Stress Distribution of Suspended Membrane for Micro-hotplate Applications

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Abstract

MEMS based gas sensor that work at high temperatures, namely 600 °C or more are necessary for some specific applications but at this temperature, more stress is introduce in the dielectric suspended membrane of the microhotplate (MHP) due to thermal effects. In this paper we report the FEM simulation of stress distribution of dielectric membrane having different thickness in temperature range 200 to 600 °C. The simulation work was carried out using ANSYS 10.0 tool.

INTRODUCTION

Microhotplate conductance-type gas sensors have been under development for at least two decades. Low-power consumption, and low thermal time constant (around 1 ms) make these devices suitable for low-cost gas-sensor applications [1,2,3,4]. For most of the applications sensor device must have very low thermal conductivity to avoid the heat cross talk with other devices. One way to minimize the thermal conductivity is by proper design of geometry of dielectric membrane. In this paper we have designed a combination of SiO_2 and Si_3N_4 membrane suspended by four bridge of the same material. If the gas sensor is operated at higher temperature (more than 500 °C) then stress is introduce in the dielectric membrane due to thermal effect [5,6,7,8,9]. In this paper we have studied the variation of stress and deflection of the dielectric membrane at higher temperature. The thermo-mechanical simulations were performed to minimize edge effects, to avoid stress singularities, to optimize heater power consumption and to achieve a homogeneous temperature distribution.

DESIGN AND FEM SIMULATION

We have design 100×100 μm^2 hotplate membrane, which is suspended by four arms by same material on a Si substrate, shown in Fig.1 [10,11,12]. The design consists of four trapezoidal openings to allow post-process etching of exposed silicon forming a 50 μm deep cavity pit so that microhotplate can be suspended in the air. The suspended structure is made of SiO_2 (bottom side) and Si_3N_4 (top side) thin films.

We have taken two different thickness of membrane 0.3 μm and 0.6 μm during simulation. The properties used in simulation work are given in Table 1.

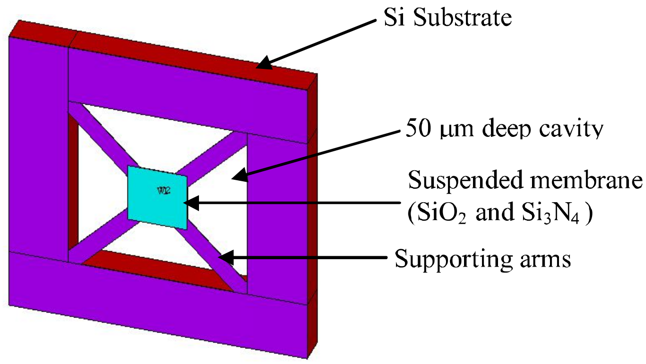


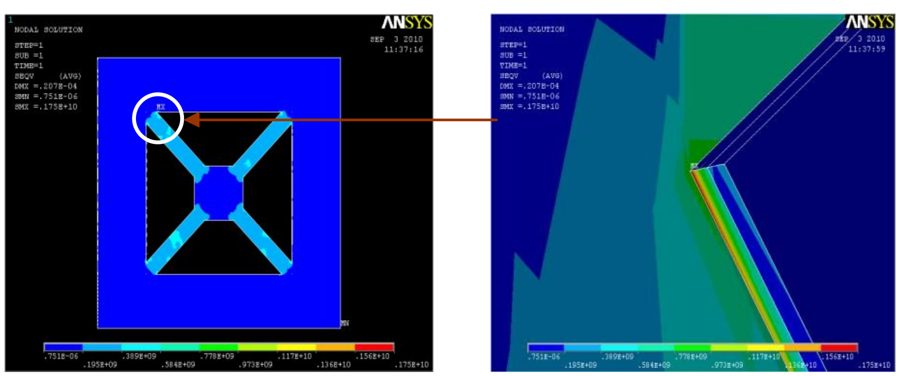
Fig.1 3-D view of the model

Table 1

Material	Si	SiO_2	Si_3N_4
Young's modulus (MPa)	1.5e+5	0.6e+5	2.9e+5
Poisson's Ratio	0.17	0.2	0.27
Density (Kg/m^3)	2330	2200	2900
Thermal conductivity(W/mK)	150	1.4	3.2
Specific Heat (J/KgK)	700	1000	170

