International Journal of Engineering, Science and Metallurgy

(Research article)

Design and Simulation of Closed Membrane type Micro Hotplate for Gas Sensing Applications

Sarjit Verma[a*], Rajnish[b], Ankur Singhal[a] and Parveen Jindal[a]

[a] Geeta Institute of Management and Technology, Kanipla, Kurukshetra, India
[b]BRCM Collage of Engineering and Technology, Behal, Bhiwani, India

Accepted 12 July 2012, Available online 1Sept 2012

Abstract

The paper presents the design and simulation of microhotplate (MHP), which requires 20.5 mW-62.8 mW power to create the temperature 227°C-645°C for gas sensing application has been carried out using ANSYS 10.0 and the results were verified using mathematical calculations. A Polysilicon-based bulk micro machined hotplate of size 500 μm × 500 μm has been designed for fabrication as a multi-layer structure on a silicon substrate with thermal silicon dioxide as the supporting membrane, followed by LPCVD silicon nitride film, sputtered Polysilicon film patterned into a double spiral geometry for heater, and PECVD oxide film for insulation of the heater. Gas sensing film (SnO_2) will be deposited on the interdigitated Polysilicon electrodes formed on the PECVD oxide layer. Silicon etching for making the suspended microhotplate structure will be performed as the last stage of the process sequence. Etching away the silicon below the thermal silicon dioxide, the hotplate will remain suspended at the four corners by diagonal bridges. Thus a bulk micro machined micro hotplate structure will be realized. The change in resistivity of the sensing films that require the elevated temperature (250 °C-500 °C) will be measured with varying gas concentration. To estimate the resistance of the Polysilicon heater, a 200 nm thick Polysilicon film has been deposited by sputtering on silicon and its sheet resistance has been measured as 20 ohm/sq. We have used this value to calculate the resistance of Polysilicon resistor, which was found 3120 ohm.

Keywords: *Polysilicon heater, Bulk micromachining, Micro hotplate, Gas sensor, ANSYS simulation.*

1. Introduction

The semiconductor industry is moving towards sensor driven processing as more stringent environmental concern arises. The on line process control system offers significant efficiency and cost benefits, but a suitable detection system does not yet exist; the microelectronics industry has not embraced this approach. The semiconductor gas sensors [1-9] are widely used for both process application and life safety. Such gas sensors include devices that detect unsafe levels of explosive and poisonous gases in breathing–space environments, and devices that continuously monitor humidity and contaminant levels within process gas streams. The chemical reaction between the probed environment and the active portion of the sensor produces the signal, which can be interpreted to provide the species concentrations. A limited level of selectivity can be introduced by altering the type of materials but it has been recognized that the change in temperature greatly affects the functionality of the devices by changing interaction kinetics and other properties. In addition, it has also been observed that on increasing the number of sensing elements, better flexibility and selectivity are provided. The combination of temperature and the multiple sensing elements is used to improve the selectivity and this approach has been followed by several groups. The advances in micromachining and thin-film processing have made this an attractive approach.

These sensors are required for such a device, which can produce the elevated temperature (250°C-500°C) with small power consumption. MEMS-based micro hotplate (MHP) have tremendous importance in this area. This hotplate can be made by using bulk micromachining [10-12] or surface micromachining. The earlier technique has the high thermal isolation of hotplate in comparison to surface micromachining but provides lower mechanical strength.

We have designed the Polysilicon based micro hotplate array [13-14] (taking the bulk micromachining into consideration). The use of Polysilicon is preferred for MHP fabrication because it is not attacked by the etchant

*Corresponding author's email: Sarjit.verma86@gmail.com

during bulk micromachining, thereby simplifying the process. Polysilicon MHPs offer the advantages of inexpensive and it can be fully integrated with drive/detection circuitry. Besides gas sensing applications, they are also used in micro fluidics, infrared emission and thermal flow sensing studies

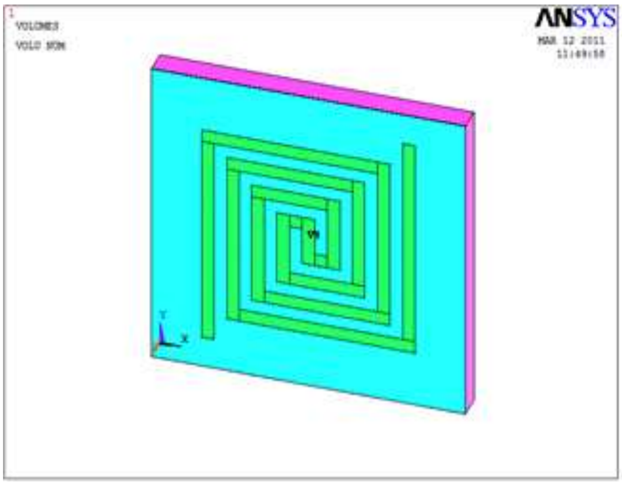

Fig. 1 Structure of Polysilicon-based micro hotplate

2. Design and simulation

We have designed Polysilicon-based micro hotplate using ANSYS 10.0, as shown in Fig. 1. In this case we have considered the only membrane area of micro hotplate. Dimensions used in design are given in the Table I. The micro hotplate is a 500×500 μm^2 membrane of thickness 1.3 micron (1 micron silicon dioxide and 0.3 micron silicon nitride) over which a Poly Si heater of 3120 ohm will be laid out.

