

열전대를 이용한 미세 열유속 센서의 제작 및 평가

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Fabrication and evaluation of a micro heat flux sensor using thermopile

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ABSTRACT

Micro heat flux sensor is used in various industries to measure heat flux. In this study, a micro heat flux sensor is fabricated using the MEMS (Micro Electro Mechanical Systems) techniques. The fabricated sensor is composed in thermopile for sensor and SU-8 for thermal resistance layer. The new method of fabrication SU-8 is proposed in this study. The sensitivity is $44 \mu\text{V}/(\text{W}/\text{cm}^2)$ at steady state and Reynolds number is 91322.

Key Words : Heat flux (열유속), Thermal resistance layer (열저항층), MEMS, SU-8, Thermopile (열전대)

1. Introduction

The last ten years have seen significant advances in the development of thermopiles, devices that measure temperature differences in a silicon chip. Thermopiles have various attractive properties compared with the other sensors which are frequently used for temperature difference measurement [1].

- The thermopile has an output signal without offset and offset drift, because there cannot be any output signal without input power.
- The thermopile does not suffer from interference from any physical or chemical signals.
- The thermopile does not need any biasing.
- The readout is very simple, only a voltmeter is required.
- There is no interference caused by power supplies.
- The thermopile fabrication process is fully compatible with MEMS technologies.
- The thermopile can be applied to other devices with easy, such as micro calorimeter, micro heat flux sensor, and others.

In this study, the micro heat flux sensor is realized

by a new method. The micro heat flux sensor is composed in thermopile, for heat flux measurement and SU-8 for the thermal resistance layer. Cu and Ni is used for thermopile

SU-8 is a negative, transparent and epoxy type. The resist has been specifically developed for applications requiring high aspect ratio in very thick layers. So SU-8 is widely used in micro channel, micro lens, and so forth.

2. Theory

Thermopile is based on the Seebeck effect. The Seebeck effect is that a temperature difference between two points in a conductor or semiconductor results in a voltage difference between these two points. At a steady state, the Seebeck voltage, caused by the electron concentration difference, balances the driving force for diffusion. The Seebeck coefficient is defined as

$$\alpha = \frac{dV}{dT} \quad (1)$$

The Seebeck coefficient is a material property that depends on temperature. Given the Seebeck coefficient $\alpha(T)$ for a material, the voltage difference between two points where temperatures are T_1 and T_2 .

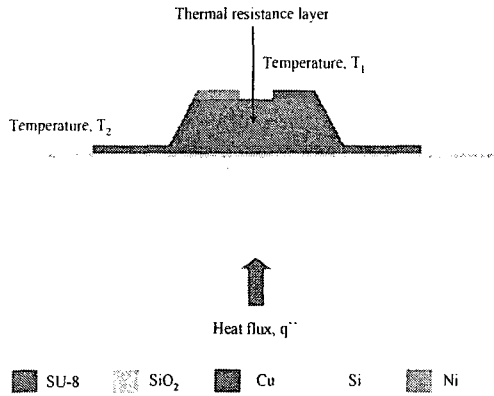


Fig. 1 Schematic diagram of the micro heat flux sensor

$$\Delta V = \int_{T_1}^{T_2} \alpha dT \quad (2)$$

Connecting n pairs of dissimilar conductors, i.e. thermopiles, together in series results in a thermopile for which the temperature sensitivity, S , is directly proportional to the number of thermopile junctions.

$$S = \frac{\Delta V}{\Delta T} = n(\alpha_a - \alpha_b) \quad (3)$$

In this study, a combination of Cu and Ni is used for the thermopile in micro heat flux sensor.

Although maximum sensitivity drives most thermopile applications, electrical resistance and thermal conductance place upper limits on the number of thermopiles that can be combined into a thermopile. Increasing the number of thermopiles to increase sensitivity proportionally increases both the series resistance and thermal conductance of the pile ultimately degrading device performance. As a result, thermopile designs usually become extremely application dependent, with tradeoffs between electrical resistance, thermal conductance and sensitivity.

