Characteristics of a Teflon rod antenna for millimeter and submillimeter wave irradiation on living bodies

研究報告 20

Characteristics of a Teflon rod antenna for millimeter and submillimeter wave irradiation on living bodies

Toshiaki TATSUKAWA, Akitaka DOI, Masato TERANAKA, Hitoshi TAKASHIMA, Fuminori GODA, Toshitaka IDEHARA,[1] Isamu Ogawa,[1] Tomohiro KANEMAKI,[1] Seiji NISHIZAWA[2] and Tunetoyo NAMBA[3]

Kagawa Medical University, Mikicho, Kagawa 761-0793, Japan

[1] *Research Center for Development of Far Infrared Region, Fukui University, Fukui 910-8507, Japan*

[2] *JASCO Corporation, Hachioji, Tokyo 192-0032, Japan*

[3] *Kagawa prefectural College of Health Science, Murecho, Kagawa 761-0123, Japan*

E-mail tatu@kms.ac.jp

Abstract

The development of a millimeter and submillimeter wave catheter for irradiation on living bodies using a Teflon rod dielectric antenna is described. The power sources of electromagnetic wave are an Impatt oscillator (90 GHz, 0.3 W) and a gyrotron (302 GHz, 30 W). Irradiation tests using various Teflon rod dielectric antennas were performed on beef livers. Irradiation results were considered by microwave theory and ray optics.

Key words; Irradiation on living body, catheter transmission, submillimeter wave gyrotron, Teflon rod antenna

1. Introduction

In the field of medical radiology, there is a growing interest in the possibility to treat various diseases (such as cancer) by the catheter irradiation of millimeter and submillimeter wave radiation. Such irradiation is promising because of the following advantages: 1) Millimeter and submillimeter wave radiology allows irradiation of a thin surface and of any spot size on a living body tissue by use of a waveguide vent antenna (WVA) and a Teflon rod antenna.[1~3] 2) The power absorption of a living body surface is large in these waves region, because the amplitude and phase of the wave are well controlled by microwave technique. 3) Millimeter and submillimeter waves can be transmitted by a slim catheter in the living body.

A novel system for applied medical studies, using one of gyrotrons developed at Fukui University (Gyrotron FU-IV), has been designed in collaboration with Kagawa Medical University. [1,4,5] The irradiated region of the living body is decided by characteristics of irradiation antennas. In order to obtain an appropriate irradiation tract, many shape rod antennas have been designed and tested. The preliminary tests of antennas are carried out using Gyrotron FU-IV and an Impatt oscillator as the radiation sources. In this paper, we describe the characteristic results of catheter irradiation using rod antennas in the submillimeter and millimeter wavelength range.

2. Experimental setup

2.1 Irradiation apparatus using Gyrotron FU-IV

The irradiation appratus using Gyrotron FU-IV as a radiation source is shown in Fig. 1. The left-hand side of the figure shows the gyrotron oscillator and the right-hand side, the catheter radiation system as reported previously. The catheter waveguides at the right-hand side are a straight or bend copper waveguides with inner diameters of 5 mm. The different shape dielectric rods are inserted into the tip part of catheter waveguides ; these are called dielectric rod antenna.

