Flexible Microwave Antenna Applicator for Chemo-Thermotherapy of the Breast

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***Abstract*—In this letter, we propose a flexible microwave antenna applicator to induce mild hyperthermia that can be used in conjunction with chemotherapy. The antennas used were designed and tested using *in vitro* gels that mimic the electrical properties of human breast skin, fat, fibroglandular, and muscle tissues. Experiments show that the applicator can provide up to a 3 °C temperature increase within the breast to successfully achieve mild hyperthermia. The results obtained in this letter suggest that a cost-effective local hyperthermia treatment technology that can be widely used at local clinical cancer treatment centers is plausible without using expensive applicators and electromagnetic shielding rooms.**

***Index Terms*—Microwave hyperthermia, thermotherapy.**

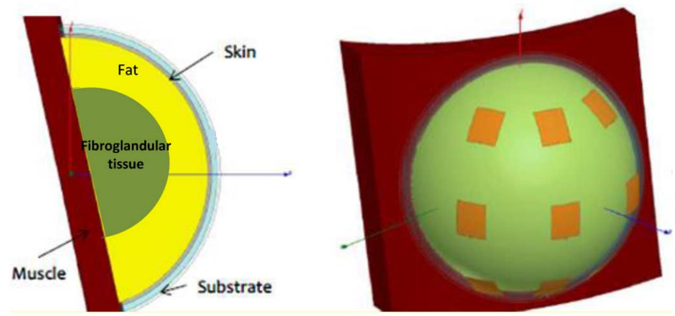

Fig. 1. Simplified breast model for simulations (Ansys HFSS). Breast geometry (left), Microwave antenna applicator on the model (right).

I. Introduction

APPROXIMATELY 12% of women will develop breast cancer at some point in her lifetime, and as of 2014, there were more than 2.8 million women with a history of breast cancer in the U.S., and that number only continues to grow with each passing year [1]. Conventional treatments of cancers include chemotherapy, radiotherapy, and surgery. Although microwave hyperthermia, which is increasing the temperature of cancerous tissue to 45 °C, has been studied over the past four decades, recent clinical trials have shown promising results when used in conjunction with radiation and chemotherapy [2]–[8]. This type of therapy exposes cancer cells to electromagnetic energy as heat, thus reducing the resistance of the cancer cells for the affected tissue [9]–[13]. Because vascularization and blood flow in tumors is lower than that of regular tissue, cancerous cells are more heat sensitive than normal tissue [11]. Hyperthermia uses this vascularization and blood flow to its advantage by increasing perfusion, which increases drug delivery and radiotherapy efficiency [11]–[13].

In this letter, our goal is to apply mild hyperthermia using a low power applicator in conjunction with the conventional cancer treatment therapies to destroy the cancerous tissue with minimal damage to the healthy cells. This is achieved by using the applicator to increase the temperature of the whole organ or tissue a few degrees (between 39 °C and 42 °C) before applying conventional therapies. In addition to mild hyperthermia's ease of use, this method is inexpensive and requires low power (< 10 W). For this purpose, we designed and manufactured a microwave hyperthermia applicator operating at 1.6 GHz. This frequency was chosen to allow the deployment of multiple small antennas for heating. The frequency of operation can be easily manipulated by changing the topology or the size of the antennas [18]–[20]. A flexible polydimethylsiloxane (PDMS) material is used to give the desired shape to the applicator. The details of the applicator will be explained in the following sections.

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II. Design and Simulation

Fig. 1(a) shows a simplified geometry of the breast, showing the skin, fat, fibroglandular tissue, and muscle layers. The microwave antenna array is placed on the breast model [Fig. 1(b)] [17]. This array includes 9 (3×3 grid) MW antennas designed in [6] offset by 45 °. The number and the location of the antennas are obtained using particle swarm optimization (PSO) [17].

The designed model with the applicator attached is simulated using HFSS to observe the specific absorption rate (SAR) inside the breast tissue. The SAR distribution of the array shown in Fig. 2 [17] indicates the concentration of the energy radiated by

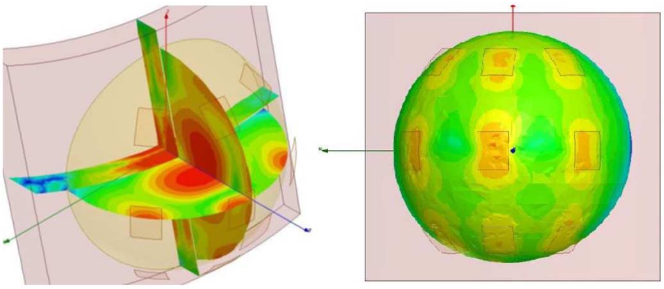


Fig. 2. Simulation of SAR distribution in the breast model.

