Design of electro thermal MEMS mirror with wider scanning angle for endoscopic imaging

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Endoscopic imaging and scanning inside the human body is having high relevance in medical diagnosis. For imaging of cells and tissues in the optical biopsy, the size of the scanning device must be as small as possible. So merging Micro Electro Mechanical System (MEMS) with optical technology is an attractive solution. This paper proposes a novel design of MEMS mirrors with a wider tilting angle for better endoscopic scanning. Mirrors are modelled so that a wide scanning angle is achieved at low voltages. Specific Thermal actuators are actuated by varying the applied voltage. Common materials like Aluminium and Silicon are used for mirror design. A MEMS mirror with increased aperture size and reduced device size than existing mirrors is modelled. It is observed that both the fill factor and the tilting angle of the mirror are improved. The increased tilting angle helps in wider scanning angles. Since Thermal actuators are used for tilting, the proposed mirror system is less complex and is highly useful for endoscopy imaging.

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Keywords: Micro Electro Mechanical System (MEMS), Endoscopic Imaging, MEMS Mirror, Electro thermal Actuators, Fill Factor

1. Introduction

Surface-based medical imaging using optical endoscope technologies [1] has wide attention due to its ability to examine internal organs or cavities of the human body. Contrary to numerous other medical imaging methods, endoscopes are straightforwardly inserted into the organ. In modern endoscopy, mirrors with a wide field of view very much necessary for navigating inside the body. The scanning angle of the mirror is an important parameter that defines the quality of imaging. With a single mirror, improved scanning area is possible by incorporating Micro Electro Mechanical System (MEMS) technology in endoscopy. Currently, endoscopic imaging is depending on MEMS technology to improve its performances in various stages of scanning [2]. The scanning range depends on the angle of the tilting motion of the mirror plate. So by increasing the tilting angle of the mirror plate using MEMS actuators a wider mechanical scanning angle is possible that helps better endoscopic imaging.

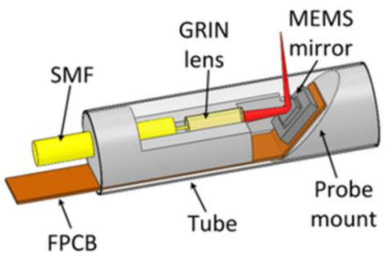

Fig. 1. Endoscopic Probe with MEMS Mirror, SMF-Single Mode Fibre, FPCB-Flexible PCB, GRIN lens-Graded Index Lens[Courtesy: Research Gate] (color online)

There are many actuating mechanisms currently employed in MEMS such as optical, thermal, mechanical, magnetic, electrostatic, etc. Thermal actuating MEMS Mirrors [3] have more advantages comparing to other actuating mechanisms in MEMS. Electro thermal actuators [4] require comparatively low driving voltages yet produce large forces and displacements. These actuators can be easily controlled as electrostatic or magnetic fields are not involved in the operation. Materials with their electrical conductivity are dependent upon temperature such as Polysilicon, which is used as the actuator material.

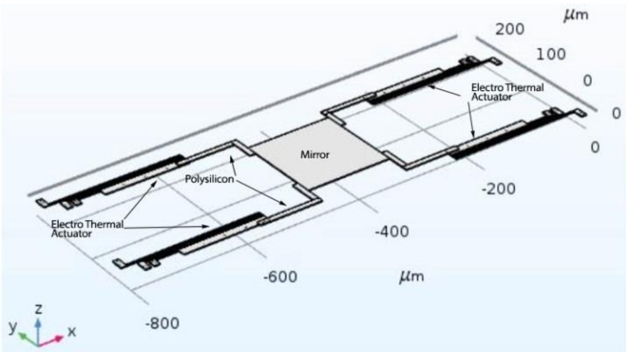

Fig. 2. Typical MEMS Mirror design

The commonly employed structure has two or more connected beams (arms) fabricated using electro-thermal material. Electro thermal actuation [5] works with the principle that the thermal expansion difference causes the bending of the beam [6].

2. Experimental design

The proposed model of MEMS mirror is designed using COMSOL® software [7]. The design aimed to provide low driving voltage, low power consumption, and high fill factor. Fill factor is the ratio of aperture size to the device size, which is a major criteria that defines the quality of micro mirrors. Also the design intends to have a simple structure so that fabrication of the mirror and actuators become easy. By applying voltage to the thermal actuators attached to the mirror, tilting can be accomplished.

