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Precise Measurement of Spatial Electric Field Vectors in Ar Plasma using a Fine Particle Trapped with Laser Tweezers

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1. Introduction

There is a strong need for processing of materials at nanometer scale to allow the continuous miniaturization of devices. Plasma processing is mainly used to manufacture these devices. The measurement of sheath electric field in a microscopic space is an important issue for optimizing plasma processing of materials. For example, small changes and fluctuations in the electric field have a significant impact on etching and deposition into high aspect ratio micro-/nano-structure.

A lot of different techniques have been developed for the measurement of electric fields in plasmas. Electric field can be derived from local measurements of the plasma potential using Langmuir probes or emissive probe [1]. However, these probes are highly invasive since typical probe size is a few mm. As a result, all of these probing techniques have in common the change of chemical reaction on the probe as well as the disturbance of the plasma. One of non-invasive technique is the measurements by laser, e.g. laser-induced fluorescence (LIF) -dip spectroscopy [2]. The sensitive detection limit of 3 V/cm with spatial resolution of several hundreds of micrometers obtained by LIF-dip allowed the measurement in the Ar plasma [2]. However, few reports have been published on sensitive measurements of electric field distributions with high spatial resolution on the micrometer scale.

One technique to manipulate micro-particles are optical traps, often named as optical tweezers [3]. Therefore, in this study, we have investigated such sensitive measurements of strength and fluctuation of electric field in plasma using optically trapped fine particles by a laser-tweezer technique.

2. Method

A plasma reaction vessel with a quartz window on the top and a sapphire window on the bottom was used in the experiments as shown in fig.1. 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 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 20μm in diameter (mass density: 1.20 g/cm^3) was introduced into plasma, it was suspended near the plasma/sheath boundary. A single particle was trapped with the laser tweezers (λ = 1064nm) and moved horizontally with the laser light until the particle was de-trapped. At the levitation position of a fine particle, the electrostatic force and the laser light force on the particle were balanced by the gravity. The force of the laser on the particle F_{ray} was obtained from a ray optical model [4], and a particle charge Q_{p} was deduced from Orbit Motion Limited model with ion collision [5]. Each z- and r- force balance equations are as follows, z-direction: $mg = Q_{\mathrm{p}}E_{\mathrm{z}} + F_{\mathrm{ray\_z}}$ and r-direction: $F_{\mathrm{ray\_r}} = Q_{\mathrm{p}}E_{\mathrm{r}}$.

Eventually, we deduced vertical electric field strengths E_{z} from these derivations. Moreover, strengths and fluctuations of horizontal electric fields E_{r} were deduced by deriving horizontal force balance. As the results, we obtained 2D profiles of electric field vector with a high spatial resolution in micrometer scale.

3. Results and Discussion

We measured the levitation positions of the laser-trapped fine particle in Ar plasma for each laser power and each position to get information of E_{r} and E_{z}. Figure 1 shows spatial distribution of electric field vectors in Ar plasma using a laser trapped fine particle. The vector of electric field is oriented toward the center of the plasma. These results of electric fields were agreed with the numerical result by PIC-MCC model. The details will be reported at the conference

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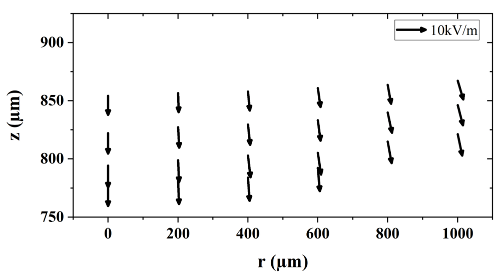

Fig.1 2D profile of electric field vector