Platform Isolation Using Out-of-Plane Complaint Mechanisms

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Abstract: This paper reports the structural solid mechanic simulation of a MEMS out-of-plane platform that provides thermal and electrical isolation for a device built on it. When assemble, the platform lifted for approximately 400 µm above the substrate level. A mechanical stress analysis is then presented in order to evaluate the feasibility of building it using commonly used materials in MEMS. Our analysis showed that polymeric materials such as polyimide and SU8 may undergo a localized plastic deformation but are not likely to fail upon assembly. Polysilicon on the contrary, showed high failure probability.

Keywords: Out-of-plane, MEMS, Polyimide, FEM Analysis, Thermal Isolation, Electric Isolation.

1. Introduction

In the Micro-Electro-Mechanical Systems (MEMS) field there are several applications that may benefit from thermal and electrical isolation from the substrate to operate with greater efficiency and higher sensitivity [1-4], such as antennas [2], gyroscopes, accelerometers[4], flow sensors, micro-heaters [5], among others.

Traditional manufacturing processes of MEMS devices such as surface micromachining are essentially 2.5D. Thin layers of pre-defined thicknesses are deposited on a substrate, and successively patterned and etched. Because of this in-plane construction, the fabrication of elevated structures, isolated from the substrate, is challenging. A viable solution to this manufacturing problem is to build such devices onto in-plane compliant structures that can be mechanically assembled or rotated out-of-plane to form a reliable and stable freestanding structure. Examples of these structures are the Tsang suspension [1,6] and the buckled cantilever plate [7]. In this work, we present the simulation of a MEMS platform that is lifted above the substrate by assembling two opposing out-of-plane Tsang suspensions. A Tsang suspension is a MEMS structure that is composed by two anchors, two springs and a central plate. In comparison to previous work for out-of-plane structures [5, 12, 13], the Tsang suspension does not require a mechanical stop due to its assembly principle [1], [6]. When the plate its in its upright position at 90 degrees, from its original position the connected springs generate a force towards the substrate, creating a self-locking mechanism. The assembly of this structure is done by using a microprobe and could be integrated in a manufacturing process by using a wire bonder tip [6]. There are other approaches to automate the assembly by building external actuators that can make this assembly process thermally [15], electrostatically [12], or with a more complex physics such as centripetal force [17] and non uniform residual stress [18].
Since these structures are compliant mechanisms, their assembly heavily depends in the mechanical properties of the material used [19,20]. Therefore, in order to understand and to design those structures using different materials we have used the FEM using COMSOL Multiphysics solid mechanics module to predict the deformation, stresses and behavior of these out-of-plane platforms.

2. Design

The assembly of two Tsang suspensions forms the out-of-plane isolation platform presented in here. A single Tsang suspension is depicted in Figure 1A, and it is composed by a free-moving plate (L= 350 µm and W=200 µm) that is attached to a set of two anchors through springs (Three loops of springs L_s= 260 µm and W_s= 30 µm). When the plate is assembled to its upright position these springs are responsible for the self-locking mechanism of the plate since their reaction force naturally points towards the substrate causing a reliable assembly.

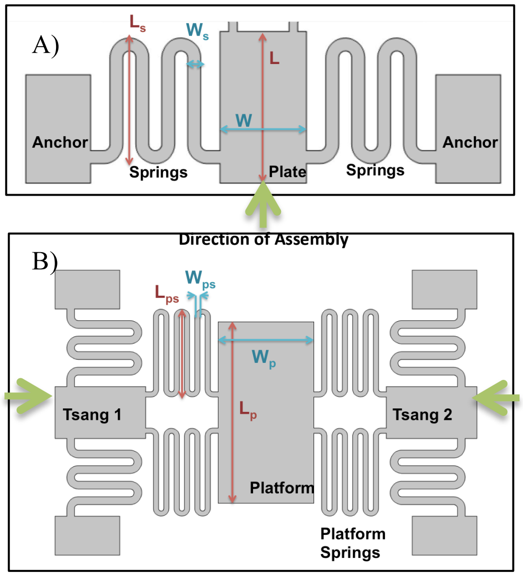

Figure 1. Layouts of the Tsang suspension and isolation platform

By assembling two opposing Tsang suspensions to their upright position a third plate (L_p=700 µm and W_p= 370 µm) connected between them through a set of four plate springs, can be lifted up parallel to the substrate. These plate springs are formed by five loops of beams as shown in Figure 1B (L_{ps}= 320 µm and W_{ps}= 20 µm).

