Design of MEMS Based Elecrostatically Controlled Micromirror Using COMSOL Multiphysics

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Abstract- In this paper, we have addressed the Design and simulation results of an electrostatically controlled micro mirror using COMSOL multiphysics Software. The structural mechanical properties of the actuation mechanism of a square shape micro-mirror with the lift-off of the structure used four springs simulating a prestressed cantilever beam. There are few base materials were introduced like Alumina, Aluminum 3003 H18, Copper and Aluminum. To make the leg or cantilever more efficient the Steel AISI 4340 was introduced together with base materials to further reduce the lift-off stress. From the analysis, we concluded that the best material combination is Aluminum 3003-H18 + Steel AISI 4340 which have less stress level and desired lift-off stress. Another important parameter have to measure in this structure is generally what prestress level is necessary to result in a desired lift-off.

Keywords: Al, COMSOL, DMD, IC, MEMS, Micromirror, 3D

INTRODUCTION

Micro Electromechanical systems show an extra-ordinary technology that transforms the whole industries and drive the next technological revolution. These devices can replace bulky actuators and sensors with micron-scale equivalent that can be produced in large quantities by fabrication processes used in integrated circuits (IC) photolithography. This reduces cost, size, weight and power consumption while increasing performance, production volume and functionality by orders of magnitude.

For example, one well known MEMS device is the accelerometer i.e now being manufactured using MEMS which have low cost, small size, and more reliability. Furthermore, it is clear that current MEMS products are simply precursors to greater and more pervasive applications to come, including genetic and disease testing, guidance and navigation systems, power generation, RF devices, especially for cell phone technology, weapon systems, biological and chemical agent detection, and data storage [3,7].

Recently, MEMS based micro mirrors have been applied in optical switch and displays [5, 9]. They are also used in a wide range of applications such as interferometric systems, confocal microscopes [8], wavelength-selective switches, variable optical attenuators, and biomedical image [6]. MEMS-based micromirrors have higher operating speed and lower mass as compared to traditional fabricated technology, and potential for lower cost through MEMS fabrication process. A successful example of MEMS-based micromirrors is Texas Instrument's digital micromirror device (DMD) [10]. In most applications, electrostatic actuators are preferred because of their low power consumptions.

The research was referring to Digital MicroMirror Device (DMD), an optical semiconductor which is the core of DLP projection technology invented by Dr. Larry Hanbeck and Dr. William E "Ed Nelson" of Texas Instrument in 1987 which used Aluminium as mirror materials [10]. This paper is organized as follows. First, we describe the Micromirror design and materials used. Next, we present the simution details and results. Finally, we show the

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simulation figures and conclusion. In this paper, we have reported the design and modeling of Prestressed micro mirror by COMSOL Multiphysics version 3.5a [11].

MICROMIRROR DESIGN

This micromirror model uses 3D structural analysis. The micromirror has a stiff, flat, reflective center portion which is supported by four prestressed plated cantilever springs as shown in figure 1. To keep the mesh size small and the solution time reasonable, it studies the plated structure with two layers. It assumes that in the top and bottom layers, the plating process creates equal and opposite initial stresses. So it is easy to set the model.

The purpose of the model is to elaborate the use of pre-stresses in plated metal layers in order to create a desired lift-off of a MEMS structure. The model shows the use of the Initial Stresses feature in the Structural Mechanics Module.

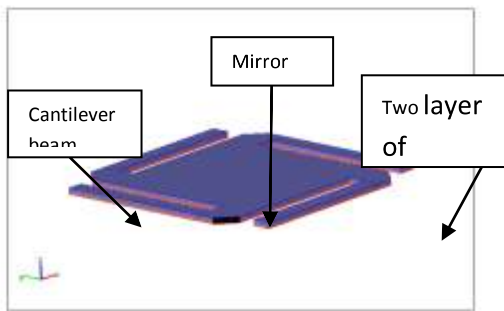

Figure 1.Model Geometry

Note in particular that a 3D structure with thin layers such as the one in this model leads to a very large unstructured tetrahedral mesh. To avoid this case, we first generates a 2D quadrilateral mesh by mesh mapping and then extrudes it into 3D to produce a mesh with hexahedral elements as shown in figure 2 and 3. This way we can have the mesh generator create structured elements with a high aspect ratioNote in particular that a 3D structure with thin layers such as the one in this model leads to a very large unstructured tetrahedral mesh. To avoid this case, we first generates a 2D quadrilateral mesh by mesh mapping and then extrudes it into 3D to produce a mesh with hexahedral elements as shown in figure 2 and 3. This way we can have the mesh generator create structured elements with a high aspect ratio.

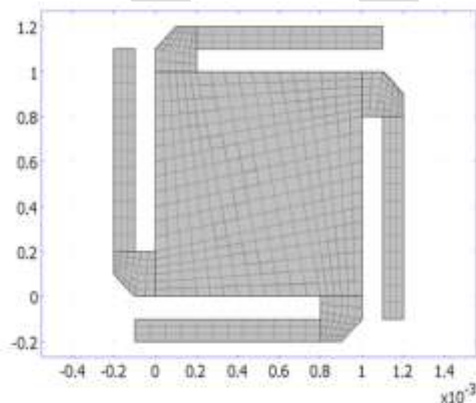

Figure 2.The geometry with the 2D mapped mesh.

