DESIGN AND OPTIMIZATION OF AN ELECTROSTATIC ACTUATED MICROMIRROR WITH ISOLATED BOTTOM ELECTRODE ON SILICON SUBSTRATE

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Abstract–*In this paper one type of an electrostatic actuated micromirror structure was simulated using Coventorware software, taking into account the material properties and structure geometry in order to optimize the structure. A characteristic response (displacement versus voltage) for simulated structure is the hysteresis loop of displacement. By reducing the length off the bottom electrode and also the length of the upper isolating layer we can obtain larger displacement of 12 μm. The optimized mirror reflective surface has a size of 120 μm x 120 μm*
Keywords: *electrostatic actuation, micromirrors.*

1. INTRODUCTION

MEMS structures are an expanding area for low power devices. Such devices are used as sensors, switches, digital devices, etc. MEMS technology has become compatible with various areas such as communication, sensors, etc.

Optical MEMS (MOEMS) are widely used in various applications such as optical tomography, optical switches, laser adjustable cavities, and many other applications.

As a specific type of MOEMS, movable micromirrors are widely used in different types of applications such as displays, miniature scanning devices, communication and sensors applications, [1], [2], [3].

The requirements of micromirror devices vary with the application, for example flatness, roughness and reflectivity are common to most applications.

Micromirrors can be used in projection displays, shape generators in mask less lithography, optical scanners, printers, optical spectroscopy, correction of the optical aberrations with lenses, adaptive optical systems, cross connects and switches in optical systems.

In this paper are presented the results of micromirrors simulations using Coventorware based on finite element method software taking into account the material properties, structure geometry, dimensions and applied voltage on the device. All the simulations were realized in order to obtain an optimized structure.

2. TYPE OF SIMULATED STRUCTURE

In Fig. 1 is presented the working principle of the micromirrors that were studied in this paper.

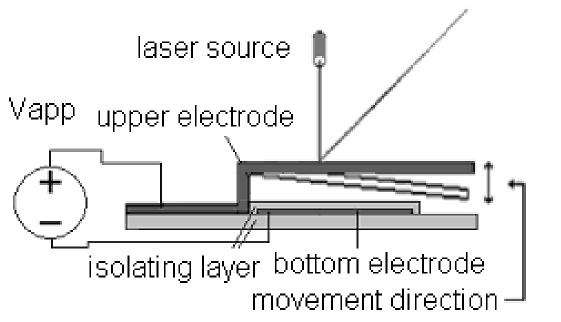


Fig. 1. Working principle of the micromirrors.

These structures present displacement in one direction (the z axis). When a voltage is applied between upper and bottom electrode, the upper electrode bends toward the bottom electrode and when the voltage is reset to 0V structure returns to the initial state.

In order to characterize the response of an electrostatic actuated structure one must firstly determine the pull-in voltage. The pull-in voltage is the voltage applied on the structure at which the upper parts of the structure hits the upper isolating layer and the structure achieves maximum displacement, [4]. The factors that have an influence on the pull-in voltage are:

- the thickness of the upper reflective layer;
- the length of the sustaining wall that can be patterned in either in 1, 2 or more parts;
- the gap value;
- the dimensions and geometry pattern of the bottom electrode;

The main goal is increasing the maximum vertical displacement and consequently the maximum angle of deflection.

The fabrication process flow for obtaining the structures is presented in Fig. 2.

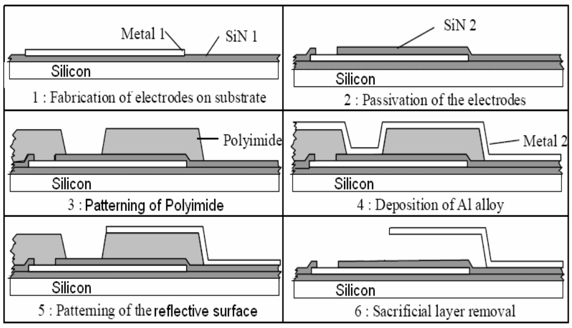


Fig. 2. The technological processes used for obtaining the structures.

