§28. Research on Dust Generation and Its Observation Method by Light Scattering

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Dust generation in nuclear fusion reactors, as a result of peel-off from reactor wall or homogeneous nucleation in plasma, is becoming a serious problem. Such dust can become a source of core cooling and tritium pollution. Although studies on the generation and behavior of dust in such a high-density plasma device are important, many phenomena, such as the generation of dusts containing carbon or tungsten and their growth and transport, have not been well analyzed and clarified. *In-situ* measurements and analyses of dust behaviors, such as Mie-scattering ellipsometry[1)] and integral photography[2)], are important issues to reduce the generation of dusts in a plasma reactor. We are developing a new Mie-scattering ellipsometry system for the analysis of the generation and transport of dusts in a large plasma device like the Large Helical Device (LHD).

The new system is a rotating-compensator type consisting of polarizer and analyzer modules and a 2D image sensor. Although a rotating-compensator, which is a compensator rotated by a motor, is set in analyzer modules in conventional rotating-compensator ellipsometers, it is set in the polarizer module in our new system because the analyzer module is installed in the vacuum vessel of LHD. The difference between this system and conventional Mie-scattering ellipsometers is the imaging of the distribution of fine particles using a 2D image sensor instead of a photodetector. The advantage of this method is easy confirmation of optical adjustment from a long distance by the image of fine particles, as well as the analysis of distributed fine particles for each separated area, i.e., 2D Mie-scattering ellipsometric analysis.

The ellipsometer consists of polarizer and analyzer modules. The polarizer module is composed of a 532 nm wavelength laser, a polarizer (azimuth angle: 90° from scattering plane), and a rotating-compensator. The analyzer module is composed of a wire-grid polarizer (analyzer, azimuth angle: -45°) and a mirror. A video camera containing an image sensor for the detection of change of light intensity during the modulation of polarization state was set at a distance about 2 m from the mirror. We attached the ellipsometer system to an RF fine particle plasma equipment.

Spherical divinylbenzene polymer particles of 2.25 ± 0.05 μm in diameter were injected and suspended in an argon plasma under the pressure of 50 Pa. Light scattered by thousands of particles passing through the analyzer was observed and recorded with the video camera. Video images were captured 30 times per second during the compensator rotation at a speed of 0.5 turn per second.

For rotating-compensator ellipsometer, light intensity I changes with compensator azimuth angle C as,

$$I = A_0 + A_2\cos 2C + B_2\sin 2C + A_4\cos 4C + B_4\sin 4C.$$

Through Fourier transformation of measured light intensity, Fourier coefficients, A_0, A_2, B_2, A_4, and B_4 are obtained. Then ellipsometric parameters, Ψ and Δ are calculated by the equation,

$$\Psi = \tfrac{1}{2}\ \mathrm{Tan}^{-1}\frac{\sqrt{{B_4}^2+\frac{1}{4}{B_2}^2}}{2A_4}\ ,$$

$$\Delta = \mathrm{Tan}^{-1}\frac{B_2}{2B_4}\ .$$

The determined values were 73.7° for Ψ and 214.5° for Δ, and they are indicated at a point in Ψ - Δ coordinate as shown in Fig.1[3)]. Calculated values, based on the Mie scattering theory for the values of the refractive index (1.56, the refractive index of divinylbenzene), diameter (2.22 μm to 2.30 μm) and scattering angle (90°), are also shown in Fig.1. By the comparison of the determined *Ψ* and *Δ* values with the calculated ones, it can be stated that they agree fairly well with each other and the measurement method is reliable.

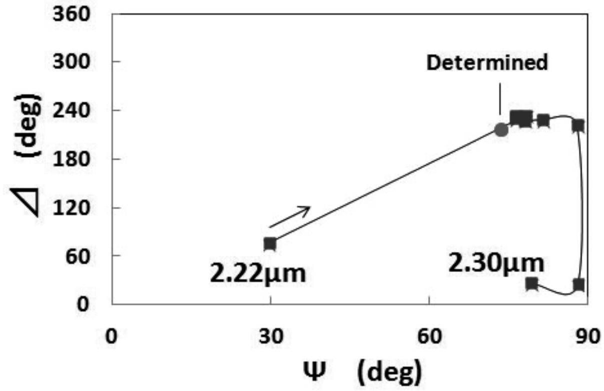

Fig. 1. Ellipsometric parameters Ψ and Δ determined by measurement (red circle) and calculation (blue squares). Calculation was carried out based on Eq.(1) and the Mie scattering theory for the values of refractive index of 1.56, the diameter of 2.22μm to 2.30μm by 0.01μm and the scattering angle of 90°.

The imaging Mie-scattering ellipsometry measurement was also carried out in an argon plasma containing two kinds of particles, 6.5 μm divinylbenzene polymer particles and 4.2 μm silica particles. The distribution of the two particles was reasonably measured [4)].

1) Y. Hayashi and K. Tachibana: "Mie-Scattering Ellipsometry for Analysis of Particle Behaviors in Processing Plasma", Jpn. J. Appl. Phys. **33** (1994) L476.
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3) Y. Hayashi, M. Kawano, A. Sanpei and S. Masuzaki: "Mie-Scattering Ellipsometry System for Analysis of Dust Formation Process in Large Plasma Device", IEEE Transaction on Plasma Science, **44** (2016) in press.
4) M. Kawano, A. Sanpei, Y. Hayashi, T. Mieno and S. Masuzaki: "Measurement of Constant-Radius Fine Particles in Plasma by Mie-scattering Ellipsometry", 16th Workshop on Fine Particle Plasmas, O-3, Dec. 10, 2015.