Oxidized Macro Porous Silicon based Thermal Isolation in the Design of Microheater for MEMS based Gas Sensors

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ABSTRACT

Chemical gas sensors suffers from the drawbacks such as high temperature ((>=300°C) and very high power consumption for sensing inflammable gases like CO, CH_4 etc. In this work a new technique for thermal isolation in MEMS gas sensors is presented by coupling micromachining of bulk silicon and oxidized macro porous silicon (OMPS) layer to reduce the power consumption. Using oxidized macro porous silicon isolation layer over micromachined silicon substrate complete electrotheral and mechanical design of a simple and effective model of micro-hotplate has been done. Heating element used is Dilver P1 which is an alloy of Fe, Ni, Co. The maximum temperature of 150 °C was achieved a power consumption of 95mW.

General Terms

Sensor, MEMS.

Keywords

Oxidised Macro Porous Silicon, Microheater

1. INTRODUCTION

Thermal effects play a quite fundamental role in the operation of many thermal effect Microsystems, such as resistive thin film thermal temperature sensor, thermal flow sensor, IR detector, gas sensor etc, which require reliable thermal isolation between their sensing elements and the sensor substrate. Minimization of thermal losses is also one of the main requirements for the fabrication of these thermal effect Microsystems [1].

Microheaters are generally fabricated either on closed membrane or suspender membrane – consisting of different material with low conductivity such as silicon di-oxide, silicon nitride and polymer films etc. But both the techniques suffers from some demerits like i) growth of thick silicon oxide layer is difficult, ii) limited layer thickness of PECVD grown silicon nitride because of poor thermal stability [2], iii) polymer films are not compatable with CMOS technology, iv) poor mechanical stability of suspender structures.

Porous silicon (PS) is proved to bear a thermal conductivity (TC) of two to three order of less than bulk crystalline silicon owing to small dimensions of the structure for thermal transport and the presence of air which have very low TC [3]. So another approach in the design of microheater can be the use of porous silicon itself as the thermal insulating material. In order to find a compromise between efficient thermal isolation and good mechanical stability of porous silicon (PS) thermal oxidation of PS is used. The main advantages of this approach are: a) Thick PS layer can be obtained easily and rapidly by electrochemical precess, b) PS layer can be readily oxidized and oxidised PS layer of any thickness can be easily achieved, [4] c) OMPS structures have very good mechanical stability, d) PS is compatible with standard CMOS technology.

To achieve isolation through micromachining one has to compromise in fragility on the other hand if the structure is made stable by reduction in micromachining thermal isolation decreases. Keeping all these factors in mind a new and efficient technique of thermal isolation where a trade off is made between the two above mentioned techniques is proposed and successfully tested. In this method oxidized macro porous porous silicon is grown over micromachined silicon such that adequate thermal isolation can be achieved without compromising the fragility of the structure. DilverP1 which is an alloy of Fe, Ni, Co has been proposed as the microheater element for the micromachined metal oxide gas sensor which have high resistivity~ $49e\text{-}^{8}\Omega$m and high yield stress~680MPa and on the other hand low thermal conductivity ~17.5w/m/°C [5].

2. DESCRIPTION OF THE DEVICE

The device geometry is pictorially depicted in figure 1. The starting wafer is a 280 μm thick P-type Si substrate. A thick layer (40 μm) of oxidized macro porous layer is modeled at the top side of the silicon rim by choosing the thermal conductivity of 1 w/m theoretical calculation of which is presented elsewhere [6]. At the top of the OMPS layer a thin tetraethylorthosilicate (TEOS) layer is deposited to planarize the surface. 0.2 μm thick Dilver P1 (259 Ω) constitute the spiral shaped microheater with line width of 70μm. Dilver P1 is an alloy of Ni, Co and Fe is chosen as the heating element because it has fairly good resistivity (~4.9e-7 Ωm) stability and relatively low cost. The lines constituting the micro-heater are spaced by 70 µm. Over the micro-heater another layer of Sio2 of 0.4 µm thick were deposited. The Active area comprising the micro-heater is 0.95mm x 0.95 mm and the wafer surface is 3 x 3 mm^2. Finally the wafer is back etched resulting the membrane.