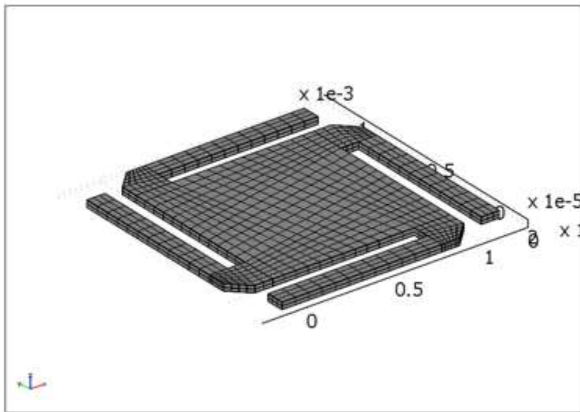

Figure 3.The geometry after extruding the mesh into 3D.

The table 1 specified the materials used for designating of this device and properties of these materials such as Young's modulus, Poisson ratio etc. In this we designed a micromirror by using these materials**SIMULATION DETAILS**

SIMULATION DETAILS

The simulation was done using COMSOL software, which was well known as one of the software normally used to simulate all MEMS device prior to fabrication steps. There is also other software such as COVENTOR, ANSYS etc. Before start the simulation all the available materials for micromirror was studied and selected from the COMSOL Software. The selected one is presented in Table below. In this, Simulation the Initial Press was set at 5GPa [4], which was advised from COMSOL. For simulation, we used parametric non linear solver to model the performance of micro mirror. So this model uses the large-deformation analysis type with both the linear and parametric linear solvers.

TABLE 1 : Materials used and its Properties

Material ↓ / Characteristics ←	Young's modulus (E)	Thermal Expansion (alpha)	Poisson ratio (nu)	Density (rho)
Alumina	300e9[pa]	8e-6 [1/k]	0.222	3900[kg/m3]
Aluminum 3003-H18	69e9[pa]	23.2e-6 [1/k]	0.33	2730[kg/m3]
Copper	110e9[pa]	17e-6 [1/k]	0.35	8700[kg/m3]
Aluminum	70e9[pa]	23e-6 [1/k]	0.33	2700[kg/m3]
Steel AISI 4340	205e9[pa]	12.3e-6[1/k]	0.28	7850[kg/m3]

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RESULTS

Simulation Cantilever Change to Different materials as per Table: from the table we can observe that different micromirror material with the same cantilever material have different stress level and lift-off accordance with the material characteristics. Observation is particularly on the stress on the edge of mirror and lift-off. In the paper [1], Hazian Mamat et al. observe that if we used same materials for micromirror and cantilever it results high stress level and lift off.

And then used structural steel as a micro mirror material so he observed the improved results. We used Steel AISI 4340 as a micro mirror and we find that stress level have comparatively low and desired lift- off stress as shown in the table. The further simulation with improvement on the cantilever materials has dramatically change the surface deformation and lift-off, which is able to solve the over-stress problem [1].

The figures [4-7] compare lift-off and stress level for different materials combinations. The steel, being harder than aluminum, deforms less. Table 2 shows the stress level and lift-off of different materials combinations.

TABLE 2: Different Materials used with Steel AISI 4340

Cantilever Materials	**Micromirror Materials**	**Lift-off**	**Stress Level**
Alumina	Steel AISI 4340	Low 2×10-5	Low 2.355e-5
Aluminum 3003-H18	Steel AISI 4340	Good 5×10-5	Low 5.194e-5
Copper	Steel AISI 4340	Very low 1×10-6	Very low 1.202e-6
Aluminum	Steel AISI 4340	High 2×10-4	Medium 2.447e-4

Figure 5 shows that lift-off and stress level of micro mirror when Aluminum 3003-H18 is used for cantilever beam and steel AISI 4340 for micro mirror. It dramatically reduces lift off and low stress level which is 1.95e-4.This is the best combination in all

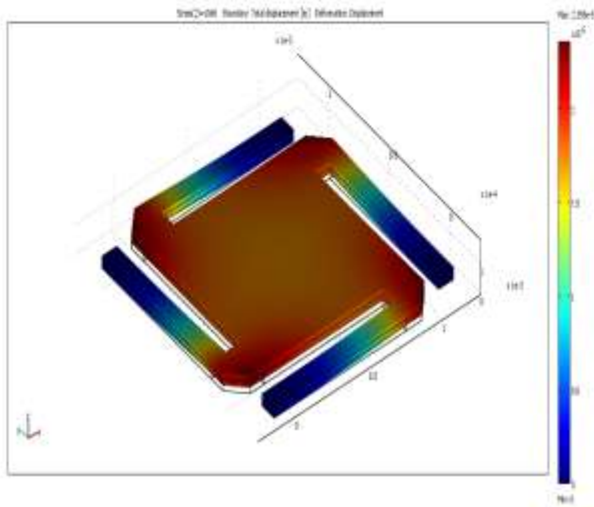

Figure 4: Alumina+Steel AISI 4340

Figure 4 shows that lift-off and stress level of micro mirror when Alumina is used for cantilever beam and steel AISI 4340 for micro mirror. It have lift off and low stress level which is 2.335e-5 when prestress 10e8 is applied.

