Measurement of complex permittivity for biological cells at 1.7-2.6GHz by waveguide penetration method

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Abstract

In vitro studies to investigate biological effect of electromagnetic field are performed for microwave to millimeter-wave frequency band. A reliable measurement method of complex permittivity for biological cells is required for the dosimetry. The feasibility of applying the waveguide penetration (WP) method to measure complex permittivity for cells in the frequency range from microwave to millimeter-wave frequency band is investigated. In this study, complex permittivity measurement was performed at microwave frequency band from 1.7 to 2.6 GHz by the WP method, as a preliminary study. Lichtenecker's logarithm mixed law was applied to estimate macroscopic complex permittivity for cells. As a result, real part and imaginary part of complex permittivity of CHO-K1 cell were estimated to be 60.2 ~ 62.9 and 3.0 ~ 3.2, respectively.

1. Introduction

Recently application of the millimeter-wave frequency band is expected to increase. The opportunity that common people are exposed to millimeter-wave will increase. Thus, it is worth evaluating the effect of the millimeter-wave on the biological body.

Currently, we are preparing to investigate biological effect of microwave to millimeter-wave frequency band on the biological body by *in vitro* study. Electromagnetic field dosimetry is required to evaluate the effect of high frequency electromagnetic field (EMF). Theoretical, numerical, and experimental approaches have been examined to estimate specific absorption rate (SAR) for *in vitro* studies [1, 2]. In any cases, reliable values of complex permittivity for biological cells are required. Also, WHO announced that obtaining the permittivity data of biological tissue is overarching issue in EMF project [3]. The evaluation of effect of EMF exposure on cells and substructure of cells is required for future study. In past works, there are few studies to measure complex permittivity for cells [4, 5]. Those studies are performed in the frequency range from 45 MHz to 26.5 GHz, and indicated effectiveness to measure complex permittivity of cells. However, those studies do not consider measuring complex permittivity at millimeter-wave frequency band. We focused this study on the waveguide penetration (WP) method developed by Nishikata [6] as a candidate for measuring complex permittivity from microwave to millimeter-wave frequency band.

In this paper, we tried WP method in the microwave frequency band from 1.7 to 2.6 GHz, as a preliminary study. The purpose of this study is to estimate macroscopic complex permittivity for biological cells, by applying Lichtenecker's logarithm mixed law (LLML) from the effective complex permittivity, which is mixed value of cells and it's isosmotic liquid. The volume of specimen is required more than 100 ml by the coaxial-line probe (Agilent 85070E), which is widely used. It can measure complex permittivity in the frequency range from 200 MHz to 20 GHz. On the other hand, the volume of specimen is required less than 1.5 ml in the frequency range over 1.7 GHz in the WP method. When measuring complex permittivity over the 1.7 GHz, the WP method requires much less volume than the widely used method. Thus, it is thought that the WP method has an advantage in the preparing volume of specimen over coaxial-line probe method.

2. Waveguide penetration method

Figure 1 shows a schematic diagram for the WP method. This is a method to perform two-port scattering parameters measurement by a vector network analyzer. Complex permittivities are estimated numerically by measured scattering parameters in three conditions, waveguide inserted dielectric tube filled with specimen, waveguide inserted dielectric tube without specimen, and waveguide only. The detail of the theory to estimate complex permittivity is explained in Refs. [6, 7].

As a preliminary study, the measurement frequency range was selected from 1.7 to 2.6 GHz, which is restricted by the waveguide dimension shown in Fig. 1. The dielectric tube is made of PMMA, and the dimensions are shown in Fig. 1. The volume of the specimen is less than 1.5 ml. If the coaxial-line probe (Agilent 85070E) is used for this frequency range, the volume of specimen is required more than 100ml. Thus, this method has an advantage over the coaxial-line probe method in the volume, because required volume of prepared specimen is approximately 1/60 less than that of the coaxial-line probe method.

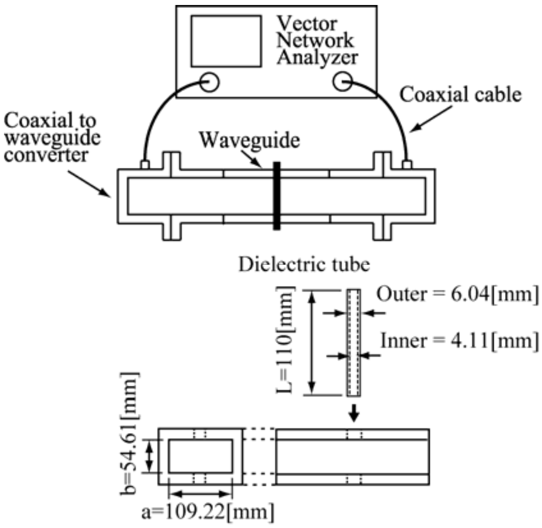

Figure 1: Schematic diagram of waveguide penetration method.

