TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 2978 - 2983

Design and Simulation of MEMS Based Electrothermal Micro Mirror for Optical Switching

K. Anitha, P. Mahiz Mathi, T. Aravind, S. Ramya

Article Info
Volume 82
Page Number: 2978 - 2983
Publication Issue:
January-February 2020

Article History

Article Received: *14 March 2019*
Revised: *27 May 2019*
Accepted: *16 October 2019*
Publication: *19 January 2020*

Abstract

Micro mirror is a versatile MEMS device which is used in many application areas. Significant efforts have been made for the development of scanning micro mirror for optical switching applications. In this paper, an electrothermal driven micro mirror is designed that is capable of producing large deflections in all directions. The study and stimulation of electrical, thermal and most importantly the mechanical behavior of the mirror system are done using COMSOL Multiphysics. Micro mirror is made up of silicon so that micro mirror produces large deflections. Electro thermal actuator is made up of polysilicon, silicon dioxide and aluminum. When a voltage is applied, temperature will change yielding a bending of both angular rotation as well as a vertical displacement, which can be used for the tip tilt motion. The device has an average of 1.78 µm deflection in either direction for an input voltage of 1V. The ability of controlled deflection of the micromirror in space is likely to have potential applications in optical switching

Keywords: *Micromirror, COMSOL, Electrothermal, Optical Switching.*

I. INTRODUCTION

In the present scenario of advancement in science and technology, there is still lack in the tools available for the micro level manipulation, where the existing components fail to handle micro objects of size less than 1mm. Small components with the purpose envisioned in microassembly, microrobotics, single cell manipulation and positioning, cell separation, modestly invasive and living cell surgery throws a stern challenge in front of the technological fraternity. Micromirror devices are microscopically small mirrors with mirror arrays. In Micromirrors, voltages are applied between two electrodes around the mirror arrays. Micromirrors are used in Televisions and HDTVs, Holographic Versatile Discs, Head-mounted displays, Digital cinema, DLP (Digital Light Processing) projector, Metrology (optical metrology), Laser beam machining and optical Switching.

Electrothermal actuation is gaining more attention as it is a viable method for actuating Micro Electro Mechanical System. Microactuators are widely used in variety of fields such as Microgripper, Micropumps, Microassemly, Micromirror etc,.

Electrothermal actuators are having main advantage over the conventional electrostatic actuators interms of producing high force output with very low actuation voltage. In resistive heating, Thermal expansion has been developed at both in-plane and out-of-plane actuators

The in-plane thermal actuator configuration is widely used because of its advantage over out-of-plane configuration. Since out-of plane displacement reduces the gripping efficiency. So the in-plane displacement is properly achieved by considering the aspect ratio (width to thickness), stiffness and symmetric nature of the overall structure. They are two ways in designing thermal actuator: U-Beam type and V beam type. In U-beam actuator, the deflection are obtained by asymmetric heating of beams due to unequal width of the hot and cold arm. V-beam configuration has the number of hot beams stacked one above another to form an array like structure for uniform heat generation. These beams are undergoing uniform heat generation in clamped clamped beam which automatically deflect laterally from thermal expansion. Shuttle is the middle part of the actuator joined by beams which decides the stiffness of the actuator and helps to move the actuator in forward direction. In this way uniform actuation of each beams are achieved in-plane using V–beam configuration.

Joules heating effect and thermal expansion principle is used in bent beam actuator which states that the heat produced by the electric field is directly proportional to the resistive losses in the material. Various applications in thermal actuators are listed as follow biomolecule manipulation, brain implantation, micromirrors, mechanically tunable photonic crystal lens and used for various applications.

In this paper, Micromirror is simulated using polyimide material. The device is structured with the thickness of 6 μm and electrode thickness of 300 μm. Initially design parameters are verified and the different characteristics of the electromechanical device are explored for simulation. The electrodes are integrated to the micromirror device. The input voltage is applied to the electrodes and analyzed actuation of the micromirror. Due to the electrode area size difference, the structure will deform to the larger area electrode side. By this principle, micromirror tilt is control according, to their input voltage. A lower power thermally actuated bi-axis SOI micromirror is developed and which is used to perform vertical and angular scan. Micromirror device consists of an aluminium which is coated to silicon base, electrothermal actuators with heaters are coated with aluminum/polysilicon and polysilicon flexural connectors. For optical coherence tomography (OCT) applications with scanning mode, micromirror can satisfy our target specifications of low power with high temperature. The speed of the scanning and timing response of micromirror is analysed.

