Visualization of Three-Dimensional Electromagnetic Power Absorption Using Gel Containing Capsulate Liquid Crystal

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Abstract: High-molecular gel containing capsulate thermo-chromic liquid crystal is made to visualize three-dimensional distribution of electromagnetic power absorption. A preliminary experiment is performed at frequency of 1.5GHz. As a result of the experiment, the three-dimensional distribution of electromagnetic power absorption is clearly visualized. The result shows that the gel can be used as a phantom for the electromagnetic dosimetry. It is necessary to adjust the electrical properties of a phantom to those of biological tissue.

Key words: capsulate thermo-chromic liquid crystal, electromagnetic power absorption, RF exposure, three-dimensional visualization, high-molecular gel phantom

1. Introduction

Wireless communications equipments such as mobile phones have become widely used in recent years. This has led to increase public concern about exposure of body to radio frequency (RF) electromagnetic fields (EMF). For that reason, it is essential to investigate the method for assessment of RF-EMF exposures on human body. One of the evaluation methods is to expose a human model called phantom to RF-EMF and estimate the absorbed energy.

In general, specific absorption rate (SAR) is used as the evaluation indicator. SAR is determined from measurements of an increase in temperature over a short period of time following the exposure. Since it is impossible to measure the temperature in human body, several methods have been developed.

One of them is to make a phantom and place optical fiber thermometers in it. Those thermometers can measure temperature without interference by RF-EMF and are fast in the response. However, a fiber can measure only a single point so it is difficult to know the temperature distribution and heat flux of the whole exposed area.

Thermographic method[1] makes it possible to measure the temperature distribution on the surface of the phantom with a thermal camera, although it is limited to two-dimensional measurement.

In order to solve these problems, a phantom containing nonionic surface active agent (NSAA) has been developed[2]. This material becomes clouded above a preset temperature called clouding point. Utilizing this method, three-dimensional (3-D) temperature can be visualized with a non-destructive way. A problem of this method is that it can only visualize the temperature higher than the clouding point. In addition, a clouding point is influenced by base materials surrounding NSAA. Thus, it is difficult to adjust both the electrical properties and the clouding point to the desired values.

We focused our interest on capsulate liquid crystal which have been used for visualization of temperature distribution of fluid[3]. The purpose of this study is to make a phantom containing capsulate liquid crystal so as to develop a method to visualize 3-D distribution of electromagnetic power absorption.

2. Visualization Method with Liquid Crystal

Micro-capsulated thermo-chromic liquid crystal (MTLC) is used for our experiments. The diameter of the capsule is about 20 to 30 micrometer. The principle to make temperature visible is shown in Fig. 1.

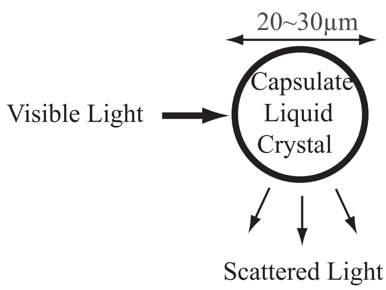

Fig. 1: Principle of temperature visualization using micro-capsulated thermo-chromic liquid crystal (MTLC).

The incident light is needed for visualization. The wavelength of scattered light depends on the temperature of the capsulate liquid crystal. MTLC are suspended uniformly in the water or the gel.

Figure 6(a) shows the correlation of the color with the temperature. This correlation is obtained in the measurement of the light scattered at 45 degrees to incidental direction [see Fig. 5]. The wavelength of the scattered light becomes shorter with the increase of temperature. In other words, the scattered light changes in its color from red to purple with the increase of temperature. We should note that the observed color or scattered wavelength as well as its intensity depends on the angle of measuring location.

The experimental set-up for visualizing the temperature distribution is shown in Fig. 2. A halogen lamp is used as the light source. The sheet of the light is focused on the water solution or the gel containing MTLC. The temperature on the plane which is illuminated by the sheet light, as shown in Fig. 2, becomes visible. The intensity of the incidental light and the transparency of the solvent govern the visualization area. Furthermore, the area is restricted to the concentration of MTLC because of its high scattering nature. In our following experiment, the visualization area is approximately 3cm depth and 5cm width as shown in Fig. 2.