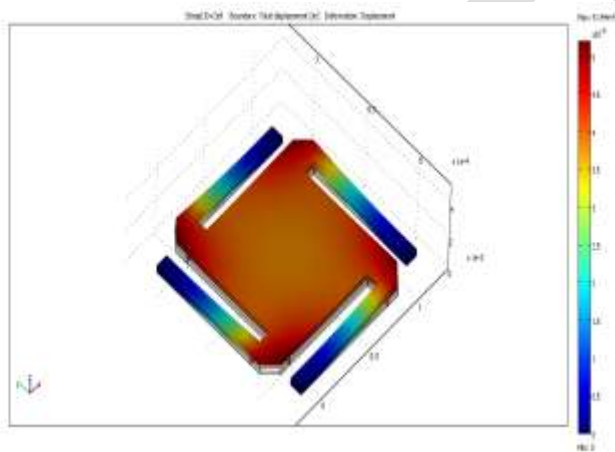

Figure 5: Aluminum 3003 H18+Steel AISI 4340

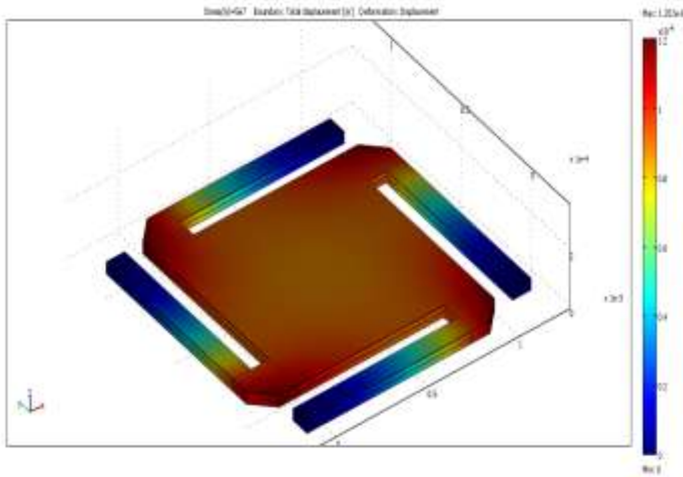

Figure 6: Copper+ Steel AISI 4340

Figure 6 shows that lift-off and stress level of micro mirror when Copper is used for cantilever beam and steel AISI 4340 for micro mirror. It have very low and low stress level and lift off. So it is not suitable for that.

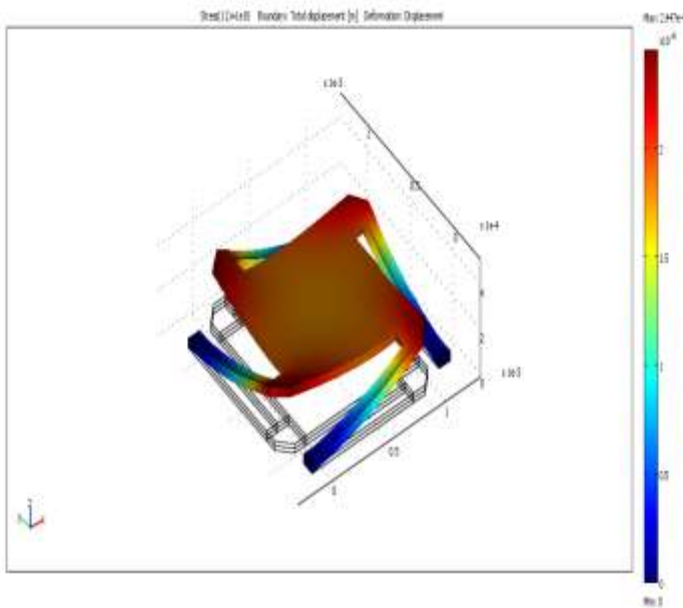

Figure 7: Aluminum+Steel AISI 4340

Figure 7 shows that lift-off and stress level of micro mirror when Aluminum is used for cantilever beam and steel AISI 4340 for micro mirror. It have medium stress level and high lift-off. We have required a stiff, flat device so this is not suitable for that.

CONCLUSION

In this paper, we have designed a MEMS based rectangle shape Micro mirror using COMSOL Multiphysics Software. For simulation, we used parametric non linear solver to model the performance of Micro mirror. We conclude that the stress can be controlled by using other cantilever materials. We have used different cantilever materials to reduce the stress. The best material combination is Aluminium 3003-H18+steel AISI 4340 which have less stress and uniformed roughness. It gives 8.6% improved result as compared to combination of Aluminium 3003-H18+structural steel which was advised in [1]. Furthermore the distance between mirror and the bottom plate are reasonably close and the voltage required to adjust the Micromirror will be reasonably low. As known theoretically, if the Micromirror are far apart from the electrode, it would bend and create stress at its four legs.

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