The temperature difference in Fig. 1 can be calculated by

$$\Delta T = T_1 - T_2 \quad (4)$$

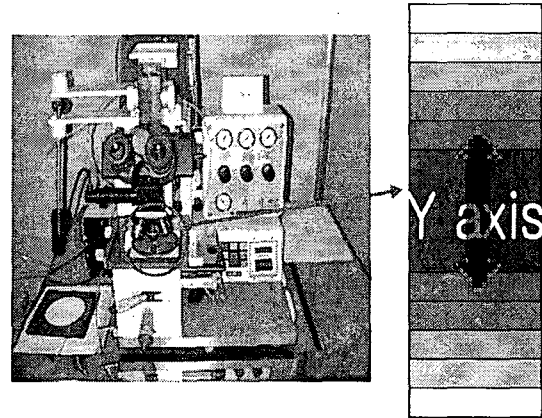


Fig. 2 The edge of SU-8 is exposed by MJB3.

The temperature difference is generated from the thermal resistance layer, SU-8. At steady state the heat flux q'' is proportional to the temperature gradient:

$$q'' = -k \frac{dT}{dx} = k \frac{(T_2 - T_1)}{t} \quad (5)$$

where the proportionality constant k is a transport property known as the thermal conductivity and is a characteristic of the material. Equation (5) is the one dimensional form of Fourier law of heat conduction [2][4].

3. Design

SU-8 is a negative, transparent and epoxy type. The resist has been specifically developed for applications requiring high aspect ratio in very thick layers. So SU-8 resist layer is good for thermal resistance layer. The key properties that make the SU-8 so attractive for ultra thick resist applications are its very low optical absorption in the UV range. This leads to uniform exposure conditions as a function of thickness, which gives rise to vertical sidewall profiles and hence good dimensional control over the entire structure height [3].

However it is difficult to connect thermopile line between the top of SU-8 and the surface of substrate for vertical sidewall profiles.

A new method of fabrication SU-8 is proposed. SU-

8 is exposed by MJB3 mask aligner in contact mode at 365 nm exposure wavelength. The exposure dose depends on film thickness. Thick films require higher dosage. It makes the round side wall to expose low exposure dose in the edge of SU-8, as shown in Fig. 2.

4. Fabrication process

Fig. 4 shows simplified fabrication steps of the micro heat flux sensor. The fabrication begins with a 4 ¼ <100> silicon wafer. A silicon dioxide film 10000Å in thickness is thermally grown on the front side of the silicon wafer using PECVD.

A SU-8 is spin coated at 2000rpm for 60seconds and cured in a hot plate. This results in approximately 65µm thick SU-8 layer. The seed layer for the electroplating of the thermopile is deposited on the substrate. Ti and Cu, respectively with 500Å and 5000Å in thickness, are deposited on the substrate. A photoresist layer is coated and patterned to form p-type using conventional photolithography techniques. Open area is filled with Cu with 10µm thickness using electroplating technique. After Cu electroplating, a patterned photoresist layer is removed by acetone. A photoresist layer is coated and patterned to form n-type using photolithography techniques. Ni with 10µm in thickness is deposited on a patterned photoresist layer.

The photoresist layer is removed using acetone. And the seed layer is removed by a Cu etching solution of ammonia, peroxide, and DI water. Finally, a Ti adhesive layer is cleaned by HF.

Fig. 3 is the optical images of fabricated sensor.

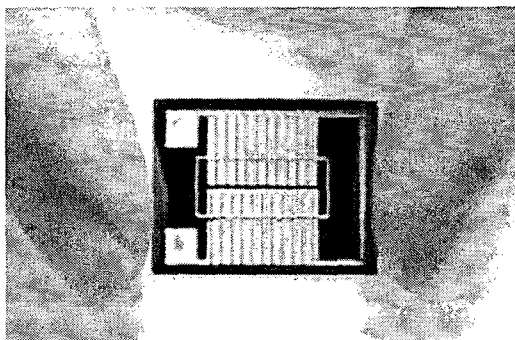
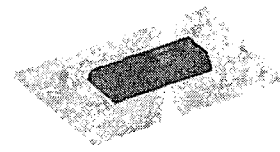
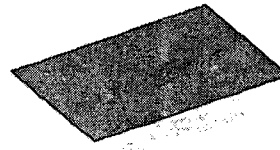


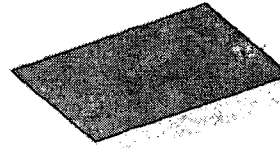
Fig.3 The optical image of the micro heat flux sensor



