Novel cell exposure apparatus for *in vitro* experiments

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ABSTRACT

A new exposure apparatus has been developed for *in vitro* experiments. A rectangular wave-guide with two slits of optimized shapes is used for this apparatus. A culture dish is put on the two slits bore on the wave-guide. Cells are exposed to the radio frequency (RF) field radiated from the slits of wave-guide. Characteristics of the apparatus are investigated by way of numerical simulations and experimental measurements. It is found that 70[W/kg] of the specific absorption rate (SAR) at the cell position is realized to the 1[W] incident power. Homogeneous exposure areas are increased by slits with optimized shape. This exposure apparatus has advantage to control the temperature at the cell position.

INTRODUCTION

Recently, numbers of studies have been performed to obtain knowledge about biological effects of electromagnetic fields (EMF), because a variety of wireless communications devices have come into wide use. It is commonly considered that the increase of temperature in biological tissue, due to the absorption of electromagnetic energy, governs the nature of EMF effects as for the radio frequency (RF) domain. Therefore, guidelines limits human exposure by the specific absorption rate (SAR), defined as the RF power absorbed per unit mass of biological tissues. However, some positive results about the *in vitro* biological effects are reported even in the conditions of low level RF field exposure[1][2]. It becomes important to investigate biological effects except those of thermal origin, or "non-thermal" effects.

In the case of the locally concentrated RF exposure on biological tissues, the guidelines restricts the localized SAR. The localized SAR is restricted 8~10[W/kg] for frequencies in the range from 10MHz to 10GHz under the occupational condition[3][4]. This restricted value of localized SAR corresponds to the internal electric field of approximately 100[V/m]. However, non-thermal biological effects caused by such a strong internal electric field have not been studied enough. It is difficult to realize the exposure conditions which satisfy the strong internal electric field with the low temperature increase.

The purpose of this study is to develop the *in vitro* exposure apparatus, which accomplishes exposure conditions of high value of SAR more than 10[W/kg] with minimum increment of temperature. In this paper, the new concept of the cell exposure apparatus which satisfies the conditions mentioned above is provided.

APPARATUS

The new cell exposure apparatus is based on the rectangular wave-guide. The schematic view of it is shown in Fig. 1. TE_{10} mode is used for this apparatus. To generate standing waves in the wave-guide, one end of it is terminated with a short circuiting plate[5]. Cells exposed to the RF field are put on slits which are bored on the wave-guide. Namely, it uses controlled EMF radiated from the slits of wave-guide. We use the culture dish of rectangular shape divided into four compartments as shown in Fig. 1. Advantages of this type of exposure setup are as follows: (1) High value of SAR can be achieved at the cell position with the strong EMF coupling. (2) Temperature control becomes easy, because the bottom of the culture dish contacts with metal wall of the wave-guide. (3) The compact design allows the use of ordinary incubators to make suitable cell culture condition. (4) Experimental apparatus becomes simple and easy to set up the experiment, due to the location of culture dish, which is merely put on slits outside the wave-guide.

OPTIMIZATION WITH NUMERICAL SIMULATION

In this study, the frequency of 2.45[GHz] microwave is used. The size of the wave-guide is determined as 110[mm](width) x 55[mm](height) x 310[mm](depth). With the numerical simulation, the location, the number, and the shape of slits are determined for this wave-guide. The numerical analysis indicates following results. To gain exposure efficiency, it is advantageous to bore slits perpendicular to the wave-guide axis at the suitable position, where the loop of the magnetic field exists. It is 1/4λg from the short circuiting plate. Here λg is a wavelength in a wave-guide. To increase the area of uniform exposure, slits are made a pinched shape (Fig. 1) which enhances the coupling of the electromagnetic field. Two slits are bored on the wave-guide, to expand the area of exposure, where the uniform

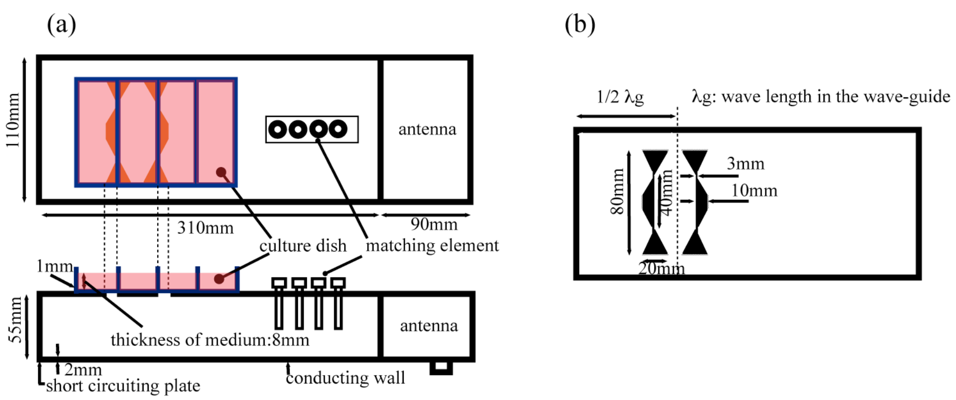

Fig. 1. (a)Schematic view of the novel exposure apparatus. A culture dish is put on the slits outside of the wave-guide. (b)Slits are optimized with the pinched shape to increase the uniform exposure area.

strength of SAR is obtained by using the EMF coupling between two slits. The distribution of electric field in the medium changes with the thickness of the medium. Therefore, it is preferable to choose the thickness of the medium that maximizes the SAR at the bottom of the medium, where cells exist. With the numerical analysis, it is found that the suitable thickness is 8[mm] which corresponds to a half wavelength in the medium.

