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2D Simulations and Electro-Thermal Analysis of Micro-Heater Designs Using COMSOL^{TM} for Gas Sensor Applications

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Abstract: Microheaters have been widely investigated because of their extensive applications in gas sensors, flow rate sensors and other Microsystems. The geometric optimization for the microheater was performed by simulating a wide range of possible geometries using COMSOL^{TM}, a commercial Finite Element Analysis (FEA) package. The simulated results of Microheaters having an improved temperature distribution over the sensing area and a higher density of integration is presented in this paper. The microheaters are designed to ensure low power consumption, low thermal mass and better temperature uniformity. In this paper we have presented six different patterns of microheater like Plane plate with central square hole, Double spiral, Honey comb, S- shape, fan shape and meander type with their Electro thermal simulated temperature profile. For the same supply voltage applied, the uniform temperature profile and the power consumption of the heater to get 400^{o}C is analyzed for all the six patterns and compared.

Keywords: Microheaters, Low Power Consumption, Heater geometries, Thermal profile

1. Introduction

A large number of gas-sensitive materials like semiconducting metal oxides operate only at elevated temperatures. Microheaters are the most important devices in the field of high-temperature gas-sensing devices since they allow the reduction of the sensor power consumption and also enable in temperature modulation of the gas sensing in performance improvement of gas selectivity. In this paper, we report on the design and simulation of microheaters used in the gas sensors with the aim of improving their performance at high temperatures. The design has been supported using Electro-Thermal FEM simulations using the COMSOL^{TM}. In our Simulations we assume the temperature and potential gradients in the z-direction (perpendicular to the heater plane) are small in comparison to the gradients in x-y plane. There by reducing the problems to two dimensions. This is a reasonable assumption given the relative dimensions of the structure; the thickness being much smaller than the length or width.

2. Electro Thermal Mathematical modeling of microheater

In Joule heating, the temperature increases due to the resistive heating from the electric current. The electric potential *V* is the solution variable in the Conductive Media DC application mode. The generated resistive heat *Q* is proportional to the square of the magnitude of the electric current density *J*. Current density, in turn, is proportional to the electric field, which equals the negative of the gradient of the potential *V*:

$$Q \propto |J|^2 \qquad (1)$$

The coefficient of proportionality is the electric resistivity $\rho = 1/\sigma$, which is also the reciprocal of the temperature-dependent electric conductivity $\sigma = \sigma(T)$. Combining these facts gives the fully coupled relation.

$$Q = \frac{1}{\sigma}|J|^2 = \frac{1}{\sigma}|\sigma E|^2 = \sigma|\nabla V|^2 \qquad (2)$$

Over a range of temperatures the electric conductivity σ is a function of temperature *T* according to:

$$\sigma = \frac{\sigma_0}{1+\alpha(T-T_0)} \qquad (3)$$

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. A typical value for platinum copper is 0.00385 per^{o}C

The equations have been solved under Dirichlet, Neumann, and mixed boundary conditions numerically using the Finite Element Method (FEM) when the Electro-Thermal module is selected in COMSOL™. Fixed temperature and potentials are assumed at ends of the heater. Several material properties are required to solve the mathematical equations mentioned above.

Table 1: Properties of the heater material (Platinum-Pt) used for simulation

Parameter	Value
Heat capacity at constant pressure (C)	133[J/(kg*K)]
Young's modulus (E)	168e9[Pa]
Thermal expansion coefficient (α)	8.80e-6[1/K]
Thermal conductivity (k)	71.6[W/(m*K)]
Poisson's ratio (μ)	0.38
Density (ρ)	21450[kg/m^3]
Electric conductivity (σ)	8.9e6[S/m]

3. Meshing optimization

The optimized meshing for the simulation is determined by performing an independent grid study to minimize the modeling error. When the change in the solution between subsequent stages of meshing refinement is considered to be negligible, the lower but still sufficient, mesh resolution is kept.