A novel CMOS compatible device is designed fabricated and characterized two dimensional MEMS scanning mirror which is based on hybrid actuation mechanism. CMOS compatible fabrication process allows device to be monolithically integrated with CMOS IC. In this paper, a design of both electrothermal and EM actuation mechanism are integrated within the device for slow and fast scanning purposes. By electrothermal actuation in mirror, the two side scanning are vertical scans and horizontal scans.

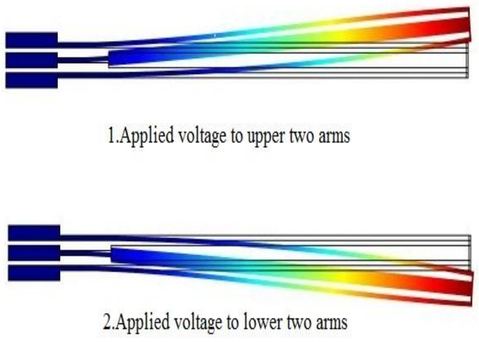
Micro mirror for laser tracking applications is achieved by large quasi-static deflection The principle used in micromirror is ultra-sonic motors which are based on the hemisphere. According to the deflection in mirror, the electrostatically driven oscillation leads to a periodic momentum will transfer by stages. The actuator is designed and fabricated in a standard SOI technology. In stage hemisphere, the system is excited in resonant (2900Hz) and non-resonant frequency (2000Hz). In resonant frequency operation, the maximum quasi state deflection of mirror +/−35.2◦ and maximum angular velocity 732◦/s is simulated and analyzed the crosstalk is less than 32%. In the nonresonant frequency operation, a quasi-deflection +/−10.5◦ , the cross talk is reduced less than 10% significantly.

Sangnik pal et.al., designed a circular micromirror with an optical scan of 60º. When an input voltage of 0.68V and power input of 11mW is applied. The mirror is actuated by aelectrothermal with a principle of joule heating and expansion multimorph bends and twists. The semicircular aluminum (Al) – tungsten(W) acts as a active layer in multimorph and a resistive heater. In circular micromirror a curved actuator design as advantages of maximizes the efficiency of a chip and high resonant frequency in structure deformation. The first three resonant modes of the micromirroris analyzed at 104Hz, 400Hz and 416Hz, respectively. Two dimensional (2D) optical scanning is achieved in second resonant frequency leads to low power consumption at single actuator beam.

Past research efforts have primarily focused in the design of electrothermalmicromirror with number of beams are limited to four. Also temperature distribution and displacement profile were analyzed by deriving equations with respect to the applied voltage. In this paper, a novel structure of MEMS based electrothermalmicromirror is designed using joule heating and thermal expansion module in COMSOL software. Finite Element Analyses is carried out by considering the governing equations with respect to the thermal expansion principle.

II. DESIGN AND PRINCIPLE

While designing the micromirror three major components used are mirror plate, spring and actuator. The electrothermalmicromirror has mirror plate is reflecting material. The actuator works in the Joules heating and thermal expansion principle. The conventional U beam actuator, there are two arms, wider arm and thin arm schematic diagram of bimorph actuator is shown in Fig.1.


1.Applied voltage to upper two arms

2.Applied voltage to lower two arms

Fig.1 Bimorph Actuator

When a voltage is applied between both arms, the thin arm acts as hot arm and wider arm acts cold arm which expands a device and cause to tilt or bend.

