A MEMS-BASED DUAL-AXIS TILT SENSOR USING AIR MEDIUM

*J. C. Choi, C. M. Park, J. K. Lee and S. H. Kong**
School of Elec. Eng. and Comp. Sci., Kyungpook National University, Daegu 702-701, Korea

ABSTRACT

In this paper, a MEMS-based dual-axis tilt sensor, which utilizes a free-convection-based air medium, is fabricated and its operating characteristics are evaluated. The key components of the proposed tilt sensor, microheater and temperature sensors, are designed to have various patterns in order to examine an optimized geometry for achieving high sensitivity. Six different types of tilt sensors are fabricated and measured. The proposed tilt sensor operates in a wide detecting range of ±90° on two axes. Output characteristics show excellent linearity and symmetric sensitivity. Fabrication sequence is also very simple owing to its monotonous structure and heater/sensor material, thus it fits mass production at a low cost.

KEYWORDS

Tilt sensor, Inclinometer, Air medium, Convection, MEMS

INTRODUCTION

Inclination sensing is becoming a quick need for many applications in aerospace, automobiles, entertainment, computer peripherals, health sciences and so on [1][2]. The development of low-power and low-cost sensor would further broaden the scope of those applications.

A MEMS-based tilt sensor, which is simple to fabricate and measurable on two axes, is proposed in this paper. A superior performance could be achieved with the proposed convection-based tilt sensor compared with the previously proposed electrolyte-based tilt sensor [3]. Moreover, a superior linearity and symmetric output on two-axis inclination is observed. The proposed tilt sensor is small, simple, easy to fabricate and durable.

STRUCTURE and FUCTIONAL MACHANISM

Figure 1 shows the schematic diagram of proposed sensor. It consists of separately-fabricated and finally bonded top and bottom wafers. The top wafer provides an encapsulated air cavity for thermal convection. The bottom one contains a central microheater to heat up the air medium and temperature sensors to detect temperature profile in the encapsulated air cavity. The central microheater is placed to be surrounded by four temperature sensors. The heater and temperature sensors are simultaneously manufactured by lift-off process on SiO_2 thin membrane for thermal isolation.

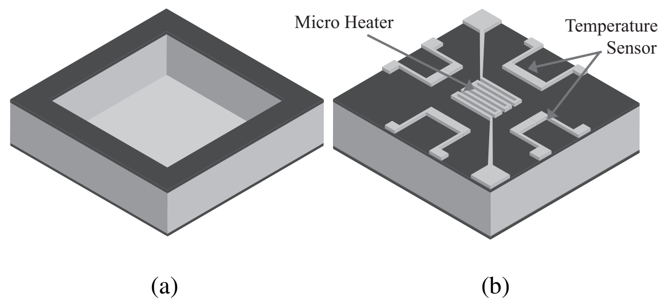

Figure 1. Schematic diagram of MEMS-based two-axis tilt sensor using air medium; (a) top wafer, and (b) bottom wafer.

The operating principle of proposed sensor is shown in Fig. 2. When the sensor is balanced with no inclination, the microheater produces a symmetric temperature profile in the sealed cavity. With an inclination, temperature sensors formed around the heater measure the changed temperature profile caused by the effect of inclination on free convection in the surrounding air medium.

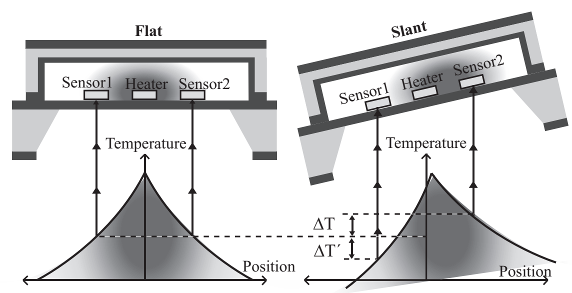

Figure 2. Functional mechanism of proposed tilt sensor.

FABRICATION

Figure 3 shows the fabricated tilt sensors before and after bonding. The fabrication process is quite simple, as shown in Fig. 4; the top and bottom wafer are processed independently and bonded using epoxy when both wafers are completed. Top one is etched by deep reactive ion etching (D-RIE) to form an air cavity and thermally oxidized for suppressing thermal interference. The back side of the bottom wafer is etched back using tetra-methyle ammonium hydroxide (TMAH) solution until the whole bulk silicon is removed in the open area to form a thin silicon dioxide membrane. The heater and sensors are then formed with composite layer of titanium (Ti) and nickel (Ni) using lift-off process on the membrane.

