Thermal Analysis of Fingerprint Sensor Having a Microheater Array

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Abstract:
For the purpose of properties security, in particular of information systems, demands for portable fingerprint sensors are increasing. We proposed a new type of fingerprint sensor having an arrayed microheater, and successfully fabricated one-dimensional array of sensor elements on a silicon wafer using micromachining technologies. Electric resistance of each heater element is measured as signals of temperature difference between elements that are in contact or non-contact with ridges of the fingerprints.

In this paper, we analyzed thermal characteristics of our sensor device using computer modeling. Effects of the following parameters were investigated; cavity under heater, SiO_2 film between heater and sensor base, heater size, input power and pulse time duration applied to the heater, material properties contacting to sensor surface etc. We concluded that making cavities under the microheater elements and having SiO_2 film layer between heater element and sensor base both for the purpose of thermal insulation, is necessary to realize the performance of the proposed sensor system. From the simulation results, it was clarified that such a miniaturized heater element will work quite effective for detecting fingerprint patterns.

1. INTRODUCTION

The fingerprint is known to be the most representative biometric for authentication of individual persons, and various ID devices have been developed. Optical methods are now commonly used for detecting fingerprint for accessing personal computer, but optical system needs lots of elements, such as laser diode, photo diode, and prism etc., thus is not suitable for portable device. Micro Electro Mechanical Systems (MEMS) technology allows a new type of sensor having robustness in sensing and providing more portable systems with less production cost. We proposed a new type of fingerprint sensor and fabricated it by MEMS technologies. Using MEMS technologies, it is possible to produce many kinds of micro device with low cost, but before device design and development, work with computer modeling and calculation is necessary and useful. Computer modeling can reduce the total time to transfer a device concept into a commercial product, and thus reduces development time and cost. Device modeling also can help us working on advanced device concept to try out ideas, finding practical device configurations and getting estimates of device performances. This paper introduced the principle and fabrication process about our new type of fingerprint sensor device and discussed many kind of conditions for new device design with computer modeling software α-FLOW, and proposed some useful suggestions.

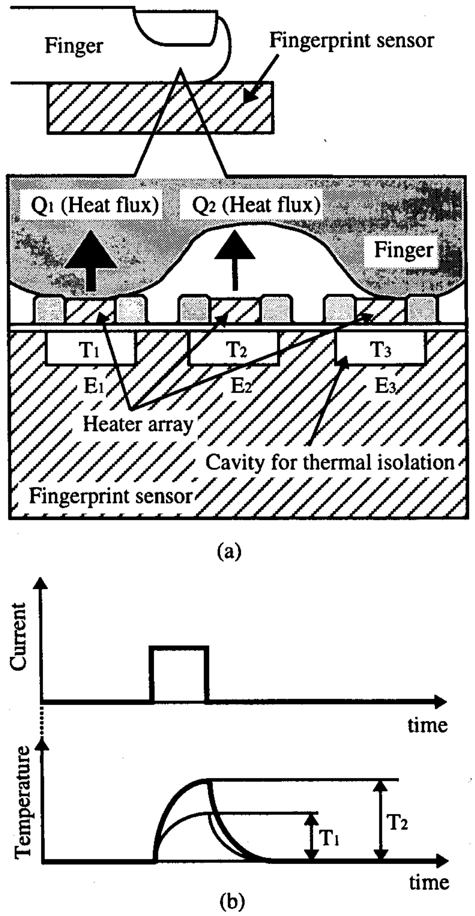

Fig. 1. Fingerprint sensor with an arrayed microheater.
(a) Device structure, (b) Sensing principle.

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2. PRINCIPLE

The structure and the working principle of our device is schematically shown in Fig 1. It has an array of microheater elements. A cavity is formed under each heater element for enhancing heat insulation between the heater and substrate. When a fingertip is pressed to the device surface, heater element in contact with a ridge of human fingerprint (E1) shows less temperature rise than that which is facing a recess of fingerprint (E2), because the finger acts as a heat sink. When one applies a pulsed voltage to each element as shown in Fig. 1(b), element E1 shows less increase in temperature rise than element E2 as schematically shown in the Fig. 1(b). The proposed type of sensor has an advantage over the conventional type which has an array of CMOS gates for attachment/detachment sensing and inevitably containing problems such as stray capacitance and charges on a human body.