RESULTS AND DISCUSSION:

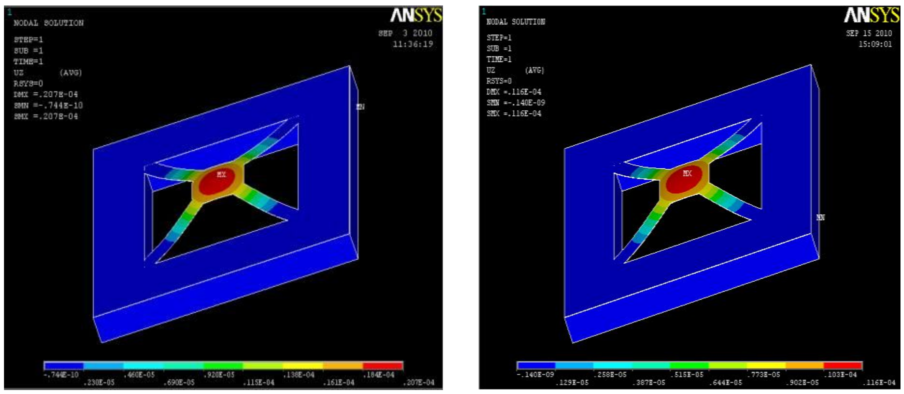
The simulated stress distribution of 0.3 μm (0.15 μm SiO_2 and 0.15 μm Si_3N_4) membrane at 600 ^{o}C is shown in Fig.2.



(a) (b)

Fig.2 Von misses stress distribution at 600^{o}C (a) complete view (b) enlarged view

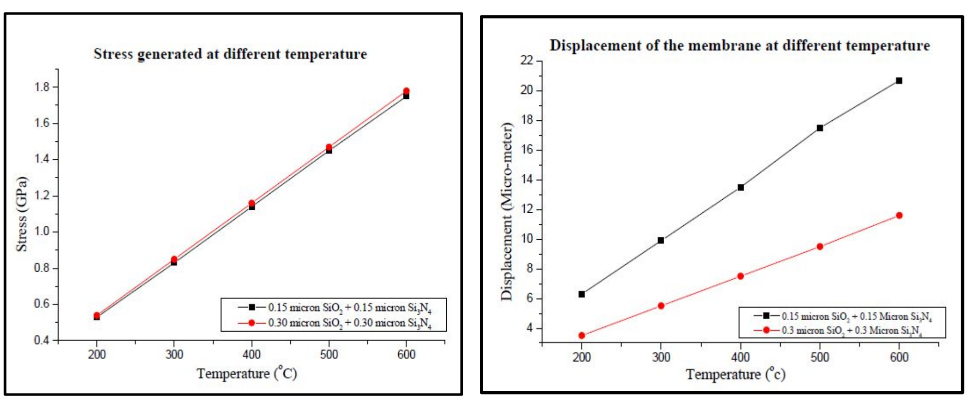
In the mechanical stress distributions figure, the maximums stress is observed at the junction between membrane arm and Si substrate (edge effect). The vertical displacement of the 0.3 μm and 0.6 μm thick membrane at 600 °C are shown in Fig.3



(a) (b)

Fig.3 FEM simulation of suspended membrane showing vertical displacement at 600 °C for (a) 0.3 μm (b) 0.6 μm thick membrane.

(a) and (b) respectively. The red color in Fig.3 shows the maximum vertical displacements, which are more than 10 μm and 20 μm in case of 0.3 μm and 0.6 μm thick suspended membrane respectively at 600 °C. The variation of mechanical stress and vertical displacement of suspended membrane (of different thickness) with temperature are shows in Fig.4.



(a) (b)

Fig.4 (a) Linear variation of stress generated in the membrane with increasing temperature (b) Linear variation of vertical displacement of membrane with temperature.

CONCLUSION:

Mechanical stress and vertical displacement analysis of suspended membrane (of different thickness) with variation of temperature has been done using ANSYS 10.0 Tool. The results obtained from the simulation work show that at higher temperature the stress generated in 0.6 μm thick suspended membrane is slightly higher in comparison to 0.3 μm thick membrane. But in case of displacement due to the thermal effect, it is approximately double in 0.3 μm membrane in comparison to 0.6 μm membrane. Therefore, higher thickness of membrane has the advantage of less displacement at high temperature namely 600 °C or more.

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