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ANALYSING DIFFERENT GEOMETRIES OF MICRO HOTPLATES

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ABSTRACT
During the last years, so called 'Micro Hotplate' has been developed in order to reduce the thermal mass of metal oxide gas sensor. Micro Hotplate consists of a thermally isolated stage with a heater structure, a temperature sensor and a set of contact electrodes for the sensitive layers. By using such Microstructures high operation sensors can be reached at comparably low power consumption (<100mW).Micro hotplates are generally micro heaters which work as plates and are available in different shapes and sizes as per their requirements and other parameters such as sensitivity, response time, power consumption, thermal expansion.

KEYWORDS: Microhot plate, thermal mass,sensor,microstructures.

INTRODUCTION
In recent years, there has been increasing interest and development efforts in miniaturizing gas sensors and systems. Particularly strong efforts have been made to monitor environmentally relevant gases like Carbon Mono-oxide (CO), Methane (CH_4) and Ozone (O_3).

Commonly used chemically sensitive materials for there target gases are wide bandgap semiconductor oxides such as Tin oxide (SnO_2), Tungsten oxide, which are operated at elevated temperature of 200°C-400°C [4]. At these high temperatures these oxide shows considerable resistance changes upon exposure to a multitude of inorganic gases and volatile organics. The most prominent example is SnO_2 which shows large electrical resistance changes upon exposure to the above mention gases at operating temperature range is 250°C-300°C.

During the last years, so-called micro hotplate (μHP) have been developed in coding to shrink the overall dimensions and to reduce the thermal mass of metal oxide gas sensors. Micro hotplate consists of a thermally isolated a heater structure, a temperature sensor and a set of contact electrodes for the sensing materials.

By using such microstructures, high operation temperature can be achieved compulsory low power consumption (<100mW). Moreover, small time slots (10ms) enable applying temperature modulation technique to improve the sensor selectivity and sensitivity.

AIMS AND OBJECTIVES
- Design and simulation of micro hotplates using different material and compared to others.
- Design and simulation of different micro hotplate structures and compared to others.
- Design and simulation of different micro hotplate sizes and compared to others
- Analysis of a micro hotplate.

The methodology that has been adopted to carry out the work is given below:

1. **Selection of Material**
   Finding out the materials used in making of gas sensors in past years as like Fe, Cu, Alloys like CMS C17500, Dilver P1.
2. **Design using COMSOL Multiphysics**
   1. Finding out the geometry which best suited for the previous results.
   2. Trying to get different geometries for better results.
   3. Designing using COMSOL Multiphysics in Thermal Expansion Module in MEMS Module.
3. **Simulation using COMSOL Multiphysics**
   1. Implement the design in COMSOL Multiphysics software
   2. The designing will be done in 3D design concept in Thermal Expansion Module in MEMS Module. The heat distribution in 2D design concept is not so good due to the spreading of heat and thus quite large power

consumption. This is improved by using a 3D design concept.

4. **Comparing** Comparing the results with previous results and gets the best one design.

Tool-COMSOL MUTIPHYSICS

COMSOL Multiphysics tool is used worldwide because of its extreme applications in designing. By using COMSOL Multiphysics, the designing of various geometries becomes easier. Simulation using COMSOL Multiphysics is quite simpler and this is the way to get more efficient designs. Implementation using COMSOL Multiphysics saves the material thus saving energy. COMSOL Multiphysics is a TOOL used in many applications like Multiphysics, Chemical Engineering, Earth Science, Heat Transfer Mechanism, RF Mechanism, Structural Mechanics, MEMS etc.

This dissertation describes Joule Heating and Thermal Expansion Model under the Structural Mechanics Module in MEMS Module in COMSOL Multiphysics.

This model consists of two sets of physics:-

1) A thermal balance with a heat source in the device originating from Joule Heating (Ohmic Heating). Air cooling is applied on the boundaries except at the position where the device is attached to a solid frame, where an insulation condition is set.

2) A force balance for the structural analysis with a volume load caused by thermal expansions. The device is fixed at the position where it is attached to a solid frame [COMSOL].