Table 1 Design parameter for MHP

Hotplate size:	500 × 500 μm^2
Polysilicon heater size	340 × 340μm^2
Heater finger width	20 µm
Gap between fingers:	20 µm

The chip level design of unit cell of MHP consists of four trapezoidal openings to allow post-process etching of exposed silicon forming a pit so that the micro hotplate can be suspended in the air. There are four supporting beams for each MHP membranes, which gives the mechanical strength to the membrane and the connection for heaters. The mask layout of the hotplate consisting of six photo masks: MHP1 for cavity opening for bulk micromachining, MHP2 for patterning the Polysilicon resistor, MHP3 for contact opening, MHP4 for interdigitated electrodes, MHP5 for sensing films and MHP6 for plating. The electro-thermal simulation of unit cell of micro hotplate array has been carried out by using ANSYS 10.0, widely used finite-element based software for simulation of MEMS devices. In the present simulation work, the properties used are given in Table II [15]. In this simulation, the SOLID69 element has been used, which supports the basic thermoelectric analysis taking the joule heating effect into consideration. SOLID69 has 3-D thermal and electrical conduction capability. In this analysis, a Si substrate has been taken on which there is a 1.0micron thick SiO_2 and 0.3 micron Si_3N_4 layers for supporting the membrane. Above Si_3N_4 layer there is a 0.2 micron thick Polysilicon layer for micro heater. The temperature of Si substrate surrounding the hotplate was fixed at 25 ^oC as the boundary condition. The mathematical calculation of temperature of membrane has been carried out using equation [1]

$$\text{Temperature} = \frac{\text{Heat}}{\text{Sum of multiplication of Masses and Specific heat of Poly Si, SiO2, Si3N4}} \quad [1]$$

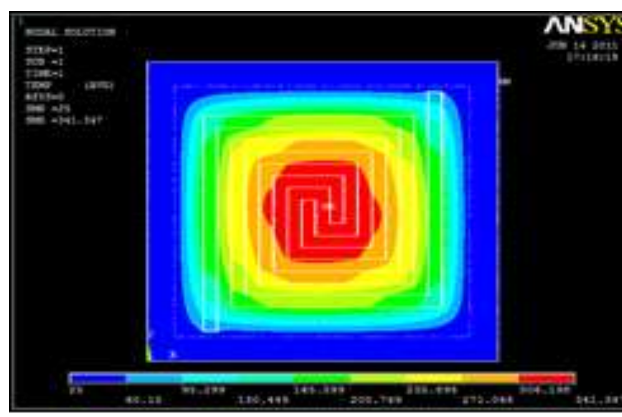

Fig. 2(a)

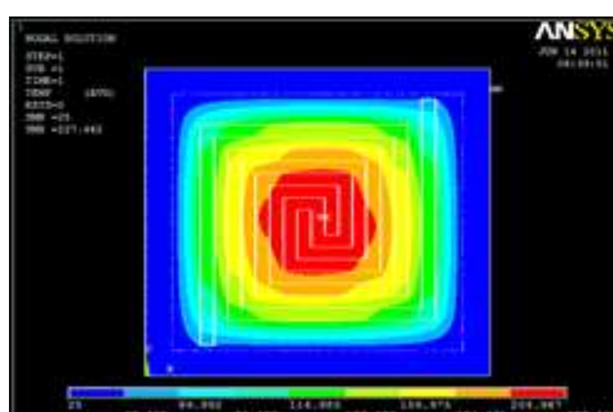

Fig. 2(b)

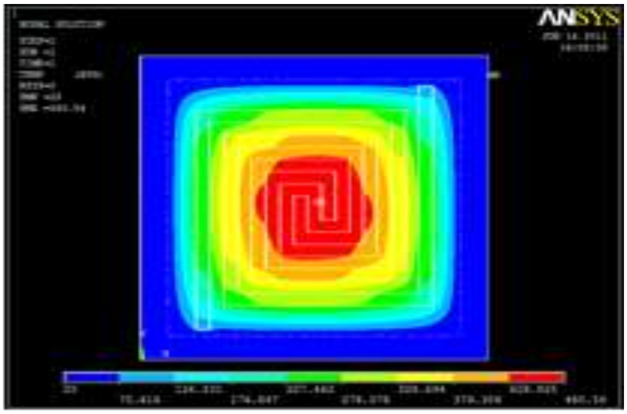

Fig 2(c)

