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DESIGN AND COMPARISON OF ELECTROSTATICALLY ACTUATED MICRO MIRROR WITH DIFFERENT ASPECT RATIO

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ABSTRACT: The micro mirror is a versatile MEMS device which is mainly used for light deflection and control. The micro mirror state is controlled by applying voltage between the electrodes around the mirror arrays. Electrostatic actuation is the methodology used for precise control of mirrors. We have designed arrays of electrode of different dimension which produces different tilting angle. We have analyzed that when aspect ratio of fixed electrode is increased corresponding tilting angle get increased linearly. Also, analyzed that when applied voltage increases corresponding tilting angle gets increased. The micro mirror is designed and the deflection value is simulated by using COMSOL Multi physics Software.

KEYWORDS: MOEMS, MEMS mirror, electrostatic actuation, array of electrodes, COMSOL Multi physics.

INTRODUCTION

Micro-Opto-Electro-Mechanical Systems (MOEMS) technology merges MEMS with Micro optics which involves sensing and manipulating optical signals on a very small scale using integrated optical, electrical and mechanical systems. It provides directivity, sensing and actuation solutions to many high performance systems. This paper describes the design and analysis of a particular Micro-Electro-Mechanical-System (MEMS) micro mirror device that can be used for video projectors and optical communications application. MOEMS technology enhances the level of perception and control. These devices are usually fabricated using micro-optics and standard micromachining technologies.In electrostatic actuation the potential difference between a micro actuator and its electrode induces electrostatic force. Applied voltage and displacement are linearly dependent on each other in electrostatic actuation. It consumes low power consumption, fast response time and easy to integrate and implement. It is used for precise control of mirrors. Mirror on ribbon actuator (MOR) structure resembles torsional parallel plate capacitor. It supports two stable positions (+/-degrees with respect to rest). The large scale integratibility and low cost for high volume mass production of MEMS components create significant potential for ever expanding optical communication network.

The MOR (mirror on ribbon actuator) consists of ribbon actuator and a mirror placed over it in parallel state. The ribbon actuator used in MOR generates high resonant frequency. The very thin air gap between the ribbon actuator and the substrate generates the large damping factor. As MOR has the simplest structure it can be used to integrate easily into a large array format. The project aims at designing an individual micro mirror of size in order of a few micrometers to obtain maximum tilt angle with a minimum driving voltage.

The response of the micro mirror (Voltage versus tilting angle) and (aspect ratio versus tilting angle) would be studied to optimize the design for achieving maximum tilt angle displacement.[4]The Aluminium material is used for mirror as it has greatest extent of spectral reflectivity than silver and highly durable. Aluminium is remarkable for the metals low density and for its ability to resist corrosion due to the phenomenon of passivation. Most importantly it provides a more faithful representation of colors. The ribbon actuator is also made from Al layer.

DESIGN AND OPERATING PRINCIPLE

The MOR mainly consists of a ribbon actuator, a fixed electrode and a mirror. The Aluminium material is chosen for mirror and ribbon actuator and fixed electrode. The substrate is made up of Si(c) material and anchors are made of SiO_2 insulator .The fixed electrode is placed above the substrate, and the ribbon actuator is placed above the fixed electrode which is fixed at both the ends using two anchors.

The mirror is placed above the ribbon actuator by means of anchor. The beam of the mirror is placed between the center and the anchor of the ribbon actuator. The shape of a mirror is square and for ribbon actuator it is short and wide. The submicron gap between the ribbon actuator and the substrate should be 250nm.The submicron gap is responsible for obtaining large damping factor.