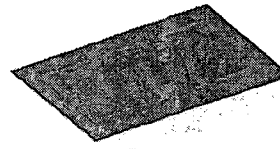
(a) SU-8 coating & patterning



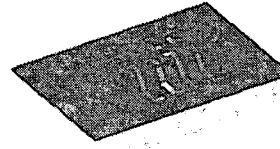
(b) Seed layer deposit



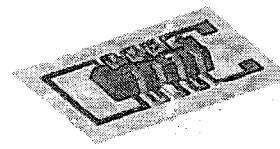
(c) PR coating & patterning



(d) Cu electroplating



(e) PR coating/patterning & Ni electroplating



(f) PR & seed layer remove

Fig. 4 Simplified fabrication steps of the micro heat flux sensor

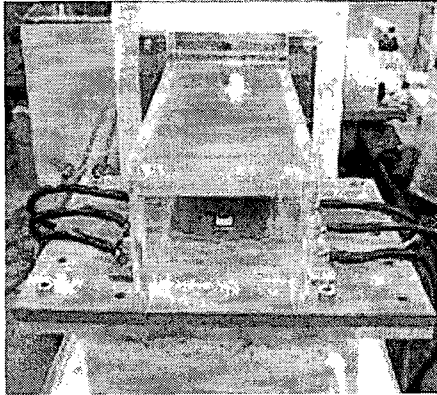


Fig. 5 Experiment set-up

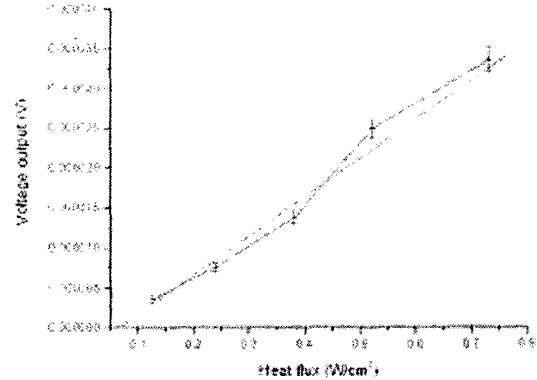


Fig.6 The result of the micro heat flux sensor

5. Measurement

The fabricated sensor is placed on a stainless heater. Test section is composed of bakelite, a stainless steel heater and a copper block, as shown in Fig. 5. For a steady state, a wind tunnel is used for this measurement. The flow is generated by the blower. The flow temperature is maintained 25°C and become uniform at the test section. The heat flux is generated from the stainless heater and controlled by the power supply. During the measurement, Reynolds number is constant, $Re = 91322$.

6. Results

Fig. 6 shows the result of the micro heat flux sensor according to heat flux. Voltage output is proportional to heat flux. The fabricated micro heat flux sensor shows a linear behavior.

The sensitivity is about $44 \mu V/(W/cm^2)$. This sensitivity is not higher than others. So it needs further research. Voltage output in low Reynolds number is higher than that of high Reynolds number. Reynolds number is so high in this experiment. It is believed that low Reynolds number increases the sensitivity of micro heat flux sensor

7. Conclusion

A new fabrication method of a micro heat flux sensor is proposed. SU-8 is good material for the thermal resistance layer.

The sensitivity of the micro heat flux sensor is $44 \mu V/(W/cm^2)$. Although this value is not higher than others, the fabricated micro heat flux sensor shows a linear behavior.

References

1. A. W. van Herwaarden, D. C. van Duyn, B. W. van Oudheusden, and P. M. Sarro, "Integrated thermopile sensors," *Sensors and Actuators A: Physical*, Vol. 22, Issues 1-3, pp. 621-630, 1989.
2. Warren M. Rohsenow, James P. Hartnett, Young I. Cho, "Handbook of heat transfer," McGraw-Hill, Third edition.
3. M. Despont, H. Lorenz, N. Fahrni, J. Brugger, P. Renaud and P. Vettiger, "High-aspect-ratio, ultrathick, negative-tone near-UV photoresist for MEMS applications," *MEMS 97, Proceedings, IEEE, Tenth Annual International Workshop*, pp. 518-522, Jan. 1997.
4. Jaechul Chun, Oh S. H., Lee S. S., "Design and fabrication of micro heat flux sensor," *Intelligent Robots and Systems, 1999 IEEE/RSJ International Conference*, Vol. 2, pp. 1045-1048, 17-21 Oct. 1999