

Reflection Spectroscopy on Solutions of Biological Materials in Millimeter Wave Frequency

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Abstract— We attempted to analyze a solution of biological matter of sugars, amino-acids, and electrolytes using a millimeter-wave reflection spectroscopy. The sensitivity for the concentration of solutes was improved markedly, when an adequate dielectric layer was inserted at the interface of incident side of the solution as impedance matched layer. The sensitivity was covered fully in the range of adequate blood sugar level of human as 0.07-0.16 g/100ml H₂O in the case of glucose solution.

I. INTRODUCTION

Terahertz (THz) spectroscopy is a novel technology that is just beginning to be applied to many applications, yet its technological development is still in its infancy. Nevertheless, THz imaging has unique characteristics that have already found some niche applications inaccessible to other imaging technologies. In the last few decades, perceived applications in scientific research and information communication have been achieved because of the rapid development of the technology for the generation and detection of THz waves.

THz technology has numerous advantages such as the radiation is non-ionizing and does not damage a measuring object, and the waves of THz can identify intermolecular stretching, hydrogen bond stretching, and crystal lattice modes of organic compounds with certain penetration characteristics. On the other hand, water, the most important matter in life, has a remarkable THz-wave absorption; hence most THz studies have avoided aqueous materials.

In this study, we attempted to analyze solutions of biological materials using a millimeter-wave reflection spectroscopy in the range from 20 to 43.5 GHz. As a system, network analyzer (N5244A, Agilent Technologies) has been used with a conversion adaptor from coaxial to waveguide for s-parameter measurement. It is notable that an adequate dielectric layer with some refractivity and a thickness was inserted at the incident interface of air and the solution to improve the sensitivity for the solved biological materials for reflection spectroscopy. The system and the principle of measurement are shown in Fig. 1.

When we consider a lossless dielectric layer (medium 1), Fresnel coefficients at the interface of medium 0 /medium 1, and medium 1/medium 2 are

$$\rho_0 = \frac{n_0 - n}{n_0 + n}, \text{ and } \rho_1 = \frac{n - n_m}{n + n_m}, \text{ respectively,}$$

where, n_0 , n , and n_m are the refraction factors of medium 0, medium 1, and medium 2, respectively. The reflectance can be written as

$$R = 1 - \frac{4n_0 n^2 n_m}{n^2 (n_0 + n_m)^2 - (n_0^2 - n^2)(n^2 - n_m^2)} \sin^2 \delta,$$

where, phase variation δ can be written as $\delta = 2\pi nd/\lambda$. If $nd = 4/\lambda$, then $\delta = \pi/2$, here d is the thickness of medium 1. We can

achieve $R = 0$, at the condition of

$$\frac{4n_0 n^2 n_m}{n^2 (n_0 + n_m)^2 - (n_0^2 - n^2)(n^2 - n_m^2)} = 1,$$

to give

$$(n^2 - n_0 n_m)^2 = 0, \text{ therefore, } n = \sqrt{n_0 n_m}.$$

This condition leads so-called impedance matching of the incident wave and the reflection wave.

The reflection spectra were measured on a glucose solution covered with polyethylene (PE) as dielectric material in the range 23 to 42 GHz. When we chose an adequate refraction factor and a thickness of the dielectric film as shown in following formula, the condition leads impedance matching of the incident wave and the reflection wave, then, the reflection intensity should be minimized.

$$n^2 = n_0 n_m, \text{ and } 2nd = \lambda/2.$$

Here, n , n_0 , and n_m are the refraction factors of PE, air, and the solution, respectively, and d is the thickness of PE layer.

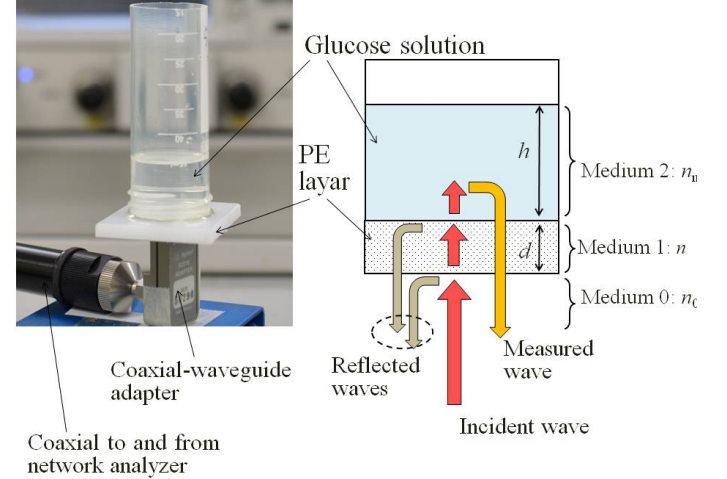


Fig. 1. Photo of the system of reflection spectroscopy on a glucose solution, and a diagram of wave reflection from the structure of test sample.

II. RESULTS

To confirm impedance matching of the incident wave and the reflection wave, the reflection spectroscopy on distilled water via PE layer was measured as a parameter of PE layer thickness. The distilled water was selected instead of glucose solution for a constant value of n_m , and the height, h was selected enough high as 18 mm. As shown in Fig. 2, when we use a matching-like thickness of 1.61 mm-thick PE layer, the intensity was minimized about -30 dB at 28.8 GHz in comparison with a mismatching-like film of 3.00 mm-thick PE

layer. From the results, 1.61 and 1.82 mm-thick PE layer may be suitable to minimize the reflection, however 1.61 mm-thick one seems like suitable, because of the lowest reflection intensity at near the center of measured frequency region, then, we adopted 1.61 mm-thick PE as for the following measurement of reflection spectroscopy on glucose solutions.

