between the ring electrode and the lowest grounded electrode, h can be changed from 5 to 9 mm. Acrylic particles of 3 μm in diameter, dropped from the top flange, are introduced into the plasma. Dust particles are irradiated by green sheet laser (532 nm), which is reflected at vertical direction by a small mirror at 13 cm below the rf electrode. Particles are recorded by high-speed CCD camera of 400 or 500 fps.

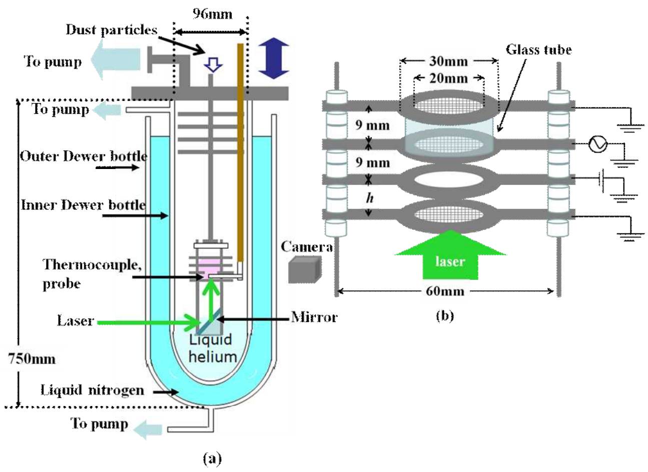

Fig. 1 (a) Experimental apparatus. (b) Structure of the electrodes

2.1 *He gas at room temperature and cooled by liquid nitrogen*

Plasmas are produced in helium gas at room temperature and cooled by liquid nitrogen. Experiments are done at various conditions, such as h = 5 mm, 7 mm, and at 100, 200 and 500 Pa. Neutral temperatures between the ring electrode and the lowest mesh electrode are ~300 K and ~ 80 K in

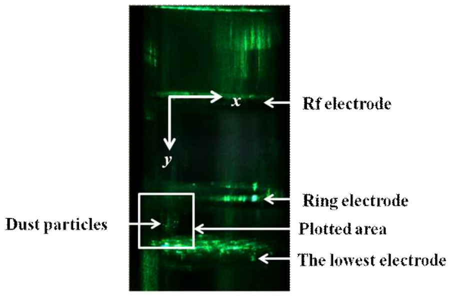

Fig. 2 Dust particles levitating between the ring electrode and the lowest grounded electrode at room temperature helium gas, 130Pa, power supply 7W and h = 5 mm.

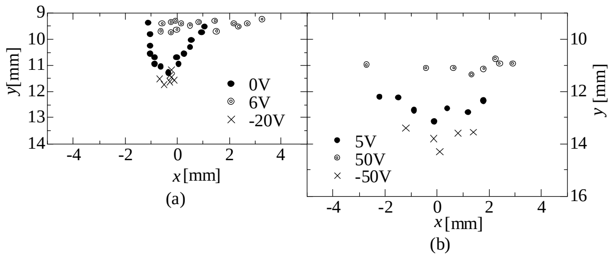

Fig. 3 (a) Positions of dust particles at 130 Pa, power supply 7 W and h = 5 mm at room temperature. (b) Positions of dust particles at 100 Pa, power supply 3 W and h = 7mm, cooled by liquid nitrogen.

helium gas at room temperature and cooled by liquid nitrogen, respectively. At room temperature, dust particles are observed between the ring electrode and the lowest electrode at all conditions, while dust particles are observed in the region at 100 Pa at h = 5mm, and at 100, 200 Pa at h = 7 mm in the helium gas cooled by liquid nitrogen. Figure 2 shows a dust cluster at room temperature and x and y axis, where x axis is in a horizontal direction, y axis is set at a center of mesh electrodes in a vertical direction toward downward, and y = 0 is set at the rf electrode. Figure 3 shows the position of dust particles at the lowest edge of the cluster in helium gas at room temperature and cooled by liquid nitrogen.

2.2 *In the vapor of liquid helium*

In the vapor of liquid helium, same experiment is done as 2.1. The background neutral temperature is kept to be cryogenic in the presence of the temperature gradient of 3 K/cm. Dust particles all diffuse toward liquid helium surface. Figure 4 (a) shows that neutral temperature increases after discharge, while neutral temperature gradient is kept constant about 3 K/cm, and (b) shows that dust particle are not accelerated in the presence of discharge. The time t = 0 is set when dust particles are at y = 0.

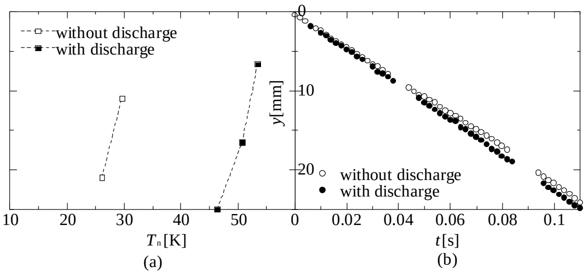

Fig. 4 (a) Space dependence of neutral temperature at h = 9 mm 120 Pa, and (b) time dependence of positions of dust particles with and without discharge in the vapor of liquid helium at h = 9 mm and 120 Pa.

3. Discussion

Ion temperature in the vapor of liquid helium is estimated to be a few meV from the neutral temperature. The plasma is shown to be a non-equilibrium plasma with the ratio of electron temperature to ion temperature ~ 10^3. Spatial diffusion of charged dust particles is observed in the vapor of liquid helium. On the other hand, the diffusion is suppressed in helium gas at room temperature and cooled by liquid nitrogen. Spatial diffusion in the vapor of liquid helium becomes possible by the presence of thermophoretic force toward downward and the decreasing electrostatic field.

4. Conclusion

We produce an rf plasma in the vapor of liquid helium. Diffusion of charged dust particles is achieved in the vapor of liquid helium in the presence of thermophoretic force, while no diffusion of charged dust particles is observed in helium gas at room temperature and cooled by liquid nitrogen. The diffusion is caused by the presence of thermophoretic force and decreased electrostatic field on the lowest electrode in the vapor of liquid helium. Neutral temperature measurement estimates the ratio of electron temperature to ion temperature ~ 10^3. Non-equilibrium plasma is successfully produced.

Acknowledgments

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References

[1] O. Ishihara, J. Phys. D: Phys. **40** (2007) R121.
[2] M. Chikasue, M. Shindo and O. Ishihara: AIP conference proceedings, in press.
[3] N. Uotani *et al.*: J. Plasma Fusion Res. Series **9** (2010) 404.