The micromirror should have a very stiff, flat, and reflective centre portion. Here Aluminium is proposed as the reflective material as it is a very light metal having a density of 2.7g/cm^3, which is about one-third of steel. This helps in reducing both the weight and cost of the mirror. It is an excellent conductor of electricity and heat. It is a good reflector of visible light as well as heat. These properties together with low weight make it an optimal candidate for reflectors. Hence Aluminium is an ideal material for the fabrication of MEMS Mirrors. The typical voltage that can be applied is from 5V to 20V and the voltage may be varied according to the tilt that needed. The dimensions of the proposed thermal actuator are 240-micrometer length, 20-micrometer width, and 2-micrometer height. An Aluminium plate of size 400-micrometer length, 150-micrometer breadth, and 2-micrometer height is used for the mirror structure. By reducing the device structure and increasing the aperture size, a higher fill factor is acquired.

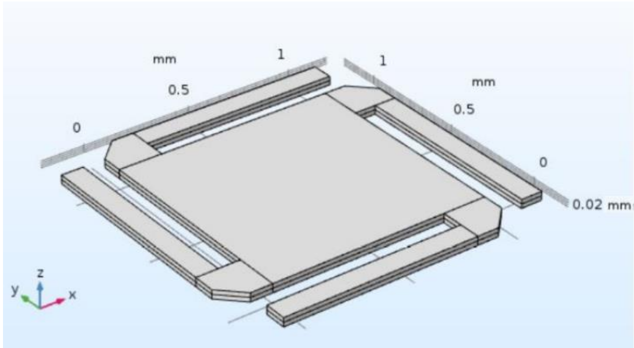

Fig. 3. Prestressed MEMS Mirror

The mirror is supported by four prestressed plated cantilever springs. Prestressing is a method to create spring type structures or inducing curvature into thin structures. Polysilicon films were deposited onto oxidized silicon substrates of the cantilever springs. The curvatures of substrate changed with temperature, as the thermal expansion of polysilicon differs from that of the single crystal silicon substrate. Equal and opposite (compressive and tensile) initial stresses are applied in the top and bottom layers [8]. Normally a pressure range of 0 to 10 Giga Pascal needs to apply. The 3-Dimensional structure of the design is modelled. The attached cantilever strings are used to actuate the mirror plate. Strings are prestressed by applying a pressure ranging from 0 to 10 Giga Pascal. The micromirror design is in such a way that the centre portion is smooth reflective at the same time very stiff. Four prestressed plated cantilever springs do the support this centre portion.