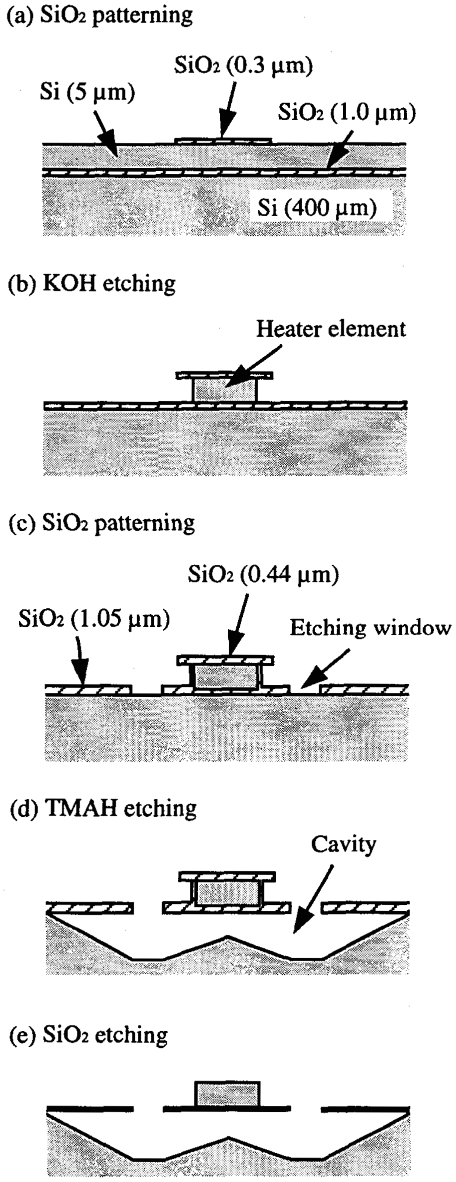

Fig. 2. Fabrication process of the fingerprint sensor element.

3. FABRICATION PROCESS

We have developed a fabrication process of the proposed device structure by using a SOI wafer as a starting material. The top silicon layer of the SOI is bonded to the substrate with 1 μm thick SiO_2 layer, and machined it to the thickness of 5.0 μm finally. The fabrication step is shown in Fig. 2. It is basically composed of two steps of wet etching. In the first step, we etched the top silicon layer to make a heater element in KOH solution. Then, the surface was protected with a thermal oxide film. The second TMAH wet etching was applied to form cavity under the heater element. We successfully fabricated an arrayed microelements (Fig. 3), whose minimum width, length and thickness are 20 μm, 40 μm and 5 μm, respectively. The minimum pitch distance of the heater elements is 80 μm. It satisfies in mechanical strength and the requirement to detect the fingerprint patterns.

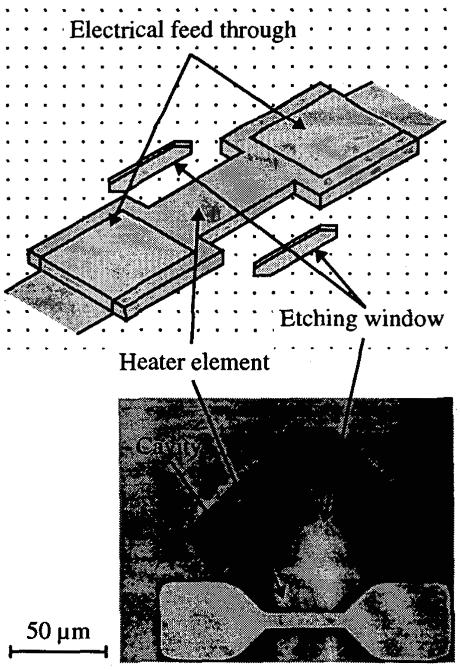

Fig. 3. Photograph of the fabricated microheater.

4. THERMAL ANALYSIS

(1) Temperature distribution characteristics on basic modeling

Figure. 4 shows our simplified fingerprint sensor modeling for computer calculation. It is one fourth of sensor element structure with vacuum cavity under heater; model surface is insulated with surroundings. Figure 5 shows the temperature distribution on heater element surface center-line along the length. Pulse time duration is in the range of zero to 1 ms. Figure 6 shows the temperature distribution on heater side-part centerline along width and Fig. 7 shows the depth temperature distribution on heater side-part center point B. Figure 8 shows the temperature at the center of heater plotted against different pulse time-duration. From Figs. 5~8, we can find the temperature distribution characteristics of sensor element. It is to say that the center point of heater surface has highest temperature, and widthwise have almost no temperature differences. SiO_2 film layer can make big temperature gradient, and the temperature at the center of the heater element shows good linear change with pulse time-duration.