When solving the models, COMSOL Multiphysics uses the proven finite element method (FEM). The software runs the finite element analysis together with adaptive meshing (if selected) and error control using a variety of numerical solvers [10]. The studies can make use of multiprocessor systems and cluster computing, and one can run batch jobs and parametric sweeps. In its base configuration, COMSOL Multiphysics offers modeling and analysis power for many application areas. For several of the key application areas there are also optional modules. These application-specific modules use terminology and solution methods specific to the particular discipline, which simplifies creating and analyzing models [21]. The Thermal Expansion Module is used for calculating the deformations across the edges of the design.

In the Thermal Expansion Module we can compare the corresponding deformations in different materials, so that we can check and verify that which material is suitable in all respects or in most of them for our requirements.

The Joule Heating Interface

The Joule Heating physics predefined multiphysics interface combines all feature from the Electric Currents interface with the Heat Transfer interface for modeling of Joule heating (resistive heating or ohmic heating).The interaction is coupled in both the directions.

Hotplate Simulation

Designing and simulation using COMSOL Multiphysics helps in reducing the waste products by failure of the implemented design. Various geometries can be easily compared by making different designs and analyzing their properties. Various properties can be easily analyzed and studied on software than implementing on the hardware first and then check its properties and responses in the given conditions which may be physical or chemical etc.

So various materials with the same conditions taken and analyze their properties on COMSOL Multiphysics. In this dissertation work different geometries also taken into consideration and analyzed.Here different materials are taking for designing the hotplates. The materials chosen must have good heating properties, because the material used in hotplate must has a good melting temperature and it should not deform at some large temperature at all.

Different shapes and sizes are taken for the analyzation of the design and comparing of the corresponding deformations in the designs. For this some parameters like different geometry with different materials, change in size with the same materials chosen and compare the results.

Analysis on different shapes and sizes are shown below:

Simulation I

On The Basis Of Materials in Spiral Shape of size around 60µm.

Platinum

It has lower density, good specific heat capacity, high electrical conductivity etc. It is a dense, malleable, ductile, precious, gray-white transition metal. It is one of the rarest elements in the Earth's crust and has an average abundance of approximately 5 µg/kg. It is the least reactive metal.

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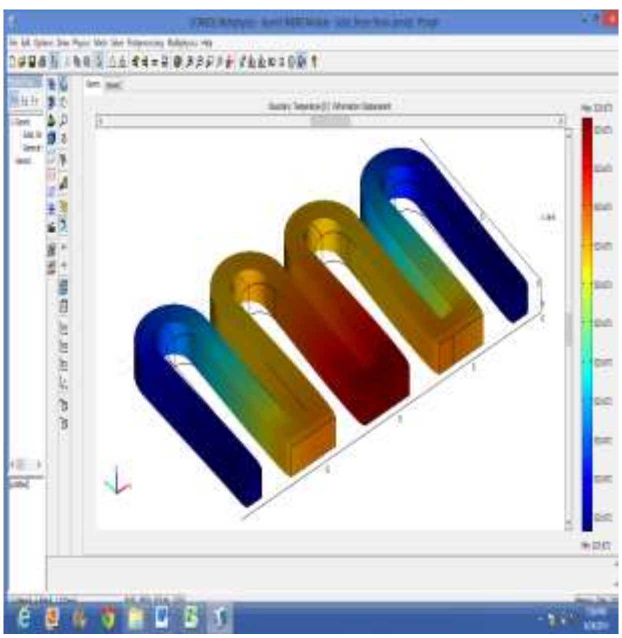
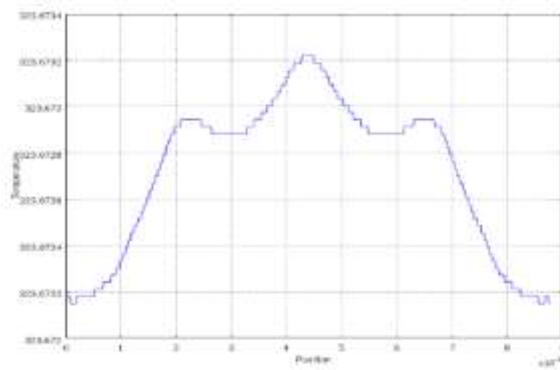
Platinum is used in catalytic converters, laboratory equipment, electrical contacts
and electrodes, platinum resistance thermometers, dentistry equipment, and jewelry. Due to high melting point of Platinum, it is used for designing. More temperature can be achieved by reducing the dimensions of the geometry.Platinum has a very good specific heat and heating properties, deformations also very low in it at high temperatures. When more heat passes through it, then its temperature rise is awesome which makes it suitable for manufacturing of heating materials in hotplates. Generally Platinum is used in making electrodes in gas sensing hotplates because it offers more flexibility than Aluminum in gas sensing hotplates.

