DESIGN OF MEMS BASED MICROHEATER

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ABSTRACT

In this paper we present an in depth design and simulation of MEMS based micro heater. Two .1% μ m thickness thin film platinum micro heaters (coated with gold of .1% μ m thickness forming the bond pad) is fabricated on two separate 10% μ m thick silicon islands which again is fabricated on 2% μ m thick them oxide and the whole structure is fabricated on 400% μ m thick silicon substrate. The temperature coefficient of resistance (TCR) of the thin film platinum is $3.7 \times 10^{-3}/K$. The average temperature of the micro heater is extracted using the determined TCR. The analysis shows that the operating temperature of 180°C can be achieved with a power dissipitation of .4 mW.

Key words: micro heater, heat loss, minimum power loss

I. INTRODUCTION

MEMS is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and Investigated because of their lower power consumption and cost effective manufacturing, providing extensive structures) that are made using the techniques of micro fabrication. Micro heaters are widely application in gas sensor [1]. Micro heaters provide the requisite operating temperatures for metal oxide gas sensors [2].

II. DESIGN CONSIDERATION

A. Design of Micro heater

Table 1. Materials used and their properties

Material	Thermal Conductivity (Kg/ μ m³)	Electrical Conductance (pS/ μ m)	Young's Modulus of Elasticity (Mpa)
Air	2.62e+4	0.0e0	1.0e0
Gold	2.97e+8	4.4e+13	5.7e+4
Platinum	7.16e+7	9.009e+12	1.45e+5
Silicon100	1.57e+8	1.4e+9	1.301e+5
Thermal Oxide	1.422e+6	1.0e–4	7.0e+4

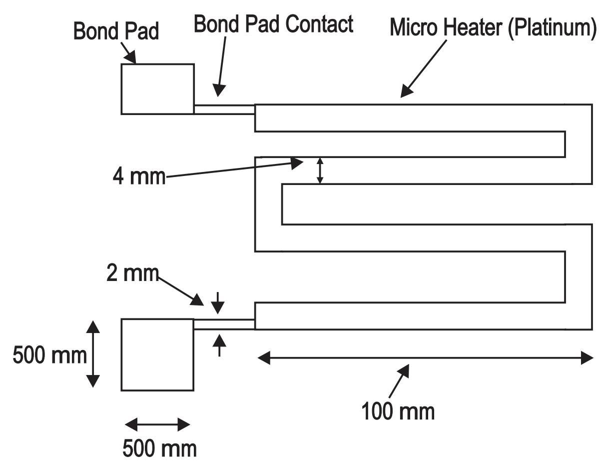

Fig. 1. The design of microheater (.1 μ m thickness) used for simulation

The total length of the microheater is 420 μ m and the thickness of the microheater is .1 μ m. The bond pad area is 500% m × 500% m. Thick SOI wafers are typically used for a wide variety of applications in power switching devices, high-speed bipolar circuits and MEMS [3]. Integrated detectors offer several advantages over monolithic active pixel sensors[4].

B. Resistence and Current Density Calculation

Total (L/A)

$$= \{ (100/4 * .1) + (8/4 * .1) + (96/4 * .1) + (8/4 * .1) + (96/4 * .1) + (8/4 * .1) + (96/4 * .1) \} \mu m^2$$

$= \{ 420/4 * .1 \} \nu \ m^2$

$= 1050 \ \mu \ m^2$

$R = * (L/A) \ \Omega$

$= 1/ * (L/A) \ \Omega$

$= (1/9.009e + 12pS/\mu \ m^2) * 1050 \ \mu \ m^2$

$= (1/9.009e + 12 * e - 12 \ S/\mu \ m^2) * 1050 \ \mu \ m^2$

$= 115 \ S^{-1}$

$I = V/R$

$= .22/115$ A

$= .0019$ A

$= 2$ mA

$R =$ Resistence

$L =$ Length

$A =$ Area

$\sigma =$ Resistivity

$\rho =$ Conductivity

$V =$ Voltage (I have used 1.5 V in the simulation as it is enough to reach 200°C as it is required)

$I =$ Current

$P =$ Power (here power is the static power i.e. the minimum power consumed i.e. power consumed at 300 K i.e. room temperature)

$J =$ Current Density

III. SIMULATION

The design and simulation in COVENTORWARE 2010 [5] (which is actually a 3D MEMS design, analysis & simulation tool).

A. Heat loss consideration

A.1 Heat loss through conduction: It is the transfer of thermal energy between regions of matter due to a temperature gradient. Heat spontaneously flows from a region of higher temperature to a region of lower temperature, temperature differences over time, approaching thermal equilibrium

Fourier's law of heat conduction:-

$$Q_x = K * A * (dT/X)$$

$K =$ thermal conductivity (W/mK)

$A =$ Area (m^2)

$dT =$ temperature difference across the material (K)

$X =$ Thickness of the material (m)

Where, $Q_x =$ heat transfer per unit time (W)

A.2 Heat loss through Concevtion: Heat energy transferred between a surface and a moving fluid at different temperatures is known as convection.