3. Results

3.1 Evaluation of reliability by measuring deionized water

The performance of this system was evaluated by measuring deionized water. The measured data were compared with the value calculated by Debye's model [8]. The measurements were performed five times, and the obtained data were averaged. The temperature of measurement was approximately 25.6 ^{o}C. Figure 2 shows the complex permittivity of deionized water. Figure 2 (a) and (b) indicate dependence of real part (ε') and imaginary part (ε'') of measured complex permittivity on the frequency, respectively. The solid line indicate theoretical vale which was calculated with Debye's model at 25 ^{o}C, and the markers on the dotted line indicate the measured values. The measured values fairly agreed with the calculated value. The relative errors between the measurement and the calculation were less than ± 4 %. The reliability of the WP method was confirmed by the measurement of deionized water in this frequency range.

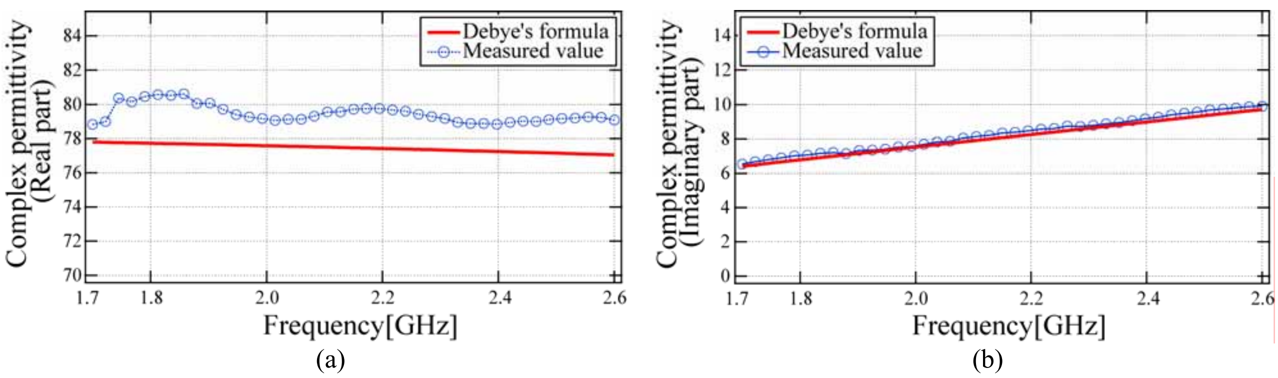

Figure 2: Dependence of complex permittivity of deionized water on the frequency. (a) Real part (ε'), (b) Imaginary part (ε''). The solid line indicate theoretical vale which was calculated with Debye's model at 25 ^{o}C, and the markers on the dotted line indicate the measured values.

3.2 Estimation of complex permittivity for biological cell

In this study, we tried to make an estimation of complex permittivities for biological cells by LLML [5]. According to LLML, the effective complex permittivity for the mixture of two kinds of dielectric materials is expressed by Eq. (1).

$$\log(\varepsilon^*_{eff}) = v_1 \log(\varepsilon^*_1) + v_2 \log(\varepsilon^*_2)\,, \tag{1}$$

where ε^*_{eff} is the effective complex permittivity of mixed sample, ε^*_1 and ε^*_2 are complex permittivities, and v_1 and v_2 are the volume ratios of each dielectric material, respectively. Here, $v_1 + v_2 = 1$ must be satisfied. This formula means that the effective complex permittivity of the specimen which consists of two kinds of dielectric material is obtained by the relationship of each complex permittivity and volume ratio.

The complex permittivity of Chinese hamster ovary (CHO)-K1 cell was tried to be measured as a sample of biological cell. Here, Ham's F-12 medium (purchased from Nikken bio medical laboratory Co., Ltd, Japan) including 10 % fetal bovine serum was used to cultivate the cell. In this study, Ham’s F-12 was assumed as isosmotic liquid for the cell. In order to estimate the complex permittivity of CHO-K1 cell by Eq. (1), two kinds of specimens were measured. One is the medium (Ham’s F-12) with the cells dispersed homogeneously, the other is only medium. The volume ratio of the cell in the mixed sample was approximately 5.2 %. The measurements were performed five times with each specimen, and the obtained data were averaged. Each temperature of measurement was approximately 27.1 ^{o}C. Figure 3 shows the complex permittivity of mixed sample and only medium. Figure 3 (a) and (b) indicate dependence of ε' and ε'' of complex permittivities on the frequency, respectively. The solid line and the dotted line indicate measured values of Ham’s F-12 with CHO-K1 cell and only Ham’s F-12, respectively. It was found that the complex permittivity of mixed sample was different from that of only medium. Both ε' and ε'' of the mixed sample were smaller than those of only medium all over the measured frequency range. Thus, ε' and ε'' of CHO-K1 cell were estimated smaller than those of only medium.

