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Design and Simulation of Pt-based Microhotplate, and Fabrication of Suspended Dielectric Membrane by Bulk Micromachining

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***Abstract*—The paper presents the design and simulation of double spiral Pt-based microhotplate (MHP) for gas sensing application. A platinum resistor of 52 Ω has been designed and simulated on a 0.3 micron thick SiO_2 suspended membrane of size 40 × 40 μm^2 using ANSYS. The SiO_2 membrane of size 40 × 40 μm^2 and thickness 0.3 micron has been fabricated successfully by bulk micromachining in <100> orientation *P*-type silicon using 25% tetra methyl ammonium hydroxide (TMAH) solution. The simulated temperature and transit time response of microhotplate were obtained as 600.5 °C and 0.2 ms respectively at 4.8 mW power consumption.**

***Index Terms*— MHP, bulk-micromachining and TMAH.**

I. INTRODUCTION

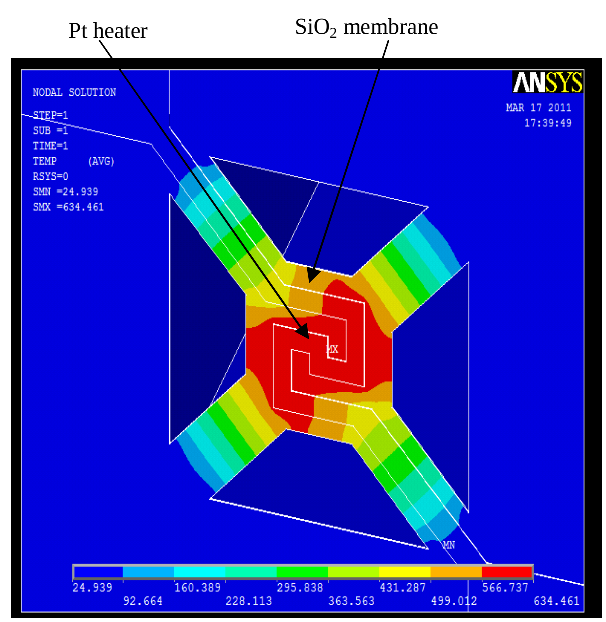
MEMS-based hotplate is used to heat the metal oxide sensing films such as SnO_2, TiO_2, WO_3 and ZnO to the elevated temperature (250°C to 600°C) with small (mW) power consumption. These films require the elevated temperature to detect hazardous gases like carbon monoxide (CO), methane (CH_4) and ozone (O_3) etc [1]. The thin dielectric membranes of SiO_2 or Si_3N_4, act as a platform for gas sensing films. Since silicon is a good heat conductor, therefore it must be removed from underneath the dielectric film to achieve high thermal efficiency [2]. Suspended dielectric membrane of MHP is fabricated either using surface or bulk micromachining of silicon. Polysilicon-based MHP using bulk-micromachining of silicon was presented by M. Y. Afridi, et al. in 2002 [2]. They had fabricated a 2 kΩ polysilicon resistor on a thin SiO_2 membrane of size 100 × 100 μm^2. In this case, the thermal properties of the MHPs include a 1-ms thermal time constant and a 10 °C/mW thermal efficiency. Several researchers have presented the surface micro-machined based MHP [3]. The hotplate membranes fabricated using surface micromachining have a higher mechanical strength but provide poor isolation, whereas bulk micro-machined based membranes have good thermal isolation but poor mechanical strength. In present paper, MHP membrane has been designed and fabricated using bulk micromachining technique.

II. DESIGN OF Pt-BASED MICROHOTPLATE

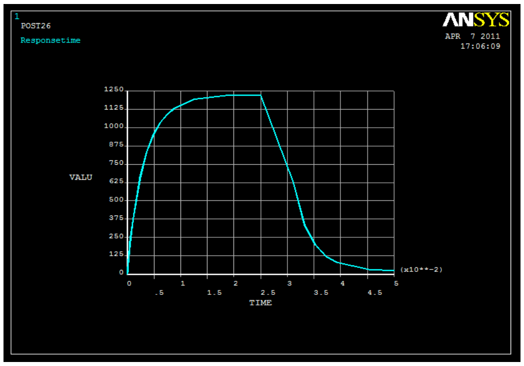
A Pt-based microhotplate has been designed and simulated using ANSYS. The material properties used in the simulation are given in Table 1. The MHP has a 40 × 40 μm^2 SiO_2 suspended membrane (supported by four arms) of thickness 0.3 μm over which a Pt heater of 52 Ω is laid out. The thickness of Pt and gap between two heater strips is 0.2 μm and 5 μm respectively. In simulation, the SOLID69 element has been used, which supports the basic thermoelectric analysis taking the joule heating effect into consideration. SOLID69 has 3-D thermal and electrical conduction capability. The typical ANSYS plots of temperature distribution at 500 mV is shown in Fig.1(a). The temperature of Si substrate surrounding the hotplate was fixed at 25 °C as the boundary condition. It is seen from this figure that a temperature of 566.7- 634.4 °C was achieved at center of the membrane. Fig 1(b) shows the transient response of MHP.