Electrostatic actuation is the methodology used for precise control of mirrors. Any electric field applied a force to any charged particle becomes electrostatic actuation. Electrostatic actuation is the simplest actuation known that makes it preferable for many MEMS applications. It is highly favored as it consumes low power consumption, high operating speed and low cost of ownership. In microscopic scale, this is a huge advantage because most of the structures have a very low aspect ratio. Every kind of micro actuator has one or more electrostatic actuation based version.

$$\text{Electrostatic Force, } F_e = \frac{\varepsilon_0 A V^2}{2d^2}$$

ε_0- free space permittivity, A-area of ribbon actuator, V-applied voltage, d-distance between ribbon actuator and fixed electrode. The electrostatic force developed between actuator and electrode was found to be 2.23 X 10^{-12}N.

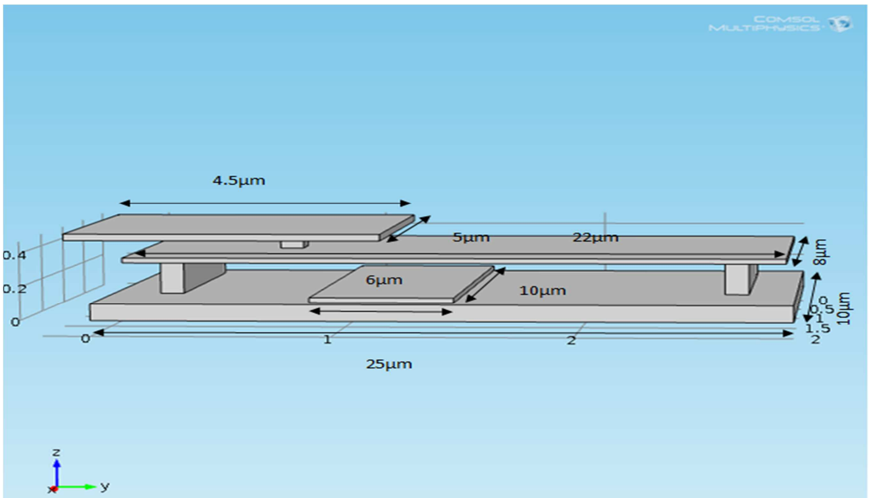


Fig-1 Shows the micro mirror in parallel state

The voltage is applied between the fixed electrode and the ribbon actuator and it is of 2V. If the drive Voltage is not applied, the mirror and the ribbon actuator will be in parallel position. When the drive voltage is applied between the ribbon actuator and the fixed electrode, the ribbon actuator gets displaced towards the substrate by means of electrostatic force. Since the mirror is anchored to the ribbon actuator, the bending of ribbon actuator results in tilting of mirror.

$$\text{Displacement, } d = \frac{PAl^3}{12EI}$$

P-applied pressure, l-length of the actuator, E-Young’s modulus, I-moment of inertia. When pressure of 2µPa was applied to the ribbon actuator, the actuator gets displaced by 0.3µm.

In this paper we have adopted array of electrodes of different dimension (different Length and Width and same Height) in mirror on ribbon actuator. The logic of choosing same height is to place all the electrodes in a complete array format. The maximum tilting angle of the micro mirror mainly depends on the mechanical stop of mirror touching the cavity.

