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DESIGN OF MICROHEATERS WITH BETTER THERMAL MANAGEMENT FOR SENSOR APPLICATIONS

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ABSTRACT:

The thermal management of integrated sensor has not received much attention so far. The importance of temperature uniformity and the ability to sense accurately the operating temperature of the thin-film sensor have been overlooked. While integrated sensor aims at precision measurement of concentration, the operating temperature of the thin film sensor should be uniform. Highly non uniform temperature profile gives rise to ambiguity of the operating temperature. It will also degrade selectivity and sensitivity. Hence it becomes essential to optimize the microheater resistor geometry in order to achieve a uniform temperature in the active area.

Keywords: microheater, thermal management, sensor application.

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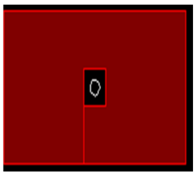
1. SYNOPSIS OF THE AVAILABLE MICROHEATER RESISTOR CONFIGURATIONS

Several microheater resistor geometries have been adopted by different authors, even if they are seldom described in detail in the related literature. Simple meandered polysilicon microheater resistors on 2 µm thick SiO_2 and 100, 200 nm thick Si_3N_4 have been used in Ref. [1], even if reaching a good temperature uniformity was not the main goal of the authors. Rossi et al. [2] and [3] used a polysilicon microheater resistor as well, defined on different types of membranes (SiO_2, SiO_2/Si_3N_4, SiO_2/polysilicon). Their goal was to reach a good temperature uniformity over the thin membrane, but the focus was on dielectric stack optimization instead of heater geometry. A novel loop-shaped polysilicon meandered heater on a stacked membrane ($SiO_2/Si_3N_4/SiO_2$) has been proposed by Laconte et al. [4]. Meandered platinum microheater resistors also have been used in Ref. [5]. But in this case the temperature uniformity was improved using a silicon island underneath the membrane. The conventional meander design found in most recent devices covers the whole active (heated) area and, thus, creates a central hot spot and a temperature gradient from the center to the border [4]–[12]. To compensate this lack of uniformity, the literature [5], [13] introduces either a silicon heat spreader under the active area, or a thermal conductive layer (e.g., aluminum) over the structure, but these solutions lead to higher thermal inertia and consumption.

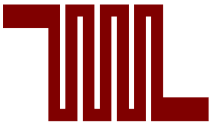
2. MICROHEATER GEOMETRIES

The geometries presented in this work are (i) Fan Shape (ii) S-Shape (iii) Double Spiral (iv) Honeycomb (v) Meander (vi) Plane plate with central hole. However the performance of basic meander and double spiral shaped structures [12-13] are explained by some researcher, the homogeneous temperature profile at the sensing area has not been achieved fully because the outer bound of the heater experiences more heat loss through conduction, while heat losses of the inner part are mainly caused by radiation and heat transfer through the passivation layer to the sensing film.

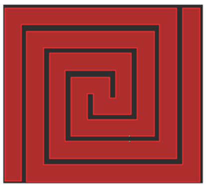
Plane plate with central hole (figure 1): This is a rectangular plate design with a square hole in its center which causes natural convection. The problem with this structure is its undistributed hot spots at the center and high power consumption. Figure 1



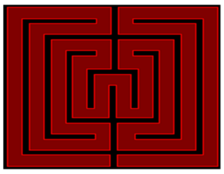
Meander (figure 2): The basic meandering structure shown in figure which is widely used by some researchers show some undistributed hot spot at very high temperature. Figure 2



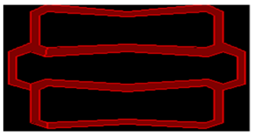
Double spiral shape (figure 3): To avoid the radial temperature gradient of the conventional meander type design, the design of double spiral was investigated. In this thesis work, a novel structure of double spiral shape which has varied gap size and spiral widths in the pattern is explained in detail in next section. Figure 3



Fan shape (figure 4): A modified double spiral shape results in a fan shape geometry. The structure is later proved to be one of the best to obtain uniform temperature profile and less power consumption. Figure 4



Honey comb shape (figure 5): the honeycomb design employs a strategy that redistributes the thermal energy. Figure 5



S-Shape (figure.6): One of the suitable structures for uniform temperature profile and lower power. But will be best for sensing film of small dimensions. Figure 6

3. DESIGN OPTIMIZATION

The aim of this section is to point out a strategy to optimize the geometrical structure designs. Resistive microheaters generate heat by the inherent resistance of metal conductors to electron flow. By controlling the voltage supplied to a resistor, a predictable amount of power in the form of heat energy per unit time can be emitted from the resistor. This heat can be then used to increase the temperature of the nearby environment, in our case the Silicon Nitride which is a thermally conducting passivation layer. The equation which relates conductor is $P = \frac{V^2}{R}$.