TABLE 1. Properties used in simulation

Material Properties (in MKS)	Si	SiO_2	Pt
Thermal Conductivity (W/m/K)	157	1.4	72
Thermal Expansion (/K)	2.33×10^{-6}	2.33×10^{-6}	8.9×10^{-6}
Resistivity (ohm-m)	1.0×10^{-1}	5.05×10^{13}	0.5×10^{-6}
Specific Heat (J/kg/K)	0.7×10^{3}	710	133
Density (kg/m^3)	2.33×10^{3}	2200	21400



(a)



(b)

FIG. 1. (a) Temperature distribution of MHP at 500 mV, (b) Transient time response of MHP.

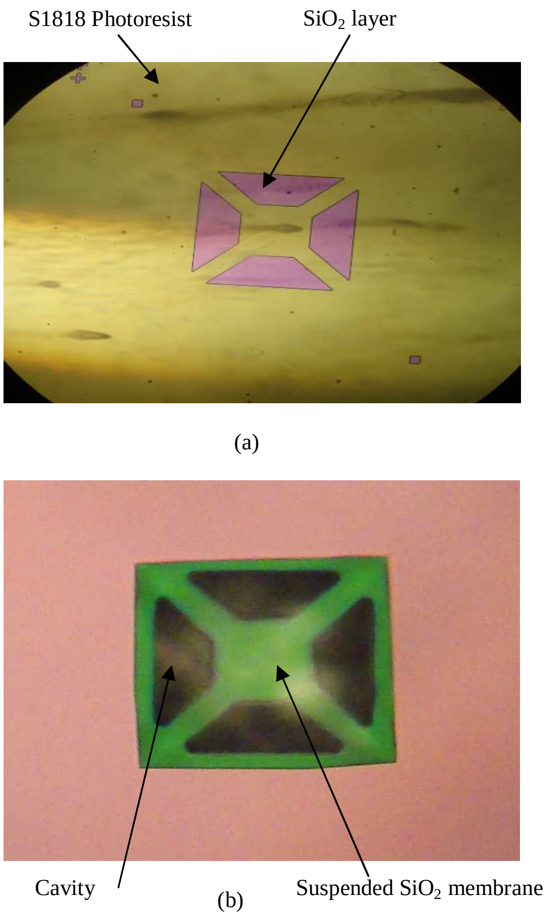


FIG. 2. (a) Structure after photolithography, (b) Structure of fabricated membrane after bulk micromachining.

III. EXPERIMENTAL DETAILS

4" *P*-type silicon wafer of resistivity 10-20 Ω-cm has been taken for fabrication of SiO_2 membrane. Thermal oxidation was done in a sequence of dry-wet-dry cycle at 1000 °C for 1 hour 30 min to get a 0.3-μm thick SiO_2 layer. Fig. 2(a) shows the structure after photolithography (Mask#1) using S1818 positive photoresist. After photolithography, thermal oxide from cavity area was etched using buffered hydrofluoric acid (BHF). Bulk micromachining of silicon was performed on this wafer using 25% tetra methyl ammonium hydroxide solution. The dielectric layer, SiO_2, served as etching mask materials. The experiment was carried out in a glass vessel with rotating Teflon-made boat at 4 rpm. Temperature of TMAH solution was kept constant at 65 °C by means of a temperature-controlled hotplate. The etching time was 3 hours and 15 minutes to form the suspended structure.

IV. RESULTS AND DISCUSSION

It is clear from Fig. 1(a) that the maximum mean temperature at center of MHP is obtained as 600.5 °C at 500 mV. The transient response of MHP is 0.2 ms (Fig. 1b). The comparison of different types of MHPs and required power consumption is given Table 2. Present work shows the low power consumption and fast response time of MHP. Fig. 2(b) shows the fabrication of suspended SiO_2 membrane of size 40 × 40 μm^2 using bulk micromachining of silicon in TMAH solution for MHP application. Cavity depth was measured by Dektak 6M surface profiler, and found to be 35.5μm to form the suspended structure.

V. CONCLUSIONS

Double-spiral Pt based microhotplate has been designed and simulated using ANSYS. It was concluded that double spiral shape heater design on SiO_2 membrane of size 40 × 40 μm^2 has the higher temperature, good uniformity and fast response time. The SiO_2 membrane of size 40 × 40 μm^2 has been successfully fabricated using bulk micromachining for MHP application. Future work will involve the complete fabrication of Pt-based MHP and deposition of sensing film for gas sensing application.

TABLE 2. Comparison of different types of MHP

Membrane size(μm^2)	Temper-ature(°C)	Power (mW)	References
85×75	350	61	[4]
190×190	300	23	[3]
100×100	550	50	[5]
210×70	600	35	[6]
40×40	600	4.8	Present work

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