Table 2: Properties of Mesh used in our Simulation

Number of degrees of freedom	31766
Number of mesh points	4232
Number of elements	7420
Triangular	7420
Number of boundary elements	1042
Number of vertex elements	156
Minimum element quality	0.623

4. Simulation and Discussion

Six different patterns of microheaters are designed and simulated and a number of 2-D simulations have been conducted to optimize the micro-heater geometry. It was believed that these structures would distribute the heat more uniformly over the heater area and so reduce the central hotspot. Coupled Electro-thermal analysis provides an estimation of thermal losses and temperature distribution on the heater plane for realistic geometrical and material parameters pertinent to the fabrication technology.

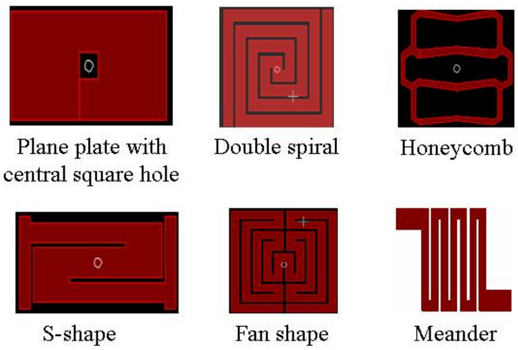

Figure 1. Six Geometries of the Micro heater

4.1 Plane plate with central square hole

This is a 500μm X 500μm square plate design with a square hole in its center, which causes to natural convection.

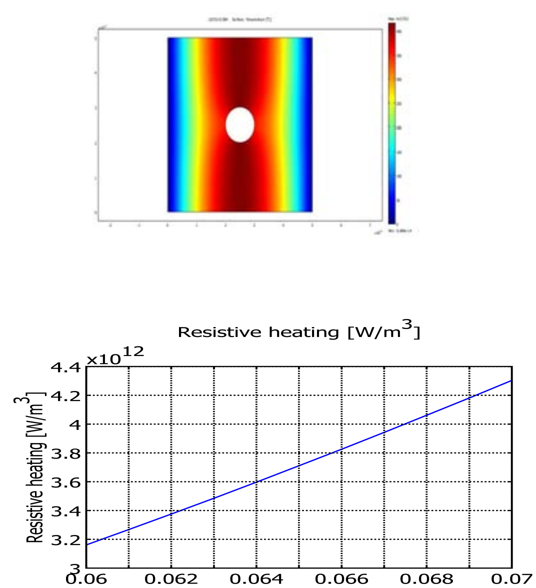

Figure 2. Thermal Profile and Power consumption of Plane Plate with Central Square Hole

4.2 Meander Type

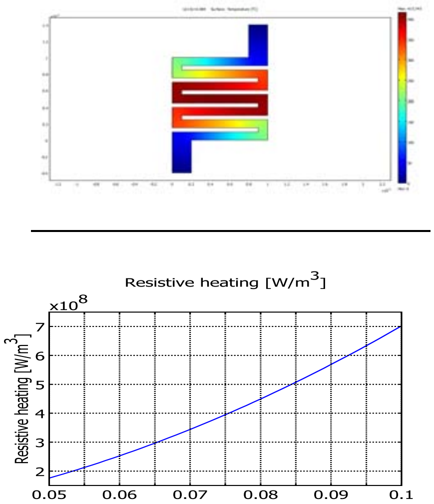

Figure 3. Thermal Profile and Power consumption of Meander Type

4.3 Double spiral Shape

To avoid the radial temperature gradient of conventional plate type and meander type, Double spiral pattern is designed.