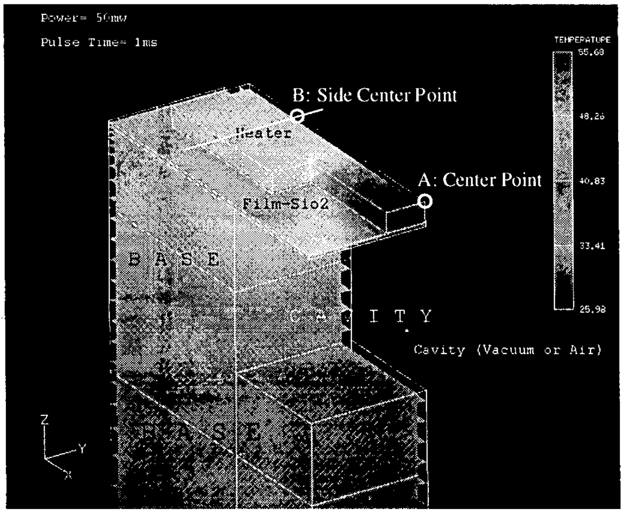

Fig. 4. Fingerprint sensor model.

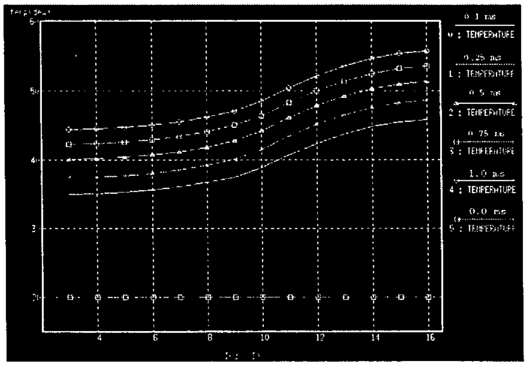

Fig. 5. Temperature distribution on heater surface. (Centerline along length)

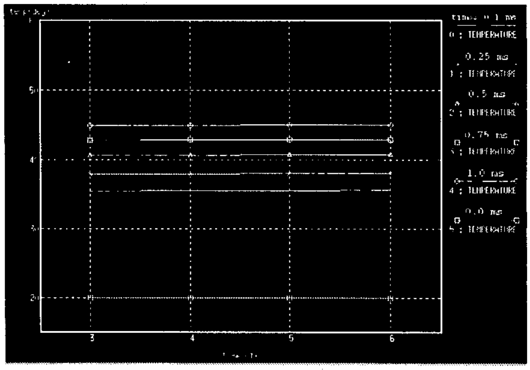

Fig. 6. Temperature distribution on heater side-part. (Centerline along width)

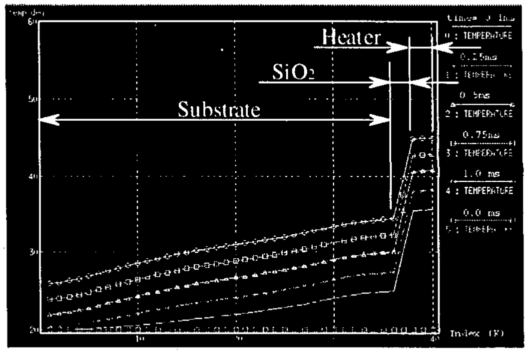

Fig. 7. Temperature distribution on heater side-part. (Center point B along depth)

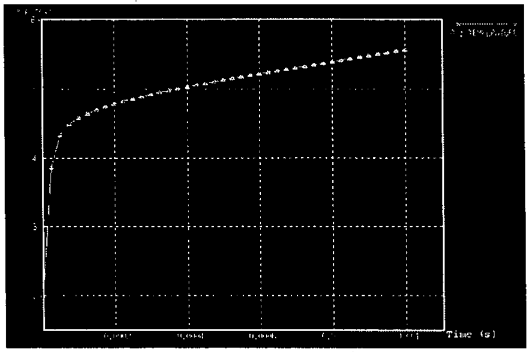

Fig. 8. Temperature at the center point A as a function of the pulse time duration.