The structures that were simulated in this paper can be obtained by using the following technological processes:

- deposition of a silicon nitride layer with 1 μm thickness on silicon substrate;
- deposition of an aluminum layer with 1 μm thickness;
- patterning of the aluminum layer;
- conformal deposition of a silicon nitride layer with 1 μm thickness;
- deposition in one or more steps of a polyimide layer with 6 μm thickness;
- patterning of the polyimide layer;
- deposition of an aluminum layer with 2.5 μm thickness;
- patterning the aluminum layer
- removal of the polyimide.

3. RESULTS

3.1. Structure A

Structure A is presented in Fig. 3. The reflective surface of the structure has an area of 50 x 80 μm^2. The metal wall that sustains the structure has 80 μm length and is 2.5 μm wide.

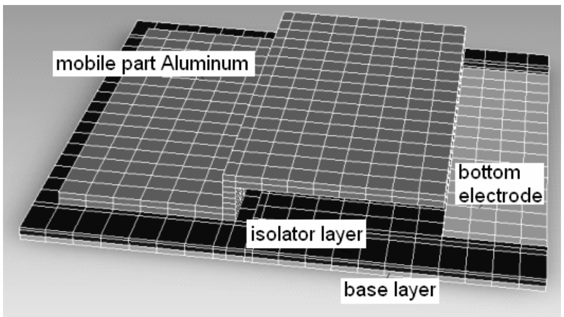


Fig. 3. Meshed model of structure A.

The gap between the mirror layer and the nitride layer is 6 μm thick.

In order to obtain the pull-in voltage the structure will be simulated at different voltages applied on the structure.

In Fig. 4 the displacement of the structure versus the applied voltage is presented, where the voltage varies from 70 V to 200V. The pull-in effect occurs when the structure displacement is half the maximum displacement. The value of the pull-in voltage is 144 V.

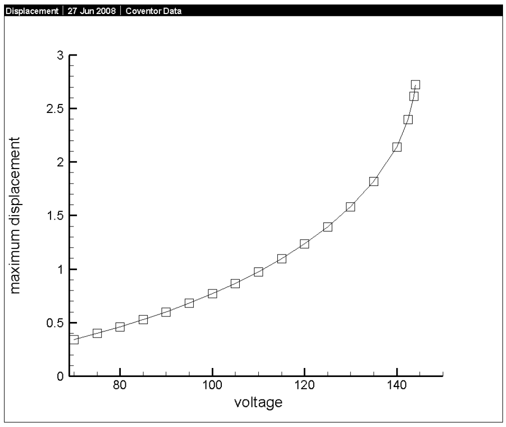


Fig. 4. Simulation of structure A: maximum displacement versus applied voltage.

3.2 Structure B

In Fig. 5 is presented structure B that was modified by reducing the length of the sustaining wall. All other sizes are the same as for structure A.

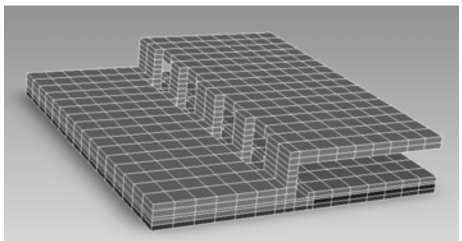


Fig. 5. Meshed model of Structure B (lateral view).

Structure B was simulated using a voltage in range 65 to 110V. The maximum displacement corresponding to 110V is 2 μm. This displacement is smaller than half of the gap (3 μm). In Fig. 6 and 7 are presented the results of simulations realized on structure B. The pull-in voltage that corresponds to structure B is 114V. In Fig. 7b is presented the displacement distribution of structure B corresponding to 114V. The structure B will be modified in order to increase the reflective surface.

