Microscopic Structure Imaging with Phase Analysis at 60GHz band

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***Abstract*—This study aims imaging and permittivity measurement for microscopic structure at 60GHz band. Main device is the waveguide type probe which has a 0.5mm aperture on the terminal wall. Using this probe, a cherry leaf is measured as a demonstration of thin film measurement. Permittivity is obtained on vein and mesophyll. Image is obtained for 5×2.5mm region with 0.25mm step.**

I. Introduction

THE study of microscopy at THz wave band has been flourishing for diagnosis of bio-, nano- and micro-structures. In the structure diagnosis THz wave has the advantages over shorter wavelength. THz wave gives no harm to the sample because of lower energy and is able to pass through dielectric sample. A narrowed aperture less than the wavelength is used to realize highly spatial resolution by limiting the illuminated region of the sample[1]. In our works, the waveguide type Microscopic Aperture Probe (MAP) has been employed[2-4]. As shown in fig. 1, MAP is made of WR-15 waveguide with one end shielded with 6mm square metal plate of 0.3 mm thickness, on which a 0.5 mm circular aperture is formed.

In order to demonstrate film measurement by MAP, in this paper permittivity measurement and imaging about Japanese cherry leaf (Prunus yedoensis) are shown based on phase analysis.

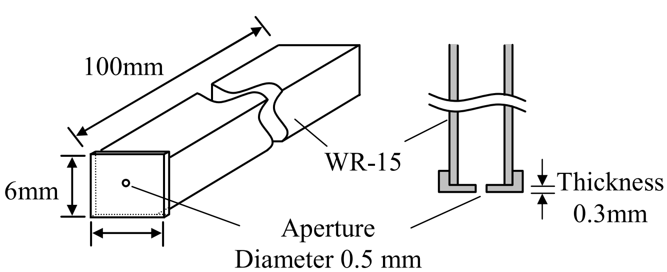

Fig. 1. Outline of the microscopic aperture probe.

II. Measurement System

Vector network analyzer MVNA8-350 (AB millimeter, France) is used to measure the transmission characteristics. Original source is generated by YIG oscillator for 8-18GHz and is multiplied by Schottky barrier diode. In V-band, it is possible to sweep continuously for 47-72GHz every 40 kHz. Accuracy of amplitude is 0.1 dB and phase is 0.4 degrees.

MAP is installed for the transmission side and horn antenna is for the receiving side. These apertures face each other 268mm apart. Surface of MAP is covered by 0.05mm-thick Teflon (PTFE) sheet to prevent harm from the leaf sample. The leaf sample is placed on xyz-axis stage to adjust the position and put to MAP aperture without gap.

III. Permittivity Measurement

Permittivity is obtained from the slope of phase difference between the case of free-space transmission with and without the dielectric sample[5]. Relative permittivity ε_r is given by

$$\varepsilon_r = \left(\frac{\Delta\phi}{1.2\,t} + 1\right)^2 \tag{1}$$

where $\Delta\phi$ (degree/GHz) is the slope of phase difference, and t (mm) is the thickness of the sample. In usual case the transmission and the receiving antennas are horn antenna, and spatial resolution of permittivity will be close to the wavelength. If MAP is used instead of horn antenna, the resolution can be improved.

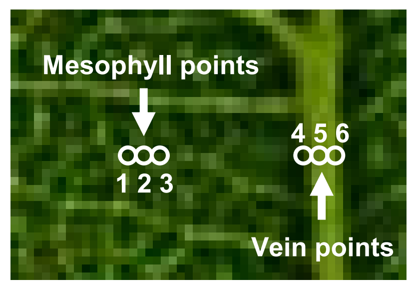

Fig. 2. Measured points for permittivity.

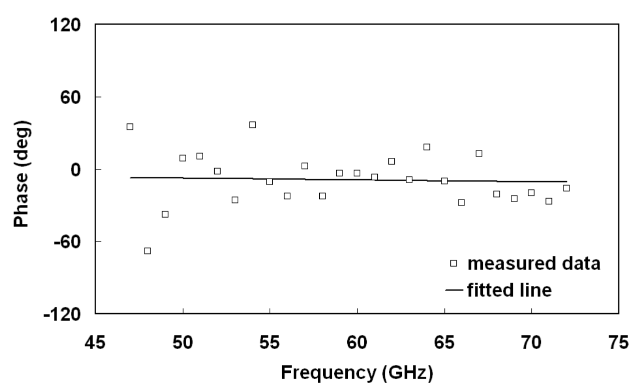

Fig. 3. Phase slope measurement on mesophyll (at point 1).