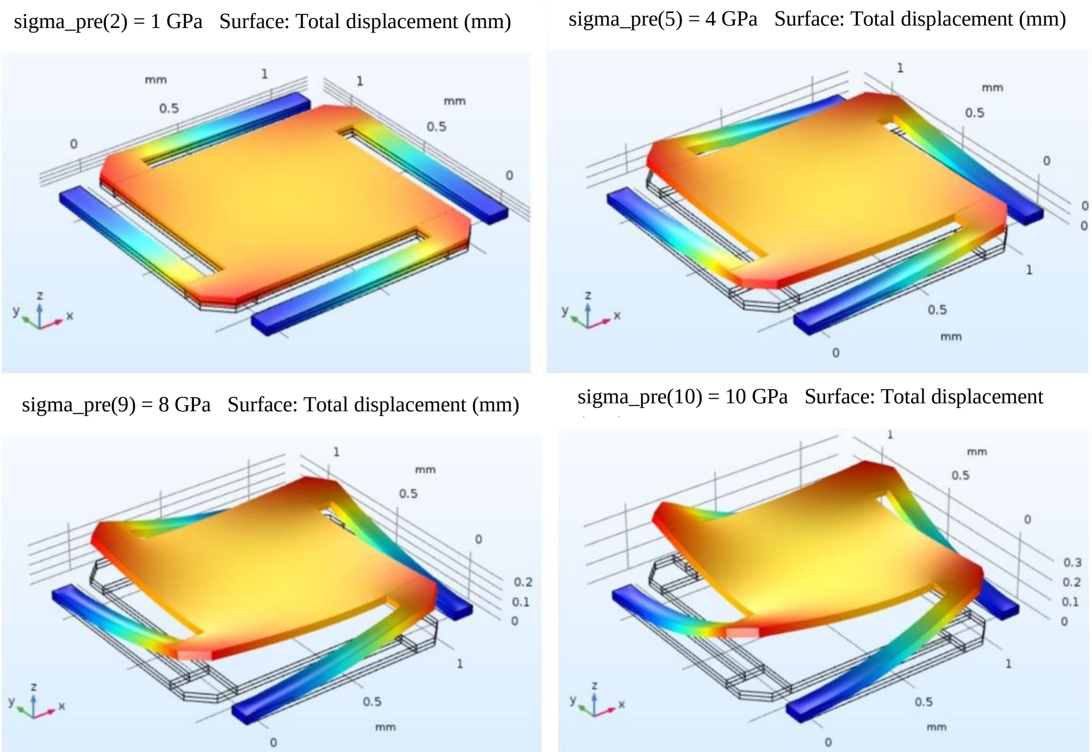

Fig. 4. Structure variation of the mirror plate on application of different amount of pressure (color online)

Initially, the plated structure with two layers is examined with a small mesh size for a reasonable time. Also, it is assumed that the plating process creates equal and opposite initial stresses (compressive and tensile) in the top and bottom layers. Since multiple actuators are used for actuation which makes the movement more flexible also square or rectangleshaped reflecting structure is more suitable than a circular. While considering the mechanical part of structural design, four actuators are connected to the corners of the rectangular (square) reflecting surface. Structure deformation of the mirror plate on applying different pressure is shown in Fig. 4.

3. Design of electro thermal actuators

The proposed model comprises of Polysilicon based two-arm heat actuator. The actuator is triggered by means of heat expansion. With Joule heating (resistive heating), the temperature of the material is increased that deforms the two warm arms and the displacement of the actuator is achieved. Compared to the cold arms, the larger extension of the hot arms enables the actuator to twist. The activity of the actuator incorporates three associated material science phenomena: conduction of electrical flow, heat conduction with heat age and warm extension basic stress and strains. Electrical potential is applied between the grapple bases of the hot arms. The cold arm anchor is electrically insulated, alongside all other surfaces. The base temperature of the three grapples and the three dimples is fixed to the consistent temperature of the substrate. Since the structure is sandwiched, with conduction through slim layers of air, every single other boundary thermally interacts with the surroundings.

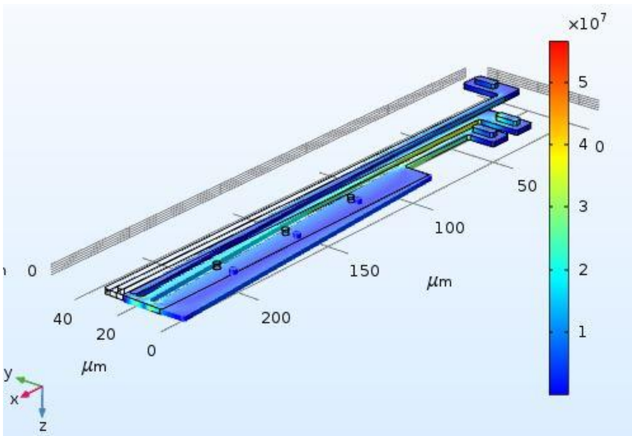

Fig. 5. Electro Thermal Actuator (color online)

All of the three arms are precisely fixed at the base of the three stays. The dimples can move straightforwardly in the plane of the substrate (the XY-plane in the figure) but do not push inverse into the substrate (the Z bearing) which is shown in Fig. 5. Polysilicon is used for designing legs/arms as its electrical conductivity is temperature-dependent.

