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Micro Channel Based Heat Sink with Integrated Thin-Film Temperature Sensors

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Abstract

The thin film sensors integrated in the microfluidic channels can monitor the temperature in the channel accurately and in real time. Results show that even small temperature perturbation within 0.1°C can be observed, and temperature profile in the microfluidic channel can be extracted. This is meaningful for thermal management of power IC.

1. Introduction

With the development of advanced microelectronic technology, heating issue becomes more critical for power IC. Compared to traditional heat dissipation methods, microfluidic channel based heat sink is of great interest because of its high performance. Infrared (IR) camera is usually adopted to monitor the heat status. However, this method requires high cost equipment, and only the surface temperature can be obtained. No temperature information inside the microfluidic channel can be extracted. Although some researchers propose microfluidic device with integrated temperature sensors to avoid using IR camera, such sensors are still placed outside the microfluidic channel [1,2,3]. Since the temperature of the cooling liquid in the microfluidic channel is critical for monitoring the working status of the heat sink and power IC, a method of integrating temperature sensor into microfluidic channel is desired.

In this paper, a microfluidic channel based heat sink with integrated temperature sensors is reported. Temperature in the channel can be real-time monitored. Results show that even small temperature perturbation can be observed, which is meaningful to both power IC and heat sink.

2. Design Considerations

The microfluidic channel based heat sink with integrated temperature sensors is shown in the Fig. 1 (a). The heat sink consists of 50 straight fluidic channels, and the dimension of each channel is 50μm * 5000μm. Two temperature sensors, named S_In and S_Out, are placed at the inlet and outlet of the heat sink. As is shown in Fig.1 (b), 9 temperature sensors, denoted as S1 to S9, are equally distributed in the central fluidic channel, and the pitch of two sensors is 500μm. This configuration ensures the temperature profile in the fluidic channel can be extracted. Pt thin film based resistor is employed as the temperature sensor, because of its high sensitivity and stability. The temperature coefficient of resistance (TCR) of the annealed Pt thin film remains stable even at elevated temperature. To precisely measure the resistance of the temperature sensor, all sensors are 4-wire connected, eliminating the effect of parasitic resistance of the connection wires. It is worth noting that a Pt thin film coil serves as the heat source, acting as the heating power IC.

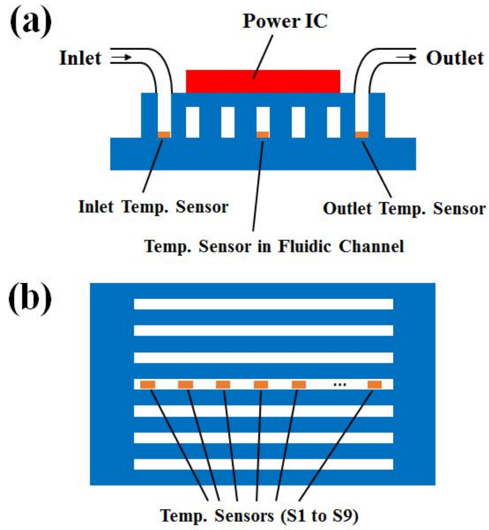

Fig. 1 (a) Schematic drawings of heat sink structure and; (b) the configuration of temperature sensors in the micro channel.

3. Fabrication and Measurement Setup

Fabrication

The microfluidic channel (Chip A) is firstly fabrication. The inlet and outlet are drilled using UV laser. After that, Ti (20nm)/Pt (200nm) thin film are deposited and patterned on the front surface of Chip A to form the heat source, where the Ti thin film serves as adhesion layer. Fig. 2 (a) shows the fabricated microfluidic channel, as well as the heat source on the front side. The thin film resistor temperature sensors are fabricated on another silicon substrate (Chip B). A thin SiN layer (1μm) is grown on the silicon substrate for insulation purpose. The Ti (20nm)/Pt (200nm) thin film are deposited and patterned to form the resistor temperature sensors. The Chip B is then annealed at 350°C for 1 hour. The Chip B after annealing is shown in Fig. 2 (b). The Chip A and Chip B are aligned and die-to-die bonded using 2μm BCB epoxy. Fig. 2 (c) shows the whole microfluidic channel based heat sink after bonding, and the microscope picture shows the outlet is well aligned with the corresponding thin-film temperature sensor.

