FEM Simulation of Micro-Hotplate for Gas Sensing Applications

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Abstract

Semiconductor gas sensors normally require high power consumption because of their elevated operating temperature (300-600°C). We can reduce the power consumption by employing the microhotplate (MHP) structure because the heat is confined in a small area with minimal thermal losses. MHP is used to produce the elevated temperature for gas sensing films. They have the advantage of being low weight, small dimension, low power consumption and very small response time. Considering the thermal resistant and sensitive characteristics of metal platinum (Pt) as well as heat and electricity insulating characteristics of SiO_2, Si_3N_4 and combination of both, a kind of the Si-substrated MHP gas sensor was designed. The Pt resistor was used as heater and SiO_2 and Si_3N_4 were used as thermal and electrical insulation respectively. The paper presents the design and simulation of Pt based MHP, which requires 31.3 mW-70.5 mW power to create the temperature 218°C-752.4°C for gas sensing applications. The simulation was carried out using ANSYS MEMCAD tool.

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-monoxide (CO), methane (CH_4) and ozone (O_3). Commonly used chemically sensitive materials for these target gases are wide-band gap semi conducting oxides such as tin oxide, tungsten oxide or indium oxide, which are operated at elevated temperatures of 200–400 °C [1–3]. At those high temperatures, these oxides show considerable resistance changes upon exposure to a multitude of inorganic gases and volatile organics. The most prominent example is tin oxide (SnO_2), which shows large electrical resistance changes upon exposure to the above-mentioned gases at operating temperatures between 250 °C–350 °C and has been engineered to provide sufficient long-term stability. We have designed the Pt based MHP [4-5] taking the bulk micromachining process into consideration. The use of Pt is preferred for MHP fabrication because it is not attacked by the etchant during bulk micromachining, thereby simplifying the process. Pt MHPs offer the advantages of reliability and reproducibility. Besides gas sensing applications, they are also used in microfluidics, infrared emission and thermal flow sensing studies.

DESIGN AND SIMULATION

We have designed Pt-based MHP as shown in Fig.1 and Fig.2. The dimension of the MHP membrane is $220\times220\mu m^2$ with thickness 1.0 µm over which a Pt heater was laid out. The Pt heater is 20 µm wide, 0.3 µm thick and 1020 µm in length, thereby having a resistance of 127.5 ohm. The gap between the heating elements is 20 µm. The FEM simulation of MHP has been carried out using ANSYS 10.0. In the present simulation work, the properties used [6] are given in Table1. The design consists of a square opening in back side of the Si substrate to allow the bulk micromachining of Si to form the suspended structure.

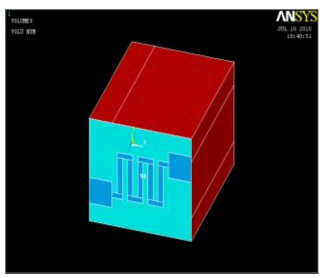


Fig 1: Front view of the model

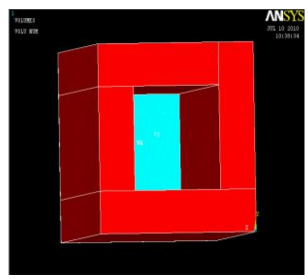


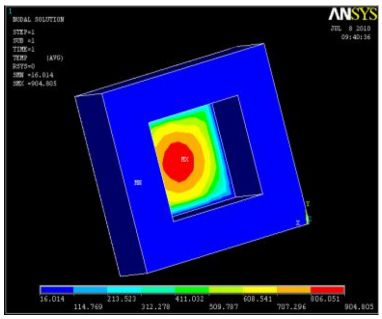
Fig 2: Back view of the model

Table1

Material	Thermal conductivity W/mK	Density Kg/m^3	Specific heat J/Kg C	Resistivity Ohm-m
SiO_2	1.4	2200	1000	1e14
Si_3N_4	3.2	2900	170	1e14
Si	150	2330	700	0.1
Pt	72	21450	133	0.75e-6
Air	0.0257	1.205	1000	1e9

RESULTS AND DISCUSSION:

The simulated temperature distribution of different membranes at 3V is shown in Fig. 3. The transient time responses of different MHP membranes are shown in Fig.4. The transient response of Si_3N_4 based MHP is smaller than SiO_2 and combination of both. The summary of the result is shown in Fig.5. It is clear that the temperature distribution of SiO_2 film is higher than the temperature of Si_3N_4 and combination of both films. It is because that the thermal diffusivity of SiO_2 is smaller than the thermal diffusivity of Si_3N_4 and combination of SiO_2 and Si_3N_4 films.