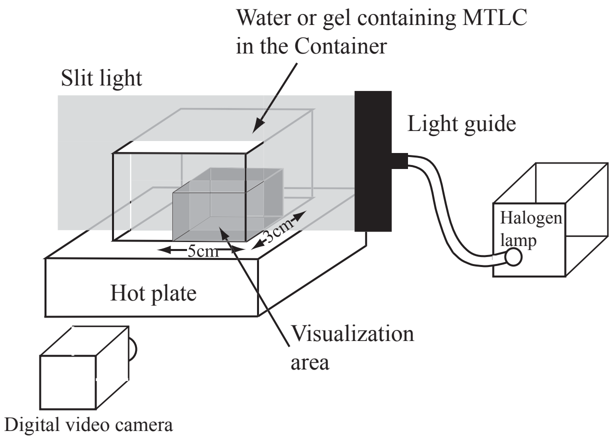

Fig. 2: Schematic view of visualization set-up for 3-D temperature distribution

Fig. 3: Visualization of thermal convection with MTLC. Solvent is heated by the hot plate below

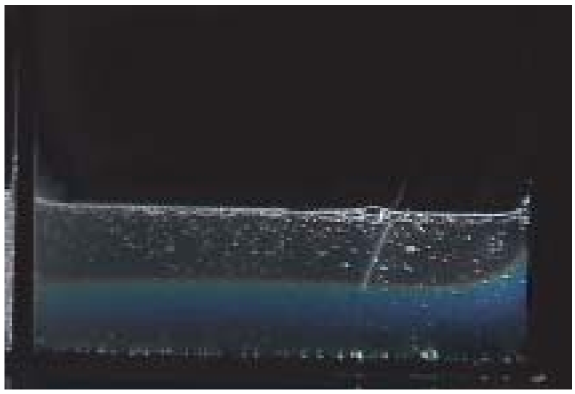

Fig. 4: Visualization of thermal conductivity for PVA gel containing MTLC. The experimental set-up is the same as Fig. 3

Figure 3 shows the scattered light in the water solution containing MTLC. The water solution is heated in the bottom of the container by a hot plate. Figure 3 indicates temperature distribution in a convectional flow, which can be visualized by MTLC.

The substrate material, however, should not be convective in order to use this method to measure SAR. Therefore, high-molecular gel constructed from polyvinyl alcohol (PVA) is used as the substrate to prevent convection. Figure 4 shows the temperature distribution within the gel phantom heated in the same way as in Fig. 3. Since there is no convection, the thermal conduction is visualized and we can see the layers of the same temperature move upwards gradually.

3. Preliminary Exposure Experiment Using Dipole Antenna

We perform a preliminary exposure experiment using above-mentioned phantom. Figure 5 shows the experimental set-up. A dipole antenna is used to irradiate a phantom containing MTLC with RF-EMF at the frequency of 1.5GHz. The applied power is 37.3 W. The phantom is placed 1.6cm apart from the antenna, and is illuminated by a slit light from the opposite side. The camera is placed at 45 degrees to the incidental direction.

An electric conductivity σ and a relative dielectric constant ε' of the PVA gel phantom which is used for this experiment is $\sim$0.76[S/m] and $\sim$73 at 1.5GHz, respectively. Those of the high-water content biological tissues at 1.5GHz are $\sim$1.2[S/m] and $\sim$54[4, 5, 6]. Therefore electric properties of the gel phantom are not equivalent to the biological tissue. To adjust electromagnetic constants is a subject of future investigation.

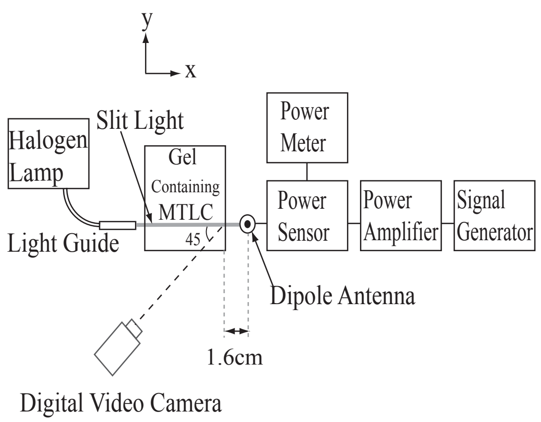

Fig. 5: Schematic view of RF-EMF exposure set-up. The location of the digital camera is at an angle of 45 degrees to x-axis. 3-D view of temperature distribution is obtained by moving the light guide along y-axis.

Figure 6 shows a distribution of the electromagnetic power absorption of the phantom irradiated with RF-EMF with a dipole antenna. Figures 6(b), (c), (d), and (e) show the distribution of power absorption at 1, 3, 5, and 10 minutes after starting exposure, respectively. The open circles in each figure indicate changes of the temperature at the same points. It is apparent that changes of the temperature distribution within the phantom are visualized over time.

The temperature distribution inside the phantom is also visualized by moving the slit light along y-axis.These observations imply the possibility of the 3-D visualization that is reconstructed by measured data at each plane.

4. Conclusion

We have developed a method for visualizing the 3-D distribution of electromagnetic power absorption. The PVA gel phantom containing MTLC is made as trial model. The thermal conduction without convection is visualized with it.