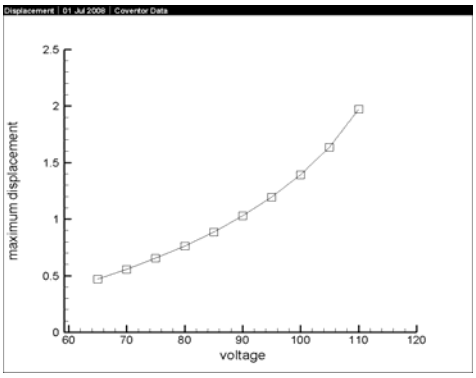
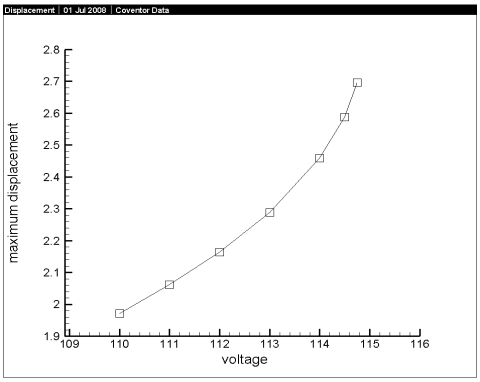
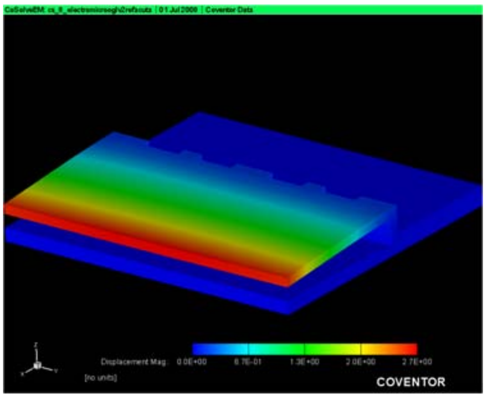


Fig. 6. Simulation of structure B: maximum displacement versus applied voltage.



a)



b)

Fig. 7. Simulation of structure B: a) maximum displacement versus applied voltage; b) view of the structure with displacement at pull-in voltage.

3.3 Structure C

The reflective surface area is 140 x 120µm^2, Structure C is presented in Fig. 8, where the sustaining wall has 2µm thickness. The sustaining has 70µm thickness and is formed from 2 pieces, each with 35µm thickness. The mobile layer that forms the reflective surface has 2µm thickness, this way we can reduce the pull-in voltage. Also by reconfiguring the other electrode and the isolator layer (silicon nitride) we can add up to 2 µm to the maximum displacement.

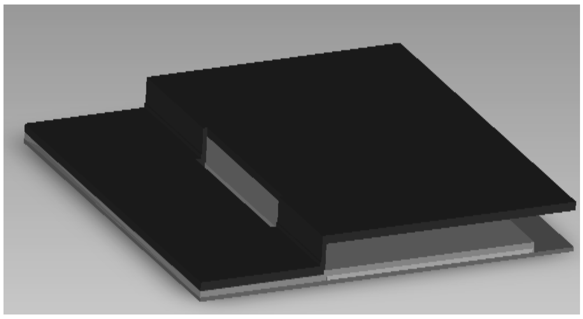


Fig. 8. Structure C- oblique view.

The main drawback is an increase of the pull-in voltage. The bottom electrode area is 140 x 98 µm^2. The gap is still 6 µm. This structure was designed in such a way that when the reflective surface hits the upper silicon nitride layer that is isolating it from the bottom electrode it also touches the bottom silicon nitride layer.

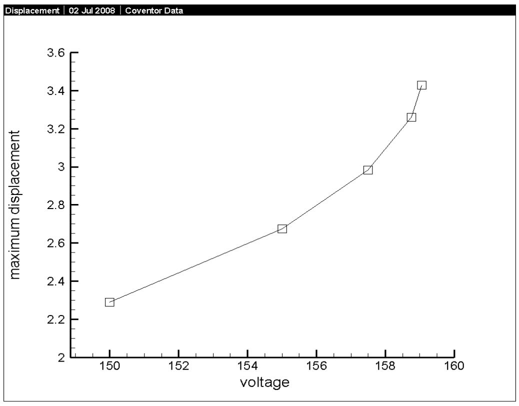


Fig. 9. Structure C maximum displacement versus applied voltage.

