PULSE MODULATED MICROWAVE IRRADIATION SYSTEM TO CULTURE CELLS

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Abstract

It has been accepted that humans and animals are affected by thermal and non-thermal effect under microwave irradiation. In this paper, to discuss the non-thermal effects of microwaves at cellular level, microwave exposure system to irradiate pulse modulated microwaves to the culture cells has been developed. In the system, the culture cells are inserted inside a cavity resonator and slight carrier frequency sweeping method is applied to obtain accurate temperature of the culture medium while subjected to pulse modulated microwave irradiation.

1. INTRODUCTION

It has been accepted that the biological systems are affected by the exposure of electromagnetic (EM) waves because the human tissue suffers functional disturbance or structural alterations[1]-[3]. Some effects are used for treatment purposes because some effects may improve the efficiency of certain physiological processes[4], [5]. Most of the biological data can be explained by thermal energy conversion. However some data can not be explained by the thermal energy conversion, which shows unique effects. Recently, thermal effects to the human health have been investigated and microwave exposure protection guidelines, which are formulated. The guidlines are based on the thermal effects [6], [7]. On the other hand, it is very important to know the non-thermal effects of EM wave exposed to the human body.

The authors have studied the non-thermal effects of EM field to culture cells by applying the pulse modulated microwaves, although it is difficult to distinguish between the thermal effects and the non-thermal effects[8].

In this paper, to study the non-thermal effects of EM field to culture cells, an adequate equipment to irradiate pulse modulated microwaves to cells have been made. The temperature characteristics of the complex permittivity of culture medium have been measured and to obtain real time temperature of the culture cells, the method of slightly sweeping carrier frequency is applied. Theoretical considerations for applying electric field is discussed.

2. THEORETICAL CONSIDERATIONS

A. Perturbation Theory Using Cavity Resonator

To irradiate pulse modulated microwaves to culture cells, the following conditions should be satisfied. The equipment should be designed to be isolated from outside circumstances and a sample is not affected by microwaves leaked from the equipment and the equipment can expose EM field on a sample uniformly and stably. The cavity resonator satisfies with these conditions. The cavity whose dimensions are 400mm × 200mm × 900mm developed in this study is shown in Fig. 1. With sliding movable short plunger, resonance frequencies can be varied. The magnetic coupling method is applied to excite TE_{102} mode EM field distribution inside the cavity. When the cavity is at the resonant state, the following equations are satisfied.

$$\omega = \omega_r + j\omega_i \tag{1}$$

$$\frac{2\omega_i}{\omega_r} = \frac{1}{Q_L} \tag{2}$$

where ω_i is the resonance angular frequency, ω_r is the loss angular frequency and Q_L is the loaded Q of the cavity. When the cell cultured flask is inserted at the maximum point of the electric field in the cavity, the resonant frequency is changed as follows;

$$\frac{\delta\omega}{\omega} = \frac{\omega_2 - \omega_1}{\omega_1} \approx \frac{\omega_{r2} - \omega_{r1}}{\omega_{r1}} + \frac{j}{2}\left(\frac{1}{Q_{L2}} + \frac{1}{Q_{L1}}\right) \tag{3}$$

where suffix 1 represents the state before sample is inserted, and suffix 2 represents the state with sample insertion. The volume of the culture medium inside the flask which is V_2 is small enough compared to the one of the cavity which is V, therefore the following equation can be obtained.

$$-\frac{\delta\omega}{\omega} = \frac{\int_{V_2}(\varepsilon_2 - \varepsilon_1)E_1 \cdot E_2^* dV + \int_{V_2}(\mu_2 - \mu_1)H_1 \cdot H_2^* dV}{\varepsilon_0 \int_V |E_1|^2 dV + \mu_0 \int_V |H_1|^2 dV} \tag{4}$$

where ε_0 is the dielectric constant in the air, μ_0 is the permeability in the air, ε_2 is the dielectric constant of the sample, μ_2 is the permeability of the sample. Here, the culture medium is nonmagnetic material, therefore $\mu_2 = \mu_0$ then,

$$-\frac{\delta\omega}{\omega} = \frac{\int_{V_2}(\varepsilon_2 - \varepsilon_1)E_1 \cdot E_2^* dV}{\varepsilon_0 \int_V |E_1|^2 dV} \tag{5}$$