The resistance of material properties and its geometry $R = \frac{\rho L}{A}$ where ρ - resistivity Ω/ , L-Length, A-Cross sectional area of the conductor. Thermo resistive effects on thin metal films can be taken advantage to measure temperature to a high degree of precision and linearity. The equation which relates the resistance and temperature for thin metal films is given by

$R_T = R_o[1+\alpha_R(T-T_o)]$ (1)

R_T - Resistance measured for different Temperature

R_o - Resistance at Room Temperature To

α_R – Temperature Co-efficient of Resistance (TCR) of the heater material

T – Measured Temperature in ^{o}C

$R_T = \frac{\rho L}{WT}[1+\alpha_R(T-T_o)]$ (2)

For a conductive line made with material resistivity ρ, length L, width W and thickness T, the heater pattern can be tailored within limits of the processing capabilities by variably reducing the line width of the pattern. The design variables chosen are gap size (g), center width (W1) as shown in fig.7 and reduction ratio (Wi/Wi+1) which controls the resistance of the heater.

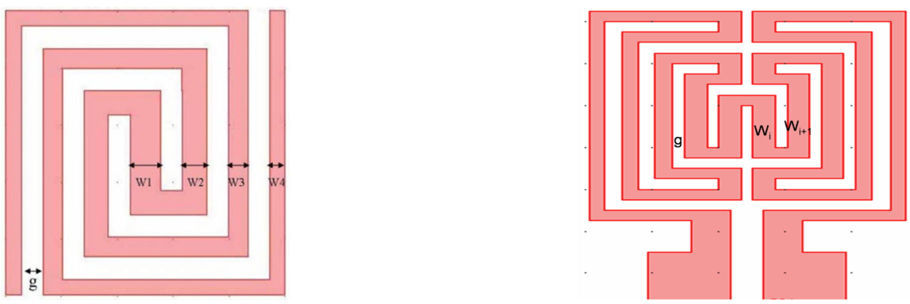


Figure 7 Double spiral shape Fan Shape

Different gap sizes **(g)** and reduction ratio **(W_i/W_{i+1})** geometries having fan type pattern , Double spiral pattern of size 500µm X 500 µm have been designed and simulated. From the temperature profile of simulation results, the standard deviation of temperature for different reduction values and gaps have been calculated and shown in figure 8.

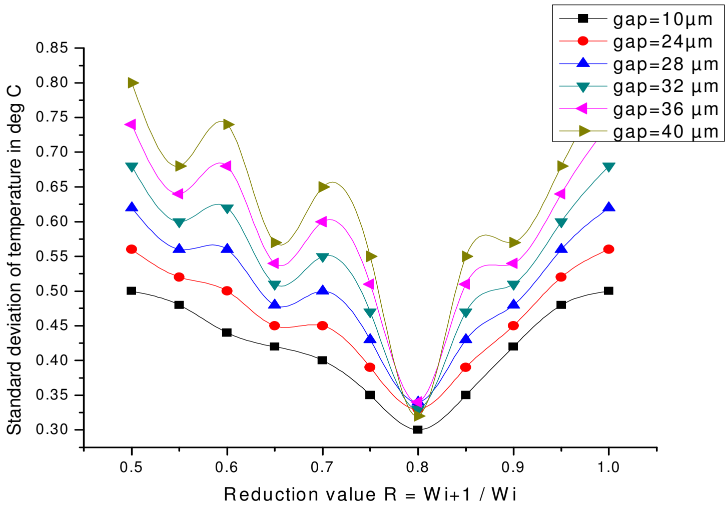


Figure 8 Thermo-graphic analysis

The desired function of the microheater is to minimize the standard deviation of the temperature across the active area. From fig.8 it is found that the standard deviation is very low at R=0.8 and gap g=10µm. Optimum temperature uniformity could be obtained with the reduction ratio R=0.80, when compared to a standard, constant pitch, heater patterns.