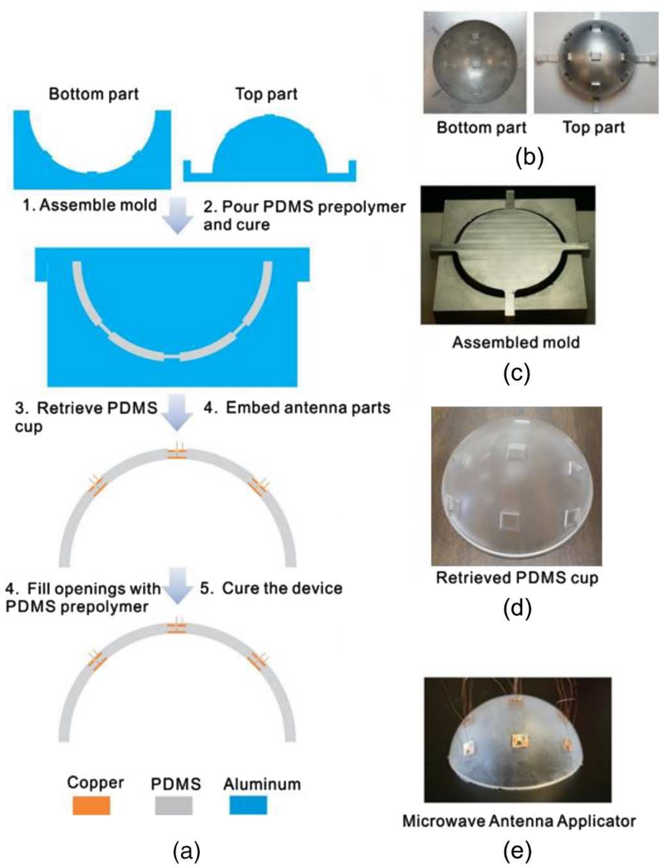
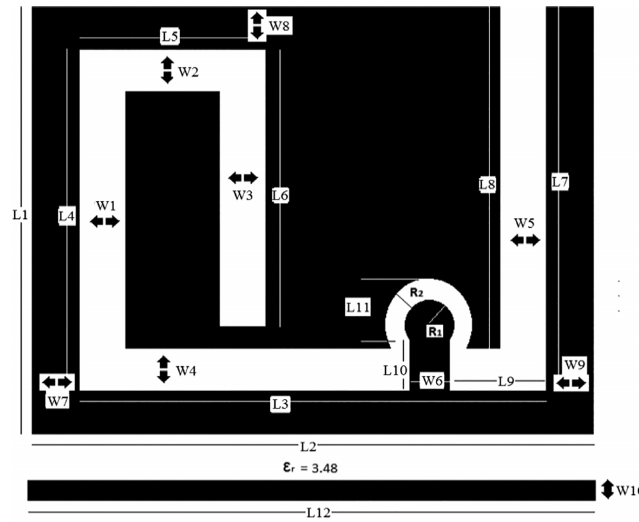


Fig. 3. Fabrication procedure of flexible microwave antenna applicator. (a) Schematics of fabrication. (b) Top and bottom parts of the aluminum mold. (c) Assembled mold. (d) Retrieved PDMS cup. (e) Final microwave antenna applicator.

the antennas, showing that energy is focused at the center of the breast.

III. Antenna Fabrication

Fig. 3 demonstrates the fabrication of the flexible microwave antenna applicator. We designed an aluminum mold for fabricating a hemispheric PDMS cup (Fig. 3). The mold was manufactured in the machine shop and includes a gap that separates the top and bottom part. The PDMS prepolymer was prepared by mixing the PDMS precursor and curing agent with a ratio of 10:1. The mixture was then cast into the spacing between the top and bottom part of the mold, degassed in a vacuumed chamber, and then transferred to a hot plate for curing at 80 °C for 1 h. Once cured, the top half of the mold was removed, and



Dimensions (mm)							
L1	10	**L7**	9	**W1**	1	**W7**	1
L2	12	**L8**	8	**W2**	1	**W8**	1
L3	10	**L9**	3.3	**W3**	1	**W9**	1
L4	8	**L10**	1.08	**W4**	1	**W10**	1.52
L5	4	**L11**	1.135	**W5**	1	**R1**	1.22
L6	6.5	**L12**	12	**W6**	0.65	**R2**	2.92

Fig. 4. Antenna geometry and dimensions.