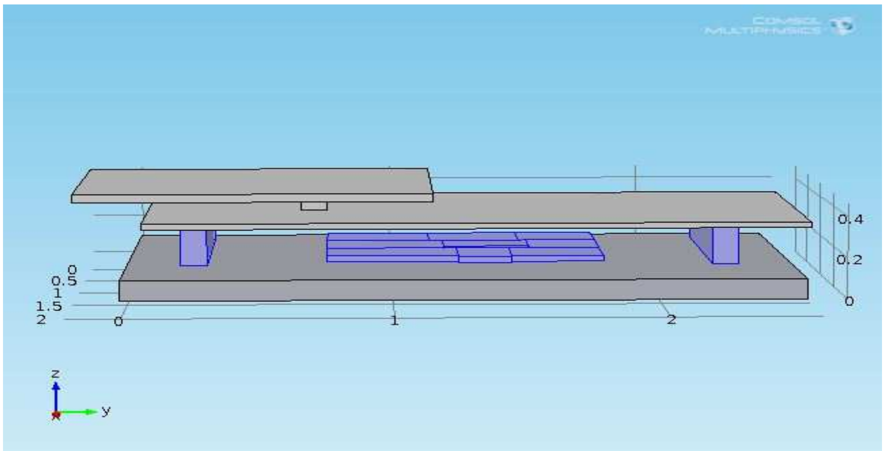


Fig-2 shows array of electrodes in mirror on ribbon actuator

DESIGN CONFIGURATION

The electrodes are arranged in 3x3 matrix format to produce 9 different tilting angle in single MOR actuator. The voltage applied between the actuator and the fixed electrode is about 2V and the pressure applied is 2µPa.The micro mirrors are designed using COMSOL Multi physics software.

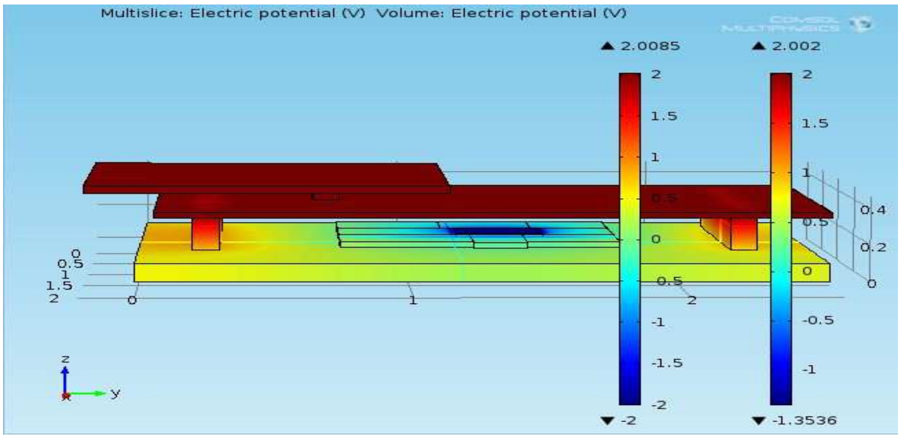


Fig-3 shows potential applied between ribbon actuator and one of the electrodes

SIMULATION RESULT

After the structure creation and material Selection, meshing is done for the structure. When the Pressure is applied the mirror gets tilted for single electrode mirror on ribbon actuator.

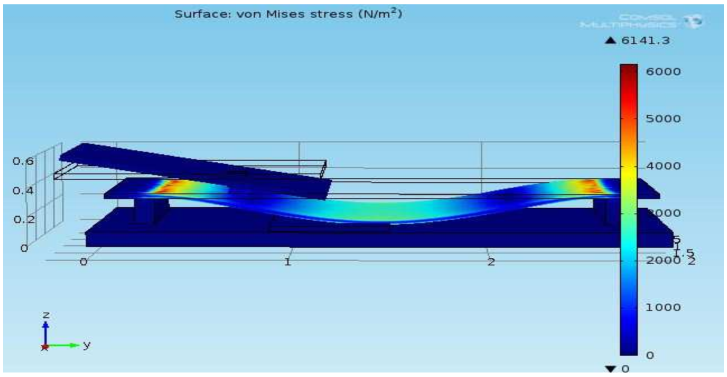
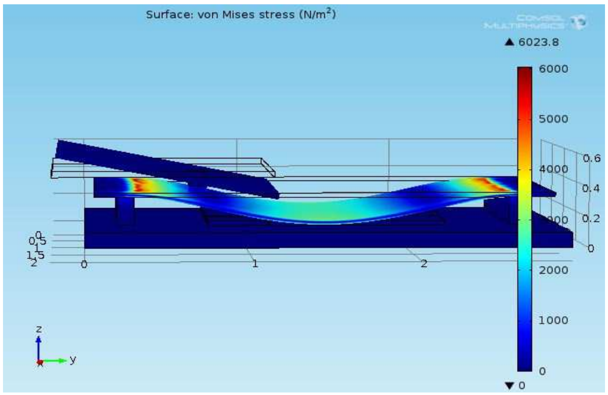