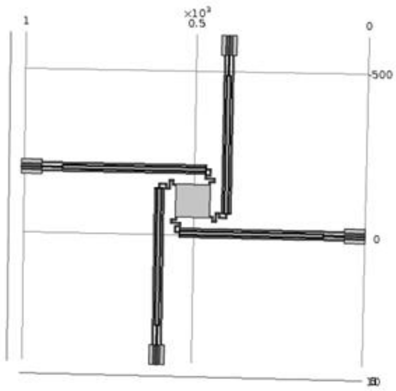


Fig.2 2D view of ElectrothermalMicromirror

The device acts as symmetry, the device reacts in an opposite direction. Due to bidirectional actuation in micromirror, the bimorph actuator has out of plane and in-plane displacement. In out of plane displacement, the actuator consists of copper as top layer and silicon dioxide layer as middle layer. In-plane displacement, the bottom layer consists of Polysilicon material. Silicon dioxide of 0.2 μm is an insulating material between the two layers. The springs of micromirror are a mechanical actuation between the thermal actuation of mirror plate and actuator. The bimorph actuator has two materials in CTE, temperature is increased and expands the actuator arms.

First the wider arm of polysilion is deposited and SiO_2 layer is coated as insulating material. Then, thin arm of copper, aluminium and nickel is coated above the insulated material. When voltage is applied between the thin arms, it tilts according to the thermal expansion and actuates. Then, the voltage is applied to the thin arm, wider arm remains cold it does not affect the thinner arm. The thin arm has high CTE when compared to the wider arm of low CTE because the compression is high at upper layer. The advantages of electrothermalmicromirror are voltage applied for four actuators leads to lateral displacement. To minimize the strain energy in micromirror that curls the bimorph layers.

The proposed system is to derive more displacement for electro-thermal micro mirror actuator by using different materials with different voltages. The electro-thermal micro mirror actuator is designed by using copper, silicon di-oxide, poly-silicon by 3 layered sandwiches like structure with large displacement is proposed. The accuracy of actuator is enhanced by studying the characteristics of the structure of software called COMSOL. The COMSOL software makes it possible to make the comparison between copper and aluminum with less applied voltage and produce more displacement.

III. DESIGN AND ANALYSIS OF ELECTROTHERMAL MICROMIRROR

The electrothermalmicromirrordesign is shown in Fig 2.

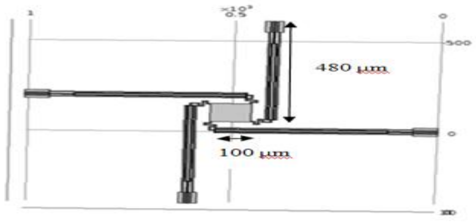


Fig.3 Dimension of electrothermalmicrogripper

It consists of micromirror, actuator and spring. The dimensions of the micromirror actuator are 480 µmlength, 4 µm in height and 12 µm in thickness is shown in Fig.3.

By applying voltage to the actuator arms the simulations are carried out in Comsolmultiphysics. The different materials with properties like aluminum, Copper, Nickel, Polysilicon, SiO_2 used for computing are given in the following table.I.

Material	Density (Kg/m^3)	Young Modulus (Pa)	Poisson's Ratio
Aluminum	2700	70x10^9	0.35
Copper	8960	1.28x10^{11}	0.33
Nickel	8908	1.90x10^{11}	0.31
Polysilicon	2300	1.6x10^{11}	0.22
SiO^2	2650	66.3x10^9	0.15

Table.I Different material Properties.

After the material dimensions is provided for actuators and then boundary conditions are specified. When the voltage is applied to the actuator arms is shown in Fig.4. To get accurate results in actuators, even load distribution is carried out by meshing.

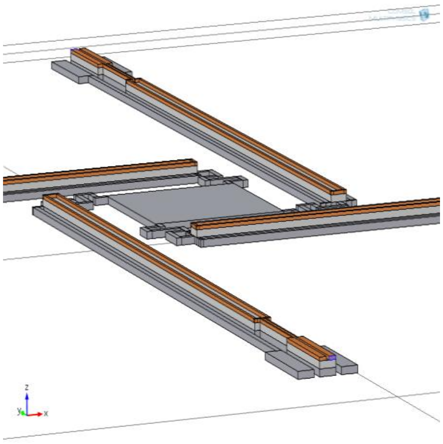


Fig.4 Electric Potential

IV. RESULTS AND DISCUSSION

The different loads with different materials results are analysed in Aluminum, Copper and Nickel are given in Table.1. While comparing the displacement result in different materials like Aluminum, Copper and Nickel.is shown in Fig.5.