Newton Law of cooling:-

$$Q = K * A * dT$$

Where,

$Q_x =$ heat transfer per unit time (W)

$K =$ thermal conductivity (W/mK)

$A =$ Area (m^2)

$dT =$ temperature difference across the material (K)

$X =$ Thickness of the material (m)

A.3 Heat loss through radiation: It is actually the heat transfer that takes place through radiation in form of electromagnetic waves mainly in the infrared region. It is given by :-

Stefan-Boltzmann Law:-

$$Q = \sigma * \in * (T_h^4 - T_c^4) * A$$

Where,

$Q =$ heat transfer per unit time (W)

$\sigma =$ Stefan-Boltzmann Constant ($W/m^2/K^4$)

$T_h^4 =$ absolute temperature of the hot body (K)

T_C^4 = absolute temperature of the cold body (K)

A = area (m^2)

$\in$ = Emmisivity of the object (indicates the radiation of heat from a **'grey body'** compared with the radiation of heat from a ideal **'black body'** with the emissivity coefficient $\varepsilon = 1$)

B Defining Process steps, 3D model generation and meshing

(a) First a 400 μ m Silicon wafer is used as the substrate.

(b) Then I grew a 2 μ m Therm Oxide Layer above it

(c) Then I grew a 10 μ m Silicon Layer above Therm Oxide layer

(d) Then I coated the wafer with photoresist and patterned the photoresist (– ve photoresist, ie the photoresist is photolithographically patterned in such a way that the surface under the mask i.e the patterned area, is etched away and the rest part of the photoresist remains the same) for the microheater structure with thickness of 0.05 μ m and deposited metal platinum of 0.05 μ m thickness in the etched out part of the photoresist and hence the total thickness of the microheater is now .1 μ m.

(e) Then I again coated the wafer with another photoresist and execute the same process as above but this time the photoresist is patterned for only "bond pad contact" & "bond pad" part only and the metal deposited is gold.

(f) Then I stripped of both the resist.

(g) Then using surface and bulk micromachining I have achieved the below structure (The micromaching is obtained in COVENTORWARE 2010 using "straight cut" option).

(h) Then I covered the whole structure with air **4000μ m** above and below the structure and **3000 μ m** on the left and right side of the structure as if the whole structure is in **AIR CHAMBER**. This is very important with respect to heat loss consideration. If I haven't made this type of structure for analysis then I would have cleary ignored the actual heat loss (of the whole structure) due to convection.

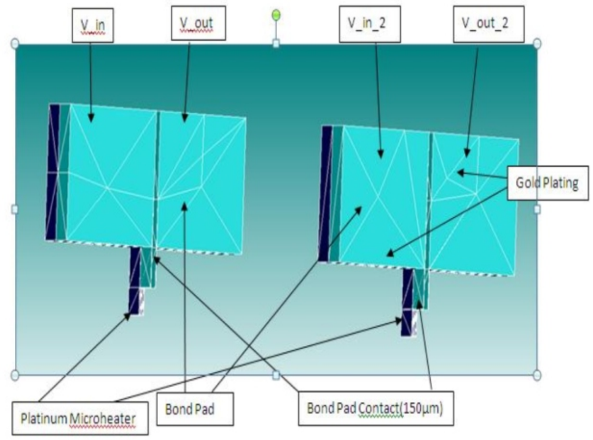

Fig. 2. 3D Model of Microheater after meshing

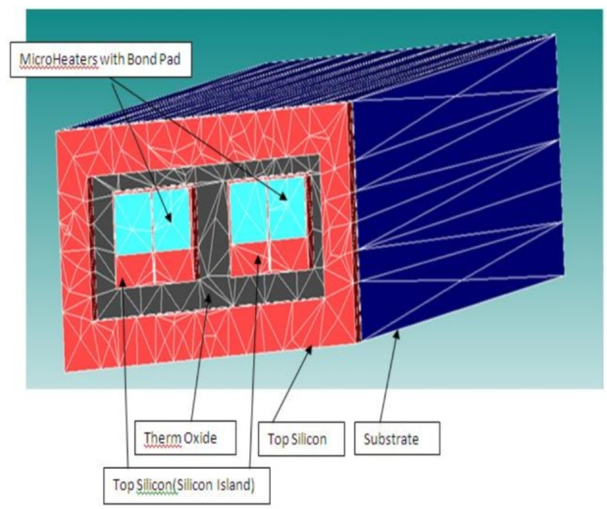

Fig. 3. 3D model of the whole structure after meshing (Top View)

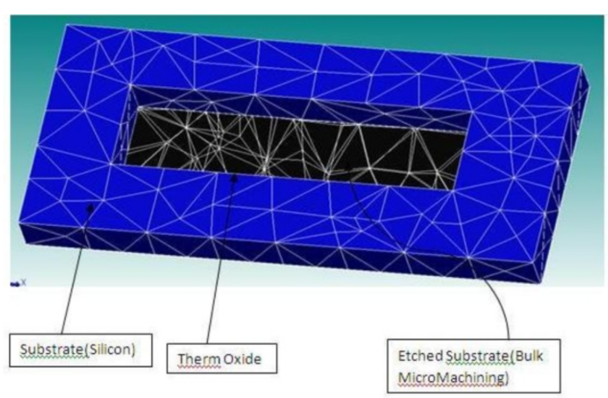

Fig. 4. 3D model of the whole structure after meshing (Bottom View)