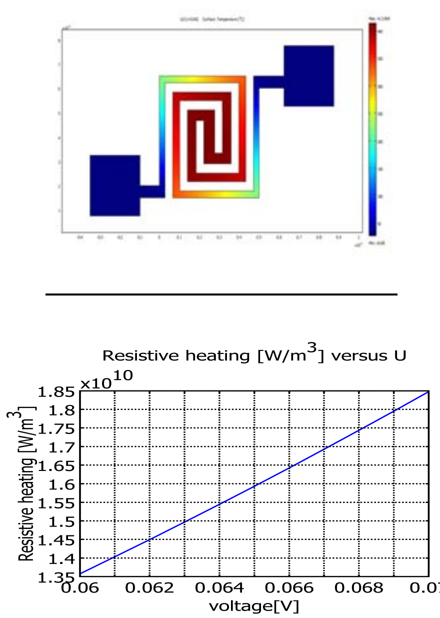

Figure 4. Thermal Profile and Power consumption of Double Spiral Shape

4.4 Fan Shape heater

Variation of Double spiral design, results in Fan shape heater geometry.

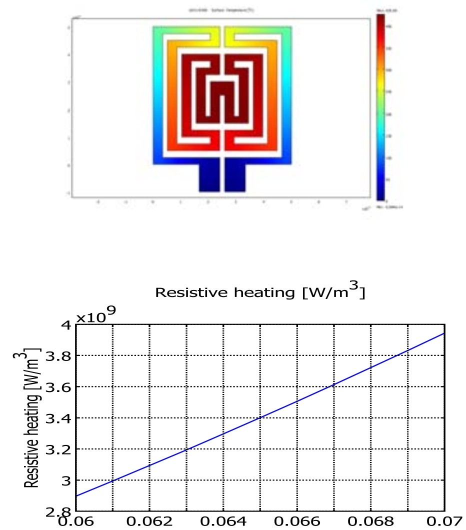

Figure 5. Thermal Profile and Power consumption of Fan Shape

4.5 S- Shape heater

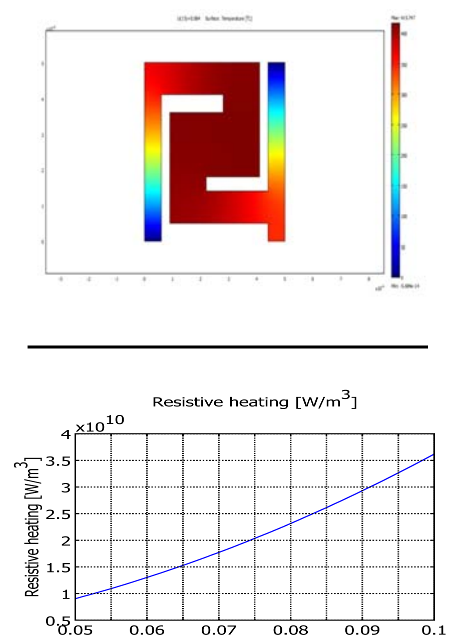

Figure 6. Thermal Profile and Power consumption of S- Shape

4.6 Honey-Comb shape heater

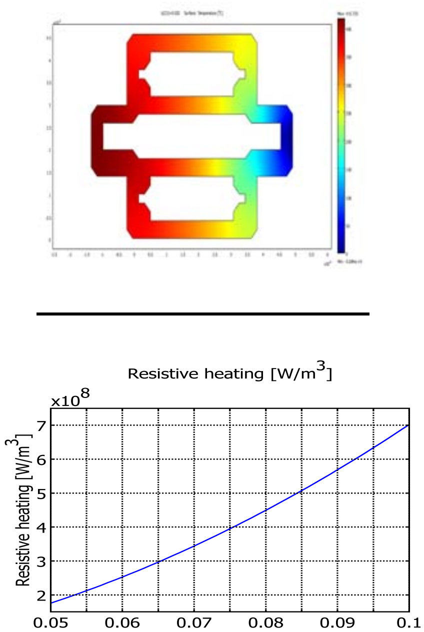

Figure 7. Thermal Profile and Power consumption of Honey comb Shape

5. Design Summary

By analyzing the different geometries and their simulation results we can compare the given designs on the basis of the following specifications:

1. The required temperature range
2. Maximum and average sensor temperature
3. Power consumption
4. Required heater resistance for the given power consumption

For each design the difference between maximum and average temperature can easily be calculated.

6. References

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