(2) Effects of Cavity

As shown in Table 1 and Fig. 9, when the cavity is formed, temperature rise of the heater is remarkable compared to the case without cavity. Cavity raised the heater surface center temperature about 40 % than that of non-cavity structure in 50 mW input power and 1 ms pulse time duration in our simulation modeling. The cavity under the microheater element for the purpose of thermal insulation is effective.and there is almost no change on heater surface center temperature, when the cavity is in state of vacuum and full of air (See Fig. 10 for modeling).

(3) SiO_2-film Layer

From Table 2 and Fig. 11 it is understood that SiO_2-film layer also brings very good thermal insulation result. It raise the heater surface temperature about 30 % in the condition of 50 mW input power and 1 ms pulse-time with vacuum cavity under the heater and insulated with surroundings.

Table 1. Cavity effect on the temperature Tmax of heater element.

Time (ms)	Tmax (vacuum)	Tmax (Air)	Tmax (non-cavity)
0.00	20.00	20.00	20.00
0.10	45.85	45.79	31.90
0.25	48.63	48.57	34.15
0.50	51.36	51.29	36.37
0.75	53.58	53.51	38.79
1.00	55.68	55.61	40.81

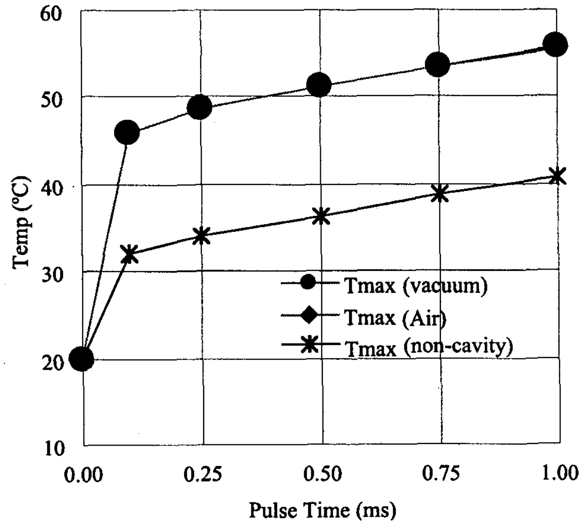

Fig. 9. Cavity effect.

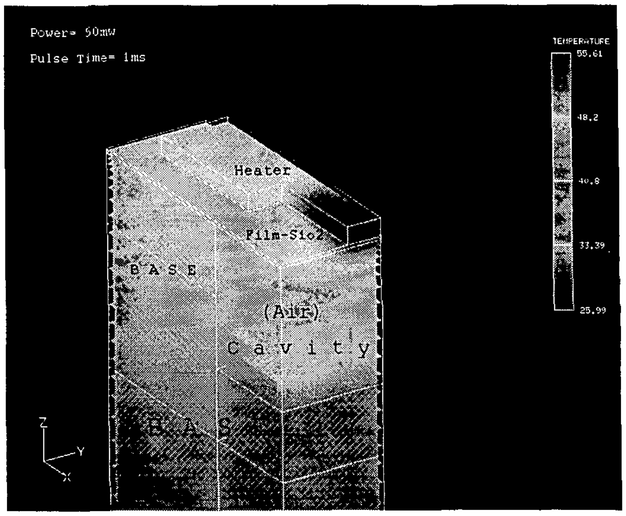

Fig. 10. Cavity (Air) and non-cavity.

Table 2. SiO_2-film layer effect on the temperature of heater element.

Time (ms)	Tmax (SiO2-Film)	Tmax (without-SiO2/Film)
0.00	20.00	20.00
0.10	45.85	34.44
0.25	48.63	36.80
0.50	51.36	39.39
0.75	53.58	41.57
1.00	55.68	43.67

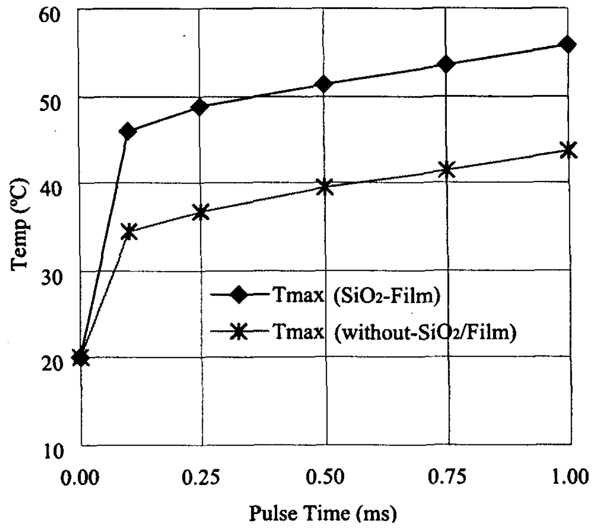

Fig. 11. SiO_2-film layer effect.

