DIELECTRIC LOADED LENS APPLICATOR FOR MICROWAVE HYPERTHERMIA

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ABSTRACT—A new lens applicator for microwave hyperthermia which is combined with a partially dielectric-filled waveguide has been developed. The applicator can change heating pattern by changing the size of the dielectric material. The heating experiment of phantom modeling material of human muscle shows the maximum heating depth is around 70 mm and it confirms to realize deep and local heating for hyperthermia.

I. INTRODUCTION

Microwave heating for the human body has a great potentiality to realize localized hyperthermia. Nevertheless, skin depth for the human muscle in the region of microwave is less than around a few centimeter. This means that a deep heating in the microwave region is difficult. The development of microwave radiation method to the human body will improve this disadvantage. The author has been developed the lens applicator[1][2]. Such lens applicator, which has metal plates inside, can radiate focusing microwaves to penetrate them deep in the lossy medium, but the structure of the lens applicator was relatively complicated.

This paper describes a new lens applicator which is partially dielectric-filled waveguide and which can be fabricated easily. Microwave field distribution on the aperture of the applicator can be changed by using various size of the dielectric material. Therefore the heating pattern inside the medium can be changed. The applicator is compact and can heat deeper portion in the human body.

II. APPLICATOR DESIGN

The applicator with centered dielectric slab in water loaded waveguide is considered as shown in Fig. 1. Fig. 2 shows the aperture of the applicator with the parameter. The phase constant of the partially dielectric filled waveguide can be calculated as

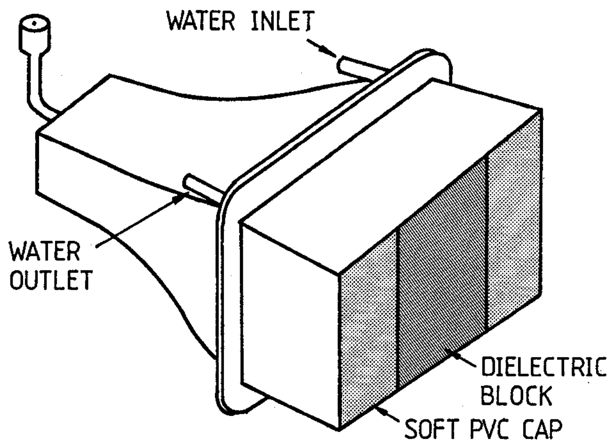

Fig. 1. Dielectric loaded lens applicator.

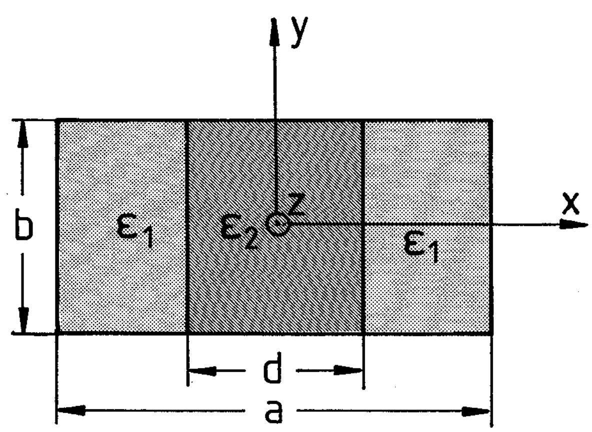

Fig. 2. The aperture of the applicator.

$$\frac{\beta}{k_1} = \sqrt{1 + \frac{\varepsilon_2 - \varepsilon_1}{\varepsilon_1}\left(\frac{d}{a} + \frac{1}{\pi}\sin\frac{\pi d}{a}\right) - \left(\frac{\pi}{k_1 a}\right)^2} \quad (1)$$

where k_1 is the propagation constant of water and β is the phase constant in the waveguide. For the center dielectric material, polyethylene ($\varepsilon_2 = 2.3$) is considered.

