MP10
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A MEM Actuator based on a Membrane, Controlled by an External Heath Source

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Abstract- **The MEM actuator is controlled by an external heat source, such as the heat gradients present in some electronic systems. As the substrate bottom is heated, the thermal expansion rises the membrane, which can be used as an actuator. The analysis was realized by means of mechanical and thermal properties of materials. We also present the effect of the physical dimensions of the walls and, thickness and the length of the membrane. The process was simulated in COMSOL Multiphysics. The membrane central deflection results, using different membrane materials, had been shown the use of Cr membrane as the best choice.**

I. INTRODUCTION

Our interest in the development of MEM actuators only controlled by external heat sources is due to the thermal gradient presence in several electronic systems. This clean energy sources sometimes reaches high density values, but it has not been well-spent. The most of MEMS thermal actuators need a current flow to heat the MEM device, by means of the Joule effect, and produce the corresponding thermal expansion. These expansions depend on electrical, thermal and mechanical properties of materials.

In this work, the MEM actuator is only controlled by an external heat source, and then, we only consider the effect of thermal and mechanical properties of the used materials. As the substrate bottom wall heats and conducts heat, the thermal expansion rises the membrane which can be used as an actuator.

II. MODELING

A) Heat transfer

Heat transfer is defined as the movement of energy due to a temperature difference [1]. In the substrate, this movement is realized basically by conduction, because the heat transfer is realized by diffusion in a stationary medium produced by a temperature gradient.

Generally, in the case of the gas filled cavity, the total flux is the sum of convection and radiation flux. In our case, the convective heat-transfer mode is natural convection. The relatively low temperature required for the operation of this device and the small cavity area makes the radiation effect negligible. Additionally, the small area of the cavity, compared with the total device area, and consequently the small amount of the enclosed gas also makes convection mechanism negligible. Then, we can conclude that the dominant heat-transfer mode is diffusion.

B) Central deflection calculation

For the case of micrometric beam [2], the central deflection *d* of the silicon bridge is approximated by:

$$d = \frac{2}{\pi} L \sqrt{\alpha\left(\Delta T - \Delta T_{crit}\right)} \qquad (1)$$

where L is the beam length, α is the coefficient of thermal expansion, and ΔT is the temperature difference between the membrane and the surrounding silicon frame.

The critical-buckling strain is given by:

$$\varepsilon_{crit} = \alpha \Delta T_{crit} \qquad (2)$$

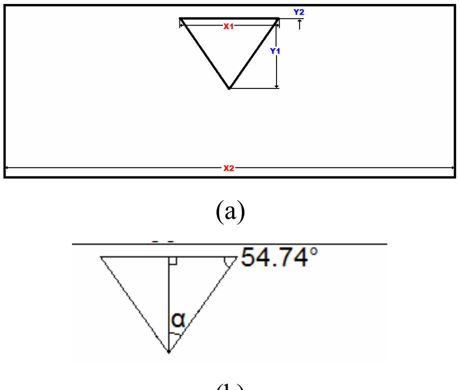
Then $\Delta T_{crit} = \frac{\pi^2 t^2}{3\alpha L^2}$ where t is the membrane thickness.

On the base of this model we propouse different cavity geometries of the actuator, considering their performance as function of their central deflection.

II. DEVICE DESIGN

Membrana sizes determination

We probed with different geometry cavity shapes in order to obtain an enough membrane warping for the use of the device as an actuator. The analyzed geometries were triangular and trapezoidals, but the differences in deflection were minimals, then, we proposed to use a triangular shape due to the smaller covered area (see figure 1). Y_1 is determined by the silicon etching, using KOH on the upper wall. The lower angle α, is obtained from:



(a)

(b)

Fig. 1. Elements (a) and angles determination of the membrane.

