Design and Fabrication of Sensor Chip with Heater for Semiconductor Flip-Chip Package Application

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***Abstract*— A heat generated from semiconductor chips and chip packages is considered a critical issue for high-performance and reliable device operation. In this paper we demonstrate a simple semiconductor chip with both heat generation and temperature sensor functions. By evaluating the relationship between the temperature of the chip and the resistance of the sensor, the thermal properties of the semiconductor package material can be determined. The heat generation block and temperature sensor are made of aluminum lines, not active circuit, so manufacturing cost is low and the processes are simple.**

Keywords- semiconductor; sensor chip; heater; micro-bump; flip-chip package; thermal reliability

I. INTRODUCTION

Due to increased complexity, integrity and operating speed, the heat generated by semiconductor chips and chip packages has been viewed as a problem to be solved for high performance and reliable device operation. The demand for diverse applications requiring small and high-speed operation, such as smartphones and wearable appliances, has dramatically increased heat generation. For this reason, testing and managing the heat of the chip has become very important in commercial devices [1], [2]. The packaging technology of integrated circuits has also been technologically advanced. As a way to solve the performance degradation problem due to the heat rise of the chip, the underfill material is used for the flip chip packaging technology.

In this paper, we propose and demonstrate a simple semiconductor chip with heat generation function and temperature sensor to test thermal characteristics of the packaging materials. This chip is much simpler than the diode temperature sensor array chip used to evaluate the thermal properties of semiconductor underfill materials and makes more profitable in terms of manufacturing cost and duration [3]. It was fabricated in National NanoFab Center (NNFC) of Korea using Complementary Metal Oxide semiconductor (CMOS) and Micro Electro Mechanical System (MEMS) manufacturing processes. The fabricated chips were characterized using an I-V measuring instrument and a temperature measuring instrument with a Thermo-Electric Couple (TEC) controller.

II. DESIGN AND FABRICATION

As shown in Figure 1, the heat generation area (heater) and the temperature sensing line (sensor) are integrated on a single chip at the same time. The heater block is placed on both sides of the sensor. Each heater block is designed for 200-ohm to generate heat. The sensor detects the temperature with a simple principle that the resistance increases when it receives heat, and it is designed 1K-ohm

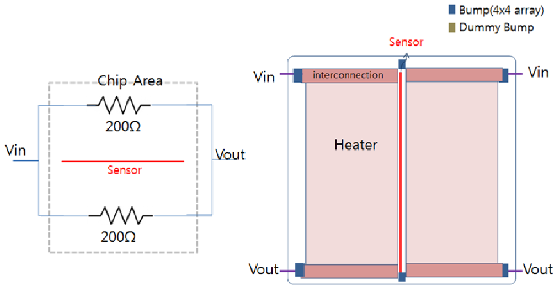


Figure 1. Schematic of chip with heater and sensor.

After deposit a protection layer and open the pad, the Sn/Ag micro-bump was formed on the chip pad with a diameter of 70um as shown in Figure 2.

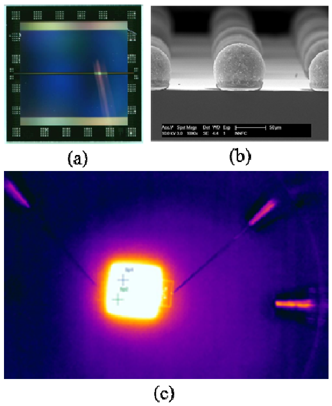
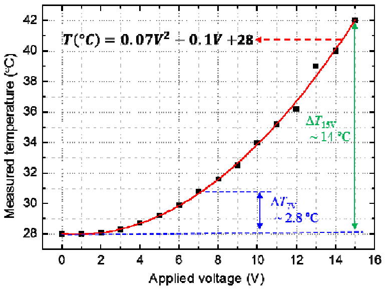


Figure 2. Fabricated a silicon chip. (a) Microscope image of chip, (b) Micro-bump array SEM image, (c) Thermal image of IR camera on flip chip packaged on PCB

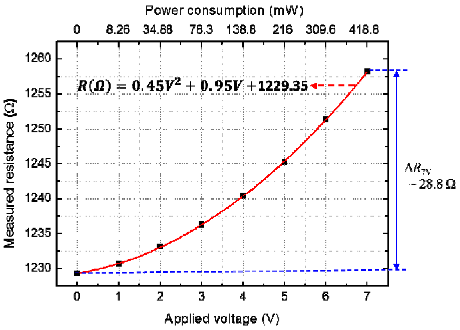
The IR camera image shows that heat is generated when the heater block is powered up, as shown in Figure 2(c). When the underfill material is filled between the chip and the Printed Circuit Board (PCB), the generated heat is transferred to the PCB through the underfill material, so that the chip temperature does not rise. The chip temperature rise rate is determined by the thermal conductivity of the underfill material.

III. MEASUREMENT

The fabricated chip was characterized with I-V measuring instrument and temperature measuring instrument with TEC controller. First, the chip temperature is measured while increasing the applied voltage as shown Figure 3(a), then, the resistance of the sensor was measured in the same way as shown in Figure 3(b). When the power is supplied to the heater block, heat is generated in the 200-ohm aluminum line per block and chip temperature rises. The generated heat is transferred to the sensor located in the center of the chip, increasing the resistance of the sensor. It can be seen that as the voltage increases, the temperature of chip and the resistance of sensor increase with the shape of the quadratic function. Based on these results, the resistance of the sensor versus temperature of the chip is derived as shown in Figure 3(c). Using this result, the temperature of chip can be determined by measuring the resistance of the sensor without measuring directly with the thermometer.



(a)



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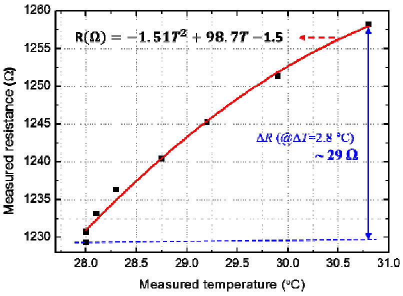

(c)

Figure 3. Electrical characteristics of the proposed chip. (a) Measured resistance of sensor, (b) Measured temperature of chip, (c) Calculated resistance as a function of temperature.

This result is very useful for testing semiconductor packaging materials such as underfill. Unerfill fills the gap between the chip and PCB for heat transfer and bump protection. The higher the thermal conductivity of the underfill material, the more heat is transferred to the PCB. As a result, the temperature of the chip and the resistance of the sensor will not increase significantly.

IV. CONCLUSION

We have demonstrated the relationship between chip temperature and sensor resistance by fabricating chip with heat generation and thermal sensor functionality using semiconductor processes. The proposed structure and method can be used to test the thermal properties of semiconductor packaging materials.

REFERENCES

[1] S. Ali, K. Sung-Mo, D. Avran, and C. Bernad, “Scanning the special issue on on-chip thermal engineering,” *Proc. IEEE*, vol. 94, no. 8 , pp. 1473-1475, 2006.

[2] M. Toshihiro, D. Haruka, and I. Hideyuki, “Tomoyuki H., Takashi, O. A test structure for analysis of metal wire effect on temperature distribution in stacked IC,” *Int. C. Microelectronic Test Structure (ICMTS)*, 2-1, pp.22-26, 2016.

[3] Lee. W.S, Han. I.Y, Yu. Jin, Kim. S.J, and Byun. K.Y, “Thermal characterization of thermally conductive underfil for a flip-chip package using novel temperature sensing technoque,” Thermochinica Acta 455, 148-155, 2007.