A Review on Electrostatic Micromirror

Umesh Uppal¹, Sandeep Singh², Poonam Beniwal³

¹MTech Scholar, ²Assistant Professor, ³Assistant Professor, Department of Electronic & Communication Engineering

Om Institute of Technology & Management, Hisar Haryana

1, uppal.umesh.25@gmail.com, ²Sandeep167hissar@gmail.com, ³pgc@omgroup.edu.in

Abstract— Micromirror is a very small mirror based on the principle of Micro Electro Mechanical Systems (MEMS). Micromirror application in areas like laser scanning displays, DLP Projection system and HDTV are realized using MEMS technology. Electrostatic actuation is one of the simplest actuation method based upon repulsive forces between same charges and attractive forces for different charges and the most widely used structures for this mechanism are electrostatically controlled prestressed micromirror.

Keywords— DMD, TI, Micromirror, COMSOL, FEM

I. INTRODUCTION

The DMD chip is a micromirrors matrix. Each micromirror is 16 μm square and there’s a gap of 1 μm between them, making it a 17 μm pitch. It reacts with a processor that allows each mirror to move in two directions that could refer to on or off. With this matrix and the fact that micromirrors reflect light, the system is able, when illuminated, to reflect the light and project an image on a screen, depending on the input signal generated by the electronic and the synchronization with the colour wheel [17,19]. Figure 1 shown a DMD chip of Texas Instruments (TI) Technology.

II. MICROMIRROR OVERVIEW

MEMS mirrors are achieved through a combination of two broad micromachining technologies, surface or bulk micromachining techniques. They have a number of attractive features, such as enormously dense structure size, small weight, potential low power and low cost, high reliability, and batched fabrication. MEMS mirrors have a large scale range from several micrometers to millimeters and a wide bandwidth in worked frequency from a low frequency (Hz) to a high frequency (kHz) in terms of different fabrications and applications [10].

By studying various MEMS mirrors, their basic characters can be derived and listed as the following:

- Fabrication processes based on surface micromachining or hybrid bulk/surface micromachining techniques
- Different materials adopted by micromirrors
- Various actuation mechanisms
- Self-assembly, assembly, or non-assembly processes for micromirrors
- Micromirror functions in optical systems: Digital, analogue, or fixed mirror

Electrostatically controlled micromirror is typically quite small, and arrays of such devices can implement a projection system. They serve as optical redirectors and similar reflection devices. The designing of prestressed micromirror and their comparison according to different materials are very useful at this scale and also used as structural or function materials with great success.

Different structures are designed using COMSOL (Common Solution Version). Depending on the magnitude of the deformations, we used to solve such simulations with a large-deformation analysis using a nonlinear or parametric nonlinear solver, noting that the latter is more likely to converge.

Thus this illustrative model uses the large-deformation analysis type with both the linear and parametric linear solvers. Actuators are used for the transformation of non-mechanical input energy into mechanical output energy. Electrostatic actuators have a long history dating back to the 18th century when several types of electrostatic motors were built. Electrostatic actuation is one of the simplest actuation method based upon repulsive forces between same charges and attractive forces for different charges and the most widely used structures for this mechanism are electrostatically controlled prestressed micromirror. It obeys the coulomb’s law. In 1784 Charles-Augustin de Coulomb found (by experiment) the law that governs the force that one charge exerts upon another. (Interestingly, Coulomb used a torsion balance similar in form to the one Cavendish used to verify Newton’s law of gravity thirteen years later. Cavendish’s balance, however, was much larger.)

Coulomb’s law applies to point charges, that is, charges whose physical dimensions are small compared to the distance separating them. (Ideally, a point charge would have all its charge confined to a mathematical point. There actually seem to be such objects: the electron, positron and a quark, for example, appear to be point charges.) Also, spherically symmetric charges can be treated as point charges (with all their charge concentrated at their centers) so long as their separation is large enough so that they do not touch one another.

According to this, the electric force acting on a point charge q₁ as a result of the presence of a second point charge q₂ is given by Coulomb’s Law:
like charges repel and unlike charges attract. Coulomb's law is a vector equation and includes the fact that the force acts along the line joining the charges. Like charges repel and unlike charges attract. Coulomb's law describes a force of infinite range which obeys the inverse square law, and is of the same form as the gravity force [9].

Any MEMS simulation software uses either rotoфф approaches. System level (or behavior alor reduced order or lumped parameter) modeling: This approach captures the main characteristic of a MEMS device. It provides aquick and easy method to predict the main behavior of a MEMS device. The requirement is that the device can be described by sets of ordinary differential equations and nonlinear functions at a block diagram level. This approach originated from control system engineering. The multi domain problem is avoided since, typically, the simulation tool sarephysically dimension less only, and the user interprets the input and output of the various block sin a physically meaningful way. Finite element modeling (FEM): This approach originated from mechanical engineering where it was used to predict mechanical responses to a load, such as forces and moments, applied to a part.