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$$\alpha = 180^{o} - 54.74^{o} - 90^{o} \Rightarrow \alpha = 35.36^{o} \quad (4)$$

The membrane depth is calculated using:

$$\tan\alpha = \frac{X_1/2}{Y_1} \Rightarrow Y_1 = \frac{X_1}{2\tan\alpha} \quad (5)$$

II. CENTRAL DEFLECTION OF DIFFERENT CAVITY SHAPES AND MATERIALS

For simulation, the substrate was constrained in order to leave only the upper walls free, and a gradient of temperature from 273 up to 400°K was applied at the base. The left and right walls as heat under flux conditions while the upper walls were considered with a fixed temperature (273.15°K). As a result we have an elongation of the membrane, as well as the whole material (figure 2). In figures 2-5, the color palette shows the complete temperature range, going from the heatest (in red) to the lowest (in blue) values. The arrange of triangular cavities (figure 3) does not show the effects of being compressed by their own walls. The device with triangular shape cavity has a silicon substrate length of 1 mm, and a width of 350 µm. The membrane thickness is of 20 µm, with a length of 220 µm. Both, the Substrate waffer and the membrane are made of Silicon, while the small cavity is filled with Hydrogen.

With substrate and membrane made with silicon, we obtain the following results: if the membrane length meaning more than the 70% of the actual size of the substrate,the membrane starts to crumble. With smaller walls than the presented in figure 2, the expansion is reduced, and consequently impractical. If the walls are much bigger, only a slight expansion is produced. The membrane thickness is also very important. In all the previous simulations, the membrane thickness was of 20 µm, when picking up a thinner membrane, such as 5µm, the membrane starts collapsing.

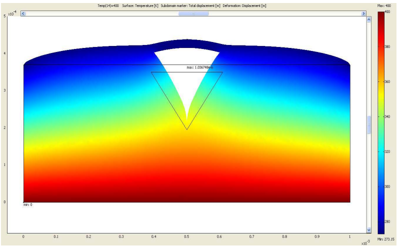

Fig. 2. Triangle shaped cavity (with a maximum deflection of 1.04 µm).

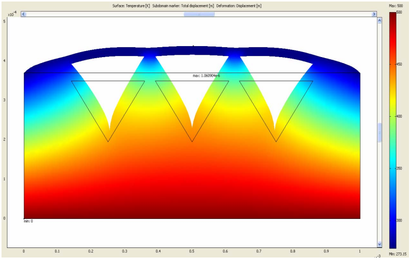

Fig. 3. Arrange of triangular cavities (with a maximum deflection of 1.04 µm)

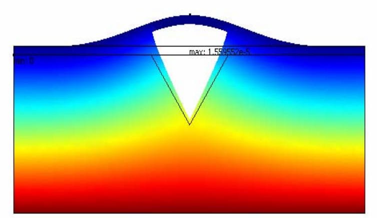

Fig. 4. Cavity with a Cr Membrane (with a maximum deflection of 15.5 µm)

Using other membrane materials, in accordance to their mechanical parameters compatibility with the susbtrate material, the longer deflection was obtained with Cr, as can bee see in figure 4, instead of using Silicon (figure 2) or Polysilicon (Figure 5).

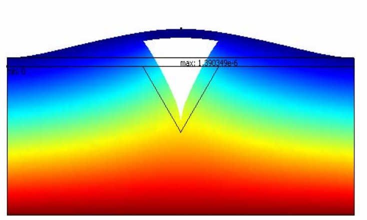

Fig. 5. Cavity with a Polysilicon membrane (with a maximum deflection of 1.4 µm)

III. CONCLUSIONS

From the obtained results of several geometries, we prefer the use of triangular cavity shapes, not only due to its elongation, but also for the amount of the hydrogen involved. With other geometries, mostly rectangular ones, the membrane showed a strange behavior; instead of moving upwards it squeezed on itself because of the contraction of the inner side walls, this phenomenon is not seen with the triangular shaped cavities, although the inner volume of the cavity is in fact contracting. We also analyzed the effect of the elements size of the device in order to obtain the most fiable and compact device, which could be used as a thermal valve if we also add a superior layer.

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