(4) Input Power Added To Heater Element

Figure 12 and 13 show the heater surface temperature with different input power by varying the pulse time duration. Even if pulse time duration is different, the relationship between the heater temperature and the input power is quite good linear. It means that when the temperature is set, the value relations between pulse-time duration and input power can be used to determine pulse width.

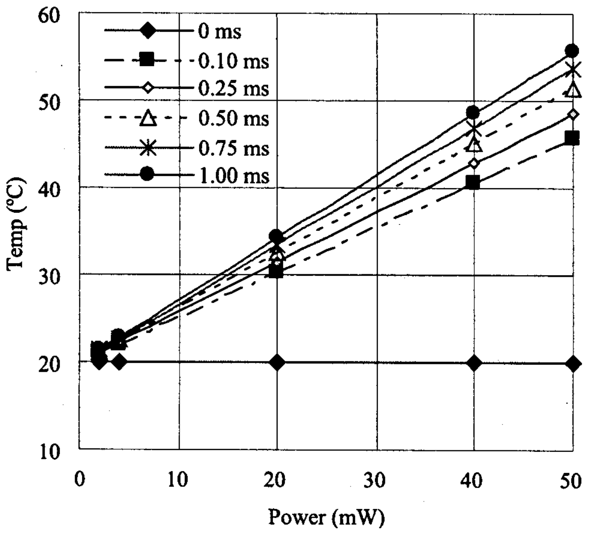

Fig. 12. Input power effect.

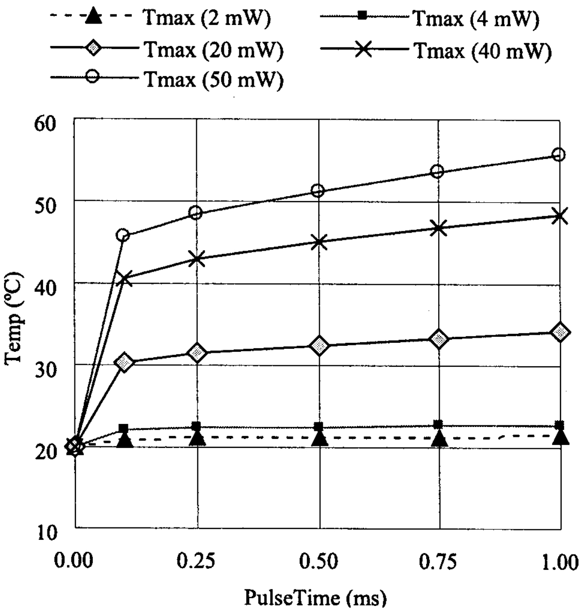

Fig. 13. Input power effect.

(5). Heater Size

From Fig. 14 we can know that at the conditions of the same pulse time duration and input power, the heater temperature is inversely proportional to heater element volume. We investigated two kinds of heater elements having same shape and different thickness. Thickness is 1 μm and 5 μm respectively. Input power is 50 mW. From Fig. 15 we can find that temperatures in the case of 50 mW input power applied to 5 μm thick heater and that of 20 mW input power applied to 1 μm thick heater are close to each other. It means that in order to get same temperature on heater element surface, small size heater ele-

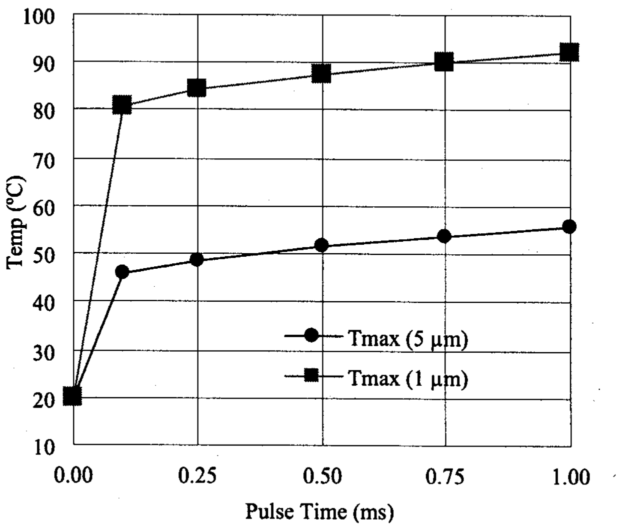

Fig. 14. Heater size effect.

