6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Optical tweezers technique for electric field measurements in Ar plasmas using a fine particle

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Plasma processing is mainly used to manufacture micro- and nano-electronics devices. The measurement of sheath electric field in micro- and nano-regions is important for improving plasma processing of materials. For example, small changes and fluctuations of electric field have a significant impact on etching and deposition into high aspect ratio micro- and nano-structure. It is essential to develop highly sensitive diagnostic methods on the sheath electric field. The purpose of this study is to evaluate electric fields strength and fluctuation in Ar plasma using a fine particle trapped with laser tweezers [1].

Figure 1 shows the diagram of experiment setup. A plasma reaction vessel was set up in an epi-illumination microscope. This vessel had a metal mesh grounded electrode and a ring-shaped powered electrode with an inner diameter of 15 mm and an outer diameter of 25 mm, which was placed on the sapphire glass under the vessel. The point at $(r, z) = (0\mu m, 0\mu m)$ was set as the center of the sapphire window.

An rf-frequency voltage of 13.56 MHz was applied between the electrodes to generate plasma. When an acrylic particle of 20 µm in diameter was introduced into the plasma, it was suspended near the plasma/sheath boundary above the powered ring electrode. This single particle was trapped in plasma with optical tweezers. When it was moved horizontally with the laser, we measured the levitation position. We deduced electric fields at the levitation position from the horizontal and vertical balances of forces on an optically trapped particle. Force balances on a fine particle in plasma were as follows : (horizontal balance) $Q_p E_r = F_{ray\_r}$, and (vertical balance) $mg = Q_p E_z + F_{ray\_z}$, where Q_p is the particle charge, mg is the gravity, E_r and E_z are the strength of horizontal and vertical electric fields, F_{ray_r} and F_{ray_z} are the force of the laser on the particle, respectively. F_{ray_r} and F_{ray_z} were obtained from an ray optical model [2], and Q_p was deduced from Orbital Motion Limited(OML) model considering ion collision[3].

Figures 2(a) and (b) show 2D distributions of E_r and E_z. E_r is found to be $0 \sim 1.4 \times 10^3$ [V/m] and E_z is found to be $7.5 \times 10^3 \sim 8.7 \times 10^3$ [V/m] $(0 \leq r \leq 1000, 770 \leq z \leq 880)$. E_r increased gradually from the center of the plasma to the edge. E_z decreased from the plasma sheath region to the bulk of the plasma. Moreover, the amplitude of fluctuation of electric field increased from the center of the plasma to the edge. We will discuss the detail at the conference.

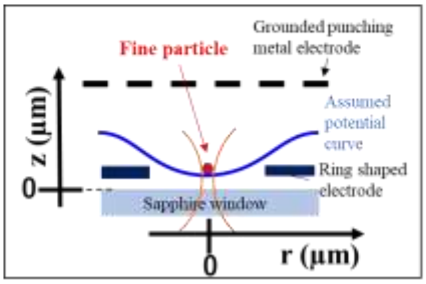
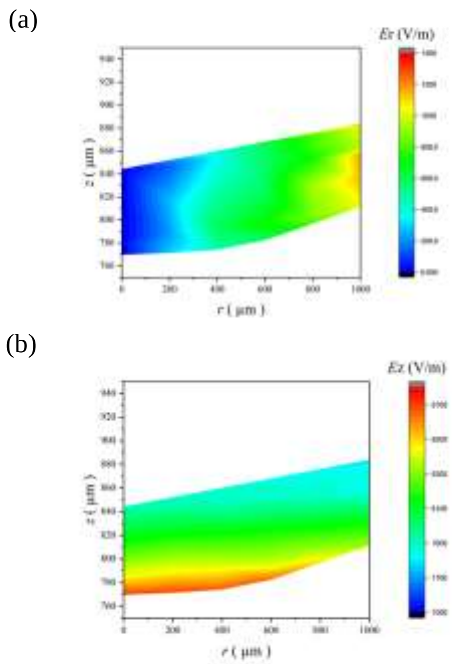


Fig. 1 Diagram of experimental setup



Figs.2 Two dimensional electric field distributions of (a) E_r and (b) E_z

Acknowledgements

This work was partly supported by JSPF KAKENHI (Grant No. JP20H00142) and JSPS Core-to-Core Program (Grant No. JPJSCCA2019002).

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