Copper material provides high displacement while comparing the different materials in when voltage is applied. Copper has more displacement among all the metals. This metal requires less potential voltage. Dissipation of heat is less and copper melting point is high so aluminum is used for thin arm.

The micromirror has degree of freedom which is used in interferometry applications. When a single or two opposite actuators are turning on and other in turning off which has two degrees of freedom. The third degree of motion is the piston mode and is used for focusing or defocusing of mirror with lens. The piston mode brings equal actuation in mirror with applied voltage.

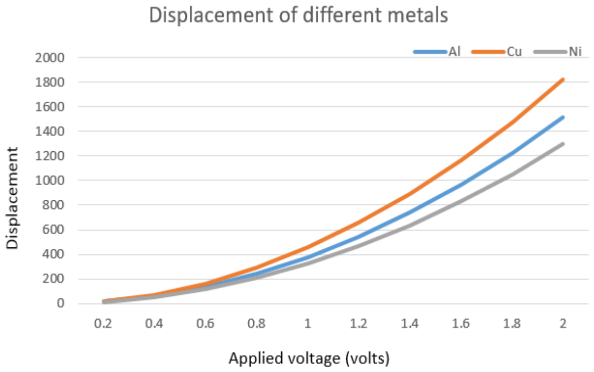


Fig.5 Displacement of different materials

When a voltage of 1 V is applied to the actuating arms, the mirror is tilted with the displacement of about 1042.2 µm shown in Fig.6.

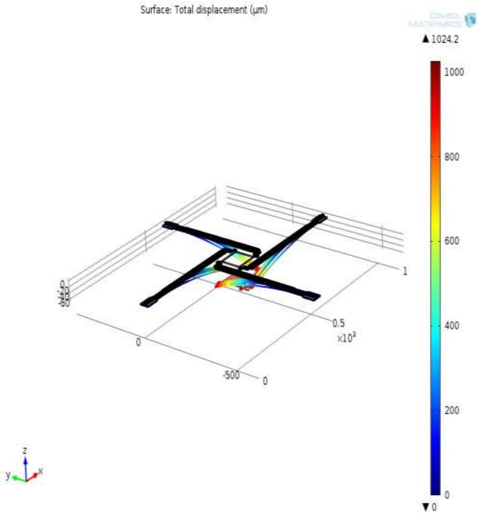


Fig.6 Displacement of Micromirror

In thermal bimorph, the tip displacement (*d*) with length *L*, total thickness, tb = (T1+T2). The temperature difference of ΔT is given in eqn. 1,

$$d = \frac{L^2}{2\rho} = \beta \frac{\Delta\alpha\Delta T\, L^2}{t_b}$$

$$\beta = 6\frac{(1+m)^2}{(\frac{1}{nm} + nm^3 + 2(2m^3 + 3m + 2))} \qquad (1)$$

$$m = \frac{T_1}{T_2}, n = \frac{E_1}{E_2} \qquad (2)$$

Where, *α*, *β*, *Ei*(i =1, 2), *m* and *n* are coefficient of thermal expansion (CTE), Curvature coefficient, elastic modulus, thickness and modulus ratios respectively.

Temperature Analysis

When voltage 1 V is applied, the displacement of about 1042.2 μm and the temperature of about $1.3072x10^4$. Aluminum is used as a heater element for bimorph layers in fabrication process. The temperature across the bimorph actuator is tuned by aluminum layer either increasing or decreasing its width and length. The temperature is inversely proportional to resistance of micromirror. Thus, the temperature is increased in mirror resistance is reduced with constant voltage which leads to power consumption in micromirror.