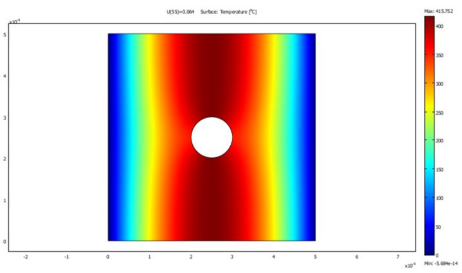
The heater geometry simulations were carried out by means of COMSOL™ version 3.5 for all the six patterns mentioned in section 2. S.Mohan et al [14] earlier showed the power analysis of all the six types and it was understood that square plate type, honeycomb type and Meander type are comparatively inferior with the other three types such as Double spiral, Fan shape and S type. So focus is given to these types to modify their pattern for better thermal profile and power consumption. The steady state temperature analysis has been performed to determine the temperature distributions and thermal resistance of the modified pattern. In the COMSOL electro thermal module the related heat equations have been solved under Dirichlet, Neumann and mixed boundary conditions numerically using the finite element method (FEM). In this analysis, according to the application requirement, the fixed thermal boundary is defined for all side walls of the 3D model. These walls were kept at a temperature of 300K while other sides were adiabatic. Fixed temperature boundary and potentials are applied at the ends of the heater. The optimized meshing for the simulation is determined by performing an independent grid study to minimize modeling error.

Table Material properties of layers used in the MEMS micro-hotplate structure.

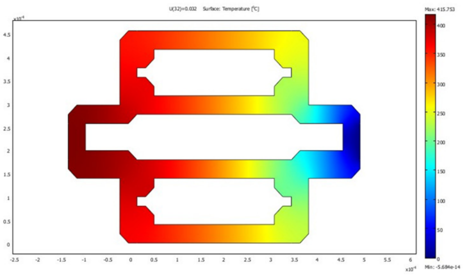
Material	**(Si)**	**(Si_xN_y)**	**(SiO_2)**	**Ti**	**(Pt)**
Thermal Conductivity (W/mK)	157	22	1.4	21.9	73
Young's Modulus (GPa)	190	290	73	104	170
Poisson's Ratio	0.17	0.24	0.20	0.342	0.39
Thermal expansion (10^{-6} K^{-1})	2.33	2.33	0.55	8.5	8.9
Density (kg/m^3)	2.32e3	3.1e3	2.2e3	4506	2.145e4
Heat Capacity (J/ kg ^oC)	700	600-800	730	522	130

4. SIMULATION RESULTS.

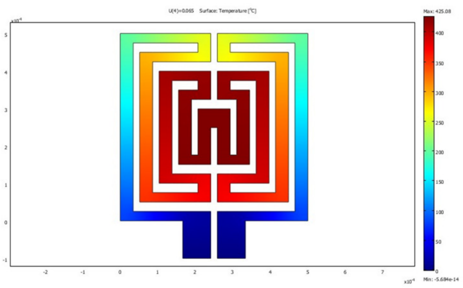
The heater resistor is modeled for the area of 500µm x 500µm and thickness of 220nm. The thermal profiles of each heater geometry to produce 400oC have been shown in figure 8. The Temperature profile of Double spiral, Fan Type and S shape has shown a very high temperature uniformity at the center for a area of 220µm x 220µm, 200µm x 200µm, 500µm x 100µm respectively , which are later selected as the area for sensing layer deposition. The complete simulation sequence is been given in Appendix.(I)



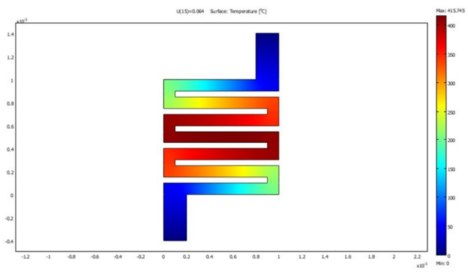
Square plate with center hole



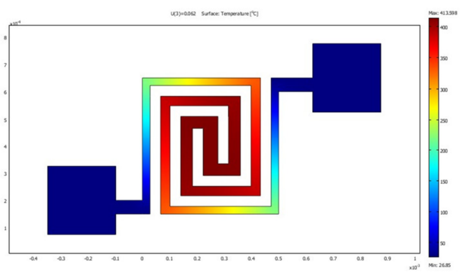
Honey Comb structure



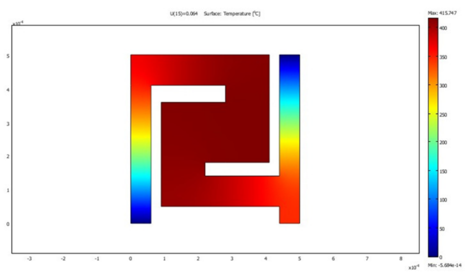
Fan Shape



Meander structure



Double Spiral Shape



S- Shape

Figure 8 Temperature profile of the microheater patterns

REFERENCES

[1] Götz, I. Gràcia, C. Cané and E. Lora-Tamayo, Thermal and mechanical aspects for designing micromachined low-power sensors. J. Micromech. Microeng., 7 (1997), pp. 247–249

[2] C. Rossi, E. Scheid and D. Estève, Theoretical and experimental study of silicon micromachined microheater with dielectric stacked membranes. Sens. Actuators A, 63 (1997), pp. 183–189.

