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Evaluation of Charge of Microparticles in Plasma Using Optical Tweezers

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Formation of nanostructures and three-dimensional integration of semiconductor devices demand ultra-precise nano-processes based on deep understanding of plasma processes [1]. For this purpose, it is crucial to elucidate the electric field distribution and control its fluctuation components in micro-scale regions in plasma. There are few reports on measurements of electric field and its fluctuation in such small space in plasma. We have previously developed a method for measuring electric field with a high spatial resolution using a fine particle in plasma as a probe with the optical tweezers method [2]. In this study, to improve the accuracy of electric field measurements, we develop new method to deduce the charge amount of a fine particle by measuring the force exerted on fine particles by the electric field and the distance between two fine particles using the optical tweezers method.

In the experiment, we used a plasma reaction vessel equipped with a quartz window on the top and a sapphire window on the bottom, attached to an epi-illumination microscope. A grounded punching metal electrode was placed at the center of the vessel, while a ring-shaped electrode with an inner diameter of 15 mm and an outer diameter of 25 mm was set on the bottom surface of the vessel above the sapphire window. Argon was introduced into the vessel, and plasma was generated by applying an RF voltage between the electrodes. The plasma was generated under the following conditions: at a pressure p of 40 Pa with RF powers P_{rf} of 3–7 W for RF power dependence measurements, and at an P_{rf} of 5 W with p of 20–100 Pa for pressure dependence measurements. Acrylic micro particles (PMMA) with a diameter of d_p =15μm were introduced into the plasma. These particles were negatively charged and floated near the plasma/sheath boundary region, where the downward gravitational force was balanced with the upward Coulomb force due to the sheath electric field. The inter-particle distance between two micro particles in plasma was measured. By analyzing the relationship between the Coulomb force between the particles and the force exerted on a particle, the charge amount of a micro particle was determined.

Figures 1 and 2 show the RF power dependence (at a p = 40 Pa) and gas pressure dependences (at an P_{rf} of 5 W) of the charge of fine particle, respectively. Typical experimental charge of fine particle at P_{rf} = 5.0 W and p = 40 Pa was Q = -4.79×10^{-15} C. The experimental charge amounts were closer to those calculated by the OML theory with ion collisions than OML theory without ion collisions [3]. Details will be discussed in the presentation. This work was partly supported by JSPS KAKEN HI (Grant No. 24H00205)

References

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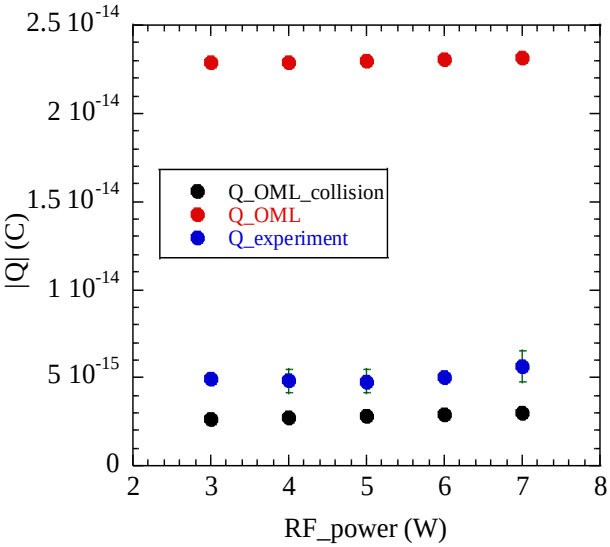

Figure 1. RF Power Dependence of fine particle Charge

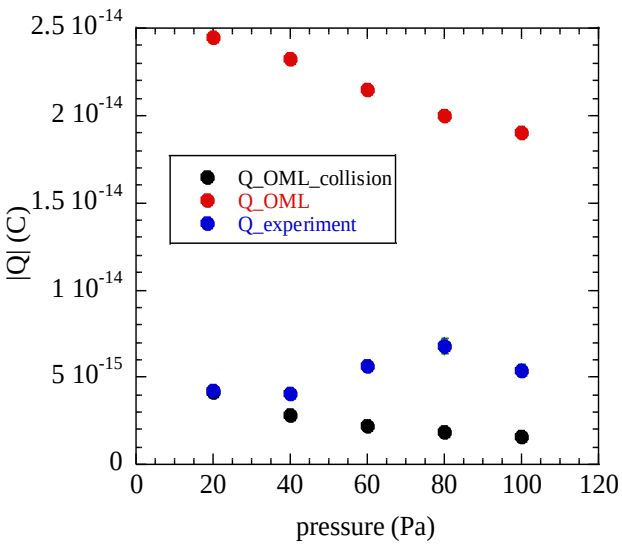

Figure 2. Gas pressure Dependence of fine particle Charge