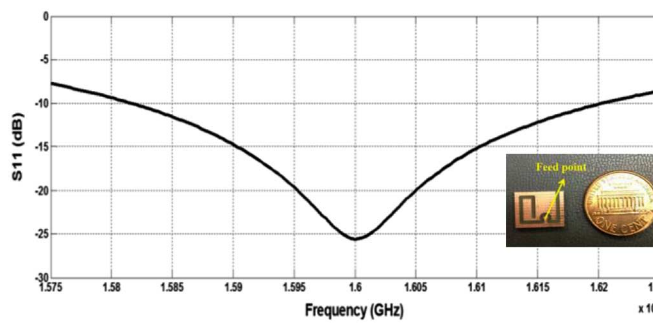


Fig. 5. Return loss of the MW antenna.

the cured PDMS cup was detached from the bottom part of the mold. Then antenna patches and grounds were soldered separately with copper wire for electrical connection. The patches and grounds were embedded in the openings of the PDMS cup and sealed inside by filling the openings with the PDMS prepolymer mixture. Once the openings were filled, the nearly complete flexible microwave antenna applicator was completed by curing the oven for 1 h at 80 °C.

IV. *In Vitro* Measurements

The antenna (Fig. 4) designed in [10] was used to create the conformal antenna applicator shown in Fig. 6. It was designed on an FR4 substrate and fabricated on a flexible material. We tested this antenna on human breast mimicking gels (Fig. 7) that contain skins, fat, and fibroglandular layers. As seen in Fig. 5, the antenna resonates at 1.6 GHz on breast tissue well below −10 dB. Fig. 8 shows the test bench, including a signal generator, an amplifier, a power divider, temperature sensors, and the computer used to monitor the temperature changes.

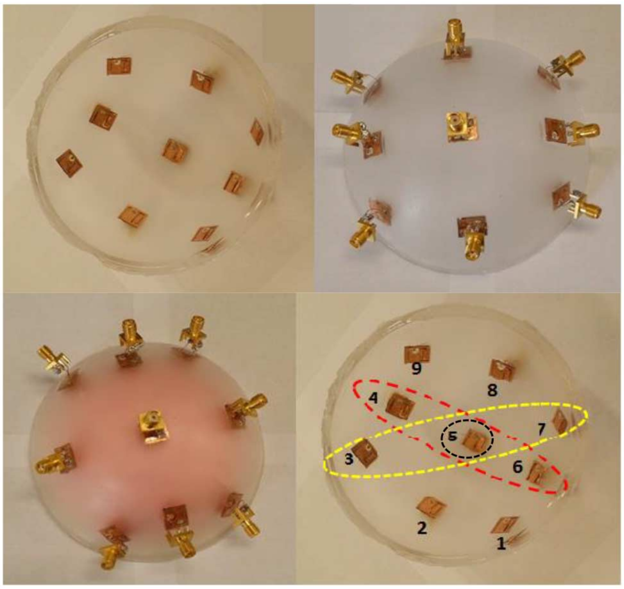


Fig. 6. Microwave antenna applicator printed on a flexible material and the combination of fed antenna during the measurements.

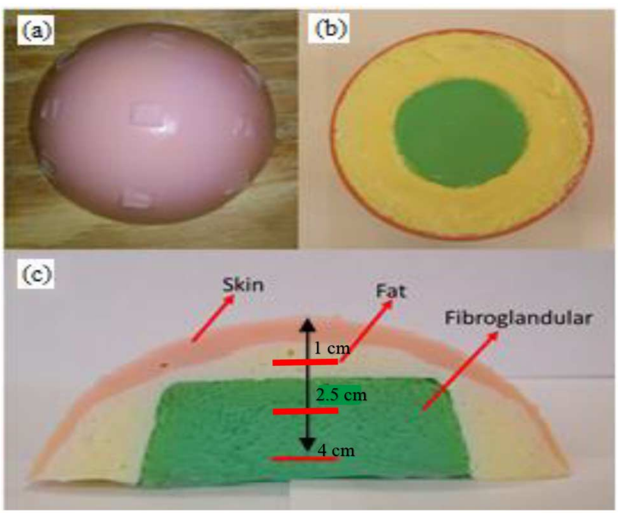


Fig. 7. (a) Top view, (b) bottom view, and (c) cross section of the breast mimicking gel.

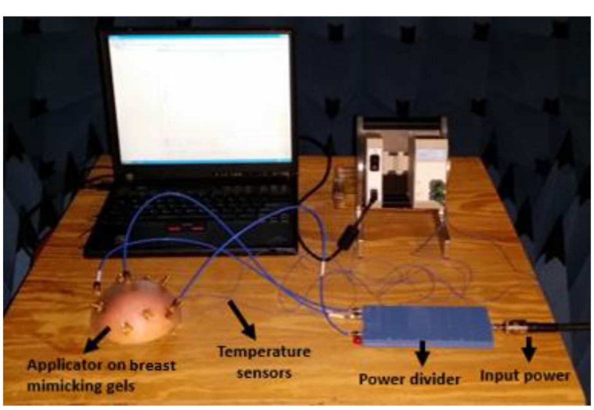


Fig. 8. Experimental setup.

