A-O5

1st Asia-Pacific Conference on Plasma Physics, 18-23, 09.2017, Chengdu, China

Local Fluctuations of Plasma Detected with an Optically Trapped Fine Particle

Masaharu Shiratani, Hiroshi Ohtomo, Kento Mori,
Daisuke Yamashita, Hyunwoong Seo, Naho Itagaki, and Kazunori Koga
Department of Electronics, Kyushu University, Japan

Plasma process has been more and more used in nanostructure fabrication such as large-scale integrated (LSI) circuits. It occupies more than 70% among 600 LSI fabrication steps [1]. Due to the large number of steps, process fluctuation should be minimized, otherwise no final products are obtained. We have studied relation between plasma fluctuation and process fluctuation [2-4]. As one of such efforts, we have developed a novel non-invasive plasma diagnostic method which offers local measurements of plasma parameters and their fluctuations using single fine particle trapped in plasma by optical tweezers. Here, we report local fluctuation of plasma detected with single fine particle trapped by optical tweezers with a high-speed camera.

Experiments were carried out with a radio frequency low pressure plasma reactor of 35 mm inner diameter and 23 mm inner hight equipped with a top quartz window and a bottom sapphire window. 3 W of rf power at 13.56 MHz was capacitively coupled to the ring powered electrode of 10 mm inner and 25 mm outer diameter, to generate Ar plasma at 100 Pa. Single PMMA fine particle of 10μm diameter was injected into the plasma and levitated around the plasma sheath boundary above the powered electrode. The optical trapping system was based on the so-called “single-beam gradient laser trap”, where the scattering forces and the gradient forces of laser beam fix a particle position near the focal point of laser light. Nd:YAG laser light at λ=1064 nm, 20 mW was irradiated from the bottom window to trap the particle. We observed the motion of the single fine particle from the top window with a high-speed camera. The frame rate was 3000 fps. Time evolution of the particle position was deduced by tracking analysis.

Figure 1 shows time evolution of particle velocity before and after the beginning of optical trapping. At the beginning of the trapping (t=0.764 s), the particle velocity increases suddenly due to acceleration by the optical trapping force of 0.4 pN. Figure 2 displays the time evolution of position from the beginning of trapping. During the initial stage of trapping, the particle shows damped oscillated motion. The equation of this motion is expressed by the Langevin equation. The characteristic time of damping is deduced to be 50 s^{-1}, being close to 53 s^{-1} due to neutral drag force. The motion in Fig. 2 also contains fluctuation part. This fluctuation arises from fluctuation of neutral drag force, ion drag force, and electrostatic force. Because of a high electric charge ($Q=-1.7\times10^{4}$ e) and large mass (6.3×10^{-13} kg) of the trapped fine particle, its motion is highly sensitive to local electric field of the order of 10 V/cm of frequency less than 1 kHz.

In short, an optically trapped fine particle can offer a highly sensitive detection of local plasma fluctuation.

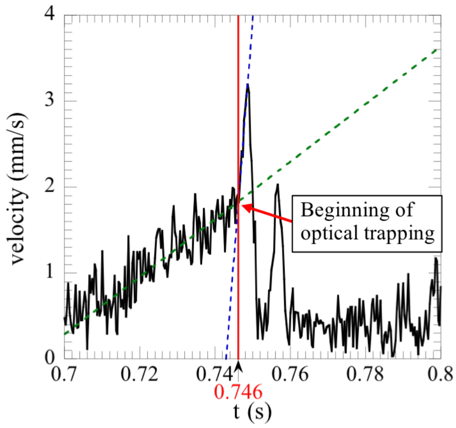

Fig. 1. Time evolution of particle velocity before and after the beginning of optical trapping.

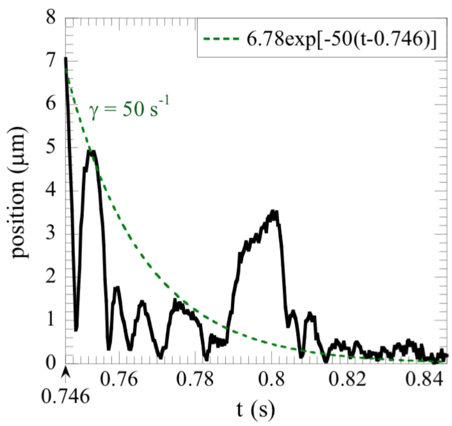

Fig. 2. Time evolution of position of the optically trapped fine particle and a fitting-curve.

Acknowledgment

This work was partly supported by JSPS KAKENHI grant number 26246036.

References

[1] C.Y. Chang and S.M. Sze, ULSI technology, McGraw Hill, 2000.
[2] M. Soejima, et al., Nanotechnology (IEEE-NANO), DOI: 10.1109/NANO.2016.7751376.
[3] M. Shiratani, et al., Jpn. J. Appl. Phys. Vol. 53 (2013) 010201.
[4] M. Shiratani, et al., J. Phys. D, 44 (2011) 174038.