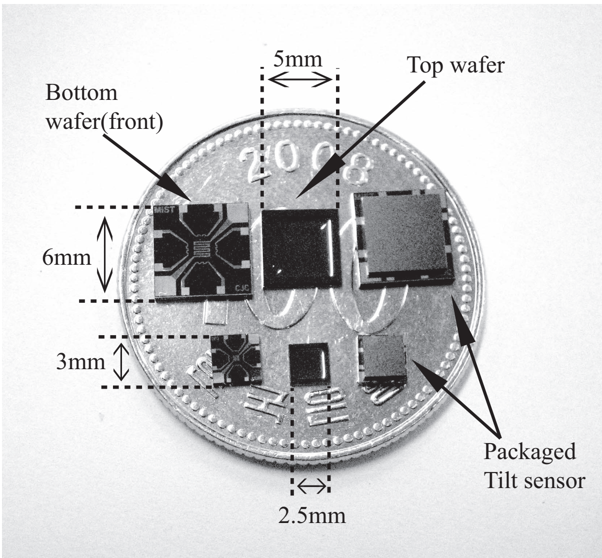

Figure 3. Fabricated tilt sensors.

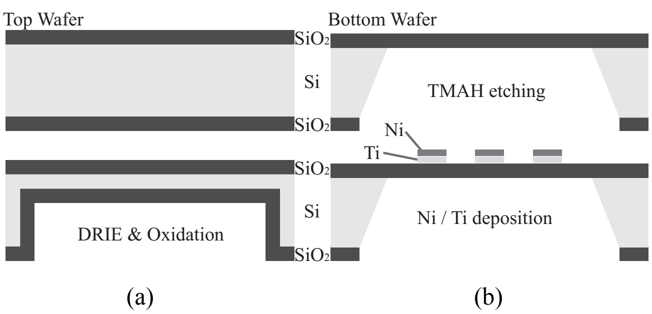

Figure 4. Process sequence; (a) top wafer, and (b) bottom wafer.

Figure 5 shows the fabricated microheaters and temperature sensors with various geometry and shapes. In order to experimentally examine an optimized structure of the key components of tilt sensor, the microheater and the temperature sensors were designed in such a way. Two types of microheaters and three different types of temperature sensors were prepared, as shown in Fig. 5.

HEATER DESIGN

Figure 6 shows the heating characteristics of fabricated microheaters that have different pattern size and shape. H_S has an area of 720 x 720 μm^2 and line width of 40 μm while H_L does 1 x 1 mm^2 and 80 μm. As shown in Fig. 6, H_S with thinner heating line shows better performance than H_L with fat heating line, because the heating performance is directly proportional to the resistance.

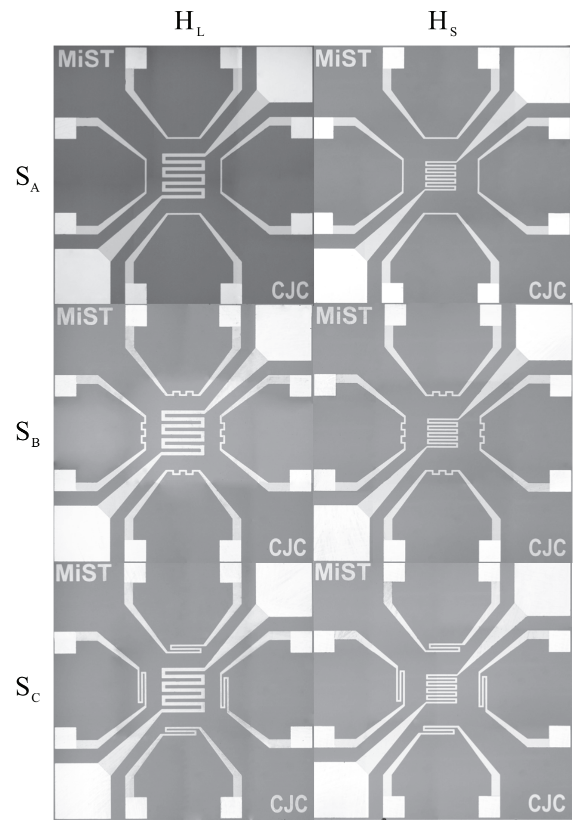

Figure 5. Fabricated microheaters and temperature sensors.