### III. LITERATURE REVIEW

Microelectromechanical systems (MEMS) have an unmatched ability to incorporate numerous functionalities into ultra-compact devices, and due to their versatility and miniaturization, MEMS have become an important cornerstone in biomedical and endoscopic imaging research. To incorporate MEMS into such applications, it is critical to understand underlying architectures involving choices in actuation mechanism, including the more common electrothermal, electrostatic, electromagnetic, and piezoelectric approaches, reviewed in this paper. Each has benefits and tradeoffs and is better suited for particular applications or imaging schemes due to achievable scan ranges, power requirements, speed, and size. Many of these characteristics are fabrication-process dependent, and this paper discusses various fabrication flows developed to integrate additional optical functionality beyond simple lateral scanning, enabling dynamic control of the focus or mirror surface. Out of this provided MEMS flexibility arises some challenges when obtaining high resolution images: due to scanning non-linearities, calibration of MEMS scanners may become critical, and inherent image artifacts or distortions during scanning can degrade image quality. Several reviewed methods and algorithms have been proposed to address these complications from MEMS scanning. Given their impact and promise, great effort and progress have been made toward integrating MEMS and biomedical imaging [1].

A Micromirror model is simulated using COMSOL Multiphysics, the results obtained from the simulation help to reduce the displacement associated with the stress developed due to the plating process during the fabrication of MEMS Micro mirror. The model consists of a square shaped Micro mirror with four serpentine or zigzag shaped beam. The results obtained for different material combinations showed that the best material combination was Aluminum 3003 for the Micromirror substrate and structural steel for the cantilever legs this reduces the stress at the edges. The reason for selecting steel for the Micro mirror substrate is to reduce the surface deformation as it is stiffer than Aluminum. The lift-off level and the associated stress for the Micromirror with S-shaped cantilever beams is 36x10⁻⁶ m and 0.032 N/m² respectively, which is lesser than that of the Micromirror with straight shaped cantilever beams (lift-off=50x10⁻⁶ m and stress level=0.0543 N/m²) [2]. This paper describes a Mem basis rectangle shaped Micro mirror with four straight cantilevers using COMSOL Multi physics. Research is carried out to design a micro mirror to reduce lift off stress. In this presentation, Aluminum 3003-H18 is used as a base material to make the legs or cantilevers and different material such as Aluminum 3003-H18, steel AISI 4340, Silver(Ag), Gold(Au), Iron, Structural steel are introduced together as micromirror materials with base materials to reduce the stress level. The best material combination is Aluminum 3003-H18+steel AISI 4340 which have less stress and uniformed roughness [3]. A study has been presented on applications and advantages of optical MEMS in different fields. Micromachining allows the tools of the integrated circuit industry, lithography and parallel processing to be applied to optical devices and systems. The payoff is integration of mechanics, fluidics, magnetics and optics into highly functional microsystems with numerous advantages in terms of functionality, flexibility, stability, sensitivity, size and, ultimately, cost. The application areas for these types of Optical MEMS include tunable optics, spatial light modulators, fiber optical communication devices and systems, opto-fluidic systems for biological and chemical analysis, and interferometric sensors. The augmentation of Optical MEMS by nanostructures has led to the development of Optical Nanosystems based on photonic crystals and ultra-compact optical resonators that are applicable to a wide range of systems across all the sub disciplines of optics [4].

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. Few base materials were introduced such as Alumina, Aluminum 3003 H18, Aluminum 6063 T18, Copper and Aluminum. To make the leg or cantilever more efficient the structural steel was
introduced. The characteristics of lift-off prestress and surface deformation were also studied. According to this paper, the best result is achieved by using Aluminum 3003 + Structural steel [5].

An individual micromirror of size in order of a few micrometers to obtain maximum tilt angle with a minimum driving voltage designed. The micromirror is based on the electrostatic principle and performed by using COMSOL multiphysics. Different beams are considered and stress is compared to each other. Serpentine Beam has minimum lift-off stress that is 2.498x10⁶ N/m². This device can be used for an optical switching and communication application [6].

MEMS based electro thermal actuators and micromirror was designed and analysed using COMSOL Multiphysics 4.2a. A 4-arm U-shaped actuator with a micromirror has been designed. The driving voltage is given in the anchor end which produces larger displacement. For various applied voltage, it produces displacements in eight different directions. By applying 10V, the maximum Stress obtained is 3985 N/m and the stress increases exponentially with increasing voltage. The Maximum Displacement is 3.65μm and the maximum current density obtained is 5388.6 A/m [7].

