Design and Analysis of Micro-Heaters using COMSOL Multiphysics For MEMS Based Gas Sensor

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Abstract: Micro-Heaters have been the subject of great interest owing to their extensive applications in gas sensors, humidity sensors and other micro-systems. A micro-heater should have low power consumption, low thermal mass and better temperature uniformity. In this paper , we have looked for geometric optimization of the heater structure to achieve high temperature uniformity by performing analysis using COMSOL Multiphysics 4.2, a Finite Element Analysis (FEA) Package. We have presented four different patterns of micro-heater, namely Single Meander, double meander, fan shape and square shape of 100×100µm with their Electro-thermal simulated temperature profile. The Maximum Temperature of 483.83K was obtained. For the same supply voltage applied, it was found that the Square shape structure gave the best result with 99.51% of the heater area having a temperature greater than 80% of the maximum temperature attained with an average temperature of 456.442 K.

Keywords: Micro-heater, COMSOL, Heater Geometries , Temperature Profile.

1. Introduction

Micro-Heaters are the key components in sub-miniature micro-sensors, especially in gas sensors. The metal oxide gas sensors utilize the properties of surface adsorption to detect changes in resistance as a function of varying concentration of different gases[5]. To detect the resistive changes, the heater temperature must be in the requisite temperature range over the heater area. Hence the sensitivity and response time of the sensor are dependent on the operating temperature of the micro-heater. So their proper design is of critical importance. In this paper, we report on the design and simulation of micro-heaters used in gas sensors with the aim of improving their temperature uniformity [3]. The design has been supported using Electro-thermal Simulations using the COMSOL.

2. Mathematical Modeling

The electric field equals the negative of gradient of the potential V. The electric current density J is in turn proportional to the electric field. Due to this electric current, there is resistive heating which is shown to be proportional to the square of magnitude of the electric current density J. Hence the temperature increases. This is referred to as Joule heating.[1]

$$Q \propto |J|^2 \tag{1}$$

The proportionality constant is the electric resistivity ρ or the reciprocal of the temperature dependent electric conductivity. Combining these facts we have

$$\rho = \frac{1}{\sigma} \tag{2}$$

$$\sigma = \sigma(T) \tag{3}$$

$$Q = \frac{1}{\sigma}|J|^2 = \frac{1}{\sigma}|\sigma E|^2 = \sigma|\nabla V|^2 \tag{4}$$

Over a range of temperatures the electric conductivity varies with T, governed by the equation

$$\sigma = \frac{\sigma_0}{1 + \alpha(T - T_0)} \tag{5}$$

Where σ_0 is the conductivity at the reference temperature T_0. α is the temperature coefficient of resistivity, which describes how the resistivity varies with temperature.

In the Electro- Thermal module available under COMSOL ,the equation have been solved under Dirichlet Neumann, and mixed boundary conditions numerically. The temperature is kept fixed at the end wherein we apply the potential and the other ends are thermally insulated to achieve higher Joule's heating profile. The material properties of the heater required to solve the mathematical equations are given in **Table 1.**

Table 1: Properties of the heater material (Polysilicon- PolySi)

Property	Value
Co efficient of thermal expansion	2.6e6[1/K]
Heat capacity at constant pressure	678[J/(kg8K)]
Relative permittivity	4.5
Density	2320[kg/m^3]
Thermal Conductivity	34[W/(m*K)]
Young's modulus	160e9[Pa]
Poisson's ratio	0.22

3. Heater Geometries

For achieving geometric optimization we have tried the following four geometries.

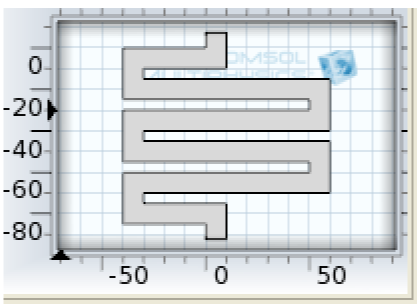

Figure 1 Single Meander Structure.

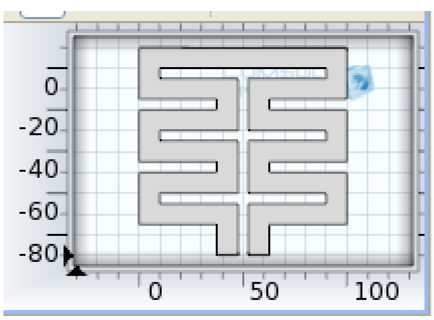

Figure2: Double Meander Structure.

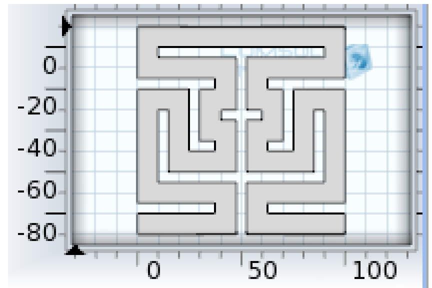

Figure 3: Fan Shape Structure.

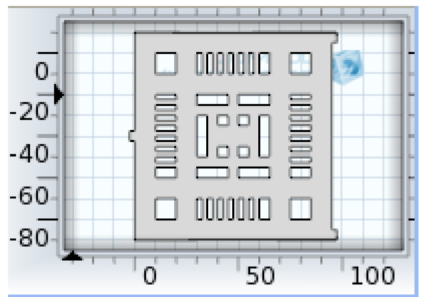

Figure 4: Square Shape Structure.

In our design, we wanted to improve the temperature uniformity of the micro-heater. Starting with the Single meander structure [1,4], we went on to make modifications to it to bring more area under heat and thus finally arriving at the square shape structure with an array of connectors.