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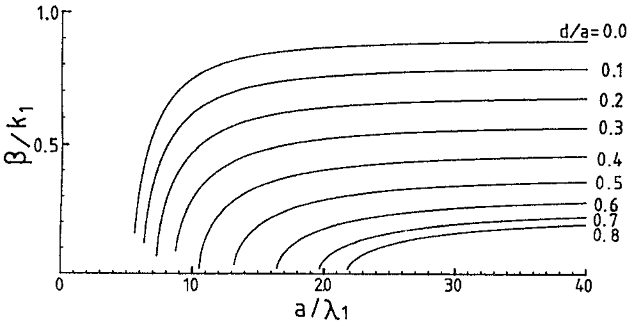

Fig. 3. Phase constant for a rectangular waveguide of the centered dielectric loaded.

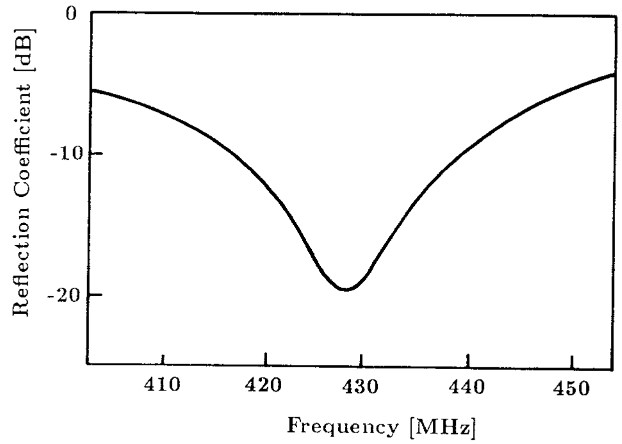

Fig. 4. Reflection coefficient of the applicator in function of the frequency.

The calculated result of β/k_1 in function of a/λ_1 is shown in Fig.3. From the result, the propagation constant inside the dielectric filled waveguide is smaller than the normal water loaded waveguide. The aperture size of the applicator was designed 150 mm × 100 mm and was designed to operate at 430 MHz. The applicator is fed by the magnetic field coupling. This coupling method makes the one compact and easy to handle. The reflection coefficient of the applicator in function of the frequency is shown in Fig. 4. From the result which is shown in Fig. 4, reflection coefficient of the applicator is around -20dB at 430 MHz and the bandwidth is relatively wide.

III. EXPERIMENT

Experiments were performed to measure the electric field distribution on the aperture of the applicator which is set in the 0.4 % NaCl solution as a electrically equivalent model of human muscle. Dielectric materials of various width d were prepared to set inside the applicator.

For the dielectric material of various size, electric field distribution on the aperture of the applicator (along the x-axis) and from the aperture of the applicator (along the z-axis) is shown in Fig. 5 and 6, respectively. The two-dimensional measurements of the electric field distribution in the 0.4 % NaCl solution were also performed. The results

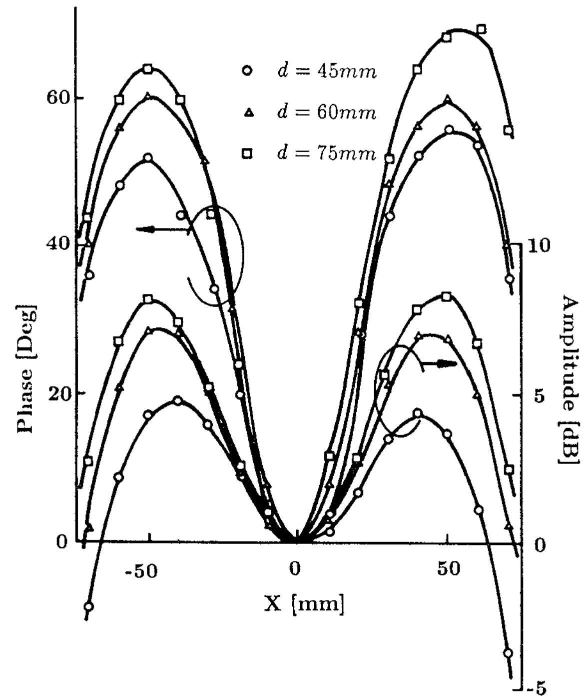

Fig. 5. Electric field distribution on the aperture of the applicator directly contacted to the simulated human muscle (0.4 % NaCl solution).