The design and simulation results of an electrothermally driven micromirror that is capable of producing 3D spatial movement. Electrothermal actuation is used to achieve in-plane as well as out-of-plane displacements. The coupled multiphysics simulation and study of the electrical, thermal and most importantly the mechanical behavior of the mirror system is done using COMSOL Multiphysics. The device has an in-plane displacement range of 3.56 μm (1.78 μm in either direction) and an out-of-plane displacement of approximately 22μm is achieved for an input voltage of only 2V. The transient cooling response has also discussed and response time is found to be satisfactory. The high temperature generated due to Joule heating is drawback of the thermal actuation process. This is however offset by the simpler fabrication processes required for these devices. The ability of precise control of movement of the micromirror in space is likely to lead to potential applications in diverse fields [9].

To optimize the design of micromirror in order to achieve the maximum deflection of micromirror with minimum pull in voltage. For this an electrostatically-actuated, aluminum, torsional micromirror (20x20) microns, is presented. The design is repeated in 25x25 arrays for high-speed deflection of incident light. The micromirror arrays are fabricated using an AI-MEMS fabrication process. The developed fabrication process uses a 4 micron sacrificial photo definable polymer and a submicron thick aluminum layer suspended over patterned gold electrodes. The sacrificial polymer was plasma ashed to release the deformable aluminum structures .The COMSOL Multiphysics finite element analysis environment is utilized to study the optimized design. Within the finite element analysis software, a 132 V electric potential is applied to an underlying electrode in order to produce a minimum of 5° tilt which yields a downward mirror-edge displacement of 1.39 μm into a 4 μm gap between the electrode and the bottom of the micromirror. When the electric potential is removed, the micro-mirror has a settle time ~10 μs .The driving voltage was calculated while varying multiple geometric parameters of themicromirror. In order to tilt to 5°, the driving voltage can be kept low by increasing the size of the electrode and by increasing the area of the micromirror that is attached to the torsional beam. The driving electrode, in the case, is 18μm x 15 μm x 0.5 μm and the length, L, of the micromirror is 18 μm . Results shows the required driving voltage drops as W increases and suggests that a long, thin torsional beam is desired in order to keep the driving voltage minimum. Theoretical and FEA was used to approach an optimal design within the application-imposed constraints .It also suggests future work will focus on packaging the micromirror arrays along with rigorous testing and characterization. A second generation design to address any issues discovered along the way, and enable individually addressable micromirrors within the overall array [10].

Efforts are made to optimize design of micromirror to reach the largest lift-off height. A novel piston/tip/tilt micromirror based on Poly- MUMPs process is designed and explored. The hexagonal micromirror with a diameter of 450 μm consists of three supporting bilayer cantilevers and a mirror plate .Two kinds of cantilevers are introduced and both designed structures of the bilayer cantilevers, formed with a polysilicon layer and a gold layer, elevate the mirror plate according to residual stress-induced bending. The first design had gold film deposited only on the first half of the cantilever, whereas the second design had gold film deposited on the entire cantilever. Both designs had the same geometry, consisting of two 195-μm-long beams. Poly2 should enclose 3 μm of Gold on each side .An analytical solution was conducted on a rectangular cantilever to estimate the elevated height of the free end of the cantilever. The lift-off heights of the micromirror with the Design I and Design II cantilevers are 3.9 and 2.8 μm, respectively. Both analytical solution and FEA performed in COMSOL are illustrated to calculate the lift-off heights of the different cantilever structures .Calculations show that the analytical result is in accordance with the FEA simulation results, whereas stresses are applied longitudinally only . Results of a three-dimensional (3D) simulation with two direction stresses applied shows the elevated height to be proportional to the width of the cantilever and the length of the gold layer .Simulation results also show the lift-off height of the micromirror with the Design I cantilever to be larger than that of the micromirror with the Design II cantilever, although the Design II cantilever has a higher deflection than the Design I cantilever. These two different cantilever designs of micromirrors are fabricated, and the lift-off heights of each are measured using Veeco optical profiler. The measurement results and simulation results show good coincidence [12].