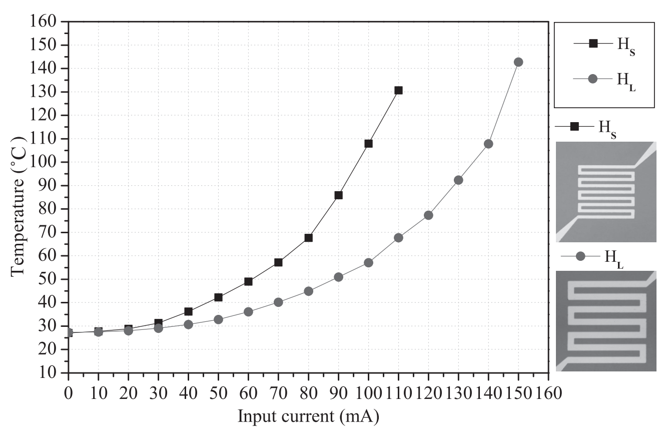

Figure 6. Characteristics of fabricated micro heater.

TEMPERATURE SENSER DESIGN

Figure 7 shows the sensing characteristics of fabricated temperature sensors with different pattern size and shape. All the sensors show linear characteristics in the temperatures range of 30 ~ 150 °C. The sensors have been designed to have three different types, straight-line (S_A), square-wave (S_B) and s-like (S_C) shapes. The s-like shape of temperature sensor (S_C) shows the most sensitive output characteristic due to the resistance effect. The sensing current for each temperature sensor was fixed at 10 mA.

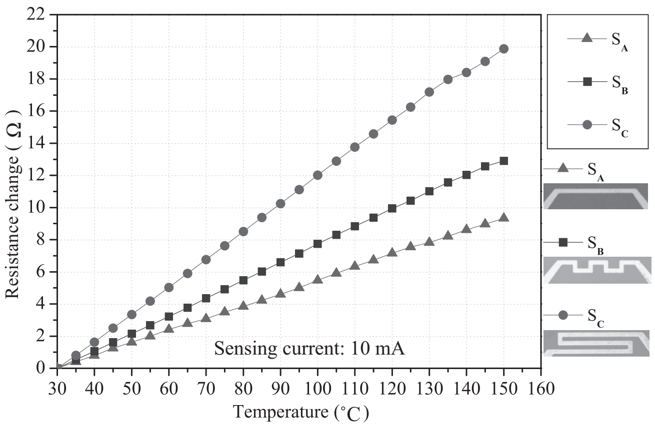

Figure 7. Characteristics of fabricated temperature sensors.

MEASUREMENT

Figure 8 shows the measurement system. A positive angle is defined for the measurement as a counterclockwise inclination as shown in Fig. 9. The tilt measurement result on one axis is shown in Fig. 10. For this measurement, fixed currents at 10 and 50 mA are supplied to each temperature sensor and heater, respectively. With an inclination, each temperature sensor experiences a change in the resistance owing to the convection-induced temperature change. The resistance change of temperature sensor corresponding to a given inclination angle is measured as the output voltage by the Ohm's law. The fabricated tilt sensor gives quite linear and symmetric characteristics with respect to three different types of temperature sensors in the whole range of ±90 °, as shown in Fig. 10.

Figure 11 shows the output characteristic of proposed sensor on two axes using four temperature sensors, formed around the central microheater. This result reveals that proposed sensor operates well and shows quite linear characteristics even on two axes.

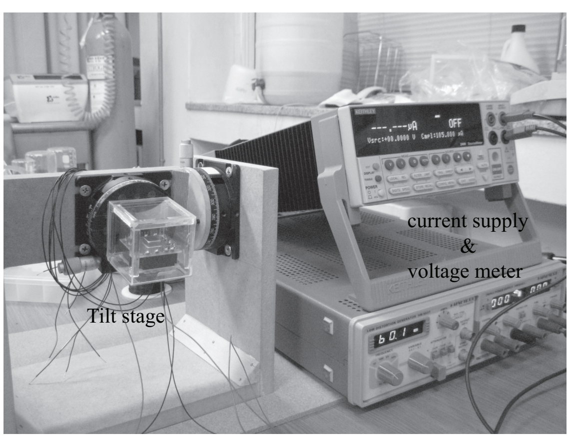

Figure 8. Measurement system.