An assembled structure that was fabricated using Polyimide is shown in Figure 2. A device fabricated on this platform will be isolated from the substrate once it has been assembled to its elevated position. If conductor lines are fabricated on top of the springs, the device on the platform can be electrically connected to contact pads on the substrate. This can be useful for several devices like: antennas [2], gyroscopes, accelerometers [4], flow sensors [20], micro-heaters [5], micro-mirrors and switches [22], among others [9-11, 21].

We have used the MEMS module in COMSOL Multiphysics to simulate the structural mechanics of our designs and select the best parameters, for the proposed platform, before manufacturing. The platform will be lifted up to a height of at least the length of the Tsang's central plate. By using COMSOL we can create virtual prototypes to select the correct parameters for the final application.

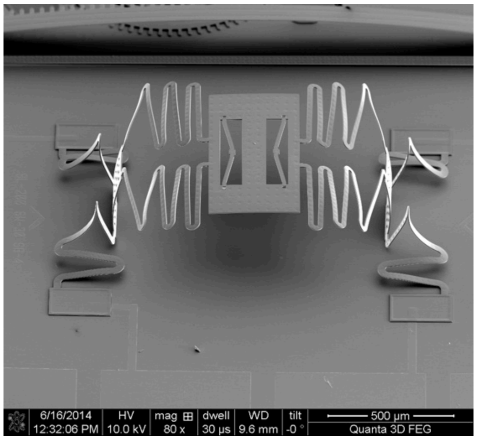

Figure 2. Polyimide Isolation Platform lifted parallel to the substrate by two opposing Tsang suspensions

The dimensions and material properties of the spring are of great importance in the assembly of the suspension. We have used these prototypes and evaluate their behavior using different materials for a particular design. Table 1 summarizes the materials simulated in this work and their respective mechanical properties.

Table 1: Materials used in this simulation work and their thin film mechanical properties.

Material	Young's Modulus (GPa)	Poisson's Ratio	Tensile Strength (MPa)	Ref
Polyimide PI 2611	8.5	0.34	350	PI 2611 Data Sheet
SU-8	2	0.22	73.3	SU8 Data Sheet
Polysilicon	160	0.22	1200	[19]

6. Equations and Simulation

In this work, we have used the Linear Elastic Material model of MEMS structural mechanics module to simulate our platforms.
This model offers different types of options for the elastic properties of the material. The different materials were simulated using isotropic conditions. The model by default uses the elastic solid mechanics equations:

$$\boldsymbol{\varepsilon} = \frac{1}{2}(\nabla\mathbf{u} + \nabla\mathbf{u}^{\mathbf{T}})$$

Where ε is the strain tensor and **u** is the displacement.

To relate the stress tensor to the strain tensor and temperature, this model follows the Hooke's law:

$$\mathbf{S}-\boldsymbol{So}=\mathbf{C}:(\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}_{0}-\boldsymbol{\varepsilon}_{\mathbf{th}})$$

where C is the elasticity tensor and S is the stress tensor. In our simulation the strain due to temperature is not considered.

The elasticity tensor in matrix form for an isotropic material, is defined in this simulation as:

$$\mathbf{C}=$$

$$\frac{\mathbf{E}}{(\mathbf{1}+\boldsymbol{\nu})(\mathbf{1}-\mathbf{2}\boldsymbol{\nu})}\begin{bmatrix} \mathbf{1}-\boldsymbol{\nu} & \boldsymbol{\nu} & \boldsymbol{\nu} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1}-\boldsymbol{\nu} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1}-\boldsymbol{\nu} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \frac{\mathbf{1}-\mathbf{2}\boldsymbol{\nu}}{\mathbf{2}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \frac{\mathbf{1}-\mathbf{2}\boldsymbol{\nu}}{\mathbf{2}} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \frac{\mathbf{1}-\mathbf{2}\boldsymbol{\nu}}{\mathbf{2}} \end{bmatrix}$$

where ν is the Poisson's ratio and E is the Young's modulus.

For initial conditions we have defined as fixed constraint the edges of the four anchors in this model to prevent motion. A prescribed displacement is given to the edges of the plates corresponding to the opposing Tsang's suspension. This displacement causes the assembly the structure in the same way as assembly is done in reality through the probes.

7. Results

From the simulation we collect important information regarding the platform height and the stresses in the spring links. In order to find the upright position of the assembled structure we used a parametric study to evaluate the height of the platform as lateral assembly progresses. The results of this study for one of the models, made in polyimide, are shown in Figure 3.The polyimide platform is lifted in the Z-axis for approximately 404 μm while the height of both Tsang suspension plates is of 370 μm.