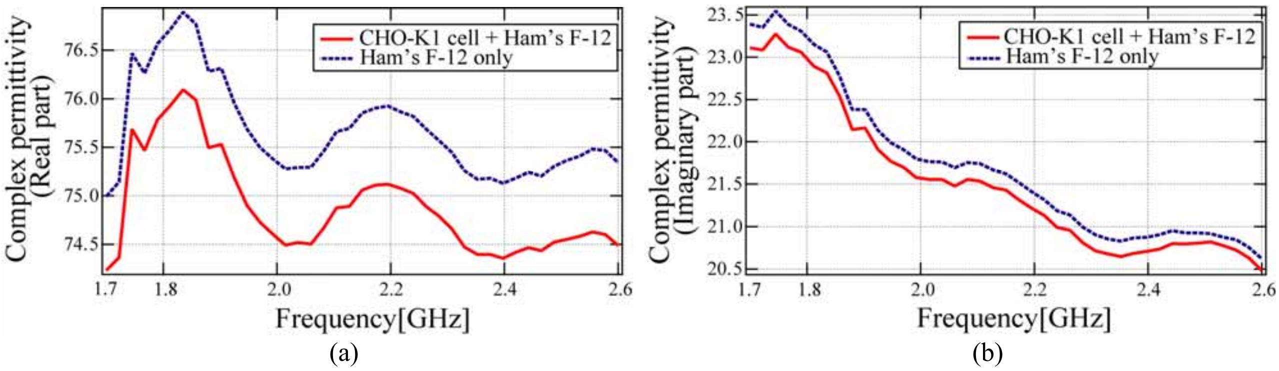

Figure 3: Dependence of complex permittivity of mixed sample and only medium on the frequency. (a) Real part (ε'), (b) Imaginary part (ε''). The solid line and the dotted line indicate measured values of Ham’s F-12 with CHO-K1 cell and only Ham’s F-12, respectively.

Figure 4 shows the estimated value of complex permittivity, which was obtained by substituting the measured values of ε' and ε'' shown in Fig. 3 for Eq. (1). The solid line and the dotted line indicate the estimated values of ε' and ε'', respectively. ε' and ε'' of CHO-K1 cell were estimated to be 60.2 ~ 62.9 and 3.0 ~ 3.2, respectively. It was found that the dependence of ε' and ε'' on the frequency was relatively small. From these measurement results, it was suggested possible to measure macroscopic complex permittivity of biological cells by the WP method. However, we have to confirm the reliability in accuracy for these results, because the volume ratio of the cell was too small in applying LLML. It is thought that approximately more than 40 % volume ratio for target cell is required to obtain appropriate result with LLML.

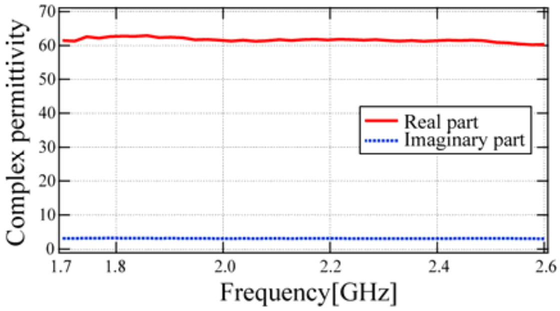

Figure 4: Dependence of the estimated complex permittivity of CHO-K1 cell on the frequency. The solid line and the dotted line indicate the estimated value of ε' and ε'', respectively.

4. Conclusions

In this study, we tried the WP method in the microwave frequency band from 1.7 to 2.6 GHz, and estimated complex permittivity of CHO-K1 cell by applying LLML. As a result, ε' and ε'' of CHO-K1 cell were estimated to be 60.2 ~ 62.9 and 3.0 ~ 3.2, respectively. Since it is a preliminary study, more consideration is required to improve the accuracy of measurement.

In the future study, we plan to estimate the complex permittivity of biological cells in millimeter-wave frequency band from 50 to 75 GHz with the same method. The volume of specimen is required less than 5 μl in that frequency range. The volume ratio of biological cells in the mixed specimen will be easily increased. We expect to obtain good performance in the accuracy of measurement in the millimeter-wave frequency range by the WP method.

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