In this study, we use a dipole antenna to observe the electromagnetic power absorption by the phantom. The result of this preliminary experiment clearly shows 1.5GHz electromagnetic power absorption in a time series. In addition, it suggests capability to reconstruct the 3-D distribution of power absorption by moving incident light. However, we need to develop a material of transparency with electric properties close to those of the biological tissue.

Acknowledgment

The authors wish thank Kaori Fukunaga, Communications Research Laboratory, for her advice on making a phantom and on measurement of electrical properties.

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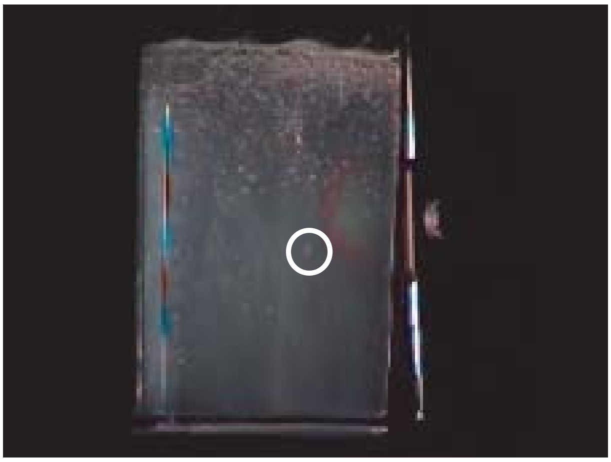
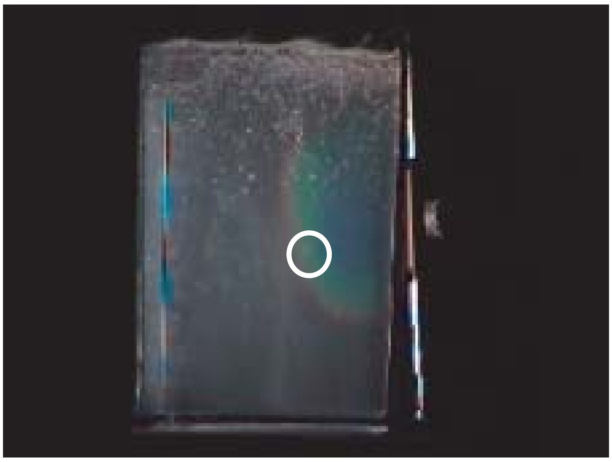
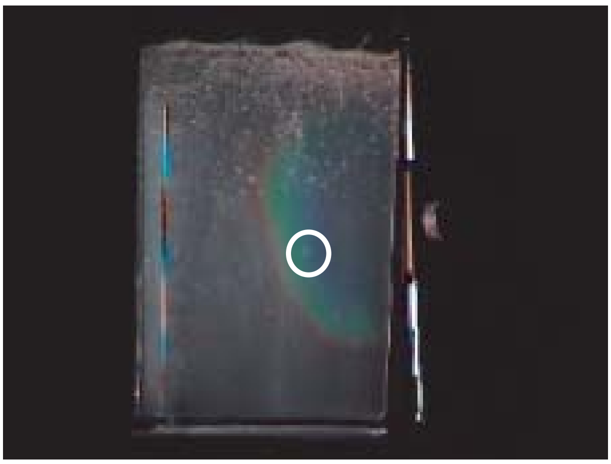
(a)



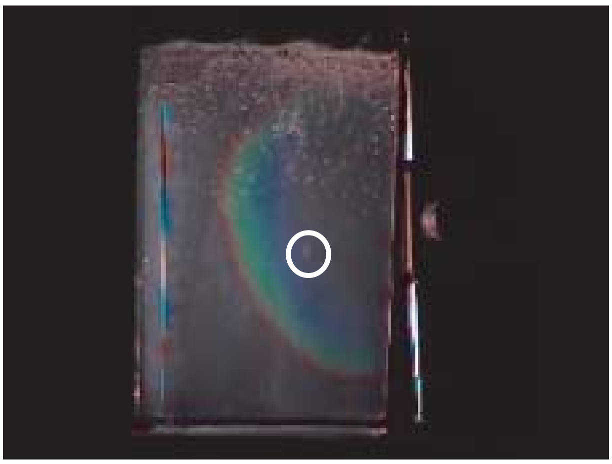
(b)



(c)



(d)



(e)

Fig. 6: The correlation of the color with temperature and time sequence of temperature distribution visualized by MTLC. The visualized area is a plane parallel to x-axis. (a) shows the color changes from red to purple with the increase of temperature. (b), (c), (d), and (e) indicate 1, 3, 5, and 10 minutes after starting exposure, respectively.