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Design, Simulation and Optimizations of Micro Cavity based Microheater Structures for Gas Sensing Applications

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Abstract: **Gases are directly linked to our life and their odors enormously affect the image of our environment. The gas monitoring system is needed in process control and laboratory analytics. We have done work on Design, simulation and optimizations of micro cavity based and without cavity based different microheater structures for gas sensing applications. We have done different pattern of micro heater namely Meander, Fan shape, square shape. We have found the best results in square shape, where the heating profile if uniform in structure and the heating area is above 95.5% . we have done all this work on COMSOL MULTIPHYSICS 4.3a.**

1. INTRODUCTION

The microheaters are used to obtain a suitable temperature of gas sensor which integrated with the design of either platinum, nichromeor poly-silicon etc. as heater element suitable for high temperature (400-700°C) regime and were fabricated with either platinum or poly-silicon as heater material as well as electrode to observe the particular ambient temperature. A Polysilicon and platinum base different shape microheater is designed for MEMS based gas sensor application. Microheater was design with different structure with cavity and without cavity using different material for micro machined Si substrate was proposed and experimentally verified for the gas sensor system. The temperature sensing allows the use of a relatively thin silicon membrane and zero Silicon SiO2/Si3N4 composite membrane differ from cavity and porous silicon resulting into temperature uniformity across the entire active area.

Gas sensor is a device which determines the information about ambient gases in atmosphere, consisting of sensitive layer called membrane and a signal transfer component [1]. Microheaters have been widely experimented because of extensive application for gas sensor, flow rate sensor, and other microsystems [1-3]. Sensor properties depend on heater properties and for example gas sensor, selectivity, sensitivity, and time response depend on strongly on temperature. The sensing films are generally oxide or metal oxide composition and used to detect gases, to discriminated odor or generally to monitor change the state [2-3]. The operating temperature for gas sensor is ~150ºC - 300ºc. The electrical and mechanical stability of the heater structure should be considered because of thermal expansion effects, specially the dependence of thermal expansion coefficient on material composition.

Micro Electro Mechanical systems (MEMS) are integrated micro devices or systems of electrical and mechanical components, fabricated using Integrated Circuit(IC) compatible batch processing techniques and range in size from micrometers to millimeters. These systems can sense, control and actuate on the micro scale and function individually or in arrays. At this microscopic level we can build sensors and actuators such as thermal sensors, pressure sensors, inertial sensors, flow and viscosity sensors, resonators, gears, transmission systems, micro-mirrors, micro actuators, valves, pumps, motors etc. together with the processor chip. They indeed compose a “system on chip” [1] along with the CMOS ASIC fabricated on the same chip.

2. SELECTION OF HEATING ELEMENT:

Most of the microheaters were fabricated with either platinum or poly-silicon or many as heater material as well as electrode to observe the particular ambient temperature. The important factors of designing of a microheater are high resistivity, high thermal conductivity and low thermal expansion coefficient. The **invar** is also use as a heating material. But since the resistivity of the material is low of the order of 80x10- 8m a longer heater is needed to serve the required purpose. The problem can be solved by the use of an element with higher resistivity and we are successful to find out such an element. The element named INVAR, which is an alloy of Fe, Ni and co have on one hand high resistivity (80X10-8m) and high yield stress and on the other hand have low thermal expansion coefficient. Because of its low thermal expansion coefficient (3.4 x 10-6/K), thermal deformation of the material will be low compared to Ni and at the same time will induce lower stress. The thermal conductivity of this material (10.4) is also almost five times less than Ni (36). Due to this reason conduction loss is small for this material and localized heating can be achieved[4].

We use ploysilicon as a heating element of the heater.

The properties of the polysilicon shown in the table 2.1

Table 2.1 Properties of Polysilicon:

Material Contents

	Property	Name	Value
✓	Electrical conductivity	sigma	sigma(T)[S/m]
✓	Heat capacity at const...	Cp	678[J/(kg*K)]
✓	Relative permittivity	epsilonr	4.5
✓	Density	rho	2320[kg/m^3]
✓	Thermal conductivity	k	34
	Coefficient of thermal ...	alpha	2.6e6
	Young's modulus	E	169e9[Pa]
	Poisson's ratio	nu	0.22

Table 2.2 Properties of SiO_2:

Output properties

Property	Variable	Expression	Unit	Size
Electrical conductivity	sigma ; sigmaii =...	0	S/m	3x3
Coefficient of thermal expansion	alpha ; alphaii =...	0.5e-6[1/K]	1/K	3x3
Heat capacity at constant pressure	Cp	730[J/(kg*K)]	J/(kg·K)	1x1
Relative permittivity	epsilonr ; epsilon...	4.2	1	3x3
Density	rho	2200[kg/m^3]	kg/m³	1x1
Thermal conductivity	k ; kii = k, kij = 0	1.4[W/(m*K)]	W/(m·K)	3x3

Output properties

Property	Variable	Expression	Unit	Size
Young's modulus	E	70e9[Pa]	Pa	1x1
Poisson's ratio	nu	0.17	1	1x1

Table 2.3 Properties of Si(Single Crystal) :

	Property	Name	Value	Unit	Property group
✓	Density	rho	2330[kg/m^3]	kg/m³	Basic
✓	Thermal conductivity	k	157	W/(m·K)	Basic
✓	Heat capacity at constant pressure	Cp	700	J/(kg·K)	Basic
	Electrical conductivity	sigma	10	S/m	Basic
	Relative permittivity	epsilonr	6.5	1	Basic
	Elasticity matrix	D	{166[GPa], 64[GPa], 166[GPa], 64[G...	Pa	Anisotropic
	Loss factor for elasticity matrix D	eta_D	0	1	Anisotropic

Table 2.4 Properties of Si_3N_4:

Output properties

Property	Variable	Expression	Unit	Size
Electrical conductivity	sigma ; sigmaii =...	0[S/m]	S/m	3x3
Coefficient of thermal expansion	alpha ; alphaii =...	2.3e-6[1/K]	1/K	3x3
Heat capacity at constant pressure	Cp	700[J/(kg*K)]	J/(kg·K)	1x1
Relative permittivity	epsilonr ; epsilon...	9.7	1	3x3
Density	rho	3100[kg/m^3]	kg/m³	1x1
Thermal conductivity	k ; kii = k, kij = 0	20[W/(m*K)]	W/(m·K)	3x3

Output properties

Property	Variable	Expression	Unit	Size
Young's modulus	E	250e9[Pa]	Pa	1x1
Poisson's ratio	nu	0.23	1	1x1

Table 2.5Properties of Pt:

Output properties

Property	Variable	Expression	Unit	Size
Electrical conductivity	sigma ; sigmaii =...	8.9e6[S/m]	S/m	3x3
Coefficient of thermal expansion	alpha ; alphaii =...	8.80e-6[1/K]	1/K	3x3
Heat capacity at constant pressure	Cp	133[J/(kg*K)]	J/(kg·K)	1x1
Density	rho	21450[kg/m^3]	kg/m³	1x1
Thermal conductivity	k ; kii = k, kij = 0	71.6[W/(m*K)]	W/(m·K)	3x3
Relative permittivity	epsilonr ; epsilon...	2	1	3x3

3. SIMULATION RESULTS OF DIFFERENT HEATER STRUCTURE:

We use Polysilicon and Pt as a heating element in the heater structure, all the results shown in figure.

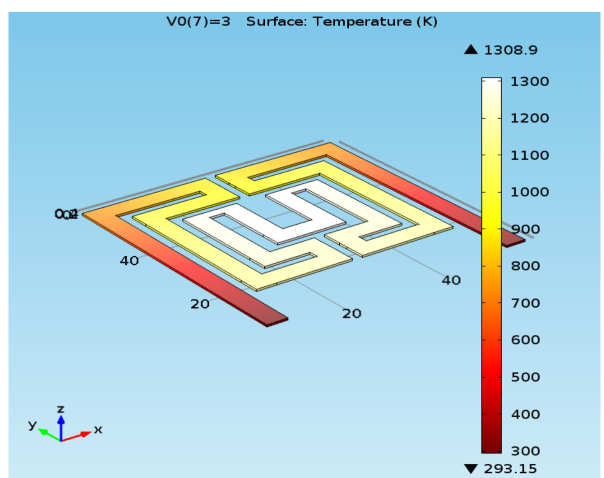

Figure 3.1 fan shape heater (polysilicon)