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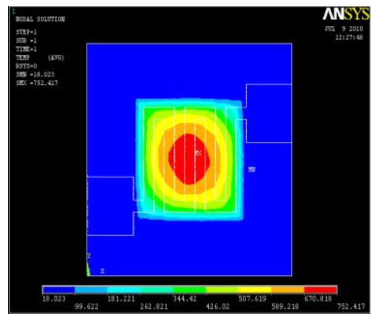

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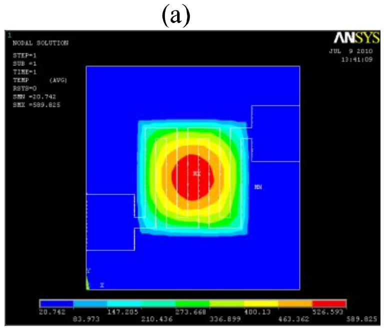

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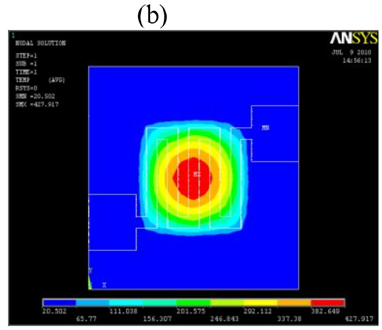
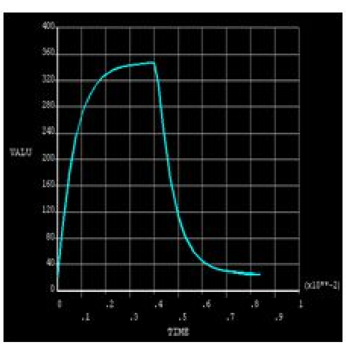


(d)

Fig 3: Temperature distribution of different hotplate membranes at 3V: (a) SiO_2 without air filled cavity. (b) SiO_2 with air filled cavity (c) Si_3N_4 with air filled cavity (d) Combination of both with air filled cavity.



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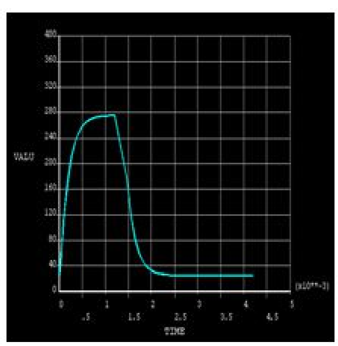

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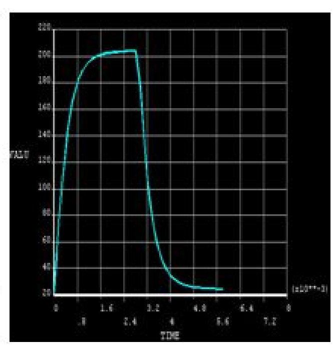

(c)

Fig.4: Transient time response of different membranes based MHP at 2 Volt. (a) SiO_2 (b) Si_3N_4 (c) Combination of both SiO_2 and Si_3N_4.

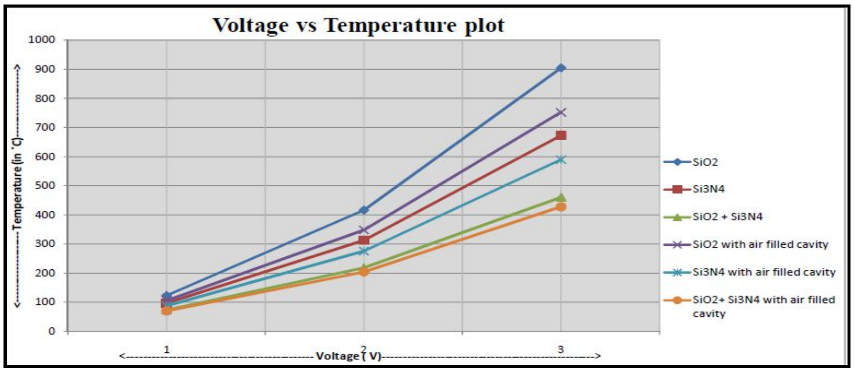

Fig. 5: Temperature variation of different membranes with applied voltage.

CONCLUSION:

Pt based MHP has been designed and simulated using ANSYS. The result obtained from the simulation work shows that SiO_2 film can make the gas sensitive film at higher temperature than the Si_3N_4 and combination of both the films at the same power consumption. Also, SiO_2 film is made as thermal and electricity insulation film between Si and heater and Si_3N_4 film is made as electricity insulation film between heater and interdigitated fingers (for sensing films). It is clear from Fig.4 that the transient time response of Si_3N_4 film is smaller than the SiO_2 film and combination of both the films to get the same temperature. Therefore, this film can be applicable to get the smaller transient time response for MHP. The combination of both the films is applicable to produce better mechanical strength to the suspended membrane.

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