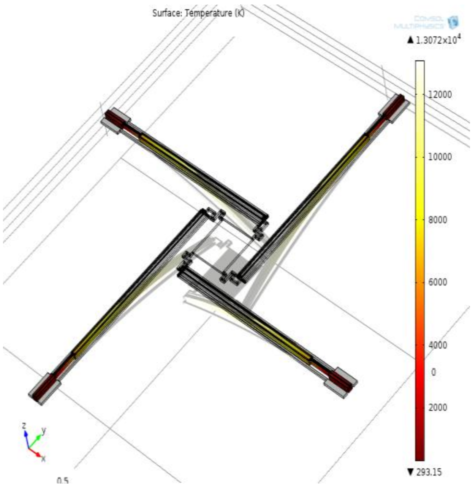


Fig.8 Temperature Analysis

V. CONCLUSION

MEMS based micro-mirror that is capable of producing electro-thermal micro-mirror actuator for optical switching, scanning, imaging and interferometry applications. The simple device is integrated to form a micromirror in Electro-thermal actuation is actuated by joule heating and thermal expansion principle. The performance of micromirror is analyzed with FEM in ComsolMultiphysics. By comparing different material of copper, Aluminum and Nickel, Al-SiO_2 has high displacement in higher CTE. Mirror can tilt with displacement of 1042.2 m and temperature $1.3072x10^4$ K with a applied voltage 1V. When constant voltage is applied, Temperature is increased so the resistance is reduced and power consumption is reduced.

VI. ACKNOWLEDGMENT

We thank Saveetha MEMS Design Centre, Saveetha Engineering College, Chennai for providing the facility to complete this project successfully.

VII. REFERENCES

[1] Jianliang You, Luis Flores, MuthukumaranPackirisamy, Ion Stiharu, Modeling the effect of channel bends on microfluidic flow, concave Research Centre, 1455 de Maisonneuve Blvd. West, Montreal, Quebec, H3G 1M8, Canada (2009).

[2] AkhilVaid, , Randhir Singh, ParveenLehana, Developement of microchannel fabrication technique and method to increase trench depth on PDMS, International Journal of Advanced Research in Computer and Communication Engineering Vol. 2, Issue 12, (December 2013).

[3] O.iRovenskaya, Computational study of 3D rarefied gas flow in microchannel with 90o bend, Dorodnicyn Computing centre, Federal Research centre, Computer science and Control of Russian Academy of sciences, Vavilova st.40,119 333, Moscow, Russia (Feb 2016).

[4] Annabel Krebs, Thorsten Knoll, Dominic Nussbaum, Thomas Velten, Polymer Based Fabrication Techniques For Enclosed Microchannels In Biomedical Applications,

[5] Fraunhofer Institute for Biomedical Engineering Ensheimer Str. 48, 66386 St. Ingbert, Germany, May 2011.

[6] X.Chen, D.F.Cui, L.L. Zhang, Design And Fabrication of Micro Fluidic Chip with Micro/Nano Structures, Nano/Micro Engineered and Molecular Systems, 2009. NEMS 2009. 4th IEEE International Conference, Jan. 2009.

[7] D.Mondal, C. RoyChaudhuri, Electrical Characterization of Biological Cells on Porous Substrate Using Comsol Multi Physics, Bengal Engineering and Science University, Shibpur, India,(2009).

[8] Xing Chen, Dafu Cui, Lulu Zhang, Micro Device For continuous isolation of Plasma From Whole Blood, Bio Medical Engineering and Informatics, BMEI 2008, International Conference, 2008.

AUTHORS PROFILE

K. Anitha Working as Assistant Professor, ECE at Saveetha Engineering College. She has 11 years of experiences in teaching. She has completed master degree in Applied Electronics and Her area of interest lies in Digitial Communication and Electronic Circuits.

P.MahizMathi Working as Assistant Professor, ECE at Saveetha Engineering College. She has 2 years of experiences and published 3 journals, attended 3 International Conferences. Her area of interest lies in MEMS and Microfulidics.

T. Aravind, Working as Assistant Professor, ECE at Saveetha Engineering College. He has 15 International and 3 National Journals in his credits and he has presented his work in 5 International Conferences. His area of interest is in Smart Grids and MEMS Sensors

S.Ramya Working as Assistant Professor, ECE at Saveetha Engineering College. She has 3 years of experiences and published 5 journals, attended 3 International Conferences. Her area of interest lies in MEMS sensors, Actuators and Microfluidics.