A new three-axis electromagnetically actuated micromirror structure has been proposed and fabricated. It is electromagnetically actuated at low voltage using an external magnetic field. The purpose of this work was to obtain a three-axis actuated micromirror in a mechanically robust structure with large static angular and vertical displacement at low actuation voltage for fine alignment among optical. The mirror plate and torsion bars are made of bulk silicon using a SOI wafer,
and the actuation coils are made of electroplated Au. As per results the maximum static actuation values of the three-axis actuated micromirror have been measured as \( \pm 4.2^\circ \) for x-axis actuation and \( \pm 9.2^\circ \) for y-axis actuation, respectively. The actuation voltages were below 3 V for all actuation. The maximum static vertical displacement was measured as \( \pm 42 \mu m \) for z-axis actuation. The simulated resonant frequencies are several kHz, and this implies that the fabricated micromirror can be operated in sub-millisecond order. The measured radius of curvature (ROC) of the fabricated micromirror is 7.7 cm, and the surface roughness of the reflector is below 1.29 nm which ensure high optical performance such as high directionality and reflectivity. The additional degree of freedom with z-axis actuation can decrease the difficulty in the assembly of optical components and increase the coupling efficiency between optical components. The mechanically robust torsion bar and lifting bar structure formed by bulk silicon allows the proposed micromirror to stably operate end extends the lifetime of the fabricated micromirror. The third configuration with an offset since the air gap along the far edge thereby creating the most torque. On the contrary, the charges are uniformly distributed in the second stacked micromirror configuration with an offset, since the air gap along the surface is quite uniform while rotating. Therefore, less torque is generated [15].

Based on shape memory effect of the sputtered thin film shape memory alloys, different types of micromirror structures were designed and fabricated for optical sensing application. Using surface micromachining, TiNi membrane mirror structure has been fabricated in this study, which can be actuated based on intrinsic two-way shape memory effect of the free-standing TiNi film. Using bulk micromachining, TiNi/Si and TiNi/Si3N4 microcantilever mirror structures were fabricated. The result shows the microbeams are either bending up or flat at room temperature, and then becomes flat or bends up with either heating the structure above 80ºC or applying voltage in TiNi electrodes (due to phase transformation and shape memory effect), thus causing the changes in angles of micromirror [16].

An electrostatic torsion micromirror is designed using the optimized spring-shaped torsion beams and U-shaped groove supporters to reduce pull-in voltage for low-voltage applications. A theoretical model has been developed to represent the relationships among the applied voltage, torsion angle and vertical displacement. The pull-in effect has been investigated. These include the pull-in angle, pull-in displacement and pull-in voltage, which depend significantly on the normalized electrode size and position, groove position, and ratio of the bending and torsion effect. The pull-in instability mode of the torsion micromirror is mainly determined by the groove position and ratio of the bending and torsion effect. An effective torsion and bending stiffness model is used to optimize the geometry of the torsion beams, and to reduce the pull-in voltage of the torsion micromirror below 2 V for low-voltage applications to ensure that it is compatible with the IC technologies. The U-shaped groove supporters are applied in the theoretical model to adjust the effective bending stiffness of the torsion beam and to switch the instability mode of the torsion micromirror [17].

They designed and fabricated an addressable 4x4 array of micromirror capable of providing up to 90 of angular deflection. In this, each micromirror is comprised of a single-crystalline silicon mirror plate supported by aluminum springs, which provides an extremely flat reflective surface and a compliant spring material that enables the integration of the device into a limited area without mitigating its performance (i.e., total angular deflection). The device is fabricated using a combination of surface and bulk micromachining processes, such as electroplating, bulk wet etching and XeF2 etch processes. Selective actuation is accomplished by the use of an electrostatic clamping force on each mirror plate. A mirror rotation angle of more than 80 can be obtained by applying an external magnetic field, and this angle can be further increased by the use of an electrostatic force. The designed structure can be used in microphotonic applications [18].

An overview of MEMS technology with emphasis on optical applications. Discussions of MEMS technology, fabrication tool, MEMS/SCAD tool, and MEM applications for sensor and actuator concentrated on micro-optics applications have been presented in this paper. Applications of MEMS devices vary in many fields from automotive transducers, biomedical technologies, communication systems, robotics,
aerospace, micro-optics, industrial sensors and actuators. The applications of MEMS in optics include display systems, optical switching, optical communication, optical data storage, optical processing and interconnection, and adaptive optics. Examples of micro-optical components and systems are also described in this paper [19].

IV. RESEARCH METHODOLOGY
The micromirrors are so designed that they can be optimally implemented in optical reflection systems to increase the efficiency of the system and to give large angle of deflection.

V. CONCLUSION
Micromirror devices are based on small mirrors which vary in the range of millimeters. They may be used in projectors inertial sensors. These mirrors used Micro Electro Mechanical System, so that their states(on/off) are controlled by applying a voltage between the two electrodes around the mirror array. Electro static forces also controls micro-mirror.

REFERENCES
[3]. P. Bansal et al. (2014)“Design and Analysis of Stress Level in Electrostatically Controlled Micromirror”PISER -Progress In Science and Engineering Research Journal ISSN 2347-6680 (E),Vol.02, Issue: 03/06 May- June; Bimonthly International Journal.
[16]. “MEMS Recent Developments, Future Directions” Published in 2007 by Electronics Enabled Products Knowledge Transfer Network Wolfson School of Mechanical and Manufacturing Engineering Loughborough University, Loughborough, Leics LE11 3TU.