[3] C. Rossi, P. Temple-Boyer and D. Estève, Realization and performance of thin SiO2/SiNx membrane for microheater applications. Sens. Actuators A, 64 (1998), pp. 241–245

[4] J. Laconte, C. Dupont, A. Akheyar, J.-P. Raskin, D. Flandre, Fully CMOS compatible low-power microheater, in: Proceedings of the DTIP Conference, Cannes, 2002

[5] D. Briand, M.-A. Grétillat, B. van der Schoot, N.F. de Rooij, Thermal management of micro-hotplates using MEMCAD as simulation tool, in: Proceedings of the 2000 Conference on Modeling and Simulation of Microsystems, 27–29 March, pp. 640–643.

[6] Fabrication and characterization of high-temperature micro reactors with thin film heater and sensor patterns in silicon nitride tubes, R. M. Tiggelaar, J. W. Berenschot, J. H. de Boer, R. G. P. Sanders, J. G. E. Gardeniers, R. E. Oosterbroek, A. van den Berg and M. C. Elwenspoek Lab Chip, 2005, 5, 326-336

[7] A portable device for temperature control along microchannels, Daniele Vigolo, Roberto Rusconi, Roberto Piazza and Howard A. Stone Lab Chip, 2010, 10, 795-798

[8] Pt/Ti Thin Film Adhesion on SiNx/Si Substrates Unbyoung KANG, Taegon LEE1 and Young-Ho KIM Jpn. J. Appl. Phys. Vol. 38 (1999) pp. 4147–4151 Part 1, No. 7A, July 1999

[9] Stability of thin platinum films implemented in high-temperature microdevices R.M. Tiggelaar, R.G.P. Sanders, A.W. Groenland, J.G.E. Gardeniers Sensors and Actuators A: Physical, Volume 152, Issue 1, 21 May 2009, Pages 39-47

[10] Low-voltage and low-power optimization of micro-heater and its on-chip drive circuitry for sensor array, Yaowu Mo, Yuzo Okawa, Koji Inoue, Kazuki Natukawa, Sensors and Actuators A: Physical, Volume 100, Issue 1, 15 August 2002, Pages 94-101

[11] A critical review of thermal models for electro-thermal simulation, Authors: d'Alessandro V.; Rinaldi N. Source: Solid-State Electronics, Volume 46, Number 4, April 2002 , pp. 487-496(10)

[12] A 2D thermal flow sensor with sub-mw power consumption Ali Sukru Cubukcu, Eugen Zernickel, Uwe Buerklin, Gerald Anton Urban, Sensors and Actuators A: Physical, Volume 163, Issue 2, October 2010, Pages 449-456

[13] J. Lee, C. M. Spadaccini, E.V. Mukerjee, W.P.King, Suspended Membrane Single Crystal Silicon Micro Hotplate for Differential Scanning Calorimetry, IEEE 22nd International Conference on Micro Electro Mechanical Systems, MEMS 2009, 25-29 Jan. 2009, pp. 852-855.

[14] Inderjit Singh ,S.Mohan, 3D Simulations and Electro- Thermal Analysis of Micro-hotplate Designs using Coventor Ware for Sensor applications., Proceedings of ISSS conference, 2005

[15] Kanna Ashok Reddy, K. Sandeep Kumar, K. Raja Sekhar Reddy, V.V.S. Harnadh Prasad and G. Arun Reddy. A Critical Review of Composite Materials for Buildings, Thermal, Aerospace and Cryogenic Applications. International Journal of Civil Engineering and Technology, 8(7), 2017, pp. 789–800.

[16] M.V. Raju, M. Satish Kumar, Hepsibah Palivela and G. Venu Ratna Kumari, A Systematic Approach for the Assessment of Environmental Quality at Thermal Power Plants Using Geo Spatial Technology: A Model Study. International Journal of Civil Engineering and Technology, 8(5), 2017, pp. 224–229.