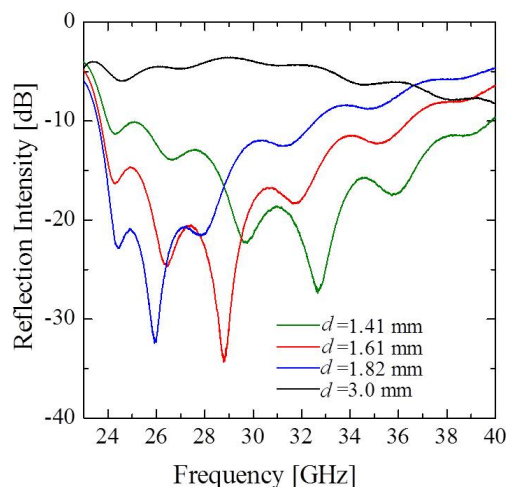


Fig. 2. Reflection spectra on distilled water covered with 1.41, 1.61, 1.82, and 3.00 mm-thick PE layer measured by network analyzer in the range from 23 to 42 GHz.

The reflection spectra measured on various concentration of glucose solutions covered with 1.61 mm-thick PE as impedance matched layer are shown in Fig. 3. As shown in left figure, the valley at the impedance matched frequency was observed at near 28.8 GHz in a wide range of glucose concentration, and the intensity at the valley was decreased drastically with increasing the concentration. And the frequency of the valley tended to shift toward lower frequency with increasing the concentration.

As shown in a narrow range of the concentration (right), the reflection intensity of matched valley at 28.8 GHz responded on the concentration from 0 to 1 g/dl with a high accuracy.

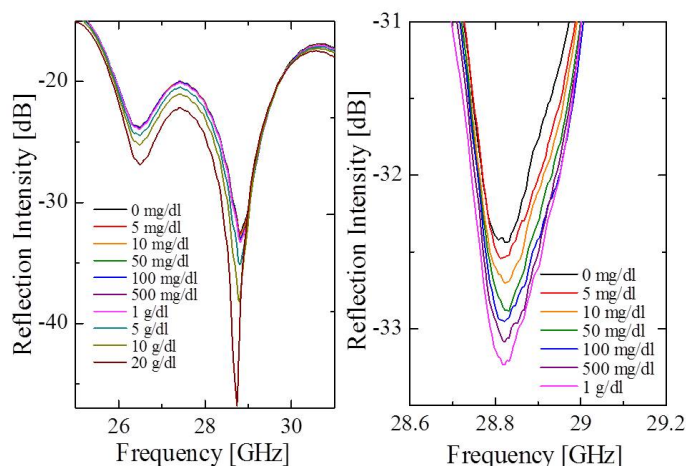


Fig. 3. Reflection spectra on glucose solutions covered with 1.61 mm-thick PE as a parameter of glucose concentration measured in the range from 23 to 42 GHz (left), and their expansion at the parameter from 0 to 1 g/dl (right).

The deviation ratio from zero concentration of reflection intensity on glucose solutions in the case of 1.61 mm-thick PE

are shown in Fig. 4, in comparison with a mismatching-like film of 3.00 mm-thick PE. In a wide range of the concentration from 0 to 20 g/dl (left figure), the deviation ratio of reflection intensity decreased almost linearly with increasing the glucose concentration in both case of PE thickness. Here, the sensitivity for the concentration of glucose was improved markedly in the case of 1.61 mm-thick PE, because the rate of concentration change was about 4 times larger than the case of 3.00 mm-thick PE.

On the other hand, the deviation ratio of reflection intensity decreased proportionally to the logarithm of glucose concentration in the range from 0 to 1 g/dl, as shown in right figure of Fig. 4. The sensitivity covered full range of adequate blood sugar level of human in the range of 0.07-0.16 g/dl. In addition, we found that this method has been performed successfully for the solution of several amino acids, and electrolyte, as will be shown in other paper.

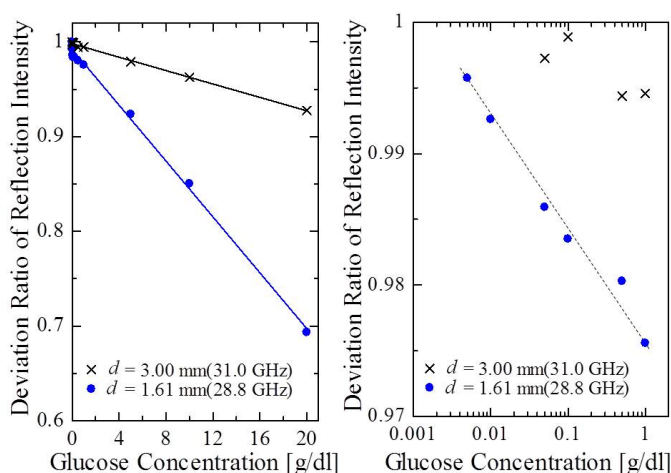


Fig. 4. Deviation ratio from zero concentration of reflection intensity on glucose solutions in the case of 3.00 mm-thick PE at 31.0 GHz and in the case of 1.61 mm-thick PE at 28.8 GHz (left), and its expansion at the parameter from 0 to 1 g/dl (right).

III. SUMMARY

We attempted to analyze a solution of biological matter by the use of millimeter-wave. A sensitive detection of reflection spectroscopy on glucose solution in millimeter wave frequency has been performed by the use of impedance matched dielectric layer at the interface of incident side of the solution. The sensitivity was improved dominantly in comparison with mismatched layer. This method will be able to apply effectively for some kinds of amino-acid solutions and a few electrolyte solutions.

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