In Fig. 9 we see the results of a simulation realized on structure C. From Fig. 8a it results that the pull-in voltage is 159V. This value is still large for such a structure, as a consequence it must be decreased.

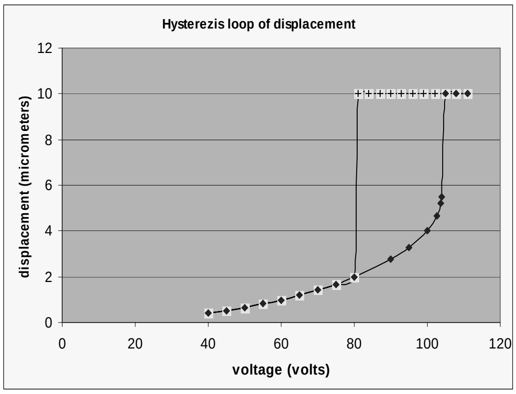
3.4 Structure D

In order to optimize the structure, the following measures were taken in order to find structure D (Fig. 10):

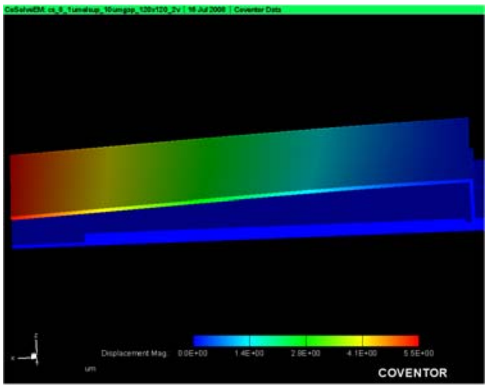
-reducing the thickness of the upper aluminum layer to 1 µm;

-reducing the length of the sustaining wall in order that the reflective surface be a square 120 x 120 µm^2. The sustaining wall is formed by two pieces with 30 µm length each and the new gap value is 10 µm.

Fig. 10. Structure D model used for simulations.



a)



b)

Fig. 11. Simulation of structure D: a) the hysteresis loop of displacement for structure; b) structure D displacement at a voltage a bit less than pull-in.

In Fig. 11a is presented the hysteresis loop of displacement versus applied voltage for structure D. In Fig. 11a the curve defined with the red points is the curve in which we can identify the pull-in voltage to be at 104V. The red curve is the curve defined by the increasing applied voltage. In Fig. 11a the curve that is defined with the yellow rectangle is the curve that defines the behavior of structure D when the applied voltage is decreasing. The maximum displacement for this type of structure is 10 µm as it results from the Fig. 11a.

It results that the pull-out voltage of structure D is in range 80 – 81 V.

From Fig. 10 we see that structure D can only be actuated at voltages below the pull-in voltage. The maximum displacement that can be obtained this way is 5.5 µm. For reasons of safe actuations the structure maximum displacement is around 4 µm, around 2 degrees in order not to enter in the pull-in region.

4. CONCLUSIONS

An electrostatic actuated micromirror was optimized by simulations in this paper.

By reducing the length of the sustaining wall the pull-in voltage decreases. Also by reducing the thickness of the layer with the reflective surface the pull-in voltage also decreases. By increasing the gap between the reflective layer and the bottom layer the pull-in voltage increases. A structure with a square reflective surface (structure D) is an optimization of a structure with rectangular reflective surface (structure C) due to the fact that the length of the sustaining wall is decreasing as also the pull-in voltage decreases. The length of the sustaining wall is the same as the length of the reflective surface in case of structure C and is larger than the width of the reflective surface. Although structure D was designed to have a maximum displacement of 12µm, due to the pull-in effect the maximum displacement of the structure is around 4µm in order to avoid the entering into the pull-in zone.

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