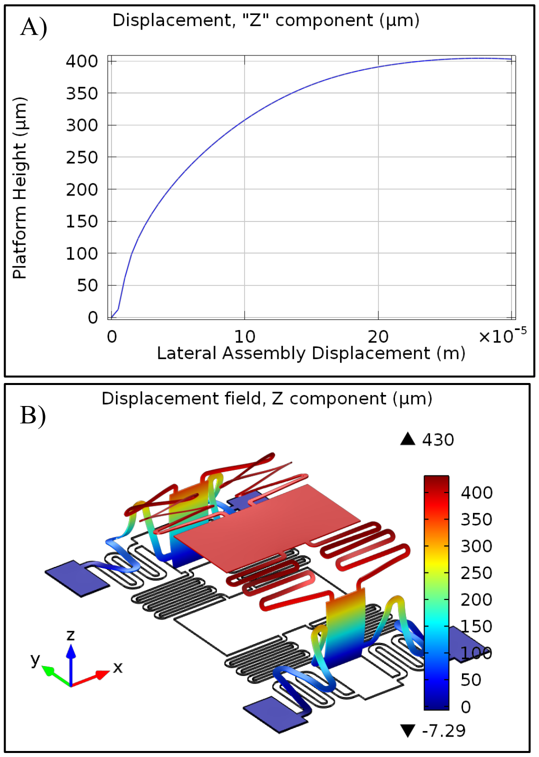

Figure 3. Displacement field in ¨Z¨ for the simulation of a polyimide isolation platform A) Height of the platform's plate as a function of the assembly distance B) Platform assembled in it upright position.

Similarly to the displacement field we can evaluate the Von Misses stress in the assembled structure (Figure 4) and compare that value with the materials´ tensile strength in order to guarantee that the compliant mechanism will not fracture during the assembly process.

Table 2 summarizes the values obtain for displacement and Von Misses stress tests for the three different materials that we have simulated.

Table 2: Summary of Simulation Results. The von Misses stress for the polymeric materials is below their tensile strength.

Material	Final Platform Height (μm)	Von Misses Stress (MPa)	Tensile strength (MPa)
Polyimide PI 2611	405	293	350
SU-8	404	71.8	73.3
Polysilicon	404	5748	1200

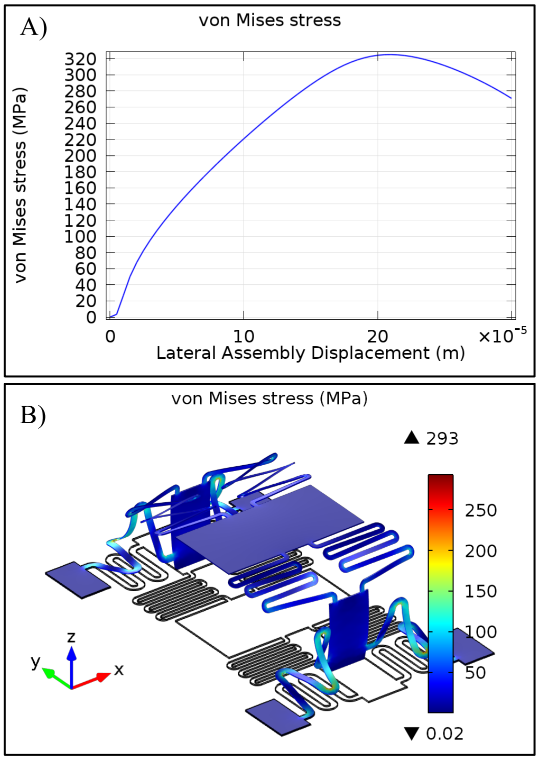

Figure 4. Von Misses Stress in the structure, for the polyimide isolation platform

Since the equivalent Von Misses stress for polyimide PI 2611 and SU-8 is lower than their respective tensile strength, the structures are not likely to fracture under assembly. Plastic deformation due to the assembly stress may occur in some of the stress concentration zones located in the inner loops of the springs, but it will not have a great impact in the assembly process since the stress rapidly drops as it approaches to the outer side. Polysilicon however, showed a much larger von Misses stress as compared to the tensile strength of the material, therefore this structure is likely to fail during assembly.

8. Conclusions

COMSOL Multiphysics is of great aid in the design of MEMS devices. Because of their size, the ability to directly measure mechanical properties on prototypes is challenging, so finite element analysis is a common solution. In this paper we have used COMSOL to simulate the assembly of an out-of-plane compliant structure, whose robustness and stability heavily depends on the dimensions and materials' mechanical properties of the springs.

By building a FEM model we have been able to predict and select the structures that will not fail in the assembly process. We have used this information to build platforms using polyimide as structural material and thanks to the FEM simulation; we have avoided the waste of space, money and resources.

Polysilicon Structures are likely to fail with under this particular design but one can use this simulation to evaluate a larger number of loops or different dimensions that may be used to build this structures using polysilicon as structural material.

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