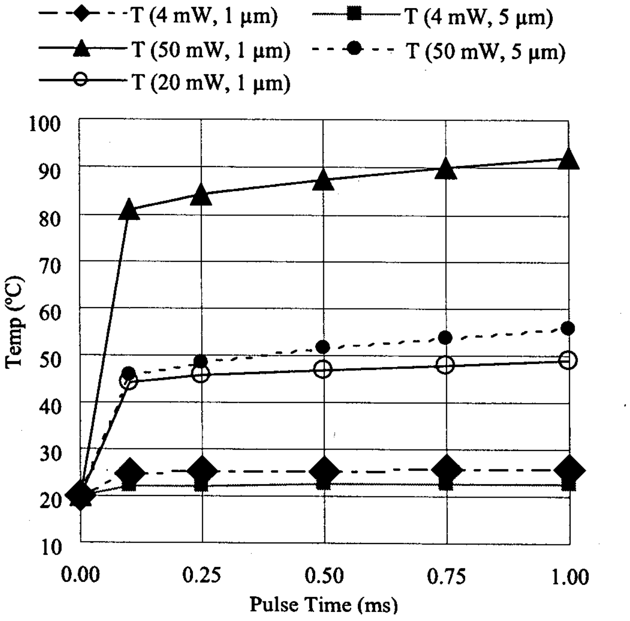

Fig. 15. Heater size and input power.

ment needs less input power. In other words, at the same conditions, small size heater element is much more sensitive.

(6) Effect of Material Properties Contacting To Sensor Surface

We investigated three kinds of contacting materials for the simulation of human fingerprint measurement (air, H_2O and leather). Table 3 and Figure 16 show a simplified fingerprint sensor modeling in touching state. Table 3 and Fig. 16 show the temperature at the center of the heater element, when the surface is in contact with air (this corresponds to valley of the fingerprint), H_2O or Leather (both corresponds to the ridge of the fingerprint). From Table 3 and Fig. 16, it is known that there exists enough temperature difference between valley (Air) and ridge (H_2O or leather) when they contact to heater surface, and the longer the pulse time duration, the bigger the temperature difference. In our simplified model, the temperature difference can reaches 12.5 °C between Air and leather, and 31.7 °C between Air and H_2O respectively, at the 1 ms pulse time duration and 50 ms input power. With another model (see Fig. 17, Table 4 and Fig. 18) found when the sensor base thickness decreases, the temperature difference will increase. For the high sensitivity of fingerprint sensor system, it will be better to reduce sensor base thickness and heater element size as can as possible.

Table 3. Material property effect.

Time (ms)	Tmax (Air)	Tmax (H2O)	Tmax (Leather)
0.00	20.00	20.00	20.00
0.25	57.49	46.93	53.68
0.50	74.12	57.19	67.76
0.75	90.73	66.67	81.45
1.00	107.30	75.61	94.84

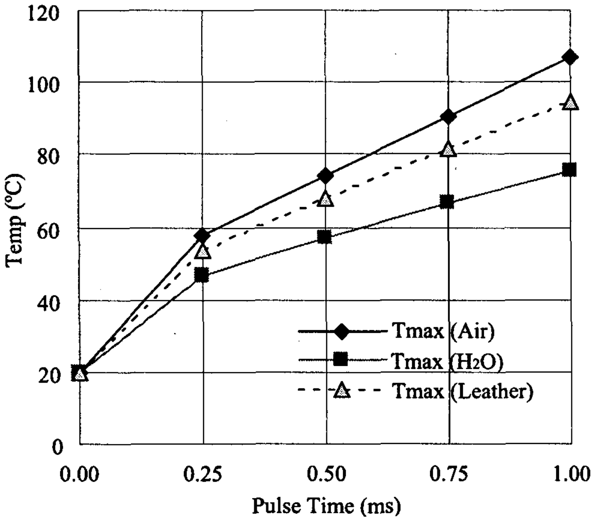

Fig. 16. Material property effect
(Materials contacting heater surface).