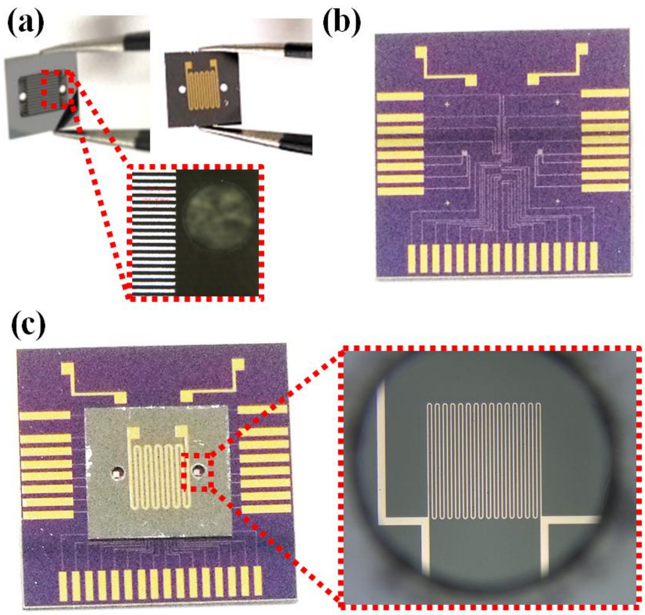

Fig.2 Pictures of: (a) microfluidic channel (Chip A); (b) Temperature sensor (Chip B) and; (c) the micro channel heat sink after bonding, and the microscopic picture of the temperature sensor through the outlet.

Measurement Setup

The as-fabricated device is mounted and wire-bonded on a customized printed circuit board (PCB). The heat source is driven by a DC power source, while all the sensors are connected to data acquisition system. The resistance change of the temperature sensor is measured and transmitted to PC for further analysis.

4. Results and discussions

The heat source resistance is measured as 90Ω. Fig. 3(a) shows the responses of all sensors under different heating voltage at a constant water flow rate of 100 ml/h. The temperature sensors can accurately read the temperature change inside of the micro channel, and the resolution is better than 0.1°C. Fig. 3 (b) shows the extracted temperature profile in the microfluidic channel. When the flow is off, the curve shows the tendency of the temperature with slight decreasing around the central heat source. When the flow is on, the tendency of temperature change is linearly increasing with the direction of flow, implying the heat is transferred to the cooling liquid. A worth noting case is illustrated in Fig. 3(c) and (d) (4.2V heating, 250ml/h flow rate). When air bubbles are mixed into the cooling liquid and flow through the heat sink, it suffers a sudden temperature change. The micro bubble may slightly affect the temperature, while the large bubble can last for as long as 20s with temperature increase of 15°C. The capability of detecting such unhealthy status is very meaningful to both power IC and heat sink.

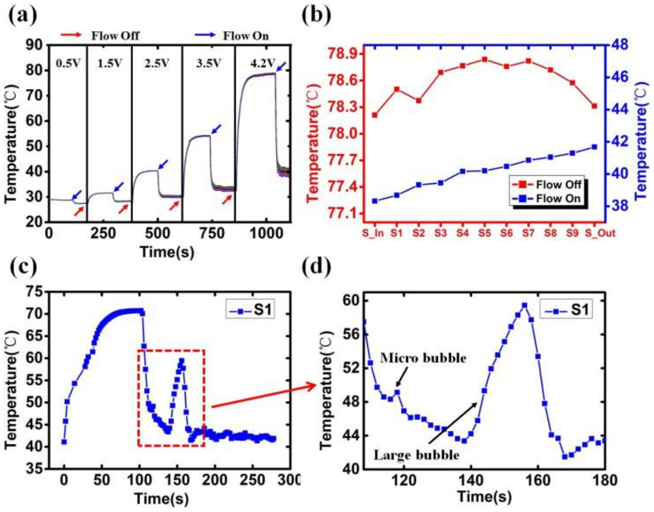

Fig.3 (a) Temperature sensor response under different heating voltage; (b) the temperature profile in the microfluidic channel from the inlet to outlet with cooling liquid flow off and flow on; (c) 、 (d) the bubbles impact on the temperature change in microfluidic channel.

5. Conclusions

Experiments show that the integrated thin film temperature sensors can real-time monitor the temperature in the channels accurately. Due to their small size, temperature profile within the micro channel can be obtained, with high resolution, high stability and high sensitivity. The microfluidic channel based heat sink with integrated temperature sensors is very important for power IC.

Acknowledgements

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