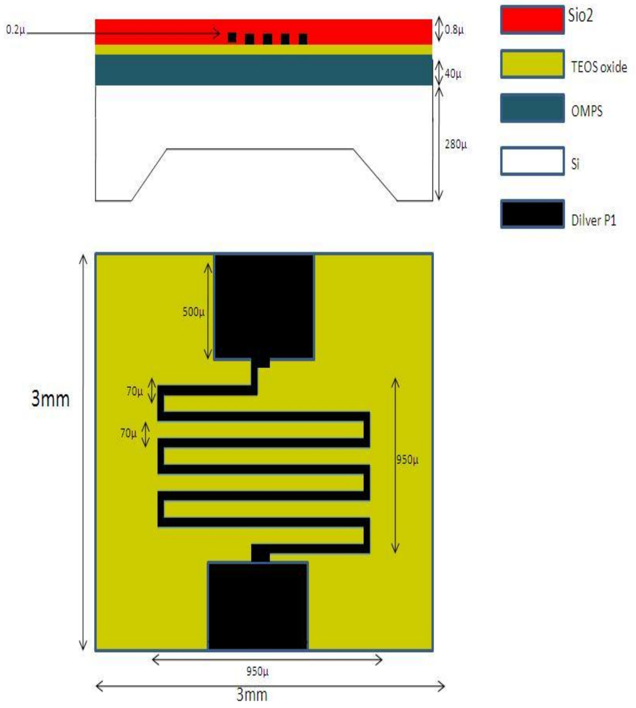

Figure 1: Device geometry

The OMPS layer is obtained by first anodization of P-type <100> Si in an electrochemical cell with HF and Dimethylformamide (DMF) as an electrolyte and then oxidizing it thermally at hign temperature. FESEM image of PS with layer thickness of 40µ is shown in fig 2. The details of the fabrication process of OMPS layer is given in [6].

3. ELECTROTHERMAL ANALYSIS

Thermoelectrical simulations using coupled field 3D model of commercial finite element model (FEM) program ANSYS has been employed to optimize the micro heater resistor geometry in order to achieve a temperature plateau in the active area with minimum power consumption. The composition of heating material is given in table 1 and the material properties of the materials used in the FEM simulation are shown in the table 2.

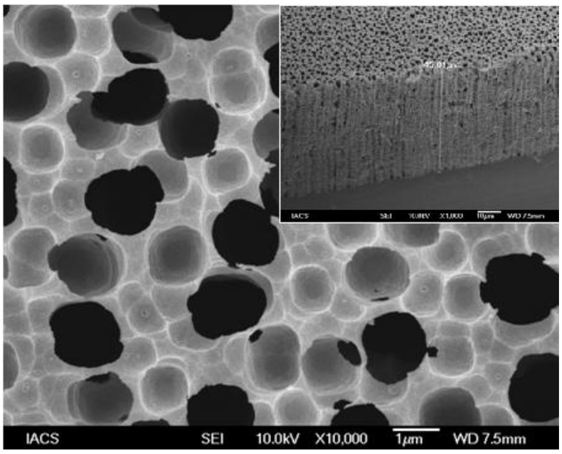

Figure 2: FESEM image of PS Top view & Cross-sectional (inset)

We consider conduction heat losses through the membrane and through air as the primary component. For low temperature range (150-300ºC) radiation losses are not considered because it has no significance contribution to total heat loss in this temperature range. Convection losses are also ignored due to small size of the heated structure. Air has been modeled as two solid blocks of static fluid having thickness 10 mm for each sides of the device.

Table1: Composition of Dilverp1 (Weight %)

Element	**Ni**	**Co**	**Mn**	**Si**	**C**	**Fe**
Typical value	29	17	≤ 0.35	≤ 0.15	≤ 0.02	Bal

Table 2. Material properties used in simulation

Material	**Thermal Conductivity at 300K W/M-K**	**Electrical resistivity Ω-m**
Si	150	2300
SiO$_2$	1.4	(10^12 –10^14)
Air	0.044	--
Dilverp1	17.5	49×10^-8
Porous silicon	1	--

4. RESULTS AND DISCUSSIONS

Fig. 3 shows the simulated temperature distribution along the membrane for an input power of 96 mW and with an input voltage of 5V. The temperature of the frame is assumed to remain at room temperature. Hence the boundary condition is 27˚ C. The power consumption for microheater made of Dilver P1, polysilicon and Platinum are compared as shown in fig.4.

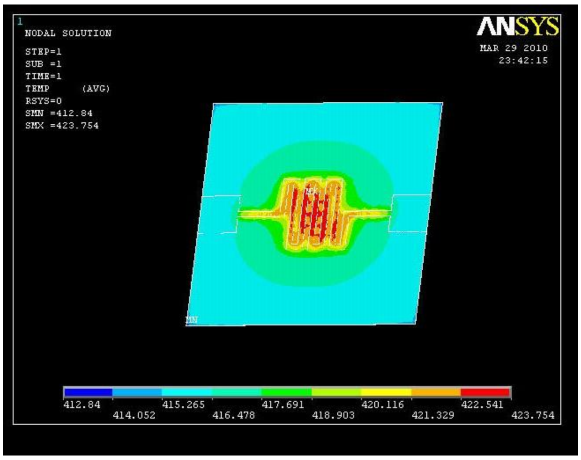

Figure 3: Temperature distribution over the OMPS layer for 96 Mw input power

Also because of low thermal expansion coefficient α in 10^{-6}/K of Dilver P1 (4 – 5.2) compared to platinum (8.8) the thermal deformation of the stacked membrane is supposed to be small and consequently the induced stress will be low.