As platinum has very good heating properties so it used in designing the hotplate which shows very good results in the given conditions, it can withstand at more temperature than Lead etc. The temperature variations are shown below:



Temperature variation in Pt

As shown in figure, temperature about 323.67°C can be achieved with the sharp edges which shows that there is no deformation in design using Platinum at this temperature. This makes platinum a good choice at higher temperature too in manufacturing of hotplates for gas sensing applications.

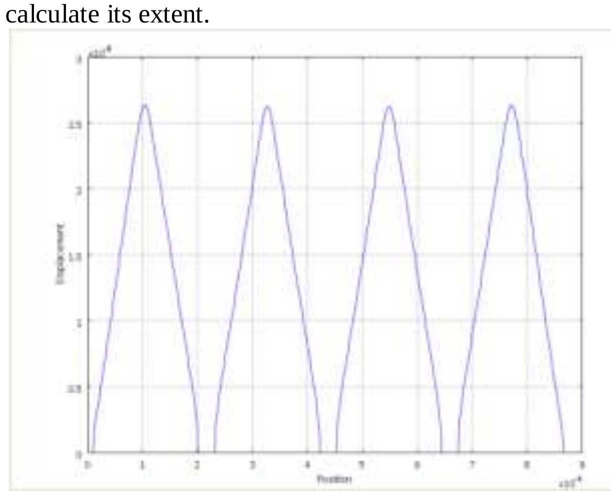


Temperature Variations across Edges

As shown in the above diagram, the temperature at the center is maximum and decreases symmetrically on either side as moving away from it. The temperature is minimum at the extreme edge of the design.

Deformation is also very useful parameter in manufacturing or designing of micro heaters or micro hotplate, because the deformation changes the geometry of the design thus causing non uniformities in the required parameters like temperature and heat etc.

The graph on the next page shows that there are deformations in platinum at the temperature of 323.67K, although the deformation is low but as it is present, so it becomes interesting for our study to calculate its extent.



Deformation across edges in platinum

Dilver P1

Dilver P1 also known as kovar alloy. It is generally available in today’s world and its thermal expansion is comparable to the borosilicate. Dilver P1 is an

alloy whose composition is tabulated below:

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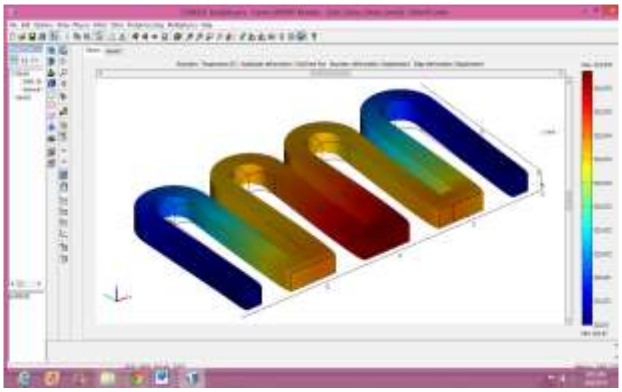
Table1. Chemical Composition of Dilver P1.