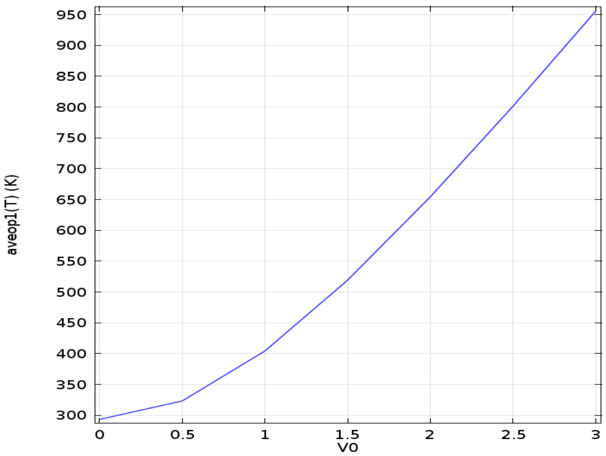

Figure 3.2 fan shape temp vs voltage curve

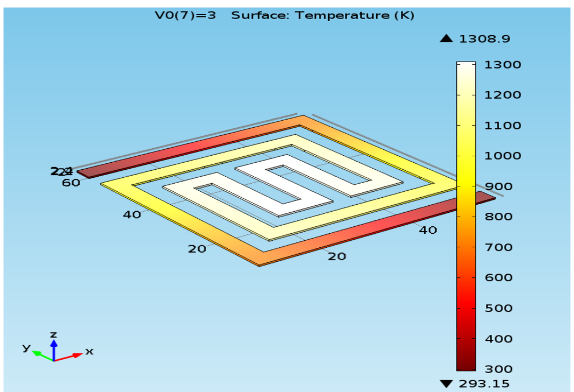

Figure 3.3 meander shape heater (polysilicon)

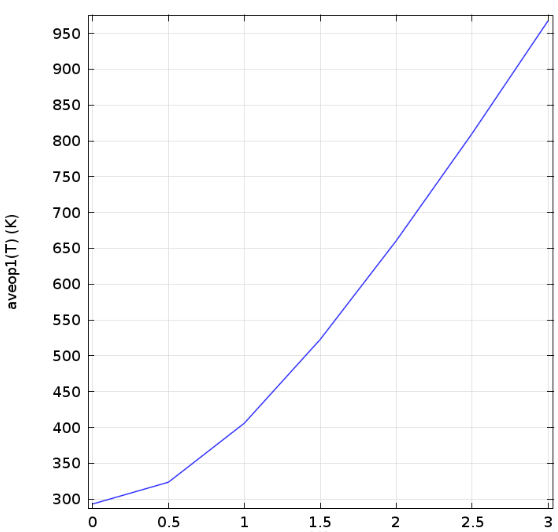

Fig3.4 meander shape heater temp-voltage curve

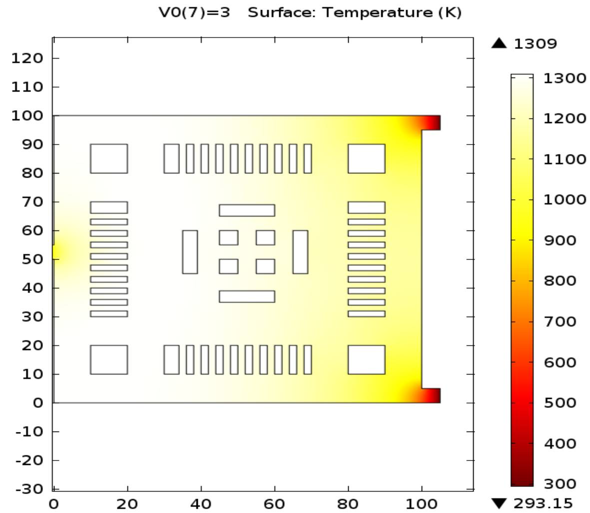

fig3.5 square shape heater (polysilicon)