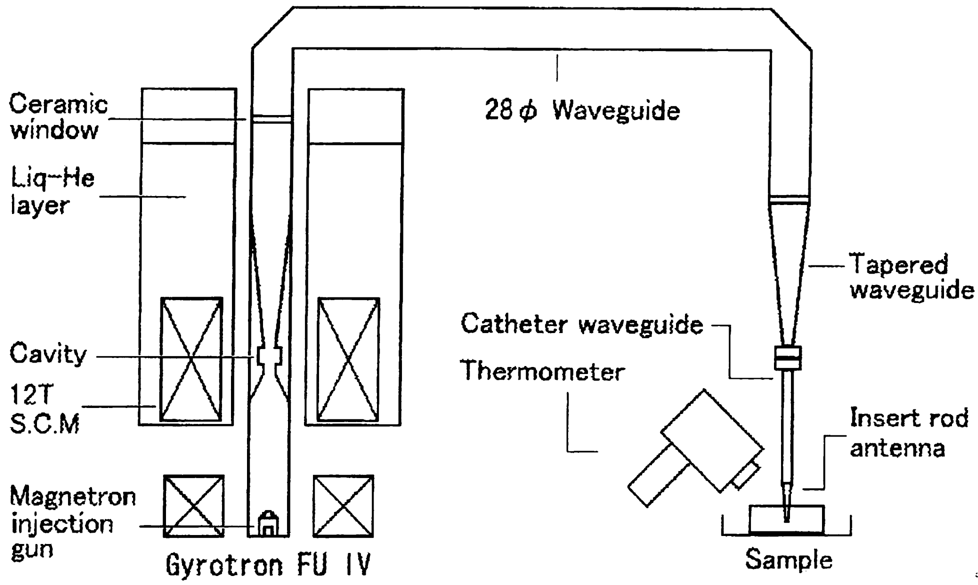


Fig. 1 Schematic of millimeter and submillimeter wave catheter irradiation apparatus for a living body using a rod antenna as a radiation antenna.

In order to study on the irradiation tract of radiation from the rod antenna, an another irradiation apparatus is also constructed using the Impatt oscillator (IO) instead of the gyrotron as a radiation source. The IO is one of QIO-9425 series (Quinstar Technology Inc) which can operate at the frequency of 94 GHz and the power of 0.3 W in CW modés[6]. The mode of output power from the oscillator is changed by a rectangular / circular mode transition and a tapered transition, and then is transmitted by a circular waveguide (a catheter waveguide) whose inner diameter is 5 mm.

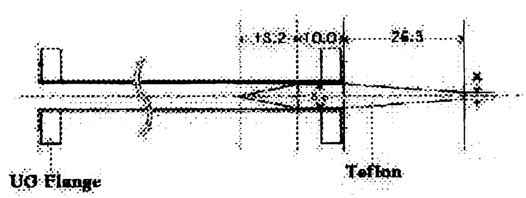


Fig. 2 Design of a Teflon rod antenna.

Figure 2 shows the schematic of radiation antennas showing a dielectric rod antenna whose shape is changed by the changing of tip length x (x = 1.1 ~ 3..3) [2]. Used material of dielectric rod is a Teflon.

The irradiated samples are cow beefs and the tip of the rod is inserted into the samples where the maximum insertion depth is 20 mm.

During the irradiation, the surface temperature of irradiated parts was measured using an infrared radiation thermometer in order to estimate the absorbed energy as in a previous report.[1] For measurement of the irradiated area, the images recorded by a camera and *subsequently* converted into computer graphics were observed.

2.2 Power measurement apparatus

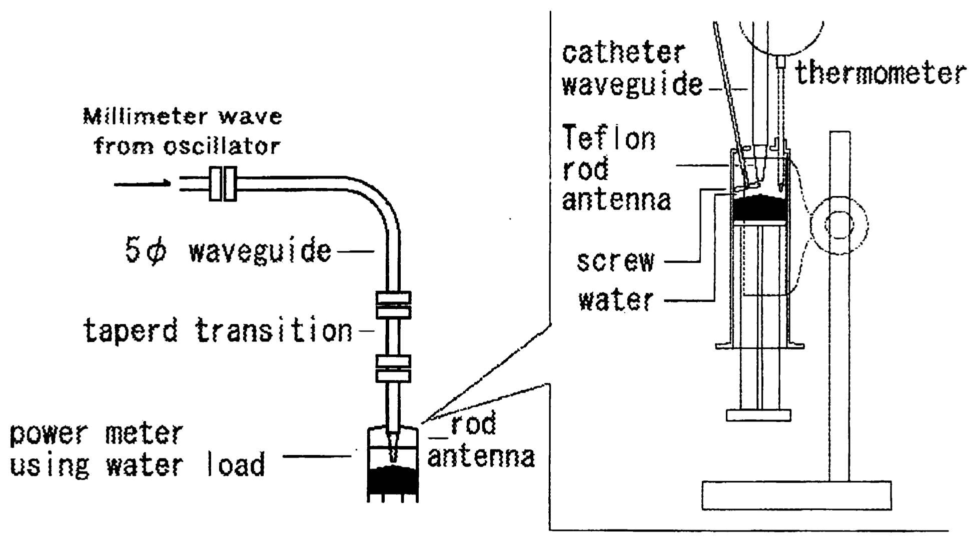


Fig. 3 A power meter of the radiation from a rod antennas

Figure 3 shows the power meter of radiation from a rod antennas showing together with the schematic of catheter waveguide parts. The right-hand side in the figure shows detail schematic of the power meter which is one of water-load apparatus. The water vessel consists of a medical injector which has a precise inner volume and a low thermal conduction to outer space.