From the static approximation, the following equations can be obtained.

$$\frac{(\varepsilon' - 1)\{1 + N(\varepsilon' - 1)\} + \varepsilon'' N}{\{1 + N(\varepsilon' - 1)\}^2 + (N\varepsilon'')^2} A = -\frac{f_{0s} - f_0}{f_0} \tag{6}$$

$$\frac{\varepsilon''}{\{1 + N(\varepsilon' - 1)\}^2 + (N\varepsilon'')^2} A = \frac{1}{2}\frac{1}{Q_s} \tag{7}$$

where f_0 is the resonant frequency without sample, f_{0s} is the resonant frequency with sample, ε' is the relative dielectric constant of the sample, ε'' is the relative loss factor of the sample and 1/Qs represents the loss of the sample. E_1 represents the maximum electric field in the cavity. From Eqs. (6) and (7), by measuring the resonant frequency and quality factor of the cavity with the sample, the complex permittivity of the one can be obtained.

B. Slight Carrier Frequency Sweeping Method

The complex permittivity of the cell culture medium is measured. Figure 2 shows the complex permittivity of the cell culture medium with pure water[9] as a function of the temperature. From Fig. 2, it is found that the complex permittivity of the cell culture medium is very sensitive to the temperature. When the pulse modulated microwaves is irradiated to the culture cells, the temperature of the one is inevitably raised. As is shown in the previous section, by measuring the resonant frequency and quality factor of the cavity with the sample, the complex permittivity of the sample can be obtained. Here, the complex permittivity is related to its temperature, the temperature can be estimated while pulse modulated microwave irradiation. To obtain the temperature of the culture medium, the reflection power from the cavity is measured with applying slight carrier frequency sweeping pulse modulated microwave.

3. EXPERIMENTS

The initial resonant frequency of the cavity is 523.0 MHz. The carrier frequency change as a function of time form pulse onset of the generated pulse is shown in Fig. 3. From Fig. 3, it is found that the carrier frequency is linearly changed as time from pulse onset. Under conditions that setting duty ratio of 0.5%, mean power of 5W, peak power of 1000W, pulse width of 10μs and period of 2000μs, absorbed power of the sample is measured around 81%. The temperature can estimated from the complex permittivity within the error of 5% compared to the actual temperature of the cell culture medium as shown in Fig. 4.

4. RESULTS AND CONCLUSIONS

The authors have investigated the system to study non-thermal effects of EM waves at cellular level under pulsed microwave irradiation. By slightly sweeping the carrier frequency of the pulse, the temperature of the culture medium can be obtained within the error of 5%.

In the future non-thermal effects of pulsed microwaves will be further studied using the cavity.

REFERENCES

[1] S. M. Michaelson, "Microwave Biological Effects: An Overview," Proc. IEEE, Vol. 68, pp. 40-48, Jan. 1980.

[2] E. H. Grant and F. P. Inst., "Biological effects of microwaves and radio waves," IEE Proc., Vol. 128, Pt. A., No. 9, pp. 602-606, Dec. 1981.

[3] M. Saito, "The effects to a living body under microwave environment," Television society Japan, Vol. 42, No. 9, pp. 945-950, 1988.

[4] G. Kantor, "Evaluation and survey of microwave applicators for local heating of tissues," IEEE Trans. Biomed. Eng., Vol. BME-31, pp. 28-37, 1984.

[5] Y. Nikawa, T. Katsumata, M. Kikuchi and S. Mori, "An electric field converging applicator with heating pattern controller for microwave hyperthermia," IEEE Trans. on MTT., Vol. MTT-34, No. 5, pp. 631-635, 1986.

[6] M. Taki, "Biological effects of microwave and protection guide for microwave exposure," MWE'92 Microwave Workshop Digest, pp. 135-143, 1992.