EXPERIMENTAL MEASUREMENT

The exposure apparatus based on above numerical optimization is made up, and experimental measurements to obtain the SAR distribution are carried out in two ways to estimate the characteristics.

One is the measurement of the electric field E[V/m] by which SAR is directly obtained. In this method, a thickness of medium is set for 60[mm], because the electric field probe needs enough depth of medium. If the measurement result agrees with the simulation result in this condition, it is expected them to agree in the case of optimized medium thickness of 8[mm]. Results of the measurement and of the numerical simulation are shown in Fig. 2. The two dimensional SAR distribution is obtained from the measured electric field for the 40[mW] incident power. The measured SAR distribution (Fig. 2 (a)) shows good agreement with the simulation result (Fig. 2 (c)). Figure2 (a) indicates that the high values of SAR are obtained between slits, and the better uniformity of SAR distribution is realized within this region.

The other is the measurement of the temperature increases with time to calculate dT/dt (where T is the temperature [K], and t is the time [s]) by which SAR is calculated as SAR=c dT/dt (where c is the specific heat [J/kg K])[6]. Results of the temperature measurements are shown in Fig. 3. This measurement is carried out under the condition of the optimized thickness of medium (8[mm]). In this figure, SAR values are normalized to the 1[W] incident power. These

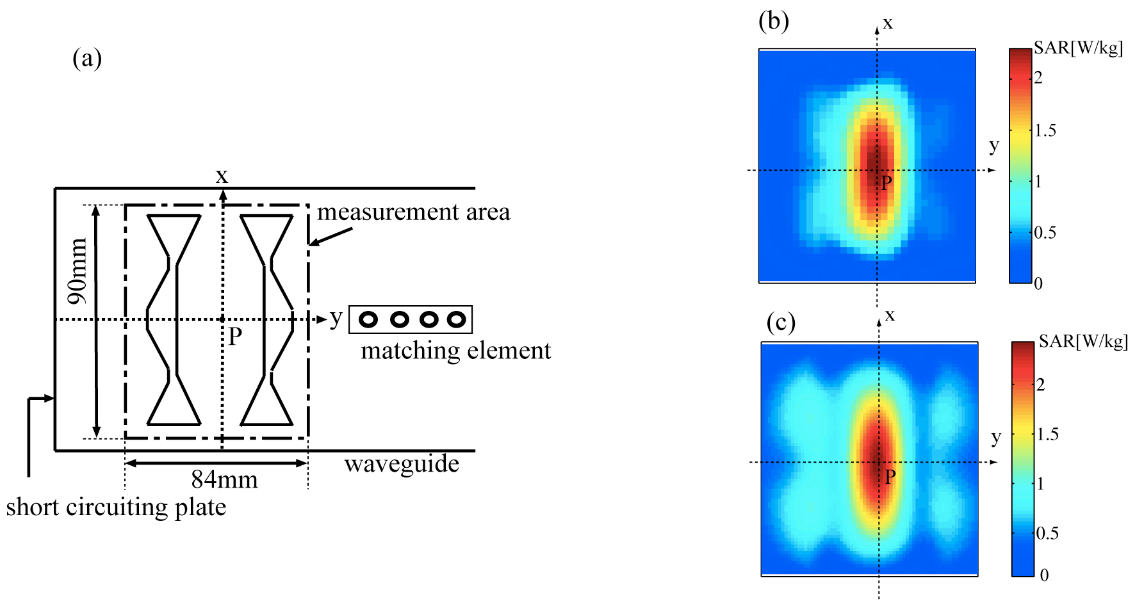

Fig. 2. The two dimensional SAR distribution obtained from electric field measurement data. A thickness of medium is set for 60[mm]. An incident power is 40[mW]. Electric field is measured at 6[mm] upper position from the bottom of medium. (a) shows measurement area. (b) is the Imageplot of measured SAR distribution within the measurement area. (c) is the result of the numerical simulation which is carried out under the same condition of the experiment.

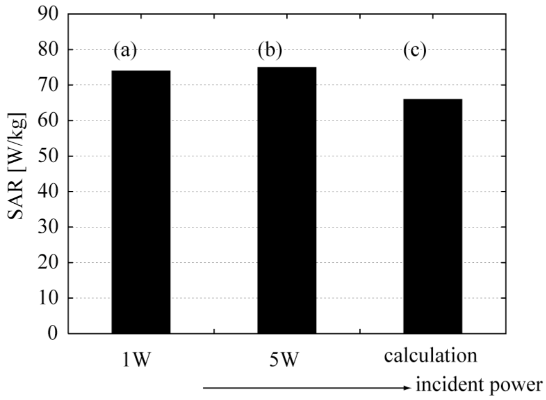

Fig. 3. SAR values calculated from measurement data of the temperature increase. These data is obtained at the position of P (see Fig.2 (a)). (a) is a condition of 1[W] incident power, (b) is a condition of 5[W] incident power and (c) is a numerical simulation, respectively. These SAR values are normalized to correspond to the 1[W] incident power.

experimental results indicate that the SAR values measured at the position of P (see Fig. 2) show good agreement with the result of the numerical simulation. It is clarified by the experiments that the maximum SAR of about 70[W/kg] is obtained at the bottom of the medium (position of cells) to the incident power of 1[W], which is consistent with the numerical result.

CONCLUSIONS

In conclusion, a new concept is applied to the exposure apparatus to accomplish the conditions of both high value of the SAR more than 10[W/kg] with minimum increment of the temperature. The numerical analysis and the experimental measurement are performed to estimate characteristics of this apparatus. Results of the numerical simulation indicate good agreement with experimental results. Consequently, this new setup shows good characteristics as follows. High efficiency of the SAR at the cell position as 70[W/kg] is realized to the 1[W] incident power. The pair of slits with pinched shape improved uniformity of exposure.

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