3. Results and Discussion

3.1 Calculation results

From the well-known microwave theory for transmission in a circular waveguide, TE_{mn} mode waves propagate at an angle $\pm\alpha_{mn}$ with respect to the z-axis (center axis of a circular waveguide). The angle (transmission angle) α_{mn} is expressed as [7,8]

$$\sin\alpha_{mn} = \frac{\lambda}{\lambda_c}, \quad \lambda_c = \frac{2a\pi}{\chi'_{mn}}, \quad \lambda = \frac{\lambda_0}{n_d} = \lambda_0\sqrt{\frac{\varepsilon_0}{\varepsilon_d}} \tag{1}$$

where λ and λ_0 are the wavelength at a dielectrics with reflection index n_d and the vaçuum, respectively, λ_c the cutoff wavelength, χ'_{mn} the root of differential Bessel function and a the radius of the waveguide.

Figure 4 shows the calculation results of the TE_{11} mode (94 GHz) ray truck from the circular waveguide to the used Teflon rod antenna[3]. As shown in figure, at the case of the dielectric tapered rod antenna, there are two cases of the transmission at the different boundary conditions which arise from the surrounding materials with a different refraction index n_s. When $n_d < n_s$, the TE_{11} mode wave with the transmission angle α_{11} is transmitted as a refraction wave except a partial reflection according to Snell's law. While, if $n_d > n_s$, the wave is changed its angle to the transmission angle α_r in the rod dielectrics because of several times reflections at the surface boundary of the tapered rod. The angle α_r is expressed as

$$\alpha_r = \alpha_{11} + 2r\beta \tag{2}$$

where r is the number of reflections at the surface of rod antenna and β the taper angle of the rod dielectrics (Fig. 4).

Finally, the wave is emitted to the surrounding at the surface of the rod 7~12 millimeters distant from the tip part, when incident angle is larger than the critical angle of the total reflection.

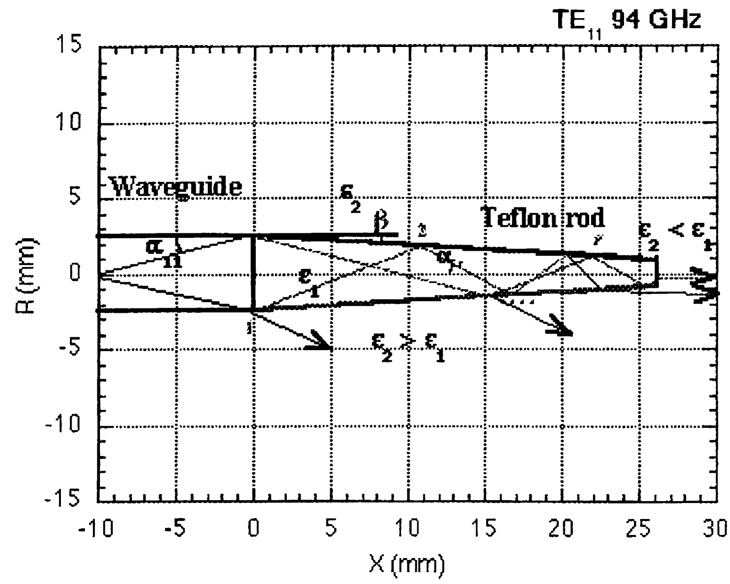


Fig. 4 Ray truck of TE_{11} mode with internal and external reflections at a Teflon rod antenna.