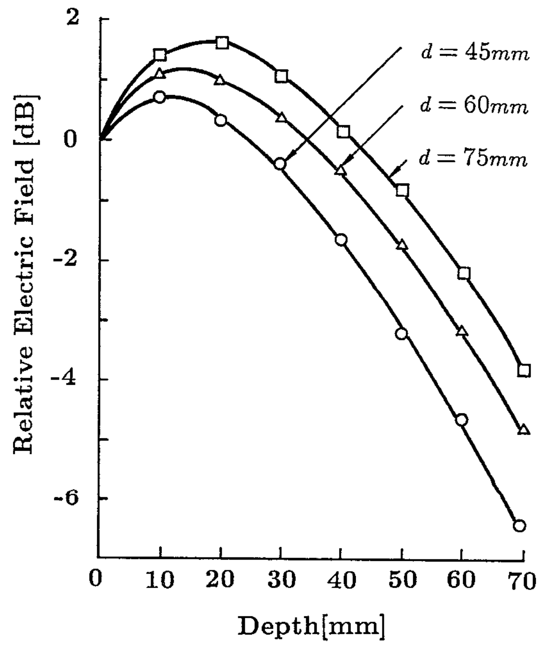

Fig. 6. Electric field distribution from the aperture of the applicator directly contacted to the simulated human muscle (0.4 % NaCl solution).

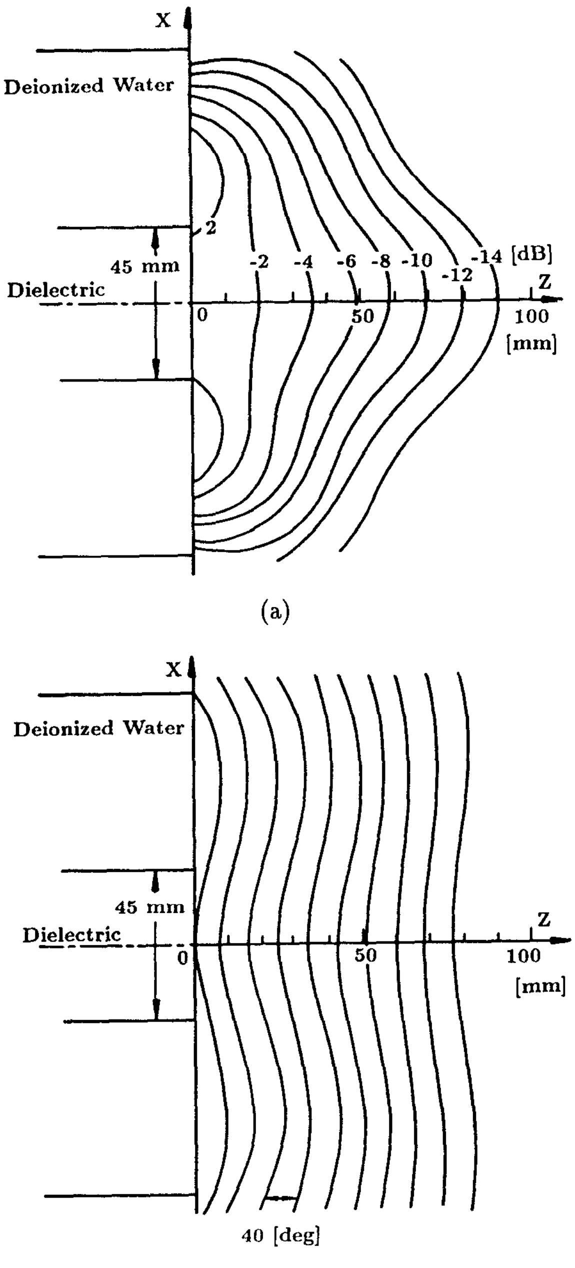

Fig. 7. Electric field distribution in the x-z plane of the simulated human muscle (0.4 % NaCl solution) from the aperture of the applicator using d=45 mm dielectric.
(a) Amplitude distribution.
(b) Phase distribution.

