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Simulations of Polymer based Microheater Operated at Low Voltage

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Abstract: This paper presents simulation results of polymer based microheater operating in the temperature range of 200-250°C which could be operated at low voltage. In the present study Poyimide (PI) is used as heater material. The designed heater will be useful for application such as MEMS based gas sensor using inorganic material, Polymerase Chain Reaction (PCR) device etc. Various micro heater geometries have been simulated using COMSOL 4.1, FEM simulation tool. For comparison of the results with different geometries for temperature distribution over the area a fixed voltage 5.2 V is applied. The resistive track width and the gap between the consecutive tracks are varied and the area over which uniform temperature is obtained is estimated. The results obtained are analyzed and discussed.

Keywords: PCR, gas sensor, microheater, COMSOL, heater geometries, heater design, polyimide.

1. Introduction

Microheaters have extensive applications in Micro Electro Mechanical System (MEMS). They have been widely used in applications such as gas sensor, flow rate sensor, microexplosive boiling, microvalve, pressure sensor, miropump, Polymerase Chain Reaction (PCR) device, etc [1-3].

In the present study Polyimide (PI) is used as heater material [4]. Advantage for using polymer material is it's compatibility with polymer micro fabrication process with benefits of ease of availability, cost effectiveness and clean room free fabrication procedures with less instrument usage.

Polyimide properties which are used for simulations are shown in Table 1.

Table1: Properties of Polyimide used for simulation

Parameter	Value
Electrical Conductivity(s/m)	10
Coefficient of Thermal Expansion(1/K)	$45*10^{-6}$
Heat Capacity @ Constant Temperature[J/(kg*K)]	1090
Density(kg/m^3)	1420
Thermal conductivity(W/mk)	0.12
Young's Modulus(Pa)	$2.5*10^9$
Poisons Ratio	0.32
Relative permittivity	3.1

The heating power (P) of a micro heater can be calculated by applying a voltage (V) across the two ends of a resister with a resistance (R). Equation (1) is a heating power evaluation.

$$P = V^2/R \qquad (1)$$

A resistance of thin-film microheater can be found by equation (2).

$$R = \rho L/wt \qquad (2)$$

Where ρ is the resistivity of material, L is the length; w and t are the width and the thickness, respectively. By combining equation (1) and equation (2) we can obtain equation (3)

$$P = V^2 wt/ \rho L \qquad (3)$$

Therefore, by controlling the sizes of L, T and W of the heater, power of the heater can be controlled precisely.

The COMSOL 4.1, Multiphysics simulation tool is used for modeling and simulation of microheater. The microheater designs have been analyzed using Finite Element Method (FEM) and Joule heating module is selected for simulation.

In microheater simulation, the temperature and potential gradient in Z direction (perpendicular to heater plane) are small in comparison to the gradients in X-Y plane. Therefore the problem simulation reduces to two dimensions.

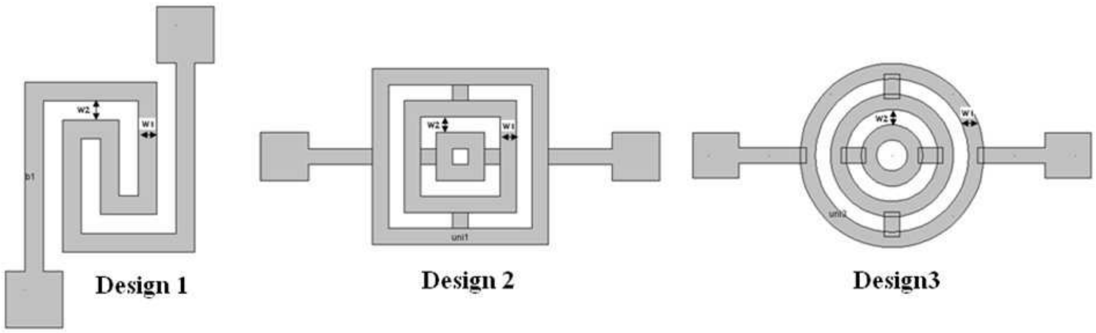

Fig 1: Three geometries of Microheater

Table 2: Variation of Track Width (W1) and Gap Width (W2) take for each sub designs and area covered by each sub designs

Designs	Track Width(W1) (µm)	Gap Width(W2) (µm)	Area Covered by the design (µm)
Design1(A)	5	5	45*45
Design1(B)	10	10	90*90
Design1(C)	10	5	80*80
Design1(D)	5	10	65*55
Design2(A)	5	5	60*60
Design2(B)	10	10	110*110
Design2(C)	10	5	90*90
Design2(D)	5	10	80*80
Design3(A)	5	5	60*60
Design3(B)	10	10	110*110
Design3(C)	10	5	90*90
Design3(D)	5	10	80*80

2. Simulation results and Discussion

Fig. 1 shows three different geometry designs which are selected for microheater simulations. For all geometries, length is taken in micrometer (µm). The Joule heating module from COMSOL 4.1 is used to get electro-thermal simulations. A reference temperature used during simulation is 20°C. Mesh sizes were chosen from the pre-defined sizes available in COMSOL 4.1. The stationary solver was used to determine the steady state temperature distribution of micro-heater.