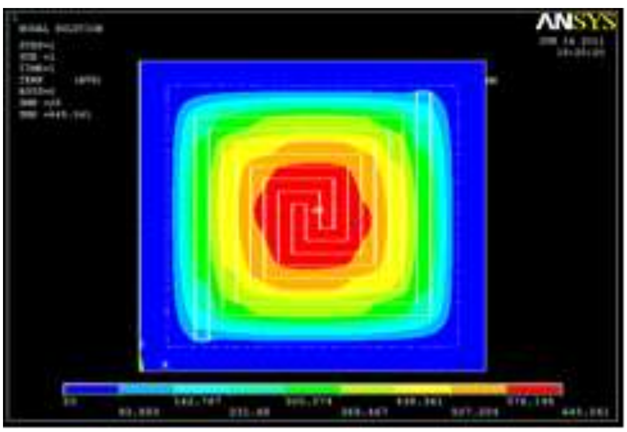

Fig. 2(d)

Fig. 2 Temperature distributions at (a) 14V (b) 12V (c) 10V (d) 8V

Table 2Material properties of MHP

Material Properties(in MKS)	Si	SiO_2	Polysilicon	Si_3N_4
Thermal Conductivity(W/m/K)	157	1.4	150	22
Resistivity(ohm-m)	$1.0´10^{-1}$	$5.05´10^{13}$	$20´10^{-6}$	-
Specific Heat(J/kg/K)	700	1000	753	170
Density(kg/m3)	2320	2200	2330	3100

The red color showing the maximum temperature at the centre and it is going downward towards edge of the membrane. The temperature versus distance from the center of the membrane at a fixed applied voltage is shown in Fig. 3. It is clear from this Fig that when we move towards the edge of the membrane, the temperature is non-uniform after a certain distance. Mathematical calculation of temperature of the micro hotplate has been carried out using equation [1].Fig.4 show stress variation with Temperature

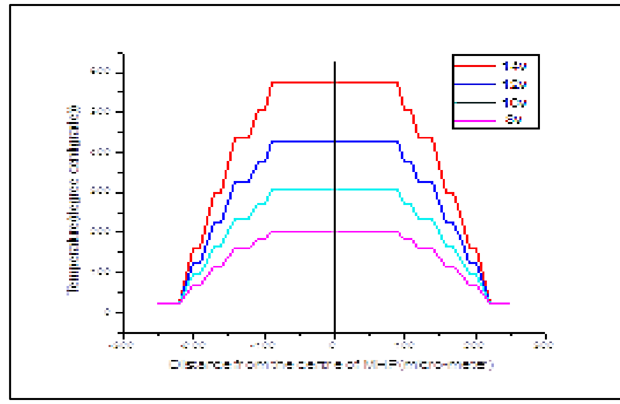

Fig. 3 Temperature versus distance from center of membrane

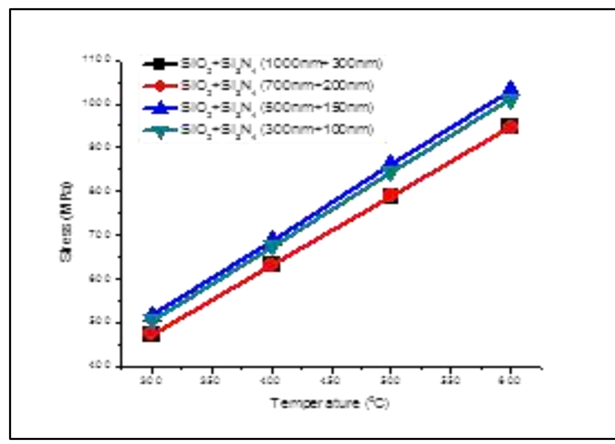

Fig. 4 Stress variation with different Temperature

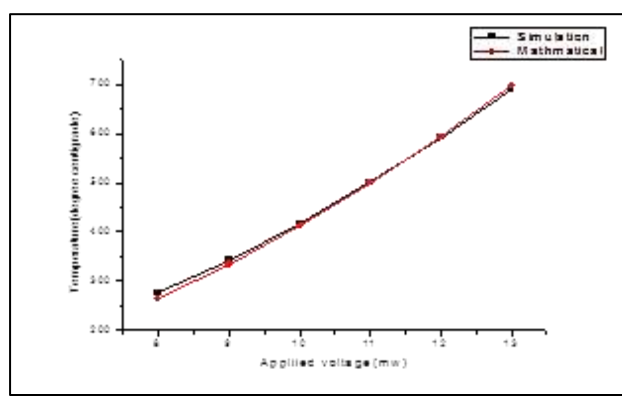

Fig. 5 Variation of temperature of micro hotplate with applied voltage

different temperature and membrane thickness. Fig. 5 shows combined results obtained from both mathematical and simulated work. Here we are getting the higher temperature in case of ANSYS results because we have not considered the air inside the cavity.