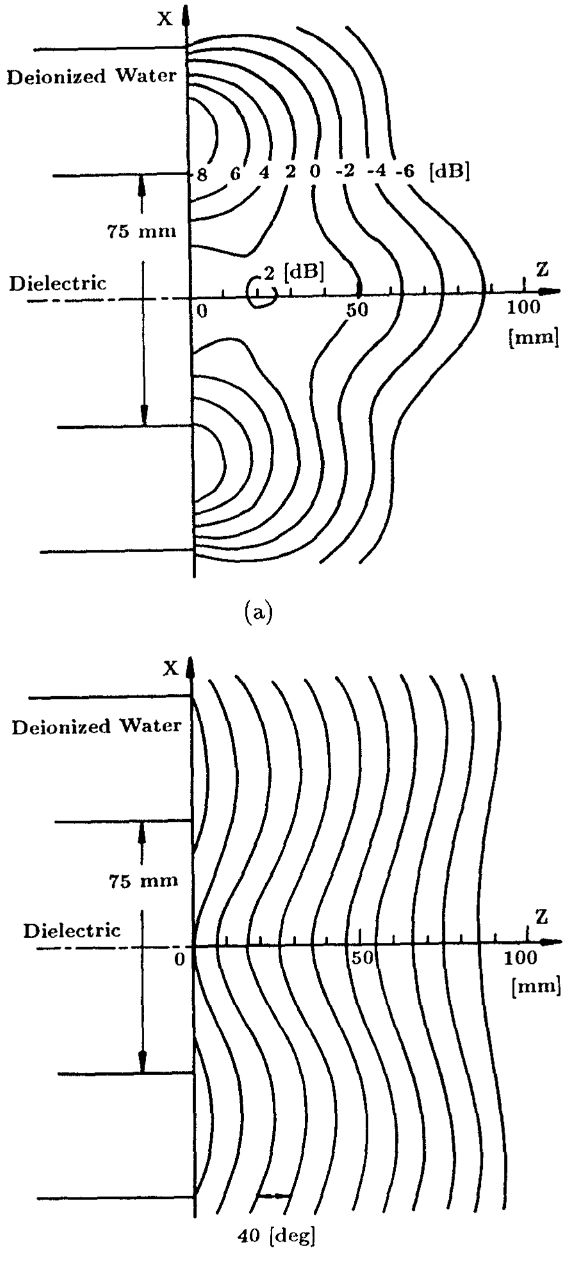

Fig. 8. Electric field distribution in the x-z plane of the simulated human muscle (0.4 % NaCl solution) from the aperture of the applicator using d=75 mm dielectric.
(a) Amplitude distribution.
(b) Phase distribution.

of the measurements in the case of d=45 mm and 75 mm are shown in Figs. 7, and 8, respectively. In Figs. 7(a) and 8(a), the electric field distributions are shown by a contour map which is normalized on the origin of the axes and with a contour interval of 2dB. In Figs. 7(b) and 8(b), phase distributions are shown by a contour map with a contour interval of 40 degree.