Figure 5 compares the effectiveness of the composite membrane of silicon and Oxidised Macro PS with that of membrane of bare silicon in terms of power consumption. It is seen that by using oxidized macro porous silicon on micromachined silicon membrane greater temperature can be achieved as compared to the conventional structure with the same input power. Hence using this method at low power a higher temperature can be achieved.

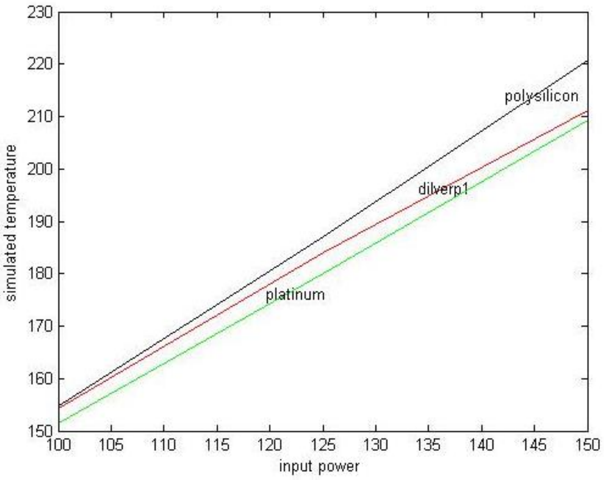

Figure 4: Temperature Vs Power plot for different heater

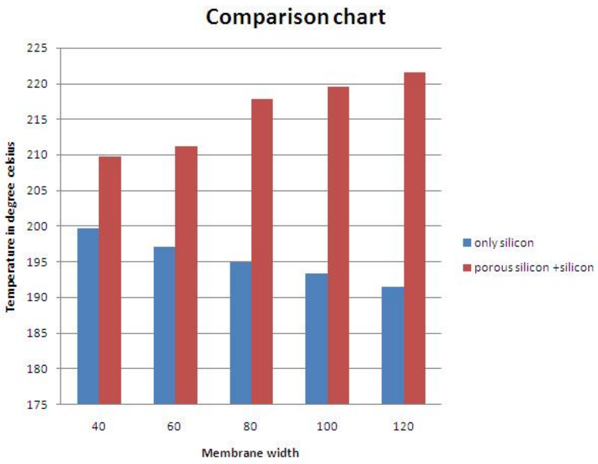

Fig 5: comparative chart of Silicon and OMPS layer as isolation layer

5. CONCLUSION

In this work the design of a micro-heater for a MEMS based gas sensor has been studied in details**.** The investigation methodology and obtained results have provided criteria and design rules for the analysis and optimization of micromachined gas sensor with low risk of break and burn through, low power consumption and good temperature uniformity over the active area. Moreover porous silicon on micromachined membrane has been established as an effective thermal isolating agent. Also the use of low thermal conductivity material DILVER P1 for the heating element results in localized heating and low thermal expansion coefficient of it induces very low stress over the microheater, keeping it well within the yield stress. Power consumption of the device is drastically reduced by mounting the microheater on a thick membrane of oxidized macro porous silicon which can be achieved by electrochemical anodization of crystalline silicon.

6. REFERENCE

[1] C.Tsamis, A.G.Nassiopoulou, A.Tserrepi, Sensors and Actuators B 95 78 (2003).

[2] S. J. Patil, D.S.Bodas, A.S. Ethiraj, R.C. Purandare, G.J.Phatak, S.K. Kulkarni, S.A.Gangal, Vaccum 65,91, 2002.

[3] V.Lysenko, S.Perichon, B.Remaki, D. Barbier, Sensors and Actuators A 99 (2002) 13-24.

[4] P.Y.Y.Kan, T.G.Finstad, Maters sc. and Engg. B 118, (2005) 289-292

[5] B. Mondal, P.K.Basu, B. T. Reddy, P. Bhattacharya, C.Roychoudhury, H.Saha, Proceedings of the international conference on ELECTRO2009, IT-BHU, Varanasi, 22-24 Dec 2009.