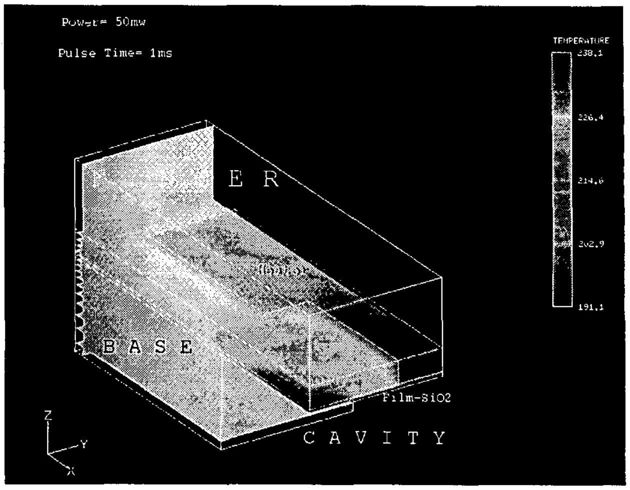

Fig. 17. Fingerprint sensor model
(With thinner size of base and finger).

Table 4. Thinner size model effect.

Time (ms)	Tmax (Air)	Tmax (H2O)	Tmax (Leather)
0.00	20.00	20.00	20.00
0.25	86.62	56.86	73.94
0.50	137.10	75.86	108.80
0.75	187.60	92.12	140.90
1.00	238.10	107.00	171.20

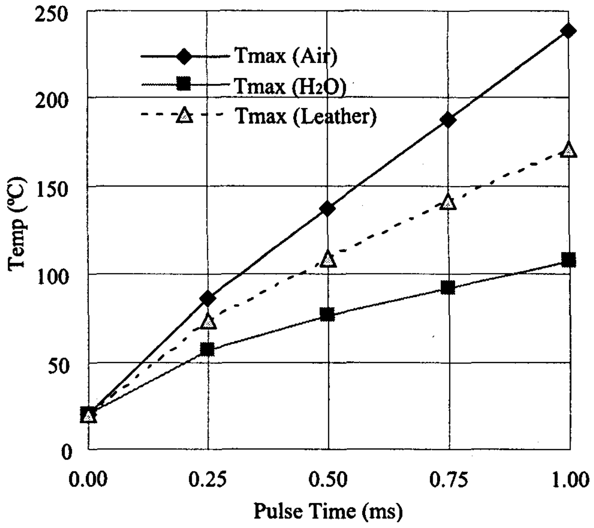

Fig. 18. Thinner size model effect.

(7) About α–FLOW

a-FLOW software system is developed by Fujitsu Japan, cooperated with numerous enterprises and university, through 4 years from Mar. 1988 to Mar. 1992 with 1.3 billion Japanese Yen. This project is supported by Tsuusansyou Japan.
a-FLOW system can make full use of super computer power. In hardware the analysis calculation is basically on super computer and man-machine inter face treatment is on workstations. It puts weight on three dimensional fluid analysis, and consist of following six independent analysis modelling, such as (a) Analysis for incompressible fluid, (b) Analysis for compressible fluid, (c) Analysis for incompressible fluid with free surface, (d) Analysis for flow including combustion and chemical reactions, (e) Analysis for heat conduction, (f) Analysis for material transference. Each analysis model and interface used the method of difference equation. We used the model of heat conduction analysis to analyze the thermal characteristics of our device.

5. CONCLUSION

We proposed a new type of fingerprint sensor device. The proposed device has an array of microheater elements thermally insulated from the substrate. We successfully fabricated an array of the sensor elements on the silicon wafer. After computer modeling calculation on this new type of fingerprint sensor with α-FLOW software, following results were clarified.
(1) Cavity under the microheater element is effective for thermal insulation, regardless the cavity is in vacuum or full of air.
(2) SiO_2-film layer acts as an insulation layer between heater and substrate effectively.
(3) Size minimization of heater element and substrate is very useful for system sensitivity.
(4) There are good linear relations between the heater temperature and the input power.
(5) Microheater arrayed fingerprint sensor can distinguish the fingerprint patterns effectively.

6. REFERENCES

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