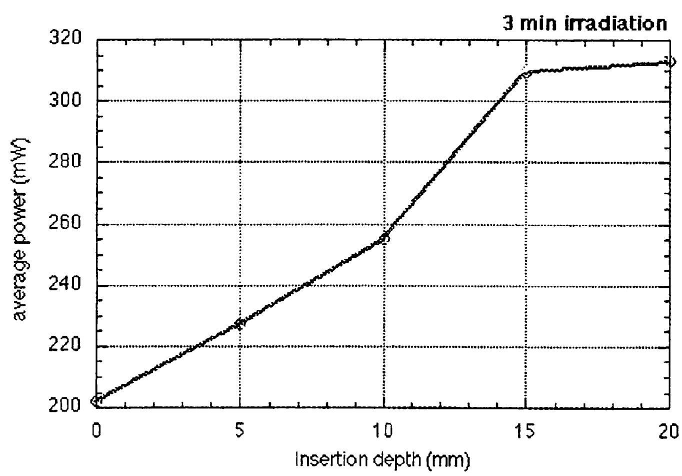


Fig. 5 Output power of millimeter waves from the rod antenna versus insertion depth.

3.2 Power measurement

Output power of the gyrotron apparatus was observed of 2 W at a Teflon rod antenna (in Fig. 1) by the power meter shown in Fig. 3. While, Fig. 5 shows observed output power of the IO apparatus from the rod antenna changing insertion depth into the water. As the chip length of the used rod antenna is 26 mm, insertion depth is set 0~20 mm to avoid an invention of water between waveguide and rod. As shown in figure, the output power slightly increases with insertion depth up to 15 mm and is nearly constant when insertion depth is deeper than 15 mm. In Fig. 4, the position at 15 mm of insertion depth is the position at 11 mm of distance from waveguide vent. At the region of rod antenna between waveguide vent and the 11 mm of distance, there is no reflection according to ray optics ; there is no irradiation from this part.

3.3 Thermal denaturation of beef

During the irradiation, the gyrotron FU-IV is operated in the CW mode at a frequency of 302 GHz (TE_{03} cavity mode) with the typical output power of 2 W at the Teflon rod antenna.[1] Figure. 6 shows an insertion depth dependence of the thermal denaturation of cow livers by the 3 minutes irradiation of TE_{03} mode through the 5 mm catheter waveguide with the rod antenna. (a) is a top view of the irradiation result and (b) cross section views. On the samples, a black carbonized region and a gray thermal denaturation region surrounding it are observed. Figure 7 shows the insertion depth dependence of the thermal denaturation region which consists of the average width and the depth of cross section. The width of denaturation region increases slightly with insertion depth, while the depth increases considerably with insertion depth ; the volume of denaturation region increases with insertion depth.