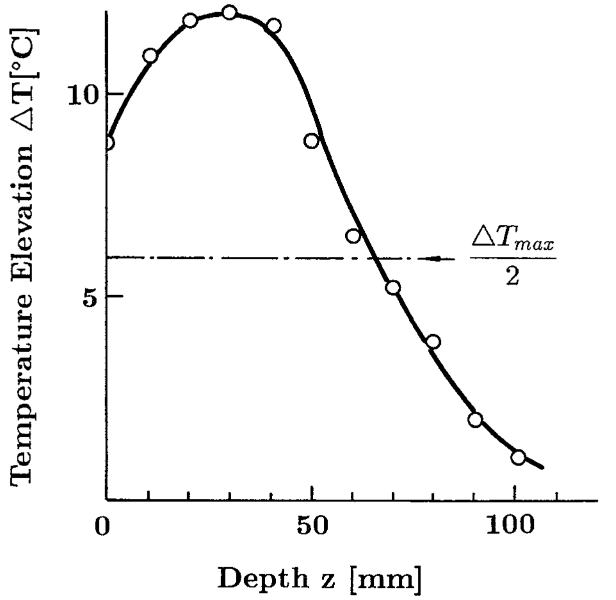

Fig. 9. Temperature elevation in the simulated muscle heated by the applicator (150W, 12 min.).

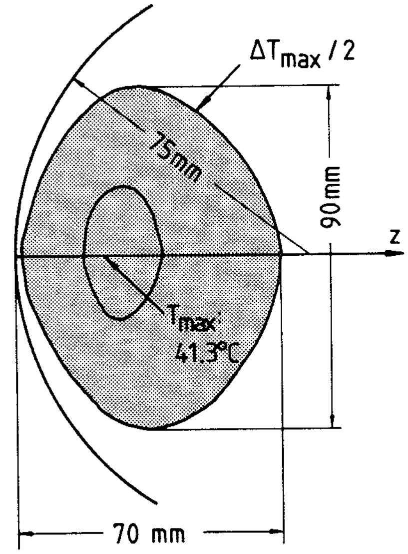

Fig. 10. Two dimensional temperature elevation distribution in the cylindrical simulated muscle heated by the applicator (100W, 10 min.).

IV. RESULTS

From Fig. 5, the phase of the side portion of the applicator is leading, thus the focusing effect of the radiated electric field is obvious. The angle of lead is over 60 degree in the case of using dielectric material of d=75 mm. The electric field distribution from the aperture of the applicator (Fig. 6) shows that the focusing effect can be changed by using the different size of dielectric material.

From the result of the two-dimensional electric field measurement, if the dielectric material of d=45 mm is used, uniform heating in the direction of the x direction will be realized. In this case, the deep heating will not be realized (see Fig.7(a)). On the other hand, if the dielectric material of d=75 mm is used, though it is necessary to apply surface cooling to reduce surface overheat at both side of the waveguide aperture, the maximum depth of the heating may be around 70 mm. Because the depth of the electric field decreasing than -3dB is 70 mm (see Fig.8(a)). For this purpose, thick bolus at the both sides also will be very useful to reduce the surface overheat. The converging effect of the electric field radiated from the applicator is also indicated by Figs. 7(b) and 8(b).

Fig. 9 shows the result of temperature distribution along z-axis in the phantom modeling material of human muscle (0.4 % NaCl, 0.02 % NaN_3, and 4 % Agar) measured after 430 MHz radiation (150 W, 12 minutes) using the applicator of d=75 mm dielectric material. In this case, the phantom model is directly contacted to the applicator. The result shows that the heating depth where the temperature is $\Delta T_{max}/2$ is over 60 mm.

Fig. 10 shows the two dimensional temperature distribution in the cylindrical shaped phantom modeling material of human muscle (diameter of 150 mm) measured after 430 MHz radiation (100 W, 10 minutes). The result shows that the heating depth is 70 mm. This result confirms the result of the electric field measurement.

V. CONCLUSIONS

430 MHz lens applicator with aperture size 150 mm × 100 mm has been developed. Converging effect of the electric field was observed particularly the width of the dielectric material d of 75 mm. The heating result of phantom modeling material of human muscle shows that the depth of heating where the temperature of $\Delta T_{max}/2$ is over 60 mm and if the cylindrical phantom material is used, the depth of heating is 70 mm. This result shows that the heating depth could be increased over by a factor of two over that obtained by a conventional waveguide applicator. The result is greatly useful for the deep and local hyperthermia.

REFERENCES

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