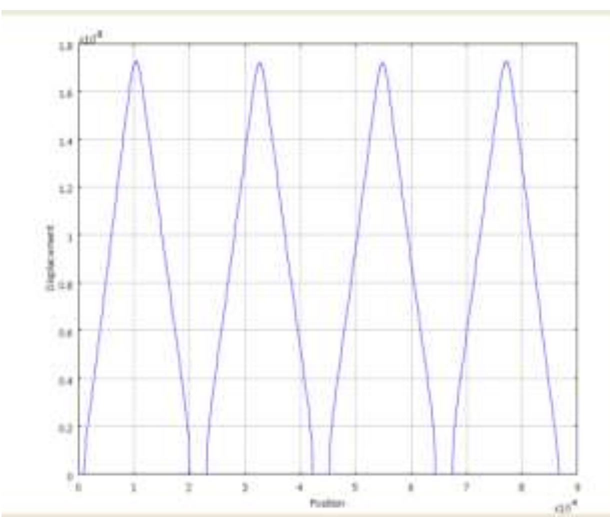
ELEMENT	N	Co	Mn	Si	C	Fe
VALUE	29	17	≤ 0.35	≤ 0.15	≤ 0.02	Bal

The melting point of Dilver P1 is too high so we can use it in designing of hotplates.



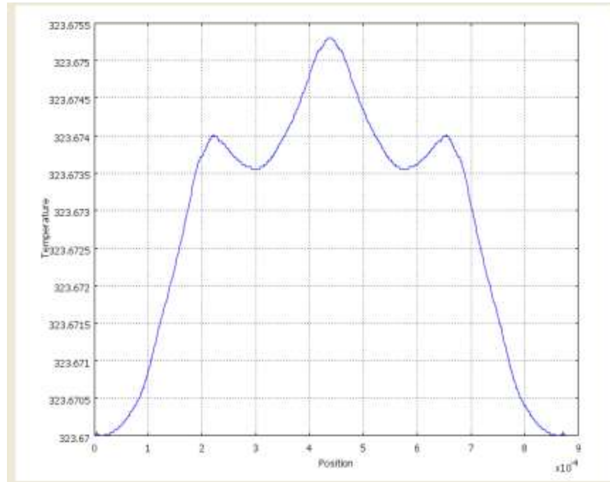
Temperature variations in Dilver P1

The figure shows the temperature is maximum at the center and decreases gradually on either side.



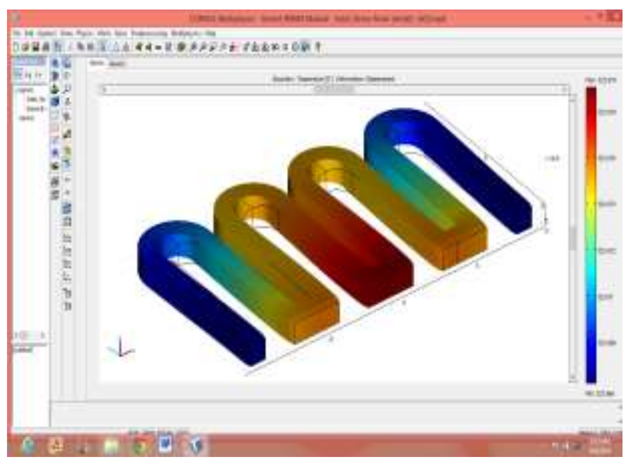
Deformation across edges in Dilver P1

As like the platinum Dilver P1 also shows the uniformity and symmetricity in the deformation across its edges.However, the Temperature Variation graph is shown below.