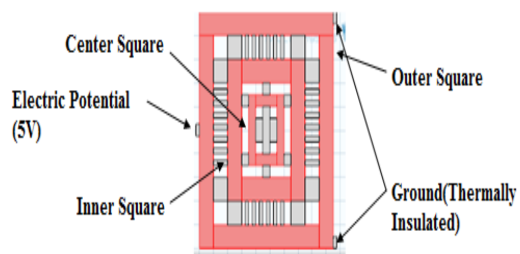

Figure 5: Square Shape Structure Detail

In order to improve the heating, we looked at increasing the number of connectors between inner squares and outer square to increase the current density all over the structure. Thermal Insulation [2] was provided to achieve an improved temperature profile.

4. Simulation With FEA

The geometries were analyzed by applying a potential of 5V.The end where potential is applied is maintained at 300K.Their simulated temperature Profile are as shown below.

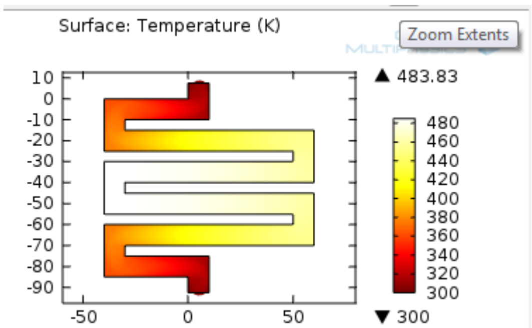

Figure 6: Single Meander

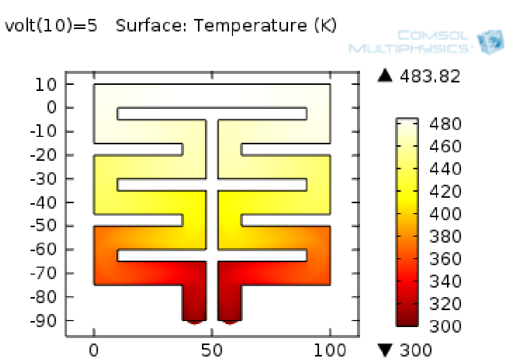

Figure 7: Double Meander

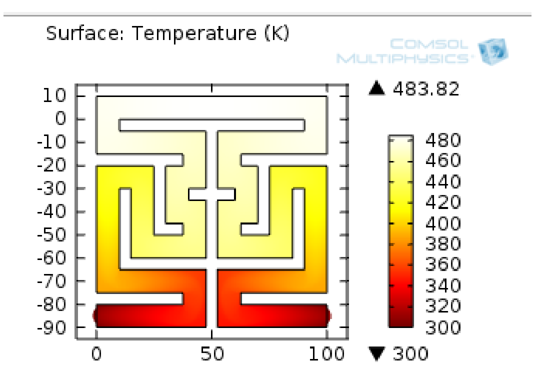

Figure 8: Fan Shape

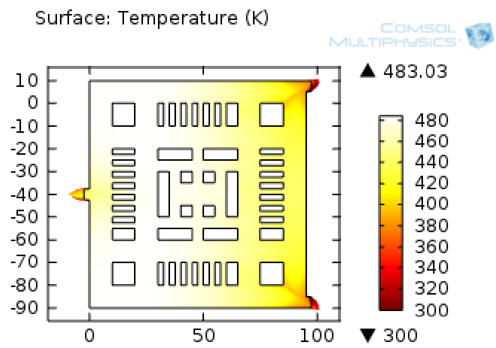

Figure 9: Square Shape

5. Results and Discussion

As the voltage is varied from 0.5 to 5 V in increments of 0.5 V the temperature increases exponentially. The same maximum temperature was obtained for all the structures; however there was a notable difference in temperature uniformity [3].

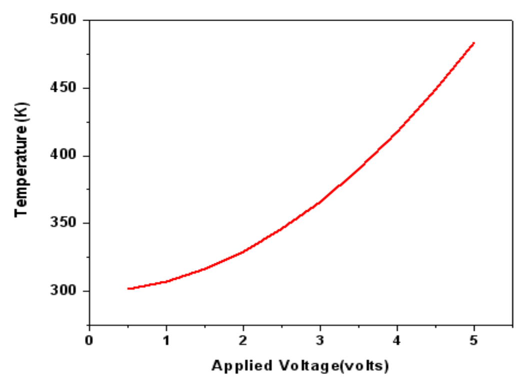

Figure 10: Maximum Temperature Vs Applied Voltage curve for Micro Heater of area 100× 100 μm

The average temperature and the percentage of area greater than 80% of maximum temperature was determined for each geometry and tabulated, as shown in **Table 2**.

Table 2: Temperature profile of Various Structures

Structure Type	Maximum Temperature (K)	Average Temperature (K)	Percentage of Area greater than 80% of maximum Temperature
Single Meander	483.82	388.356	73.14
Double Meander	483.82	406.908	68.02
Fan Shape	483.82	435.725	71.91
Square Shape	483.82	456.442	99.51

The simulated result of microheaters shows that the square shaped structure provides better temperature profile when compared to other structures with an average temperature of 456.442 K.

6. Conclusion

A comprehensive thermal model of micro-heaters is designed and simulated using COMSOL 4.2. The results show the variation of temperature across the structure for the applied voltage. It was found that the Square shape structure gave the best result with 99.51% of the heater area having a temperature greater than 80% of the maximum temperature attained with an average temperature of 456.442 K. We have found many effective improvements in the temperature upgrade path while learning new features of the new COMSOL Multiphysics 4.2. As our work is in basic level, it is our future concern to fabricate a micro- heater on the basis of these simulations.

7. References

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8. Acknowledgements

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