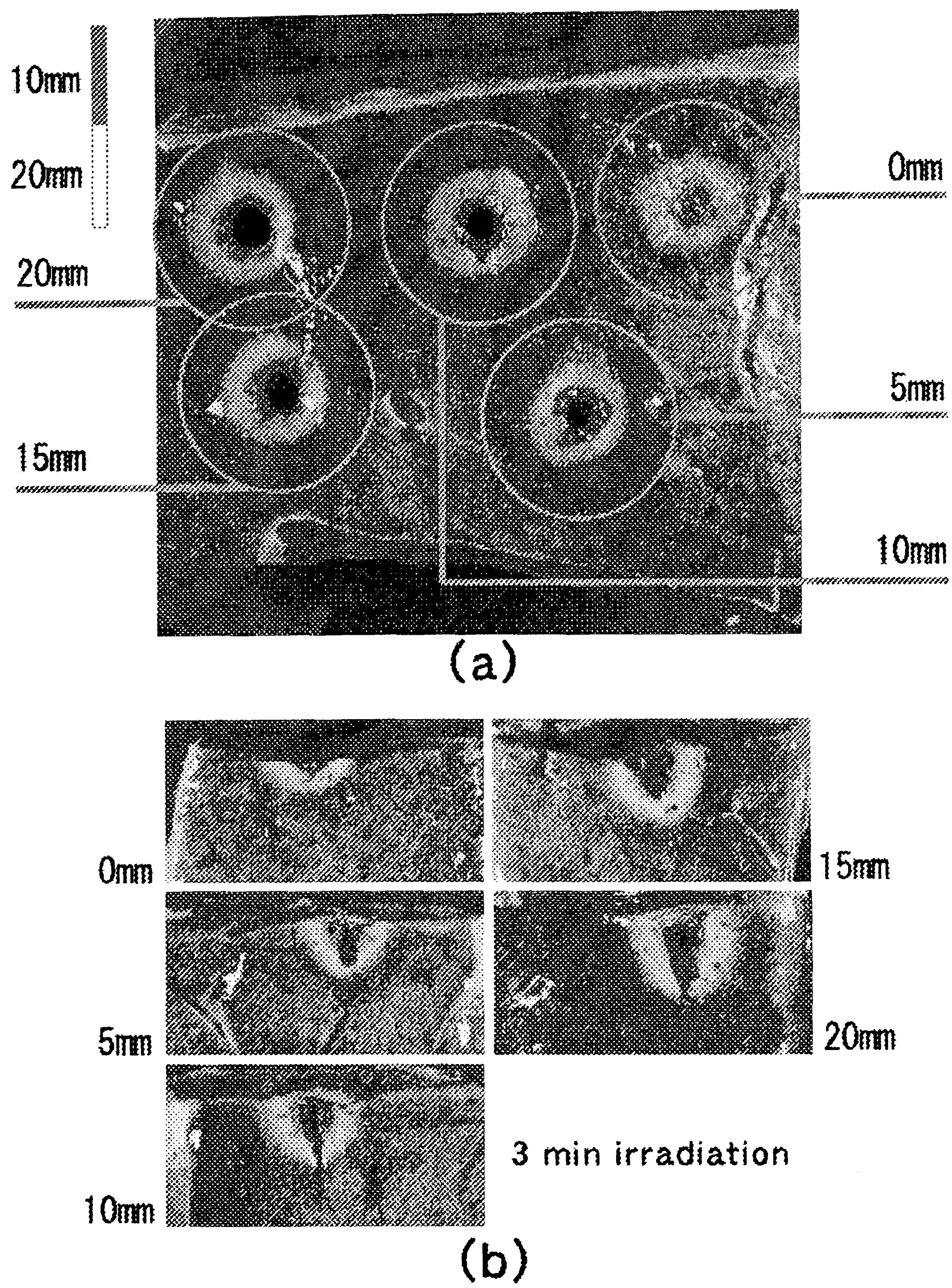


Figure 6 Thermal denaturation region of cow livers changing insertion depth of a rod antenna; (a) is top surface view and (b) cross section view.

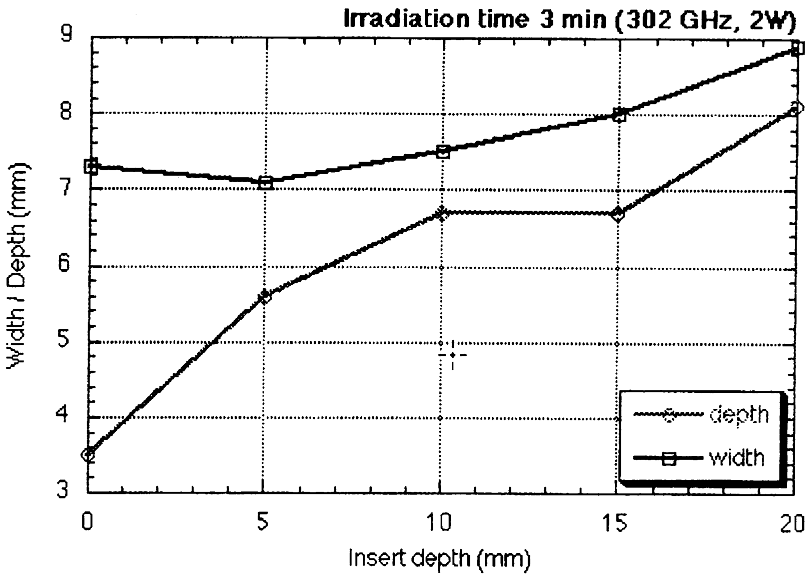


Figure 7 Denaturation width and depth of irradiated cow livers versus insertion depth of a rod antenna.