The microwave antenna applicator is placed on the breast-mimicking gels [21], and the power is applied through 3 antennas of the array on the applicator. Due to the power output limitations of the existing equipment, we could only power three out of the nine antennas up to 5 W per antenna. First, we measured the temperature rise at the depth of 1 cm with 1 W power at 1.6 GHz with power applied through antennas #4, #5, and #6. Then, the power was increased to 2.5 W at 1 cm depth. The results of the measurements are shown in Fig. 9. Thereafter, we increased the depth and repeated the measurements at 2.5 cm and 4 cm depths for both power levels again. We observed a 3 °C increment of the temperature at the depth of 1 cm. However, at 2.5 cm and 4 cm depths, we monitored the temperature increase for 10 min. The results are shown in Table I.

After these measurements, 10 W is applied through antenna #5 in Fig. 5 on top of the applicator; 5 W is applied through antennas #4, #5, and #6, separately to observe the temperature rise in the depth of 2.5 cm and 4 cm with higher input power. The results are shown in Fig. 10, Table II, and Fig. 11.

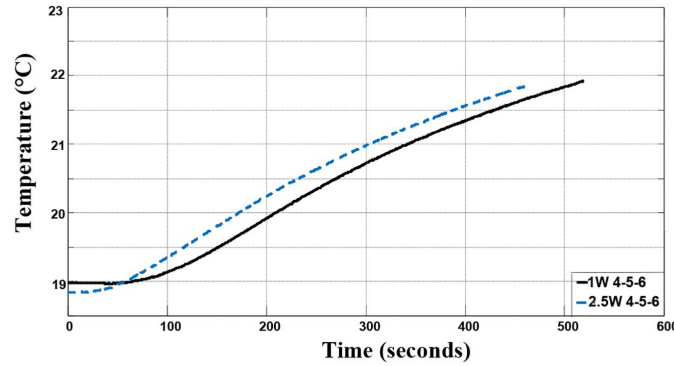


Fig. 9. Temperature increment in the depth of 1 cm at 1.6 GHz with 1 W and 2.5 W.

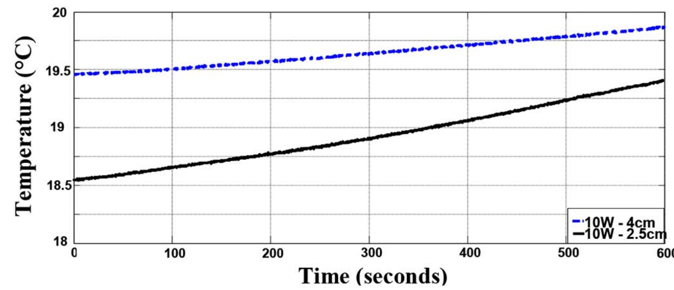


Fig. 10. Temperature increment in the depth of 2.5 cm and 4 cm with 10 W input power.

TABLE I
LIST OF DURATION OF APPLICATION

Depth	Antennas	1W	2.5W
1 cm	4, 5, 6	3°C (8min 39s)	3°C (7min 40s)
2.5 cm	4, 5, 6	0.146°C (10min)	0.197°C (10min)
4 cm	4, 5, 6	0.112°C (10min)	0.125°C (10min)

TABLE II
TEMPERATURE INCREASE WITH 10 W INPUT POWER

Depth	Antennas	10W input
2.5cm	5	0.872°C (10min)
4cm	5	0.419°C (10min)

V. CONCLUSION

In this letter, we presented a flexible mild microwave hyperthermia antenna applicator for chemothermotherapy of the

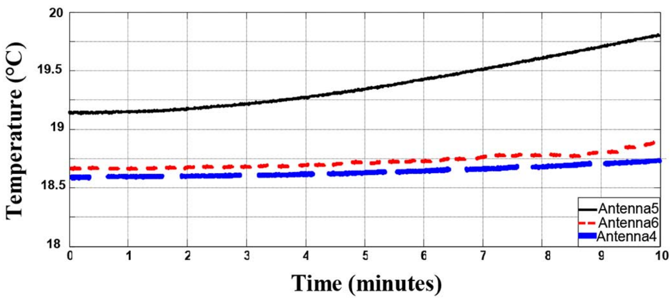


Fig. 11. Temperature increment in the depth of 2.5 cm at 1.6 GHz with 5 W input power.

breast. According to measurements of the antenna's S_{11} value, tests are performed at 1.6 GHz, and as results have shown, sufficient temperature increase can be achieved with 2.5 W or 5 W in 10 min in tumors close to the skin's surface. Efficiency of the applicator for deeper tumors can also be improved by utilizing all the antennas on the applicator and increasing the input power with proper equipment and amplifiers.

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