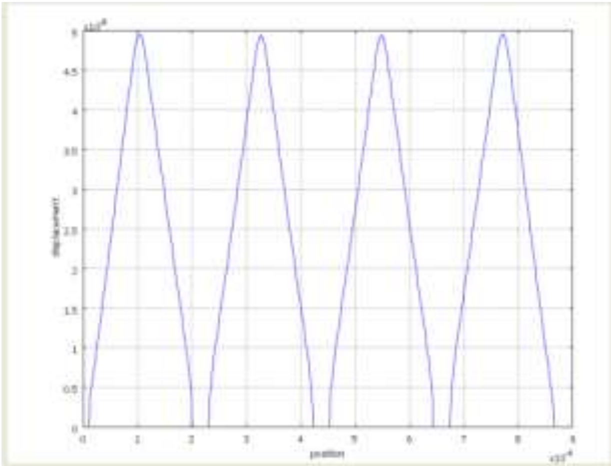
Temperature Variations across edges in Dilver P1 SiO_2

SiO_2 as everyone knows that is the semiconductor oxide which is quite cheap and easily available in today's world.SiO_2 is used as oxide layers in the fabrication of VLSI Chips. Sometimes it works as insulating layer and sometimes as conducting layer because its conductivity can be changed as per our requirements in the industry on in the applications or in projects. But the heating properties of SiO_2 are much better than many materials, So, it can also be used for the designing of the hotplates.



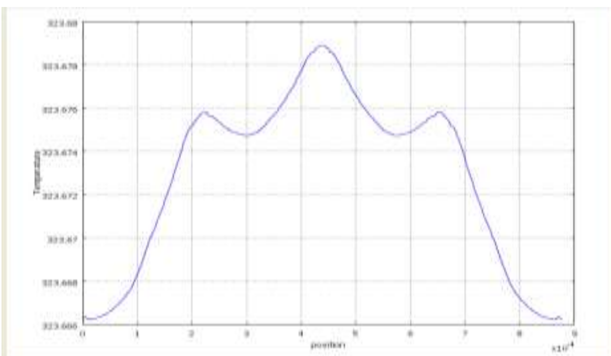
Temperature variations in SiO_2

the temperature is maximum at the center and decreases gradually on either side of it.



Deformation in SiO_2 across its edges

As figure shows that the deformation in SiO_2 is nearly twice that of platinum and it is about 4 times that of Dilver P1. It means that the deformation is more in SiO_2 than other material used like platinum and Dilver P1.



Temperature Variations across edges in SiO_2

Similarly, four different types of simulation analysis have been conducted as follows.

Simuation II: On the basis of materials in Closed Oval Shape in Size around 60µm.

Simulation III: On The Basis Of Materials in Spiral Shape of size around 6µm.

Simulation IV: On The Basis Of Materials in Closed Oval Shape of size around 6µm.

RESULT AND DISCUSSION

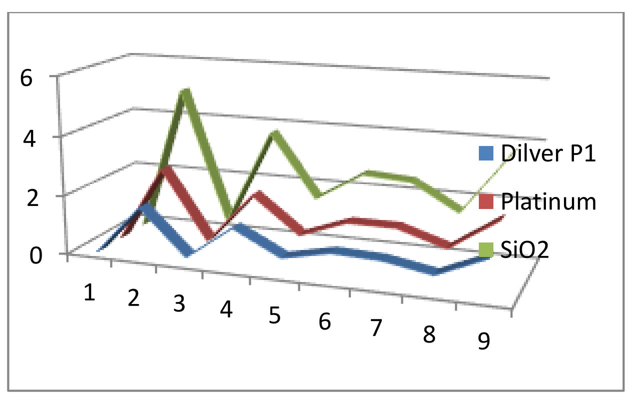
In the analysis I, shape used was spiral and the dimensions are in the range of 80µm. Since the dimensions are higher, so the temperature offered by the hotplate is also higher, on the same time the deformations are also more in these situation but as the dimensions are more, so this deformation may be ignored. At the places, where the boundary conditions are much strict and deformation causes errors or big problems in the results. So, the deformation should be minimum at higher temperatures too.