All three designs were simulated for the constant voltage of 5.2V to get temperature range from 200 to 250°C. Geometry of all three designs was varied in track width (W1), gap between two consecutive tracks i.e. gap width (W2). Table 2 shows the values taken for track width and gap width for each sub design A, B, C, D and also the total area covered by the sub designs.

Fig 2, Fig 3 and Fig 4 show the simulation results for all three designs with variation A, B, C, D respectively. The color bar on the right side of each figure represents values for temperature in '°C'. It is observed from the simulation results that the temperature is higher in the center and goes on reducing towards the periphery. Further the temperature is found to be uniform over certain area of design. Table 3 shows the area over which uniform temperature is obtained and the value of temperature.

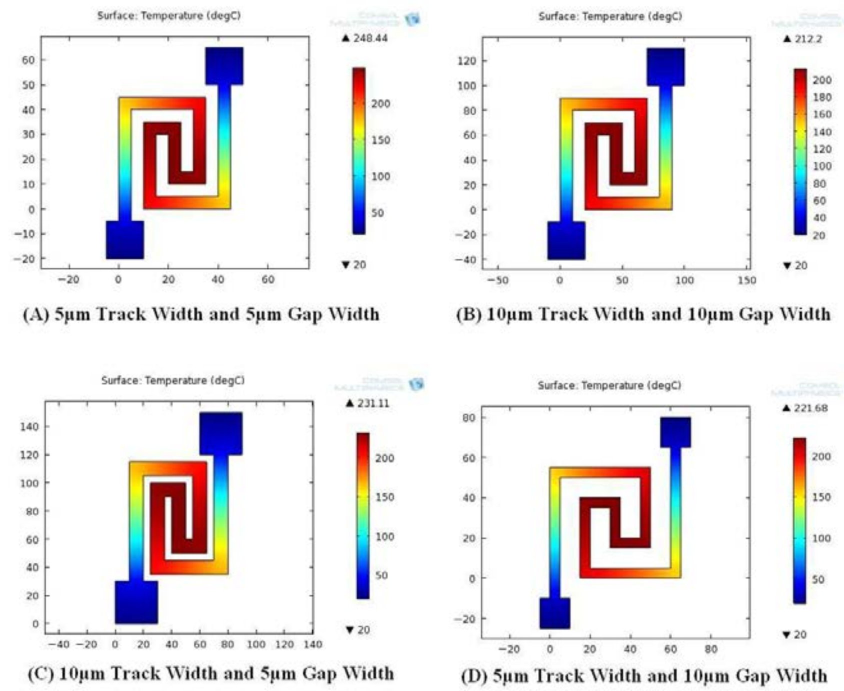

Fig 2: Design 1: Simulations for Polymer based heater at an applied voltage of 5.2V with variation in Track Width (W1) and Gap Width (W2)

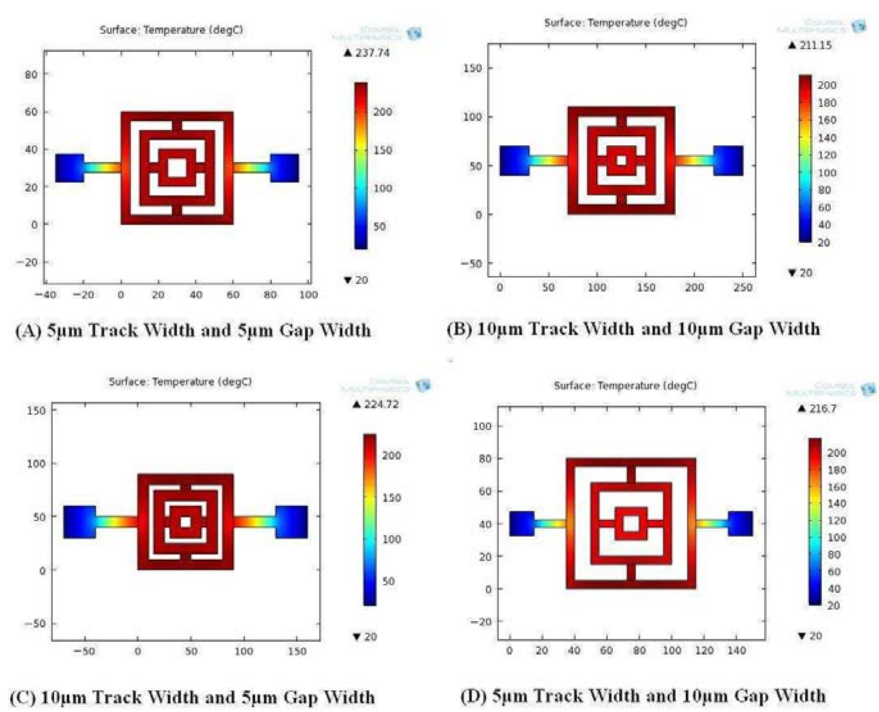

Fig 3: Design 2: Simulations for Polymer based heater at an applied voltage of 5.2V with variation in Track Width (W1) and Gap Width (W2)

