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Cooling Measurement of On-Chip Inetgrated EOF Micropump Using CMOS-LSI Components

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Abstract

We investigated the cooling effect of the integrated electroosmotic (EOF) micropump on CMOS LSI circuits. Despite the low flow-rate because of the limited size of the micropump, the thermal resistance consequently decreases. We suppose that this is because this device is valid to expand the conducive heat-transfer areas around hotspots. We consider that a low-flow-rate micro-channel device can be used as a heat-spreader, and suitable for a portable device to save cooling component space.

1. Introduction

Cooling of integrated circuits using microfluidic devices has been widely studied. Although microfluidic devices are proved as a superior cooling method to conventional cooling methods, these microfluidic devices employ large external equipment [1]. To reduce the size of a cooling system, integrated cooling microfluidic devices have also been studied. The integrated cooling devices can circulate cooling liquid by using an on-chip integrated micropump. An EOF micropump, whose flow rate is proportional to the applied voltage (V_{EOF}), has been attrractive because of its simple structure [2, 3, 4]. However, as the flow rate of the integrated micropump is not high, the cooling performance is limited. To cool circuits effectively, lots of studies have focused on hotspots, which are the power-consuming blocks in the circuits [3]. However, the cooling effect of a silicon LSI component using a low-flow-rate micropump has not been measured. In this paper, we measured cooling effect of demonstration in the fabricated chip, whose model is shown in Fig. 1.

2. Design and Fabrication

The CMOS LSI components were fabricated by a foundry company using the standard 0.6-µm CMOS technology on an SOI wafer (9 µm - 1 µm - 625 µm). First, an insulating layer was deposited on the chip, and then 1-µm-thick SiO_2 was patterned as an insulating layer. Subsequently, 20-µm-thick Ti and 200-µm-thick Au were patterned. The micro-channel was patterned in a cover of polydimethylsiloxane (PDMS) by a soft lithography method using a Si mold. Finally, the silicon chip and the cover were bonded using O_2 plasma surface activation. Figure 2 shows the fabricated chip.

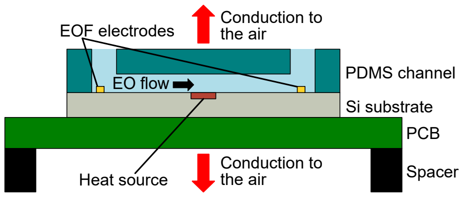

Fig. 1: Schematic of the micro-channel cooling system in the experiment.

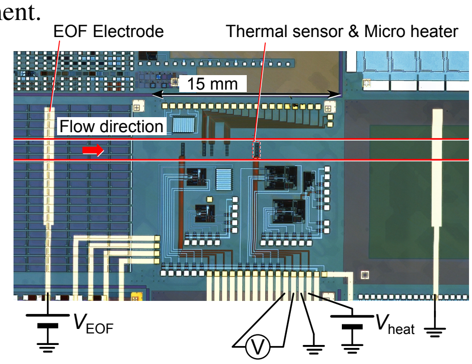

Fig. 2: Photomicrograph of the fabricated on-chip for cooling measurement.

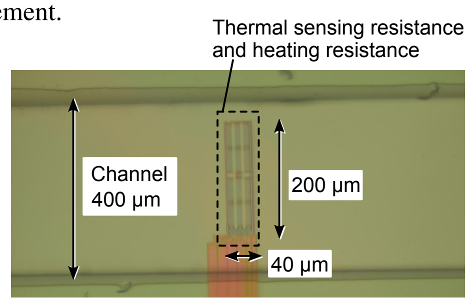

Fig. 3: Close-up image of the thermal sensing resistance and heating resistance under the micro-channel.

EOF electrodes were put at the inlet and outlet holes. Temperature is measured by a sensingpolysilicon resistor having a resistance of 8.7 kΩ, which is directly under the micro-channel, as shown in Fig. 3. The heat flux is input by applying voltages into the microheater, which is a polysilicon resistor having a resistance of 17 kΩ.

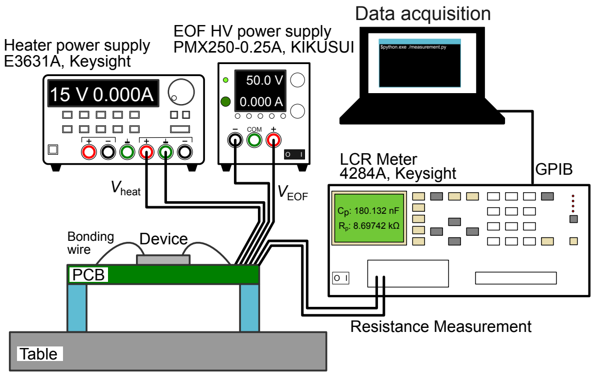

Fig. 4: Schematic view of the experimental setup used for cooling measurement.