The deformation readings are in the range of $*10^{-8}$m. The readings are listed in the table, shown below:

Table2. Deformation Comparison in spiral shape in the range 80µm

S. NO.	Position ($*10^{-5}$m)	Dilver P1 ($*10^{-8}$m)	Platinum ($*10^{-8}$m)	SiO_2 ($*10^{-8}$m)
1	0	0	0	0
2	1	1.70	2.60	5.00
3	2	0.19	0.25	0.50
4	3	1.35	2.00	3.75
5	4	0.55	0.80	1.60
6	5	0.90	1.40	2.60
7	6	0.85	1.40	2.50
8	7	0.58	0.90	1.60
9	8	1.30	2.00	3.75

For this table the corresponding graph is also shown below



Deformation Comparison in spiral shape in the range 80µm

As it is seen from the graph that the deformations are maximum in SiO_2 and least deformed material is Dilver P1. Platinum having deformations in between of SiO_2 and Dilver P1.

Analysis of simulation II

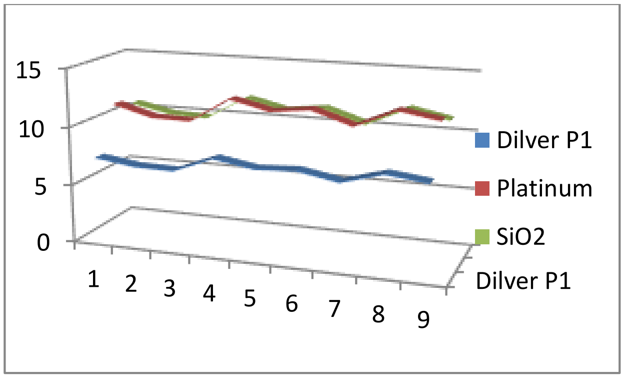
In the Analysis II, we have changed the shape of the design or geometry with the similar dimensions which lies in the range of 60µm.Again all the three material's deformations are taken into tabulated form and compared. The deformations in closed oval shape are:

Table 3. Deformation Comparison in closed oval shape in the range 60µm

S. NO.	Position ($*10^{-5}$m)	Dilver P1 ($*10^{-9}$m)	Platinum ($*10^{-8}$m)	SiO_2 ($*10^{-8}$m)
1	0	7.30	1.12	1.06
2	0.2	6.85	1.03	0.99
3	0.4	6.80	1.025	0.98
4	0.6	8.15	1.24	1.18
5	0.8	7.6	1.16	1.10
6	1.0	7.8	1.20	1.14
7	1.2	7.19	1.09	1.03
8	1.4	8.19	1.245	1.19
9	1.6	7.80	1.19	1.12

Comparison of different materials in the graph shows that the deformations are still maximum in SiO_2 while least deformed material is Dilver P1. Again, Platinum lies in the range between Dilver P1 and SiO_2.

The graph is shown as:



Deformation Comparison in closed oval shape in the range 60µm.

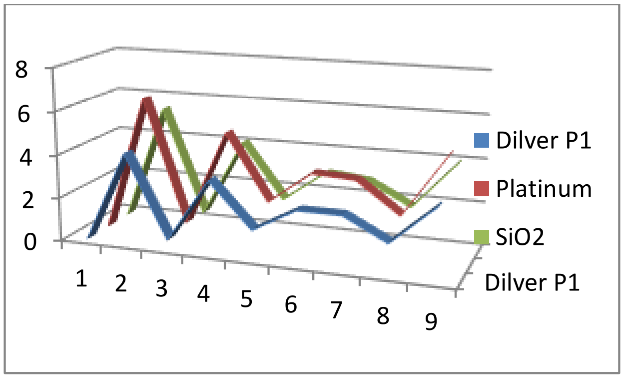
Analysis of simulation III

In the analysis III, the shape of the microheater or the hotplate remain same as spiral, but the dimensions are much lower i.e. about 10% of the previous design. This design shows negligible temperature variations as shown in graphs too and if there are variations in the temperature occur then it would be as low as possible and my analysis shows that.The temperature generation is more as compared to large dimensional geometry, thus the deformations are also present.
The deformation table showing all results together in Analysis III.