Fig-4 shows tilting of micro mirror for single electrode mirror on ribbon actuator

When same voltage is applied for different electrodes of different dimension will result in different tilting angle of the mirror. In this way various gray scales can be produced.[3]



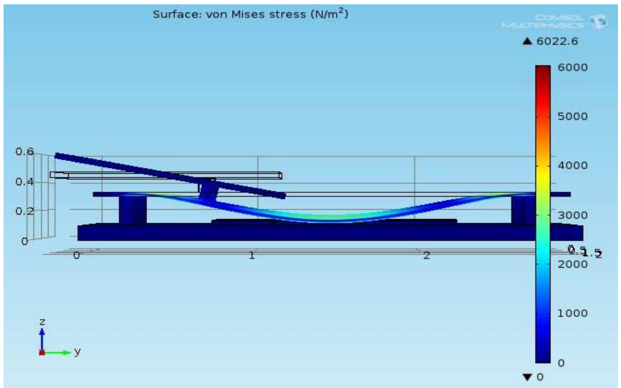


Fig-5(a) ***Fig-5(b)***

Fig-5(a) and Fig-5(b) shows the tilting of mirror of different electrode of different length.

Due to the nonlinear angular-voltage characteristics of micro mirror on ribbon actuator with single electrode, it is difficult to achieve linear stepping angles. By using micro mirror with multiple electrodes provides linear stepping angle. Array of electrodes of different dimension results in different tilting angle of mirror.

FORMULATION

Relation that connects pull in voltage and angle of tilt is given as

$$q=\sqrt[3]{\frac{v^2 e_0 w}{k}}$$

Above equation is rearranged to find the tilting angle of micro mirror

V – Applied voltage (V)
k – Spring constant (N/m)
q - Angle of tilt (degree)
e_0 - Permittivity of free space
w – Width of the electrode (mm)

Deflection of micro mirror is calculated by using following equation

$$\theta = L/EI$$

θ- Deflection
L – Length of electrode
E – Young's modulus
I – Moment of inertia

I = $(L^2+W^2)/12$

k = 192 EI/ L^3 [1]

Spring constant, k=13951937.08

Using the above formulas, the spring constant, moment of inertia, deflection and tilting angle is calculated. Aspect ratio is taken to find deflection and tilting angle for single electrode and multiple electrodes in mirror on ribbon actuator.

TABLE: Deflection and tilting angle for single electrode and multiple electrodes of different length (in micro scale)

Electrode type			Electrode			Mirror				
		Stress	**Width**	**Length**	**Height**	**Width**	**Length**	**Height**	**Tilting angle**	**deflection**
Single electrode		6141.3	10	6	2	5	4.5	2.2	4.28x10^-6	2.80x10^-6
Multiple electrodes	**Electrode 1**	6023.8	3.5	5	2	5	4.5	2.2	3.02x10^-6	2.33x10^-6
	Electrode 2	6023.8	4	3.5	2	5	4.5	2.2	3.2x10^-6	1.63x10^-6
	Electrode 3	6023.8	5	3.9	2	5	4.5	2.2	3.39x10^-6	1.82x10^-6
	Electrode 4	6022.6	4.5	3.8	2	5	4.5	2.2	3.28x10^-6	1.77x10^-6
	Electrode 5	6022.6	5.5	4.5	2	5	4.5	2.2	3.51x10^-6	2.10x10^-6
	Electrode 6	6022.6	3	5.5	2	5	4.5	2.2	2.86x10^-6	2.57x10^-6
	Electrode 7	6022.6	3.7	3.6	2	5	4.5	2.2	3.07x10^-6	1.68x10^-6
	Electrode 8	6022.6	4.2	3.7	2	5	4.5	2.2	3.20x10^-6	1.72x10^-6
	Electrode 9	6022.6	3.9	5.7	2	5	4.5	2.2	3.13x10^-6	2.66x10^-6

RESULT AND DISCUSSION

By using single electrode in mirror on ribbon actuator, the stress produced is 6141 whereas by adopting arrays of electrode in mirror on ribbon actuator, the stress at corners gets reduced. The advantage of using arrays of electrode of different length produces different deflection and tilting angle. This means that different gray scales can be produced by adopting arrays of electrode. Most importantly it provides a more faithful representation of colors if color filter is used in video projector. The submicron gap produces large damping effect.