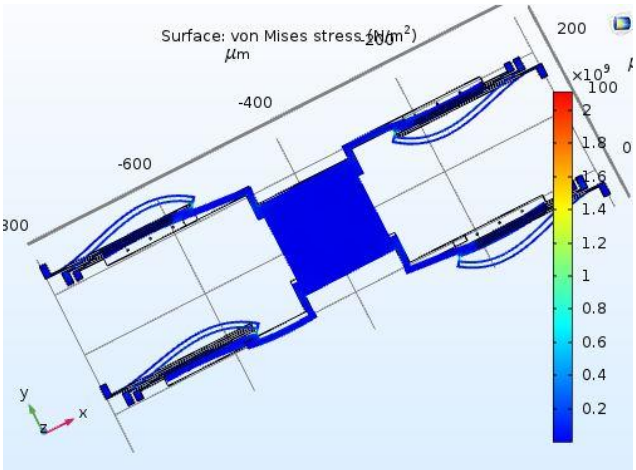

Fig. 6. Actuation of micro mirror (color online)

The high fill factor is considered one of the important features of electro thermal mirrors. A smaller device with a good aperture size is a prerequisite for tiny endoscopic probes.

For the fabrication of bimorph beams, various materials having electro thermal properties have been explored. Among different materials, the suitable choices are Al and SiO_2. It is demonstrated [9] that 2D micromirrors fabricated with Al or SiO_2 having a dimension of 1 by 1 mm with Polysilicon as the heating material had obtained a tilting angle up to 40^o at 15V. Moreover electro thermal actuation is the most preferred actuation mechanism in practice for endoscopic OCT imaging. The actuation of the mirror is shown in Fig. 6.

4. Proposed electro thermally actuated MEMS mirror

Table 1. Proposed Mirror Fabrication Steps

Sl No	Fabrication Steps
I	Design of Mirror dimensions and selection of Materials
II	Al SiO2 Biomorph beam
II	High Reflective Al Mirror
III	Fixing Mirror on to Biomorph beams
IV	Check tilting with varying Voltages
V	Modified design without polysilicon attachment
VI	Check tilting with varying Voltages
VII	Calibrate and finalize design.

In the proposed MEMS mirror design an Aluminium plate is selected as the aperture. Four electro thermal actuators are provided as the tilting legs of the mirror plate. Polysilicon is used to connect the mirror plate and thermal actuators. By varying the applied voltage typically in the range of 5 to 10V, different tilting angles can be obtained.

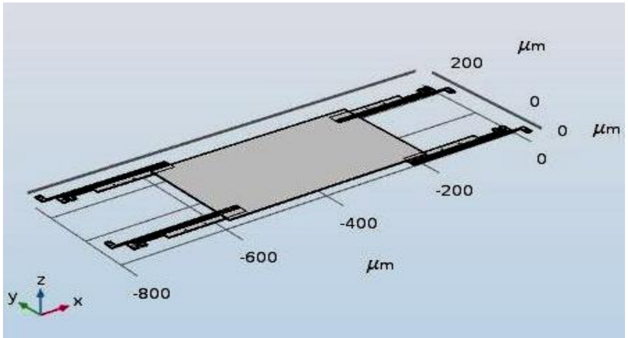

Fig. 7. Proposed Design

This design can be further refined such that actuating leg/legs may be chosen independently. In that case by applying a voltage to only one leg fine tilting of the mirror plate is obtained. Experimentation on such activation is left as future scope of this study.

The fill factor, which is the ratio of the aperture size to the device size, is an important criterion that defines the quality of the micromirror. The aperture plate can be directly placed on the four thermal actuators, by removing the Polysilicon connection between the mirror plate and the actuators. The aperture size is increased while the entire device size remains the same. Hence in the proposed design, the fill factor is improved. In this design which is shown in Fig. 7, an Aluminium plate of size 400-micrometer length, 150- micrometre breadth, and 2-micrometer height are used.

Aluminium is the most suitable material for a mirror plate because of its density and reflectivity. The flexibility of the design is that we can apply the voltage to any of the leg actuators independently at the same time. So by varying the applied voltage to the leg actuators, different stresses are applied on the mirror plate and hence more versatile tilting of mirror pate is achieved. Moreover, the application of voltage can also be varied so that fine control of tilting of the mirror surface is obtained. This property is the major advantage of this structure. The actuation of the proposed structure is shown in Fig. 8.

