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Study on measurement of strength and fluctuation of electrical field using optical trapped particle in Ar plasma

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High-precision nanofabrication based on plasma processing has been one of the main technology drivers of digital society. 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. For faster development of ultra-precision nano-fabrication methods, effects of plasma fluctuations in reactive plasma must be taken into account, since such fluctuations affect the growth of nanostructures. Here we measured the strength and fluctuation of electric field in Ar plasmas using laser tweezers [1] and amplitude modulation method [2].

A plasma reaction vessel with a quartz window on the top and a sapphire window on the bottom was used in the experiments. It was set in an epi-illumination microscope. A perforated metal ground electrode was placed in the center of the vessel, and a ring-shaped electrode with an inner diameter of 15 mm and an outer diameter of 25 mm was placed on the bottom of the vessel. A high-frequency voltage of 13.56 MHz was applied between the electrodes to generate plasma in the vessel. When an acrylic particle of 20 μm in diameter was introduced into plasma, it was suspended near the plasma/sheath boundary. A single particle was trapped with the laser tweezers and moved horizontally with the laser light until the particle was de-trapped.

Figure 1 shows that the levitation positions of the laser-trapped fine particle in Ar plasma at 60 Pa for each laser power (10.4 ~ 27.3 mW). At the levitation position, the electrostatic force and the laser light force on the particle are balanced by the gravity. The force of the laser on the particle was obtained from an ray optical model [2], and a particle charge was deduced from Orbit Motion Limited (OML) model [3]. Therefore, we deduced vertical electric field strengths Ez from these derivations. Figure 1 shows 2D profile of Ez with a range of 3 $\times 10^3$ and 4 $\times 10^3$ [V/m] in plasma, deduced from the force balance of an optically trapped particle.

To investigate fluctuation of electric field in plasma, we measured time evolution of levitation position of an optically trapped fine particle in Ar plasma using amplitude modulation method (shown in Fig. 2). This result shows that the fine particle oscillates at the modulation frequency (5Hz), indicating the plasma/sheath boundary. We will discuss details at the conference.

Acknowledgements

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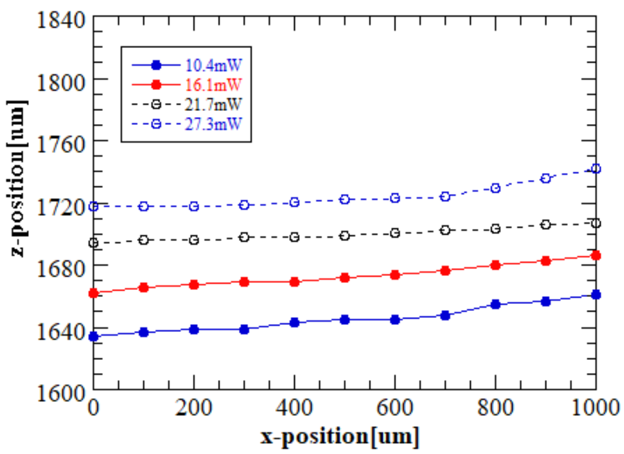

Fig. 1. Levitation positions of laser-trapped fine particles in Ar plasma at 60 Pa when they are moved horizontally with focus for each laser power.

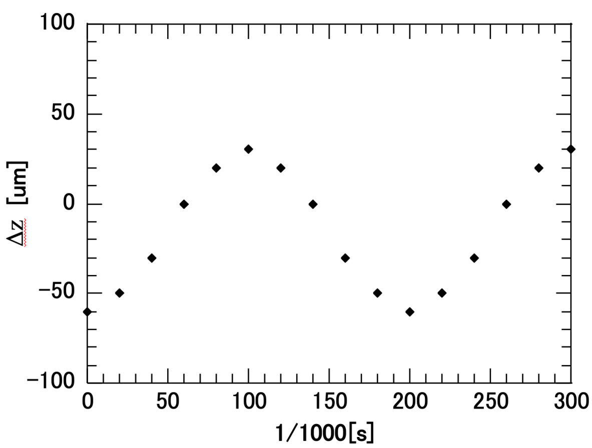

Fig. 2. Time evolution of levitation position of laser-trapped fine particles in Ar plasma with amplitude modulation method (f_{AM}=5Hz, AM level 5%.)