Electrostatic actuator is preferred here because of its fast response and low power consumption. Aluminum material is used for mirror as it has greatest spectral reflectivity than silver and highly durable and ability to resist corrosion. The large scale integratibility and low cost for high volume mass production of MEMS components create significant potential for ever expanding optical communication network.

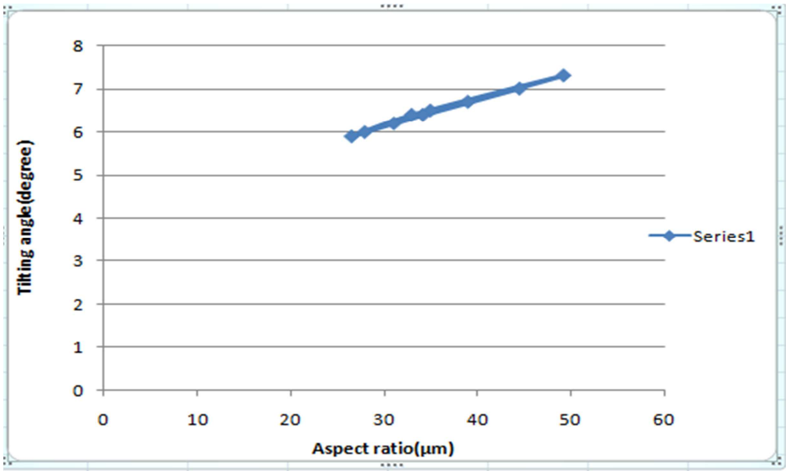


Fig-6 graph of aspect ratio vs. tilting angle

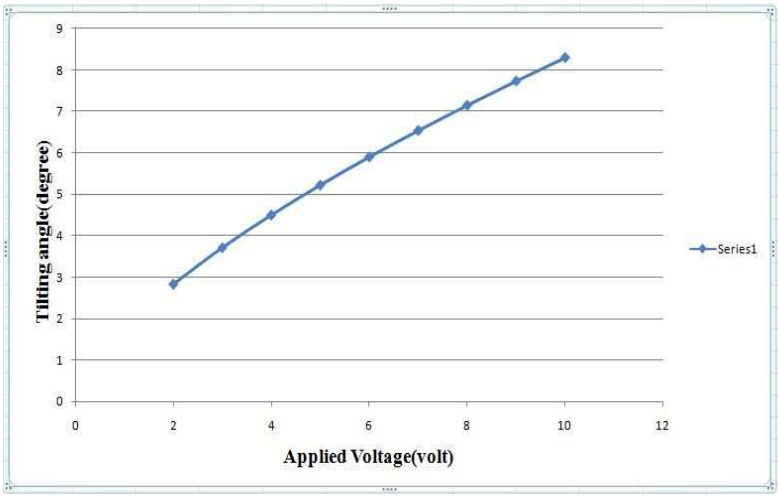


Fig-7 Applied Voltage vs. tilting angle

CONCLUSION

Here, the micro mirror consisting of arrays of electrode in mirror on ribbon actuator is designed using Aluminum material and it is electro statically actuated. The pressure of 2µPa is applied and different tilting angle for arrays of different electrode dimensions is produced. It helps in producing different gray scales. We have analyzed that when aspect ratio of fixed electrode is increased corresponding tilting angle get increased linearly. Also, analyzed that when applied voltage increases corresponding tilting angle gets increased. The micro mirror is designed and the deflection value is simulated by using COMSOL Multi physics Software**.**

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