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Micron-scale plasma fluctuation detected using paired fine particles

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1. Introduction

High-precision nanofabrication based on plasma processing has been one of the main technology drivers of modern information society [1]. Development of highly sensitive diagnostic methods in process plasmas is imperative for understanding and controlling interactions between the materials and plasma. A diagnostic method using few dust particles in plasma is a possible solution of this problem [2]. We succeed in injection of two fine particles into plasma and observed their motion, especially binary collisions between two particles as well as their paired motion, with a high-speed camera. Here, we report the results of analysis on the motion.

2. Experimental

Experiments were carried out with a radio frequency low pressure plasma reactor, where we set a quartz window at the top and a sapphire window at the bottom of the reactor. White light was irradiated from the top window to observe particle behavior from the bottom window. A powered stainless steel ring-electrode of 10 and 25 mm in inner and outer diameter was set at the bottom of the reactor. A grounded punching metal electrode was placed at the center of the reactor. Ar plasma was generated at 21.9 Pa by applying 13.56 MHz, 390 peak-to-peak voltage to the electrodes. PMMA fine particles of 10 μm in diameter were injected into the plasma from a particle dropper set above the grounded electrode. They were levitated around the plasma/sheath boundary due to vertical force balance among gravity, ion drag force and electrostatic force.

3. Results and Discussion

We drove one particle using laser light. Then, the particle approached the other one and they collided with each other based on the Coulomb interaction between them. Figure 1 shows the two-dimensional trajectories of two particles obtained by a tracking analysis to the movie. In order to focus on the interaction, we converted the system to the center-of-mass system as shown in Fig. 2. The particles are subjected to not only the Coulomb repulsive force at a distance of 130 μm but also an attractive force at a distance of 500 μm. These forces are predominant for the interaction in comparison with other forces due to neutral molecule collisions, fluctuation of charge on the particle and fluctuation of electric field. The attractive force could be attributed to the gradient of the plasma potential, the effect of ion flow and so-called the shadow effect [3]. Among these forces the shadow effect must be responsible, because the attractive motion occurs simultaneously for both particles and their motions are symmetric. The trajectory of center of mass in Fig. 1 suggests paired Brownian behavior of the two fine particles, manifesting micron-scale plasma fluctuation. We will discuss details at the conference.

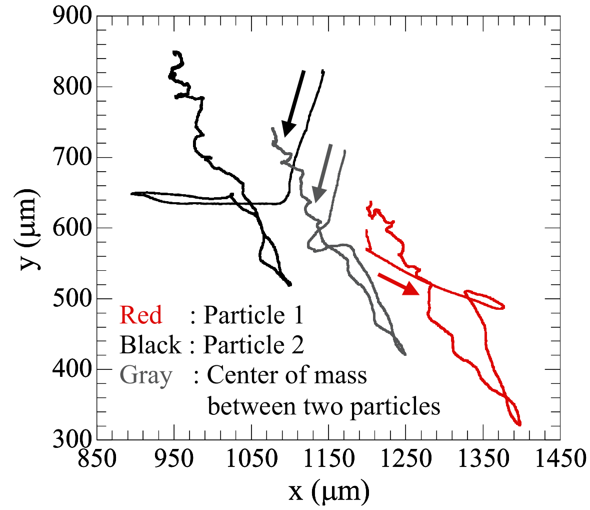

Figure 1. Trajectories of two fine particles and their center of mass during collision in laboratory system of coordinates.

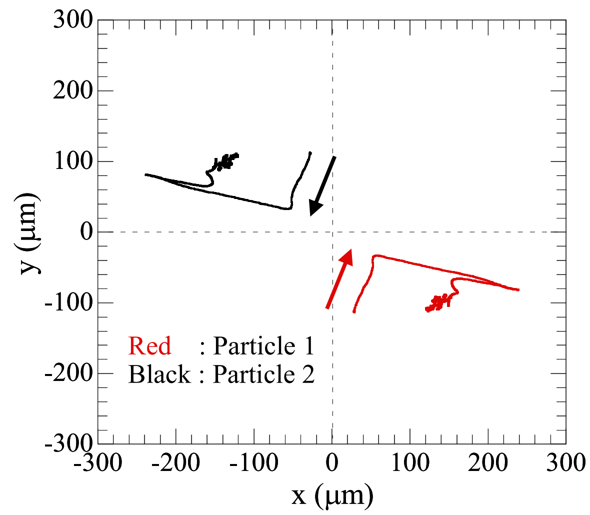

Figure 2. Trajectories of two fine particles during collision in the center-of-mass system.

Acknowledgment

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References

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