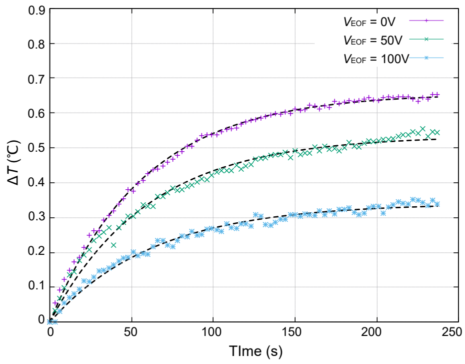

Fig. 5: Measurement result of the change of temperature. At $t = 0$, the power is supplied to the microheater.

3. Measurement

Figure 4 shows the experimental setup used in the cooling measurement. The resistance change is measured by an LCR meter. A voltage of 15 V (V_{heat}) is applied to the microheater using a DC power supply. The total input power is 13.2 mW, and the power density is 165 W/cm^2, which is a typical power density of power-consuming LSI circuits. The EOF micropump is driven by an HV DC power supply. The current consumption of the EOF micropump is 0.8 μA, and 1.6 μA when $V_{EOF} = 50$ V and 100 V, respectively.

The coefficient between the resistance and the temperature is calculated as 7.028 Ω/°C, which was measured by sweeping the temperature from 27°C up to 90°. Figure 5 shows the measurement results of the change of thermal temperature, which is calculated by using the resistance coefficient. At $t = 0$, the power is supplied to the micro-heater. When the EOF applied voltage (V_{EOF}) is 50 V, the increase of the temperature is smaller than that when $V_{EOF} = 0$ V. Besides, when $V_{EOF} = 100$ V, the temperature increase is suppressed 0.3°C more than the case of $V_{EOF} = 0$ V.

The flow rate of the micropump were 164 nL/min and 328 nL/min under $V_{EOF} = 50$ V and 100 V, respectively. In such a condition, the heat flux transferred by convection is small compared to the input power to the micro-heater. Therefore, the thermal resistance and capacitance, shown in Figure 6, are mostly derived from conduction cooling. These

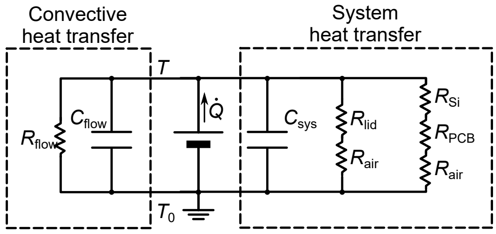

Fig. 6: Schematic of thermal equivalent circuits of the micro-channel cooling system.

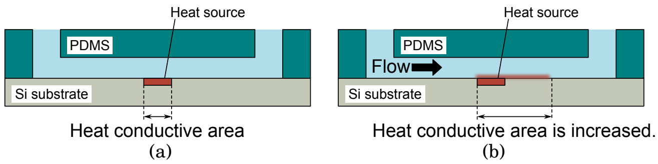

Fig. 7: Conduction heat transfer through silicon substrate (a) without flow and (b) with flow generated by an EOF micropump. When the EOF micropump is turned on, the thermal resistance of the silicon substrate is improved.

thermal resistance and capacitance are calculated as 49.6 K/W and 1.16 J/K, 40.4 K/W and 1.48 J/K, and 27.8 K/W and 2.48 J/K when V_{EOF} is 0 V, 50 V, and 100 V, respectively. The results indicate that the flow improved thermal resistance in spite of the low flow rate. We suppose that it is because of an expansion of the conductive heat transfer area between the heat source and the silicon. Figure 7a shows the schematic of the conductive heat transfer area without the flow. When $V_{EOF} = 0$ V (no flow), the area is only around the heat source. On the other hand, when there is a flow in the micro-channel, the heat is dissipated by the micro-channel. We suppose that the heat-transfer area is expended, as shown in Fig. 7b.

4. Conclusions

The cooling effect of the integrated EOF micropump is investigated. Despite the low flow-rate because of the limited size, and the thermal resistance consequently decreases. When a voltage of 100 V is supplied to the EOF micropump, the temperature is 0.3°C lower than a case without EOF. We suppose that this is because this device is valid to expand the conducive heat-transfer areas around hotspots.

Acknowledgements

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