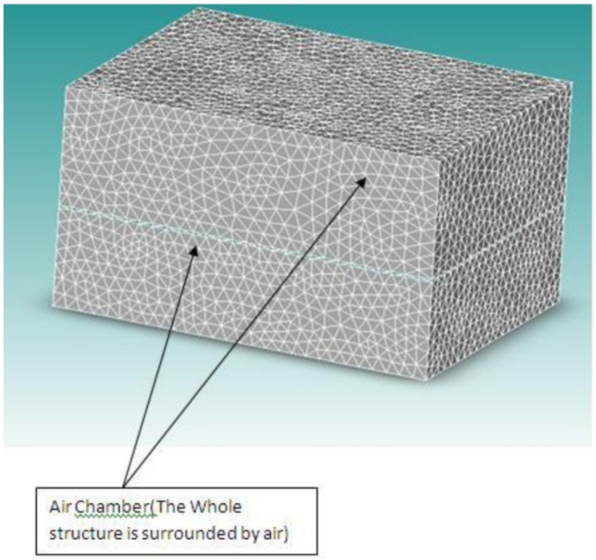

Fig. 5. 3D model of the whole structure including air chamber

The backside etched diaphragm-type structure makes the microheater has bigger thermal capacity and thermal conductance, so that to cut down its sensitivity, furthermore, this kind of structure makes the sensor element difficult to downsize [6,7,8].

C. Setting Boundary Condition

(a) From the analyser of COVENTORWARE 2010 I have selected the MEMECH option.

(b) In the MEMECH domain I have selected the ELECTROTHERMAL ANALYSIS

(c) In the Surface Bondary

(i) I have applied .22 V to V_in & V_in_2 of the bond pads of either microheater and to the other bond pads i.e V_out & V_out_2, 0V is applied.

(ii) 300 K (T_Constant) is applied to the outside surface of the air chamber i.e in all the 6 sides.

(iii) Convection is applied to all the surfaces of the actual MEMS structure, which is in touch with air (with ambient temperature as 300 K and convection coefficient as 5).

(D) Analysis

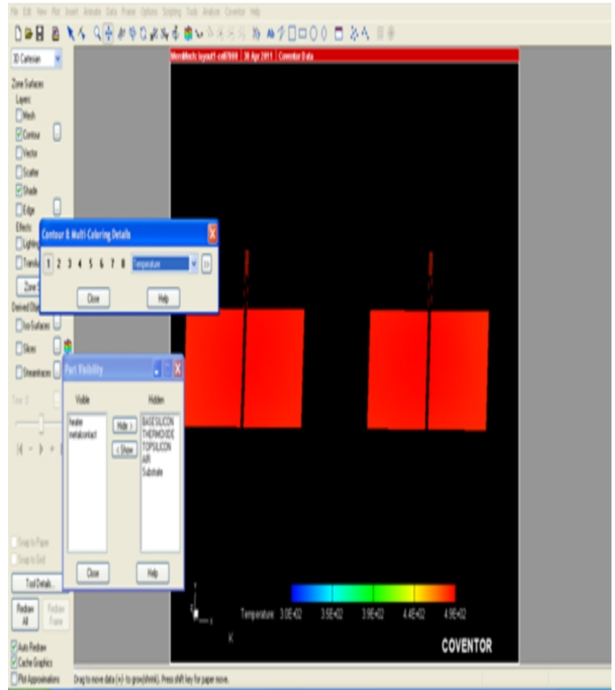

Fig. 6. Temperature analysis of bondpad and microheater

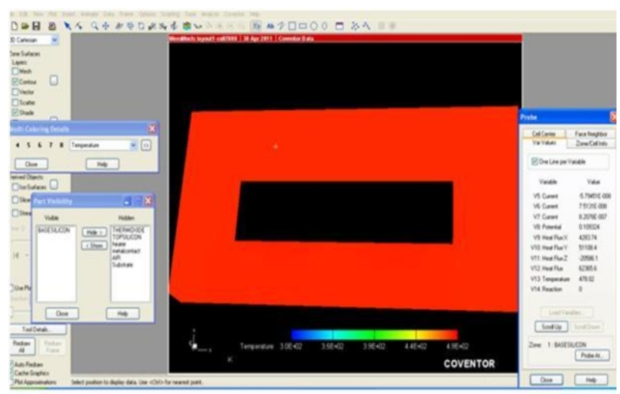

Fig. 7. Temperature analysis of substarte ie base silicon

From the analysis we can say that we achieve to reach a temperature of 180° (ie setting 300 K as ambient temperature we are able to achieve 480 K) in the microheater with excellent uniformity of temperature distribute at cost of minimum power loss ie .4 mW. But the major problem remain concentrated with the fact that the thermal loss is very high as there is same temperature rise in micro the substarte ie same temperature flows from microheater through top silicon and thermo oxide to substarte, ie no thermal insulation.

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