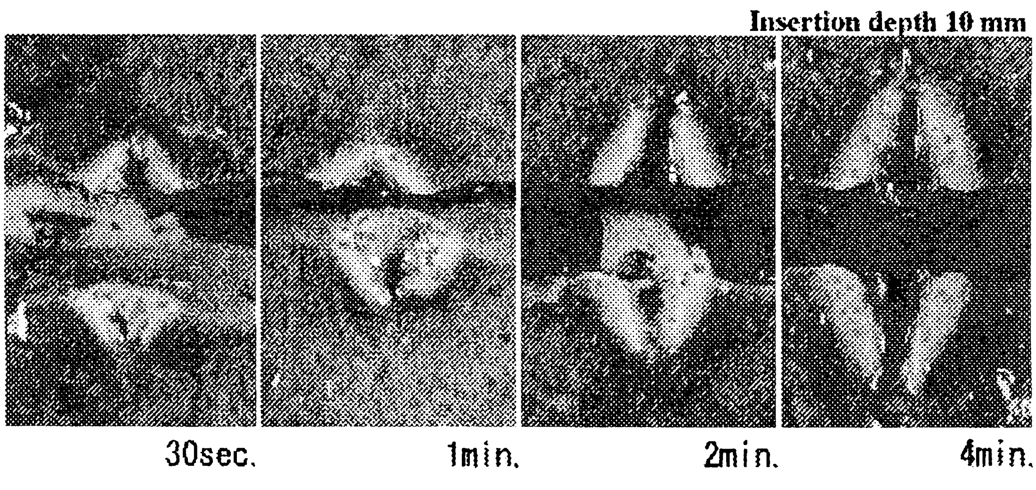


Figure 8 Irradiation time dependence of thermal denaturation region (cross section).

In Fig. 8, it is shown the cross section view of thermal denaturation changing with irradiation time at the insertion depth of 10 mm. Both width and depth increase with the irradiation time. Figure 9 shows the irradiation time dependence of the thermal denaturation width and depth shown in Fig. 8. As shown in the figure, the denaturation region rapidly increased on the initial stage (up to 30 sec) and after then, the denaturation region increased moderately with irradiation time. The time dependence is similar to the irradiation time dependence of surface temperature in previous report[1].

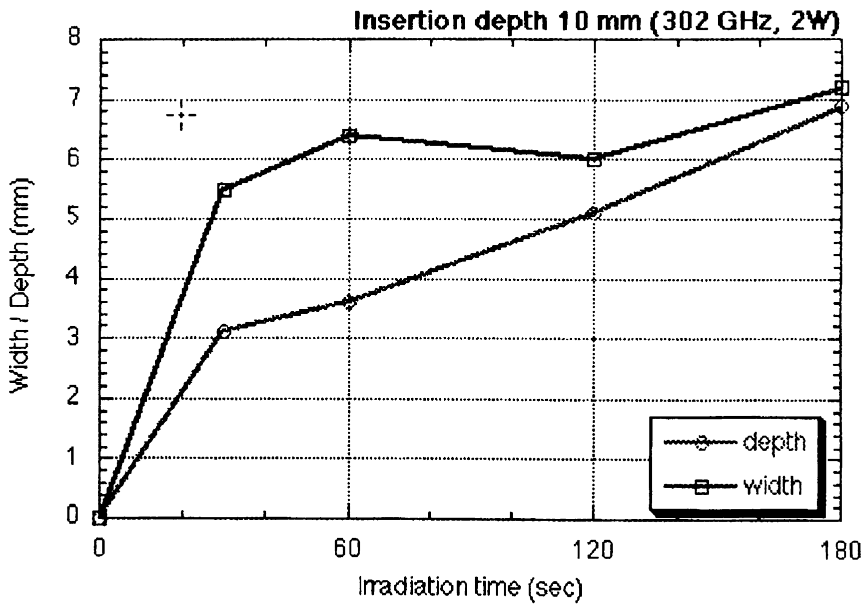
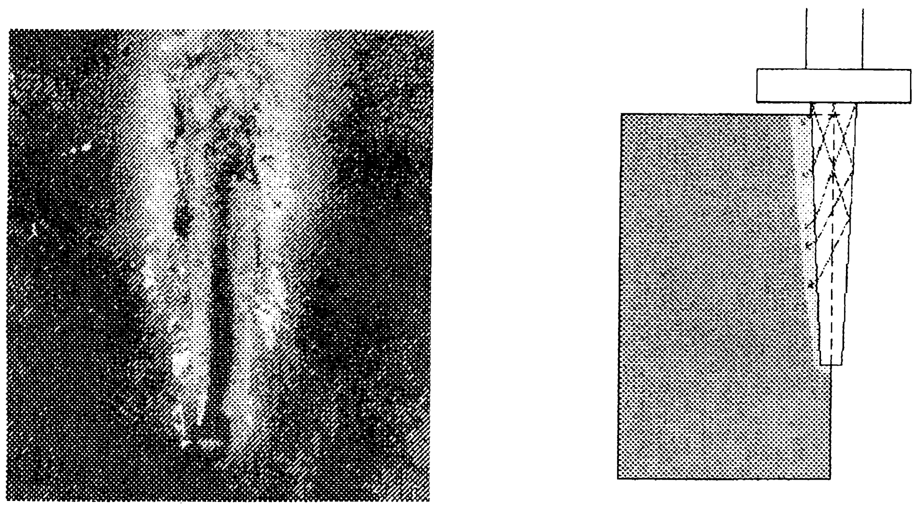