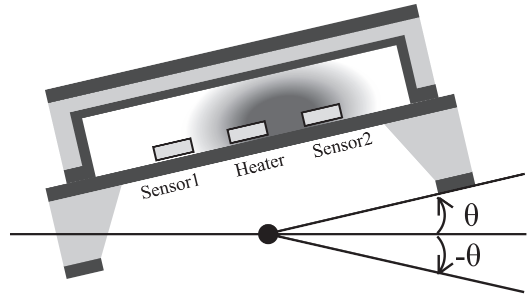

Figure 9. Definition of inclination angle.

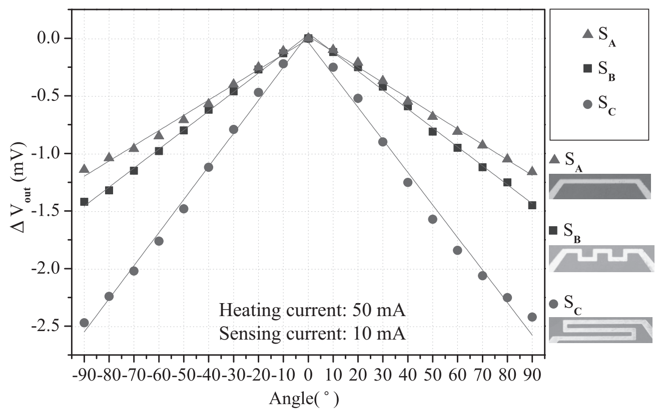

Figure 10. One-axis measurement result of the tilt sensor.

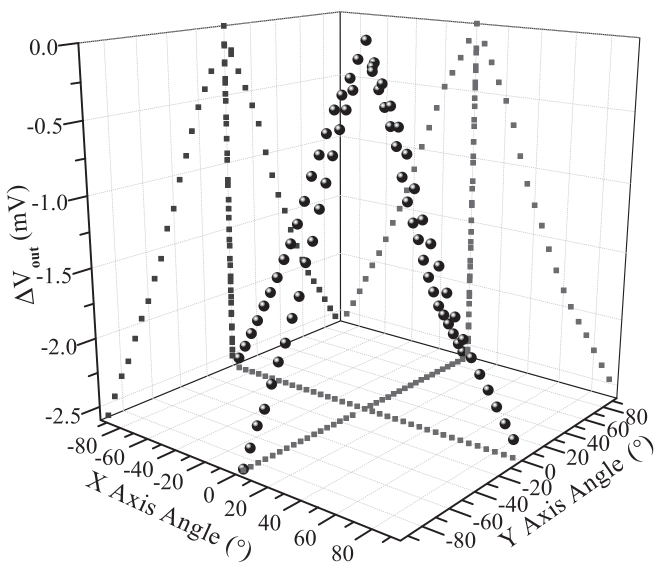

Figure 11. Two-axis measurement result of the tilt sensor.

CONCLUSION

The proposed convective tilt sensor using air medium consisted of a microheater and surrounding temperature sensors covers the measurement range of ±90 ° on two axes with superior linearity and symmetric sensitivity. The mass production of the proposed tilt sensor is feasible at a low cost and the performance of the sensor can be further improved by scaling down, replacing the gas medium, and by optimizing its structure and material. A read-out and temperature compensation circuits that suppresses the circumstance effect might be added to this sensor for better performance.

REFERENCES

[1] R. Dai, R. B. Stein, B. J. Andrews, K. B. James, M.Wieler, "Application of tilt sensors in functional electrical stimulation", *J. IEEE Trans. on rehabilitation eng.*, vol. 4, pp.63–72, 1996.

[2] Y. L. Chen, "Application of tilt sensors in human-computer mouse interface for people with disabilities", *J. IEEE Trans on neural sys. And rehabilitation Eng.*, vol. 9, pp.289–294. 2001.

[3] H. Jung, C. J. Kim, S. H. Kong, "An optimized MEMS-based electrolytic tilt sensor", *J. Sensors and Actuators A*, vol. 139, pp. 23-30. 2007.

CONTACT

* S. H. Kong, tel: +82-53-950-7579; shkong@knu.ac.kr.

ACKNOWLEDGMENT

This work was sponsored by Human Resource Development Project for IT SoC Architect conducted by ETRI SoC Industry Development Center, and also supported in part by the Ministry of Knowledge Economy (MKE) and Korea Institute of Industrial Technology Evaluation and Planning (ITEP) through the contract RTI 04-03-01.