[7] Y. Amemiya, *et al*, "Researches on Biological and Electromagnetic Environment in RF and Microwave Regions in Japan", IEICE Trans. Commun., Vol. E77-B, No. 6, pp. 693-698, June 1994.

[8] S. Izumidate, Y. Nikawa, T. Ishihara, M. Masae and N. Kubota, "A Study on Biological Effects of Microwaves at cellular level", Spring National Convention of IEICE Japan, D-211, 1995.

[9] A. V. Hippel, *etal*, "Dielectric materials and applications", Technology press of M. I. T and John Wiley & sons, New York, pp. 361, 1954.

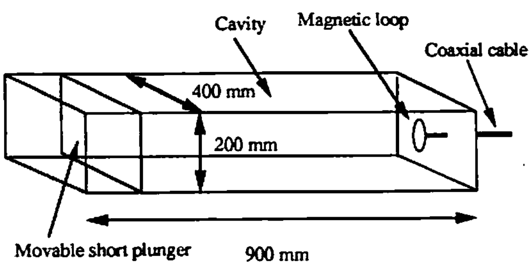

Fig. 1. Rectangular cavity to irradiate pulse modulated microwaves to the culture cell.

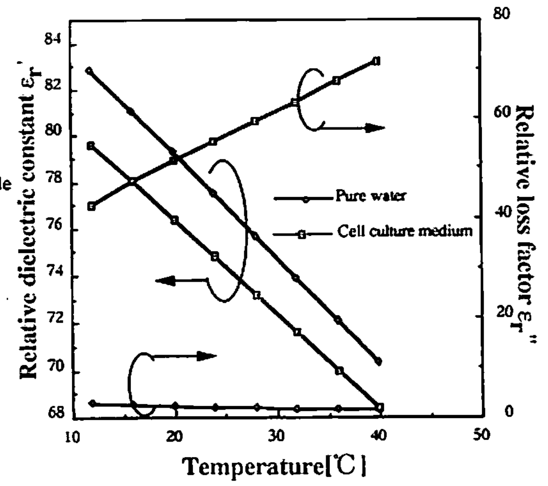

Fig. 2. Complex permittivity of cell culture medium as a function of temperature.

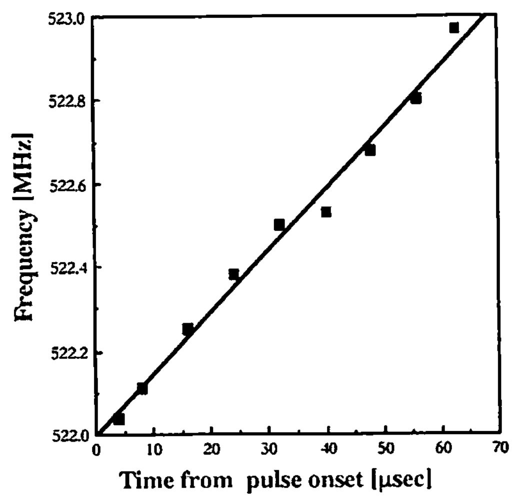

Fig. 3. Carrier frequency of the pulse modulated microwave versus time from pulse onset.

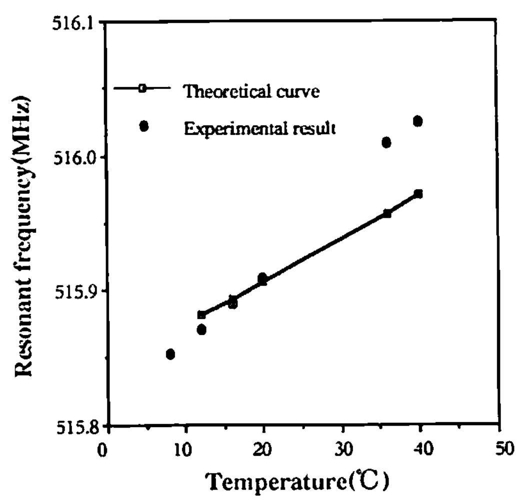

Fig. 4. Resonant frequency of the cavity versus temperature of the culture medium.