PS-7-03

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1083-1084

A Monolithic Microwave Heater in 0.18-µm CMOS Technology

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Abstract

A monolithic microwave heater has been fabricated in 0.18-µm CMOS process, where the microwave is generated by an LC oscillator, while temperature sensors are used for temperature detection. The linear operation temperature range of the temperature sensors is from -10 °C to 35 °C, where the temperature coefficient of sensors is 35 mV/°C. The key to activate the microwave heater is triggering the motions of polar molecules with time-varying electric field. When the phantom with polar molecules is placed above the inductor of the heater, its temperature is successfully raised by 1.4 °C in 30 minutes.

1. Introduction

The microwave energy could be transformed into the thermal energy when a time-varying electric field is applied to a group of polar molecules. The microwave energy first turns into the kinetic energy when the group of polar molecules are exposed to the time-varying electric field, where the polar molecules are forced to move and rotate continuously due to their electric dipoles. During these induced motions, lots of collisions occur between the polar molecules or other molecules, so that the kinetic energy of the molecules would be transformed into heat [1]. Recently, traditional heating techniques for medical treatments have been gradually substituted with microwave heating techniques for the advantages of its good precision and high efficiency. In the previous work [2], microwave heating has been applied to tumor treatments for ease of use and less invasiveness. The heating treatment can be improved if the ambient temperature of the heating target can be precisely monitored.

In this work, a monolithic microwave heater containing temperature sensors is designed and implemented. The rest of the paper is organized as follows. Section 2 describes the design of the microwave heater consisting of a 2.4-GHz LC-oscillator and temperature sensors. In Section 3, the experimental results are presented. Finally, the conclusions are given in Section 4.

2. The System Architecture of the Microwave Heater

The monolithic microwave heater has been designed and fabricated using 0.18-µm CMOS process. Fig. 1 is the illustration of the monolithic microwave heater. It consists of an LC-oscillator and 12 temperature sensors. The 2.4-GHz microwave is generated by the oscillator. During oscillation, a time-varying electric field would be created around the inductor of the LC-oscillator. Once the heating target is placed around the inductor, its temperature would be raised through the interaction between its polar molecules and the electric field. Therefore, the inductor is employed as a heat applicator of the monolithic microwave heater and is surrounded by 12 temperature sensors to detect the temperature of the heating target.

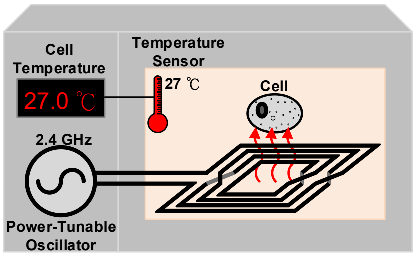
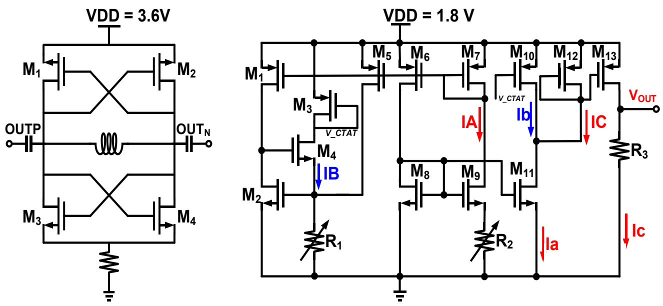


Fig. 1 The illustration of the monolithic microwave heater

The schematics of the LC-oscillator and temperature sensor are shown in Fig. 2. The LC-resonator is formed with an on-chip inductor and the parasitic capacitors of the CMOS cross-coupled pair.



(a) LC-oscillator (b) temperature sensor

Fig. 2 The schematic of the monolithic microwave heater

The temperature sensor is formed by current sources with different temperature coefficients as follows. IA and Ia are the proportional-to-absolute temperature (PTAT) currents whose temperature coefficients are positive while IB and Ib are the complementary-to-absolute temperature (CTAT) currents whose temperature coefficients are negative. Since IC is equal to Ia – Ib, it is a PTAT current with a larger temperature coefficient as compared with Ia and Ib. IC is further transformed into a PTAT voltage by R_3 and M_{13}. Then, the temperature can be monitored by observing the output voltage of the temperature sensor.

The linear operation range of the temperature sensors is from -10 °C to 35 °C, where the temperature coefficient of the sensors is 35 mV/°C [3]. The microphotography of the monolithic microwave heater is shown in Fig. 3 and the chip size is 1.5 × 1.3 mm^2. The placement of temperature sensors around the inductor is also illustrated. The temperature sensors are surrounded by metal to improve the heat conduction and the passivation layer is removed for some sensors that are labeled as VR1~6 (at the right in Fig.3). Those sensors covered with passivation layer are labeled as VL1~6 (at the left in Fig.3).