Figure 9 Denaturation width and depth of irradiated cow livers versus irradiation time.

Figure 10 shows the thermal denaturation by (a) a half side surface irradiation and (b) its schematic irradiation method using a rod antenna. The region of denaturation is explain qualitatively by the reflection from boundary side surface between Teflon rod and air shown in (b).



(a) (b)

Figure 10 Half side surface irradiation by a antenna, (b) irradiated surface view of cow liver, (b) schematic using method of a rod antenna.

4. Conclusions

In summary, we have developed a catheter apparatus with an insert rod antenna suitable for irradiation of a living body. This is the first application of a millimeter and submillimeter wave irradiation with an insert rod antenna for a biological sample. Tests of time and insertion depth dependent irradiation of a cow liver confirm the normal operation of the irradiation apparatus for living bodies.

Measurement results of the denaturation region and the surface temperature of irradiated samples in a previous report[1)] suggest that the rod antenna is one of appropriate antenna for use as a common radiation apparatus for living bodies.

Further developments are under way to improve the slim catheter waveguide and the effective antenna to enable localized irradiation.

Acknowledgments

The authors would like to express their thanks to President M. Tanabe, Kagawa Medical University, for valuable discussions. They also wish to thank Mr. K. Kitai and Mr. T. Okada, Fukui University, for their experimental assistance.

This work was partially supported by a Grant-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] T. Tatsukawa, A. Doi, M. Teranaka, H. Takashima, F. Goda, T. Idehara, I. Ogawa, S. Mitsudo and T. Kanemaki: Int. J. Infrared Millim. Waves **21** (2000) 1155.
[2] T. Tatsukawa, A. Doi, M. Teranaka, H. Takashima, F. Goda, T. Idehara, I. Ogawa, T. Kanemaki and S. Nishizawa: Jpn. J. Appl. Phys. **41** (2002) 5486.
[3] T. Tatsukawa, A. Doi, M. Teranaka, H. Takashima, T. Idehara, I. Ogawa, and S. Nishizawa : Procd. 26 th Int. Cof. Infrared Millim. Waves (2003) 5-217.
[4] T. Idehara, T. Tatsukawa, I. Ogawa, H. Tanabe, T. Mori, S. Wada, G. F. Brand and M. H. Brennan: Phys. Fluid **B4** (1992) 267.
[5] T. Tatsukawa, K. Shibutani, K. Yoshida, N. Nishida, I. Ogawa and T. Idehara: Proc. of 1996 Int.Conf. on plasma Phys. (1997) Vol. 2, p. 1162.
[6] T.Tatsukawa, A.Doi, M.Teranaka, H.Takashima F.Goda,, T.Idehara, T.Kanemaki and T.Namba ; Digest 27th Int. Conf. Infrared and Millim. waves (2002) p209
[7] R. E. Collin: *Foundations for microwave engineering* (McGraw-Hill Inc,1992) p. 197
[8] G. F. Brand and G. P. Timms: J. Electr. and Electron. Eng. **15** (1995) 7.