Permittivity of cherry leaf is measured for three points at the mesophyll part and the vein part respectively which are shown in fig. 2. Thicknesses measured by a micrometer are 0.73 at the vein and 0.16mm at the mesophyll respectively. Frequency is swept over 47-72GHz with 1GHz step. One result of phase slope measurement on the vein and mesophyll is shown in fig. 3 and 4. Square points show the measured phase differences, and

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the solid line is derived by fitting with downhill simplex[5]. Measured phase has variance because small aperture makes the transmission faint. Fitted line, however, could show good approximation[2].

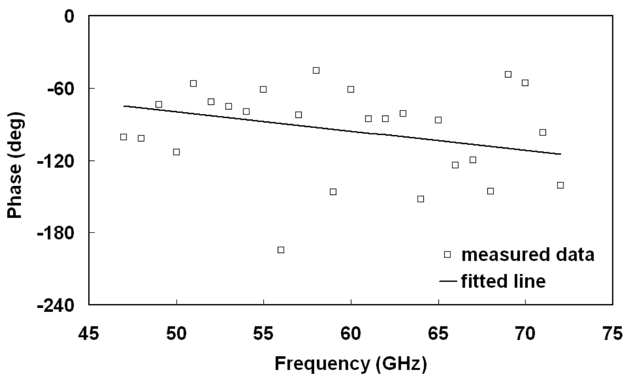

Fig. 4. Phase slope measurement on vein (at point 4).

As the result, mesophyll permittivities are 3.2, 2.5 and 1.3 and the average is 2.3. Vein permittivities are 8.0, 8.0 and 8.5 and the average is 8.2. Therefore vein shows more phase delay by thickness and permittivity than mesophyll.

IV. Imaging with Phase Slope

Phase slope distribution of a cherry leaf is obtained as the image. Scanning is made for 5×2.5mm region with 0.25mm step as shown in fig. 5. The result is shown in fig. 6. It takes about one minute to obtain one pixel; consequently water content of the leaf might be gradually decreased. The center thick vein is clearly shown as dark shadow because of larger phase delay. This result shows MAP can recognize the vein which is thinner than the wavelength. In addition, the right oblique thin vein might be shown slightly.

Assuming that permittivities of vein and mesophyll are 8.2 and 2.3 respectively, phase slope less than -0.5 shows vein and the other shows mesophyll, the leaf thickness distribution can be estimated from the phase slope distribution and eq. 1 as shown in fig. 7. Because of assumptions the image is not so accurate. This method, however, can be used for the diagnosis of film thickness distribution or the void detection of the inside of dielectric material.

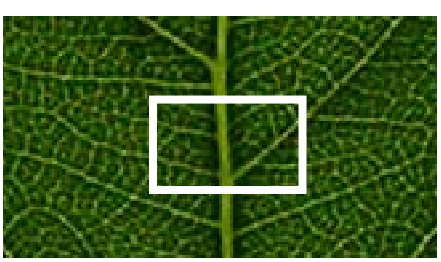

Fig. 5. Leaf sample and scanned region.

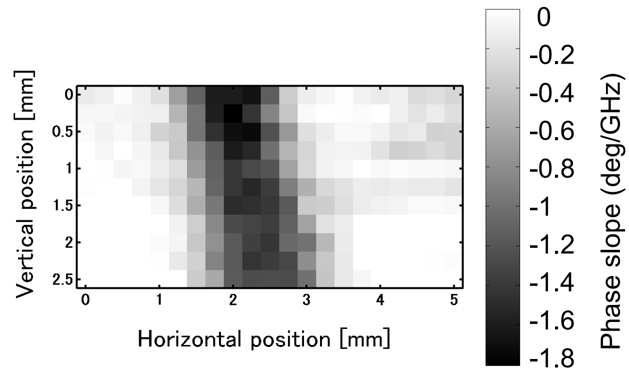

Fig. 6. Leaf imaging with phase slope.

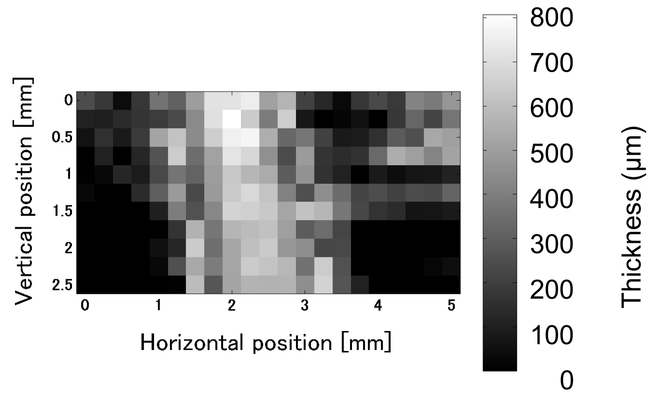

Fig. 7. Leaf thickness estimation.

V. Conclusion

Through the phase slope, permittivity of cherry leaf was measured and the leaf image was obtained in the narrower region than wavelength. Furthermore the leaf thickness was estimated. This method can realize measurements of film thickness distribution, void detection and material characteristics.

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