Table4. Deformation Comparison in Spiral shape in the range 8µm

S. NO.	Position ($*10^{-5}$m)	Dilver P1 ($*10^{-10}$m)	Platinum ($*10^{-10}$m)	SiO_2 ($*10^{-10}$m)
1	0	0	0	0
2	1	4.20	6.30	5.40
3	2	0.40	0.60	0.50
4	3	3.33	5.00	4.10
5	4	1.30	2.00	1.55
6	5	2.40	3.50	3.00
7	6	2.40	3.40	2.80
8	7	1.40	2.00	1.80
9	8	3.20	4.90	4.00

Corresponding graph with these readings is shown below:



Deformation Comparison in Spiral shape in the range 8µm

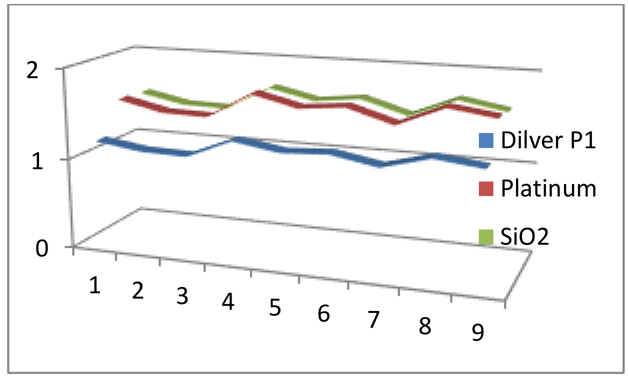
Analysis of Simulation IV

In the analysis IV, we use the same geometry Closed Oval but with reduced dimensions. The dimensions here taken are again 10% of the previous design i.e. in the order of 6µm. The temperature generated with the same conditions as in the spiral shapes is little higher and so in the deformation variations. The readings of the deformations are tabulated below.

Table 5.Deformation Comparison in Closed Oval shape in the range 6µm

S. NO.	Position ($*10^{-5}$m)	Dilver P1 ($*10^{-10}$m)	Platinum ($*10^{-10}$m)	SiO_2 ($*10^{-10}$m)
1	0	1.19	1.55	1.53
2	0.2	1.12	1.44	1.43
3	0.4	1.11	1.43	1.42
4	0.6	1.32	1.72	1.69
5	0.8	1.24	1.60	1.58
6	1.0	1.27	1.65	1.64
7	1.2	1.18	1.50	1.49
8	1.4	1.32	1.72	1.70
9	1.6	1.26	1.65	1.61

With these readings taken into consideration the graph generated as shown:



Deformation Comparison in Closed Oval shape in the range 6µm

As shown in the comparison graph, deformation is least in DilverP1 while it is maximum in SiO_2, again the Platinum lies in the range between these two materials.

CONCLUSION AND FUTURE SCOPE

In MEMS technology the designing of a micro hotplate with different geometries has done for thatdifferent shapes such that Spiral and Closed Oval Shape structures of microhotplate have been chosen which shows different variations in temperature, heat and in thermal deformations under different conditions and sizes. These parameters changes when the material for hotplate changes as Platinum, DilverP1 and SiO_2. As it is a fact that the deformations are usually occur when the temperature of any material increases, the deformations may be tolerable or intolerable. Today's world uses micro and nano technology, so the deformations must be negligible in our design. With the different geometries and different dimensions, various results comes out. Temperature variation is nearly negligible or uniform temperature generated in the smaller dimensions than in the large one. By changing the size, comparatively heat production increases. The deformations shows by all the materials used for the designing but the deformation offered by DilverP1 are quite low as compared to SiO_2 and Platinum. As we all know that Platinum is one of the most expensive metal on the Earth due to its rareness although DilverP1 is also costly but as it an alloy of Nickel and Cobalt which are present in Earth's crust more than that of Platinum, so we can make it as per our requirements, also the deformations are least in DilverP1 and the conductivity, melting point of

DilverP1 are also very good, so, as per this dissertation work DilverP1 is the suitable material for designing and manufacturing of hotplates for Gas Sensors. For the future work one can use other shapes presents or he/she can draw different geometries to increase the temperature of the hotplate and ensuring that the deformations may reduced as more as possible.

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