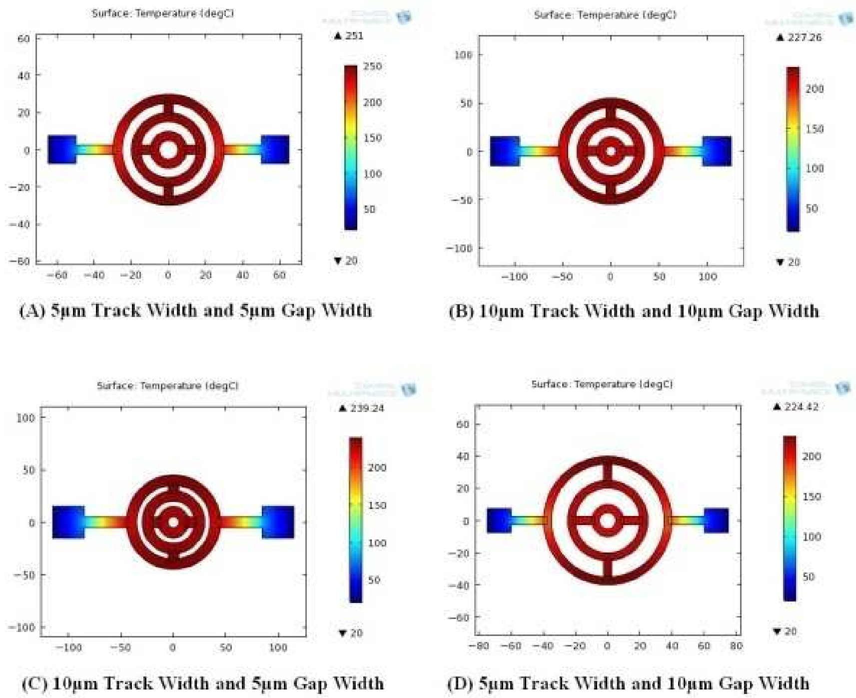

Fig 4: Design 3: Simulations for Polymer based heater at an applied voltage of 5.2V with variation in Track Width (W1) and Gap Width (W2)

Table 3: Comparison of all designs with respect to area of uniform temperature

Designs	Area Covered by the design (µm)	Area of uniform temperature(μm^2)	Temperature(°C)
Design1(A)	45*45	25*10	246
Design1(B)	90*90	50*10	210
Design1(C)	80*80	45*10	228
Design1(D)	65*55	25*20	220
Design2(A)	60*60	40*40	225
Design2(B)	110*110	70*70	195
Design2(C)	90*90	60*60	214
Design2(D)	80*80	50*50	196
Design3(A)	60*60	40*40	242
Design3(B)	110*110	70*70	215
Design3(C)	90*90	60*60	231
Design3(D)	80*80	50*50	209

By referring to the Table 3, area covered by the design 1(B), design 2(C), design 3(C) is same, but area of uniform temperature in case of design 2(C)and design 3(C) is more than design 1(B). This is because of heat spreading structure of design 2 (C) and design 3(C). Also it is observed that area of uniform temperature is same for design 2(C) and design 3(C), but larger uniform temperature is obtained. This is due to the circular geometry of the design 3(C) which is minimizing the edge losses.

Similar arguments can be compared in case of microheater design 1(C), design 2(D), and design 3(D) and also between geometries of design 1(D), design 2(A), and design 3(A).

2.1 Time Dependent Study

A time dependent study was done for design 3 to observe response time of microheater at different voltages. Fig. 5 shows a response time of design3 at 5.2V and 6V from 0 to 0.3 seconds.

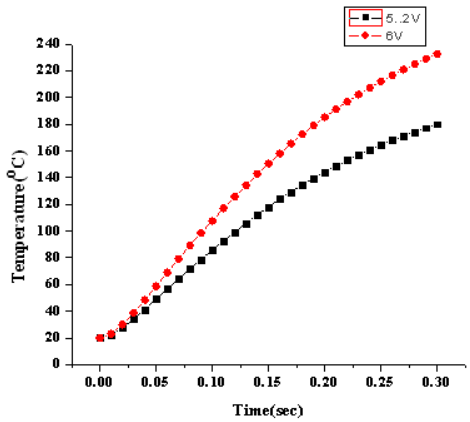

Fig 5: Heating rate of microheater at 5.2V and 6V

With an applied voltage of 5.2 V, from 0 to 0.3 sec design 3 reach up to 180 ºC. If voltage is changed to 6V, then from 0 to 0.3 sec design 3 reach up to 232 ºC. So by increasing the applied voltage, response time can be increased. Fast response time is also useful for measuring gas sensing characteristics and PCR measurements.

3. Conclusions

Using stationary analysis the performance of three designs microheater geometries was compared with respect to of area of uniform temperature. With a heat spreading structure uniform temperature area can be increased and with circular geometry it possible to minimize the edge losses. From the time dependent study it is observed that the heating rate can be varied with a change in applied voltage. Considering the low operating voltage range, present microheater can be converted into battery operated heater.

4. References

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