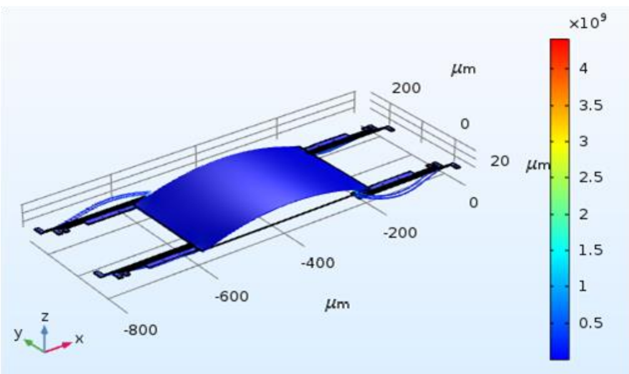

Fig. 8. Actuation of proposed MEMS Mirror (color online)

The total displacement of the mirror plate with the applied voltage when four of the thermal actuators are used is plotted in Fig. 9.

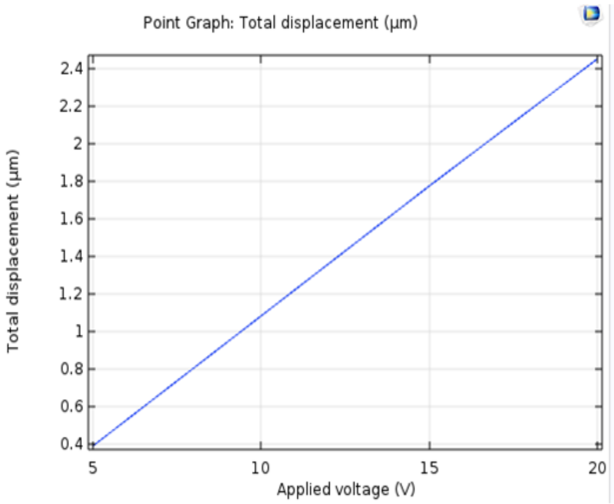

Fig. 9. Displacement of actuated MEMS Mirror

The linear relationship between the displacement and the applied voltage is the advantage of the electro thermal actuator.

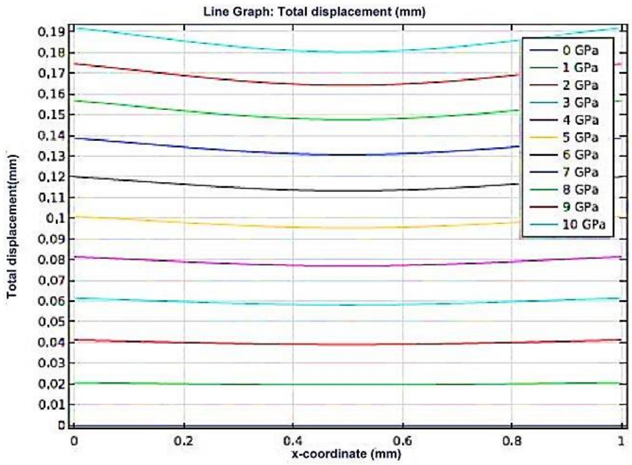

Fig. 10. Total displacement across x coordinate of the mirror plate (color online)

Points or coordinates are available from the graph and the X coordinate of the mirror plate. Hence by using simple geometry the angle is calculated as shown in Fig. 11. But the applied voltage together with the actuator legs we choose determines the tilting angle. So for each specific case, there is a different tilting angle. This is a general method specified to find the angular variation of the reflecting plate of the mirror.

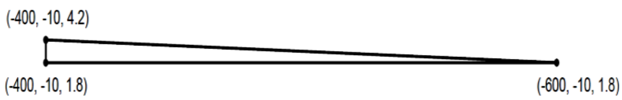

Fig. 11. Calculation of tilting angle

From the calculation of the tilting angle of this design, the tilting angle at a particular point of the mirror plate can be obtained. At the peak point by an application of 20V, a tilting of 2 degrees is achieved which is better than the previous structures.

5. Conclusion

A MEMS Mirror which makes use of electrical, thermal, and optical properties of materials with an improved scanning range is designed and simulated. An electro thermal actuator that supports the proposed mirror device is also designed and simulated. Increased fill factor and versatile tilting are the advantages of the design. Such electro thermal actuator-based MEMS mirrors are very much used in cameras, projectors, medical imaging probes, etc. The proposed structure has an improved scanning angle and higher fill factor. In endoscopic imaging applications, electro thermal actuators are preferred due to low voltage operation and large output force. Further improvement is possible using Gimbal structure in which higher scanning angles can be achieved.

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