§14. Microwave Diagnostics of Dielectric Object

Yamaguchi, S. (Kansai Univ.), Nagayama, Y.

Computed Tomography (CT) method has been well developed for plasma diagnostics and medical application last several decades. The CT method was invented by A. M. Cormack in 1963. The CT was firstly utilized as x-ray tomography for medical examination, and many types of medical imaging diagnostics have been invented until today. The x-ray tomography in plasma diagnostics was reconstructed in PLT and JET tokamaks in 70's and 80's respectively, and Electron Cyclotron Emission (ECE) CT was developed in TFTR in 90's. Recently Microwave imaging diagnostics without CT reconstruction has been developed in TEXTOR, LHD, KSTAR and DIII-D [1]. It works as a microwave camera which records the microwave movie on a focal plane of optics. These advanced imaging techniques are well developed for plasma research.

Microwave diagnostics for plasma physics can be utilized for medical screening. An incident microwave is reflected at a boundary surface between different dielectric constants. It is similar to the cutoff surface in plasma diagnostics. Microwave diagnostics techniques in plasma physics can be also utilized for industry applications, for example, non-destructive inspection of reinforced concrete of building and tunnel, food inspection, ground-penetrating radar, and so on. We can see through an inner structure of a dielectric object by using the microwave diagnostics.

Microwave CT has been proposed for medical and industrial applications. The CT shows high contrast of electrical properties in an object. High permittivity part causes microwave reflection and scattering in the object. These electric properties are available to sensitive detection of a small error part from a normal part in the object. Microwave CT was unavailable due to high device cost and low computing power for years. Recent progress in mobile communications is developing by effective and low-cost microwave integrated circuits. They help us to reduce the system cost of microwave CT. Computing power is not yet enough to reconstruct the tomographic image in practical time. In order to reduce the calculation load, improvement of both microwave components and reconstruction method is necessary as well as the enhancement of computing power.

A reconstruction method of microwave CT is under consideration in my research group to determine the complex permittivity profile in a semi-transparent weak scattering object. The complex permittivity profile of the object is directly calculated by solving a nonlinear complex matrix equation. The scattering wave can be described in the first Born approximation as Eq (1).

$$e_l(\mathbf{r}) = e_l^i(\mathbf{r}) + \iint_S k_0^2 C(\mathbf{r}') e_l(\mathbf{r}') G(\mathbf{r},\mathbf{r}') d\mathbf{r}' \qquad (1)$$

$e_l(\boldsymbol{r})$ is a total electric field, $e_l^i(\mathbf{r})$ is an incident electric field, k_0 is a wave number, $G(\mathbf{r},\mathbf{r}')$ is Green's function. The object and its surrounding area are separated by N pixels as shown in the figure 1. T_X is transmitter, R_X is receiver. The contrast function is defined to be complex permittivity difference between the object and its surrounding area as $C(\mathbf{r}) = \varepsilon(\mathbf{r}) - \varepsilon_{exp}$. The first Born approximation is not applicable to a high dielectric object, and some additional procedures are necessary in such cases. Measurable range of the contrast ratio of the permittivity in CT image is $\varepsilon(\mathbf{r})/\varepsilon_{ext} = 1.00 \pm 0.15$ by the first Born approximation, much higher contrast ratio $\varepsilon(\mathbf{r})/\varepsilon_{ext} > 10$ is necessary in industrial applications. Higher permittivity contrast is advantageous to clearer permittivity image, but the image border is obscure without correction of wavelength contraction in the program. A small object with the high contrast ratio causes a weak scattering wave, and its permittivity profile of ε(r) can be reconstructed in the weak scattering approximation. The scattering wave is weak when the diameter of a dielectric object is smaller than the wavelength of an illumination wave.

Permittivity profiles of three dielectric objects with the high contrast ratio of 5 are reconstructed by the Born approximation as shown in the Figure 1. Scattered waves are estimated by the finite-discrimination time-domain (FDTD) method. The contrast ratio of the permittivity is 10, and the diameter of the object is smaller than the wavelength of the probe wave. The permittivity image shows almost circular cross sections. The diameters are in the range from 1/8 to 1/2 wavelengths. The clear profiles are shown in both cases of 1/8 and 1/4 wavelengths. Some interference moire appears around the reconstructed object in the case of 1/2 wavelength diameter. In this case the estimation of phase shift and wavelength adjustment is not enough to reconstruct the precise permittivity around the object. The moire compensates the phase error in the CT reconstruction. When the diameter of the object is smaller than 1/8 wavelength, the scattered wave is too weak to be detectable of the CT device. Such situation is in region of Rayleigh scattering, and the scattered power is proportional to $(\text{wavelength})^{-4}$. When wavelength of the prove wave is adequately selected in according to the object diameter and wave adjustment, its CT are easily reconstructed by the Born approximation method in very short calculation time.

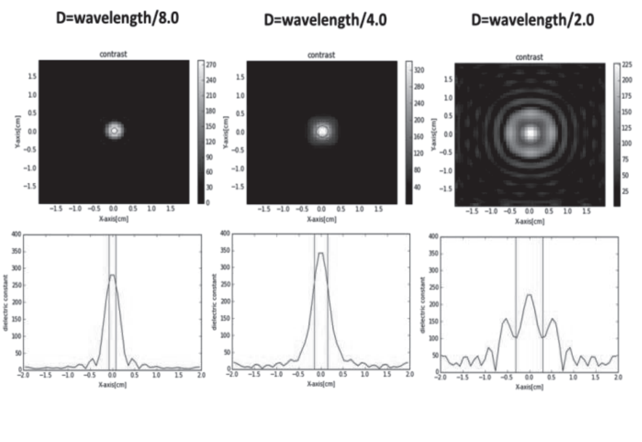

Fig. 1 Permittivity image calculated by the Born approximation (left) and the back projection image calculated of scattered wave (right).

1) B. Tobias. et al.: Plasma Fusion Res. **6** (2011) 2106042.