4. Conclusions

A Polysilicon-based micro hot plate has been designed and characterized by electro-thermal simulation using ANSYS tool and mathematical calculations. A good agreement is found between the simulated and mathematical results. The results validate the design by revealing the attainment of desired operating temperature of the micro hot plate. The future work will involve the comparison of experimental data from fabricated micro hot plate and the simulated results.

References

1. Afridi, M. Y., Suehle, J.S., Zaghloul, M.E., Berning, D.W., Hefner, A.R., Cavicchi, R.E., Semancik, S., Montgomery, C. B., and Taylor, C. J., 2002, "A Monolithic CMOS Microhotplate-Based Gas Sensor System", IEEE Sensors Journal, 2(6), pp. 644-655.
2. V. Demarne, A. Grisel, An integrated low power thin film CO gas sensor on silicon, Sensors and Actuators 13 (1988) 301-313.
3. R.E. Cavicchi, Growth of SnO2 films on micromachined hotplates, Appl. Phys. Lett. 66 (1995) 812-814.\
4. J.S. Suehle, R.E. Cavicchi, M. Gaitan, S. Semancik, Tin oxide gas sensor fabricated using CMOS microhotplate and in-situ processing, IEEE Electr. Dev. Lett. 14 (1993) 118-120.
5. L. Sheng, Z. Tang, J. Wu, P.C.H. Chan, J.K.O. Sin, A low-power CMOS compatible integrated gas sensor using maskless SnO2 sputtering, Sens. Actuat. A 49 (1998) 81-87.
6. M. Parameswaran, Alexander M. Robison, David L. Blackbun, Michael Gaitan and Jon Geist "Thermal Radiation Emitter from a Commercial CMOS Process," IEEE Electron Device Letters, Vol. 12, No. 2, Feb1991.
7. H. Mahfoz-Kotb, A.C. Salaun, T. Mohammed-Brahim, R. Le Bihan, M. El-Massi, "Polycrystalline Silicon thin films for MEMS applications" Thin Solid Films, 427 (2003) 422-426.
8. V. Guidi, Thin-films gas sensor implemented on a low power consumption micro-machined silicon structure, Sens. Actua. B 49 (1998) 88-92
9. S. Semancik, R.E Cavicchi, M.C. Wheeler, J.E. Tiffany, G.E. Poirier, R.M. Walton, J.S. Sulehle, B. Panchapakesan, D.L. Devoe, "Microhotplate platforms for chemical sensor research," Sensors and Actuators, B 77 (2001) 579-59.
10. V.K. Khanna, Mahanth Prasad, V. K. Dwivedi, Chandra Shekhar, Pankaj, A. C., and Basu, J., "Design and Electro-thermal Simulation of a Polysilicon Microheater on a Suspended Membrane for Use in Gas Sensing", Indian Journal of Pure & Applied Physics vol.45,April 2007, pp 332-335.
11. V.K. Khanna, Mahanth Prasad, Ashok Suhag,, M. K. Sharma, V. K. Dwivedi, and Chandra Shekhar, 2006, "Study of Crucial Processes in the Fabrication of MEMS Hotplate Sensor Structure", Proceedings of ISSS-MEMS 2006, National Conference on Smart Structures and MEMS Systems for Aerospace Applications, RCI, DRDO, Hyderabad, India, pp.1-6, 1-2 December, 2006.
12. V.K. Khanna, Mahanth Prasad, Ashok Suhag, Y.K. Jain, V. K. Dwivedi, and Chandra Shekhar, 2006, "MEMS- and Semiconductor Technology-Based Generic Structures for the Fabrication of High-Performance Chemical Sensors", National Conference on Sensors and Actuators: Emerging Technological Challenges, CGCRI, Kolkata, Dec. 21-22, 2006, Abstracts, p.11, Invited Lecture I-06.
13. Dae-Sik Lee, Sang-Woo Ban, Minho Lee, and Dunk-Dong Lee "Micro Gas Sensor Array With Neural Network for Recognizing Combustible Leakage Gases" IEEE Sensors Journal, 5(3), pp. 530-536.
14. D Briand "Design and fabrication of high-temperature micro-hotplates for drop-coated gas sensors"Sensors and Actuators B: Chemical, Volume 68, Issues 1-3, 25 August 2000, Pages 223-233
15. Mahanth Prasad, V.K. Khanna and Ram Gopal "Design and Development of Polysilicon -based Microhotplate for Gas sensing Application", Sensors and Transducers Journal, Vol.103, Issue4, received: Jan 09 and published: April 2009, pp.44-51