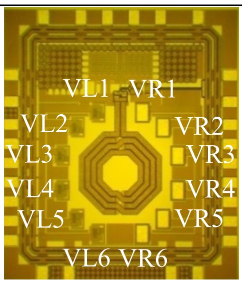


Fig. 3 The mircophotography of the microwave heater

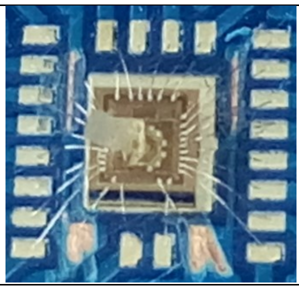


Fig. 4. The measurement setup with the agar phantom

3. The Heating Experimental Results

During the experiment, agar phantoms are used as the heating target, as shown in Fig.4. The ingredients for the agar phantoms are shown in Table I. The experimental results were obtained from 6 chip samples, where temperatures of agar phantoms were raised in 30 minutes according to the output voltage changes of the temperature sensors.

Table I Ingredients for agar phantom [4]

Ingredients	wright(g)	Composition (%)
Sodium chloride(NaCl)	0.12	0.13
Deionized Water	90	94.81
Oil	2.4	2.53
Agar	2.4	2.53

The experiment was conducted with experimental group and control group for each chip sample. The only difference between the two groups is the existence of agar phantoms. For the experiment group, the inductor would be covered with ager phantoms while there is no agar phantom for the control group. The output voltages of on-chip temperature sensors are observed during the experiments for both the control group and experimental group. For each sample, the output voltages of the temperature sensors would be checked at the beginning of the experiment, and then observed every ten minutes for three times.

From the measured voltage changes and temperature coefficients of the temperature sensors, the temperature changes can be estimated, as shown in Fig.5. The temperature increases of ~ 1 °C can be observed in the experimental groups for each chip sample, where the largest increment is up to 1.4 °C. The temperatures in the control groups remain the same for some chip samples and slightly drop for others, which so far is regarded as inevitable errors during the experiment. The different thermal behaviors of the two groups have already well proved that the microwave heater is activated when the agar phantoms containing polar molecules are exposed to and strongly influenced by the time-varying electric field.

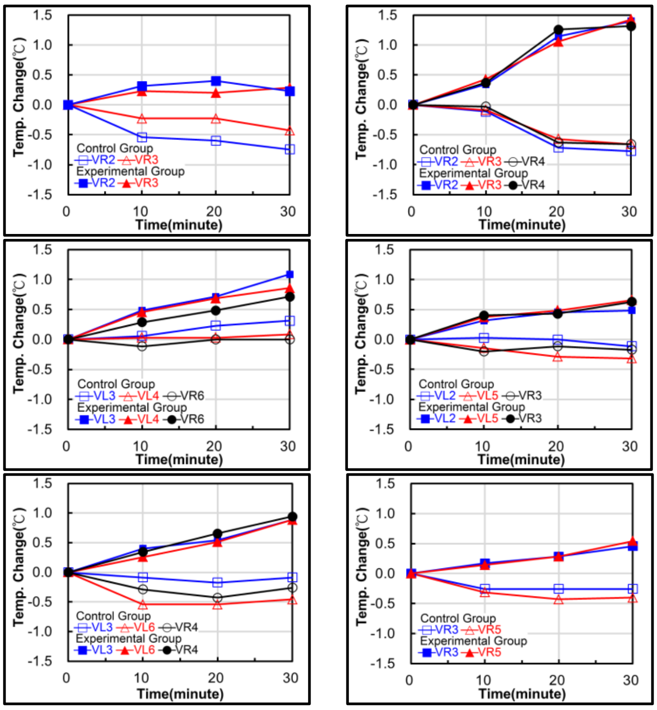


Fig. 5 The measured temperature changes versus time for 6 chip samplpes with arga phatoms (as experimental groups) and without arga phatoms (as control groups).

4. Conclusion

Based on the microwave heating mechanism, a monolithic heater with temperature sensors has been designed and implemented using 0.18-µm CMOS technology. The agar phantom is placed above the inductor of the heater to have its polar molecules exposed to the 2.4-GHz electric filed. According to the measurement results, the temperature increase up to 1.4 °C can be achieved in 30 minutes.

Acknowledgements

This work is founded by the Minister of Science and Technology of Taiwan under the contract numbers MOST 106-2221-E-011-158-. We also appreciate National Chip Implementation Center of Taiwan for their technical support during the chip fabrication.

References

[1] Handbook of Microwave Technology for Food Applications, Marcel Dekker Inc., New York, NY, USA, 2001.

[2] F. Sterzer, “Microwave medical devices,” IEEE Microw. Mag., vol. 3,no. 1, pp. 65–70, Mar. 2002.

[3] H. Q. Xiao, C. S. Yuen and H. C. Chen, "A CMOS microwave heating system," *2017 IEEE/SICE International Symposium on System Integration (SII)*, Taipei, 2017, pp. 511-516.

[4] Kihyun Kim, Taeyoon Seo, Kyunjong Sim, and Youngwoo Kwon, “Magnetic Nanoparticle-Assisted Microwave Hyperthermia Using and Active Integrated Heat Applicator”, IEEE Trans. on microwave theory and technuques 2184-2197, 2016.