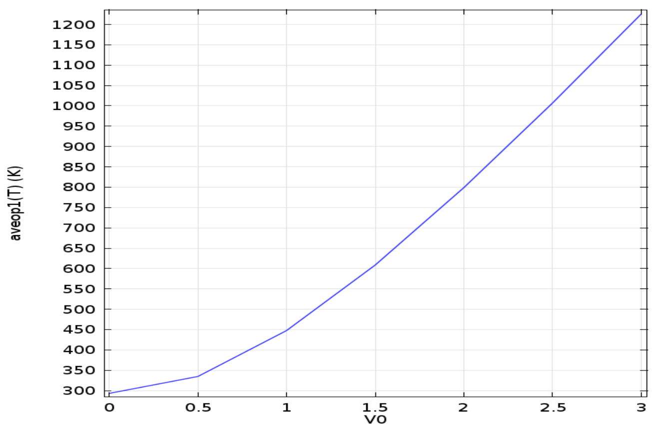

Fig3.6 square shape temperature-voltage curve

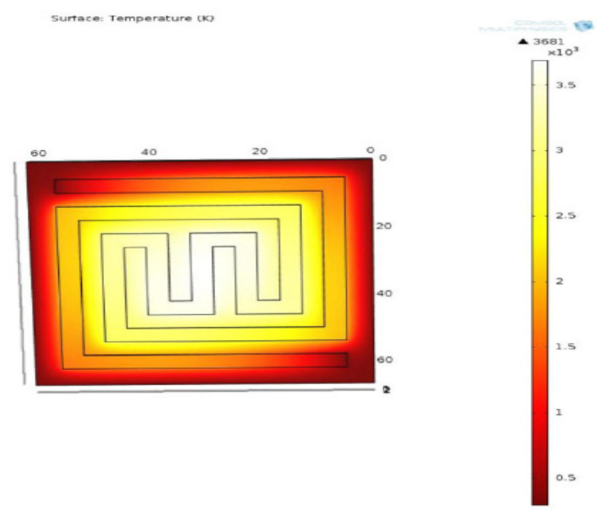

Fig 3.7 Heater Pt without cavity with sio2 membrane

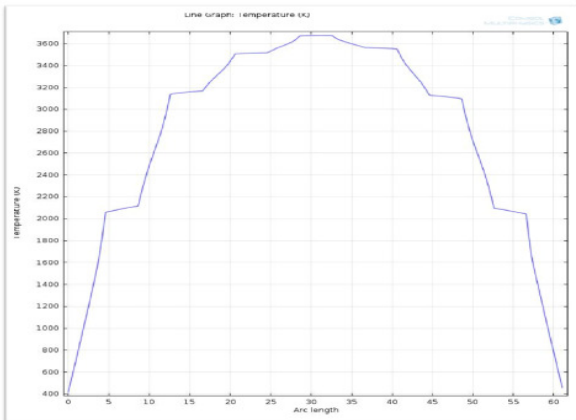

Fig 3.8 Arc length to temperature plot

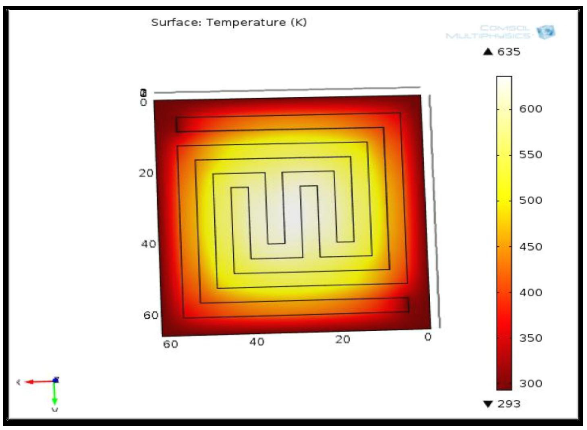

Fig 3.9Heater (Pt) without cavity with si3n4 membrane

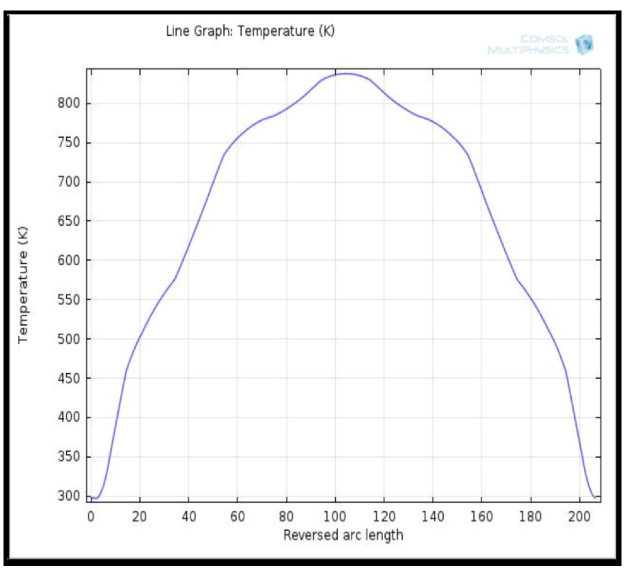

Fig 3.10 Arc length to temperature plot

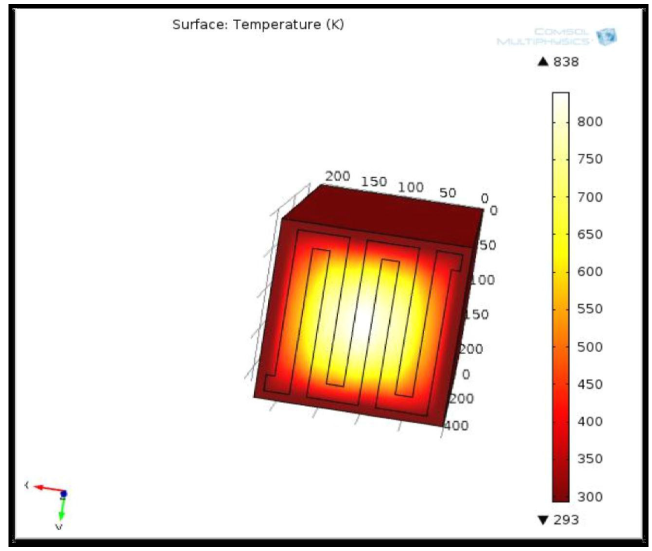

Fig3.11 Heater Pt with cavity , si3n4membrane

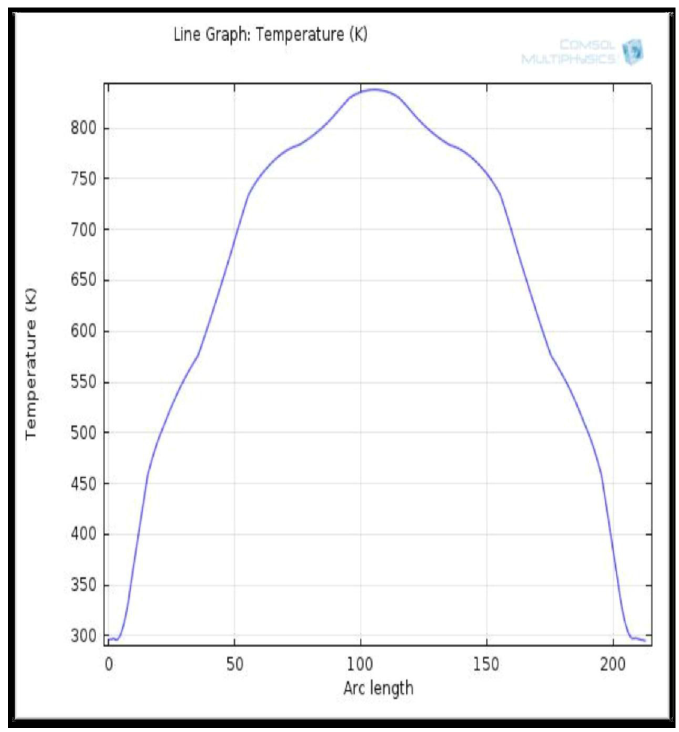

Fig 3.12 Arc length to temperature plot

4. CONCLUSION

The meander shape heater produce maximum temperature at the centre of the heater, we apply 2 V in the Pt based heaters.

As the voltage is varied from 0 to 5V in increment of 0.5 V the temperature increase exponentially. There were important differences in uniformity of temperature in different structure

Table4.1

Structure type	Maximum temperature (K)	Average Temperature (K)
Meander	1309	970
Fan	1309	960
Square	1309	1200

A thermal model of micro heaters is designed and simulates using COMSOL 4.3a,4.4. The result shows the variation of temperature across the structure with respect to the applied voltage. It was found that the square shape structure give the best result with 99.80% of the heating area having the temperature greater than 85% of maximum temperature attained with an average temperature of 1200 K.

One thing is also clear that in the structure if the numbers of interconnection are more the heating uniformity will be increase.

5. ACKNOWLEDGEMENTS

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