# A Tilting Micromirror with Well-Controlled Digital Angle Through Constrained Lever Structure

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## ABSTRACT

In this paper, a tilting micromirror device that can achieve designed angle is proposed. A lever structure, driven by electrostatic actuators, was used to enlarge tilting angle. To obtain precise deflecting angle, the lever structure is constrained by the substrate. By applying a voltage, the electrostatic actuators drive the lever down to the substrate such that the micromirror device on the opposite side of the lever structure could be lifted. PolyMUMPs process was used to fabricate proposed micromirror devices. The actuators are simulated to investigate characteristics of the micromirror devices. Experimental results had indicated that the micromirror device could reach 10-degree tilting angle with 80V driving signal with 6.4% relative error compared to designed model.

**Keyword**: micro-mirror, lever, PolyMUMPs

## 1.INTRODUCTION

There had been tremendous researches focused on the development of optical crossconnects (OXCs) block for optical communication applications [1]. In the optical fiber networks, a large quantity of optical switches, used to bypass failed nodes to reconfigure the network, are needed to preserve the network reliability. In addition, the information exchange is accomplished by switching and routing optics. MEMS technologies provide a solution to manufacture hundreds of optical switches that enable the cross-connect of light signals completely in the optical domain. The advantages of MEMS-based optical switches include large switching contrast, low unit cost/size/weight, small crosstalk, wavelength and polarization insensitive, and fast switching time [2,3].

Switching accuracy is one of requirements in designing the micromirror devices for optical switching applications. With high-accuracy switching capability, the loss during the light switching state could be controlled. In order to achieve the switching accuracy, several mechanical structures based on hinge or joint designs had been developed. However, the hinge or joint design usually causes tolerance in the designed mechanism that challenges the desired accuracy. Alternatively, *Toshiyoshi* et al. [4] realized an optical switch matrix with 90-degree etched walls as limiters. In addition, *Lin* et al. [5] fabricated a back-to-back optical switch array with a bonded plate as 45-degree

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stoppers. However, specific fabrication processes such as flip-chip bonding are required to integrate micromachining technologies that may bring fabrication yield problem.

In this regard, a tilting micromirror device with well-controlled digital angle through constrained lever structure is proposed. Without the aid of other special manufacture process, surface micromachining technology was used to design and fabricate micro-mirror device. By using the gap of the sacrificial layer of the process in conjunction with designed lever structure, the popped-up angle of the micromirror could be obtained accurately. When the electrostatic force is applied, the actuators will make the lever to contact with the substrate. As a result, the mirror plate on the other side of the lever structure could be lifted to reach a designed tilting angle. Preliminary experiments had demonstrated that the fabricated micromirror could reach designed 10-degree tilting angle with 6.4% relative error. The design concept, micro- mirror layout, and experimental results are given in the following sections.

## 2. DESIGN CONCEPT

### 2.1 Lever Structure

Typically, lever structures are used to amplify small displacement or improve actuating force. As shown in Fig. 1, by applying a force at position A, a respective force/deflection will be generated in position B, which follows the given force/torque balance equations (1) and (2). Note that, a small deflection at position A could result a large deflection angle at position B.

$$F_A + F_B + F_C = 0 \tag{1}$$
$$F_A \cdot L_A = F_B \cdot L_B \tag{2}$$

where $F_A$ is the force applying at position A, $F_B$ is the force generated at position B, $F_C$ is the force that support the lever at the rotation joint, $L_A$ is the length between position A and rotation joint, $L_B$ is the length between position B and rotation joint, and $d$ is the gap between rotation joint and the substrate.

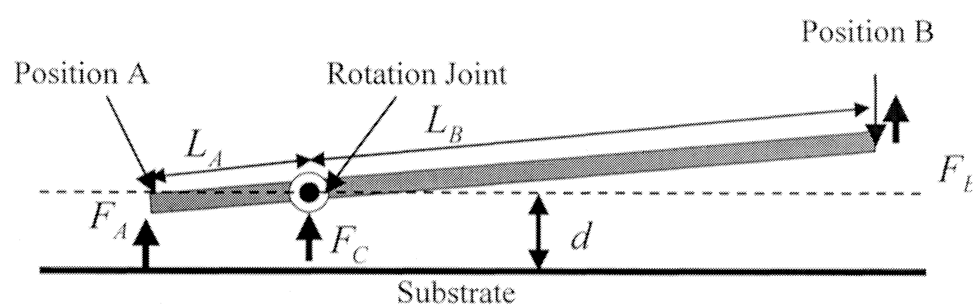

Fig. 1: Lever Structure

Note that once the lever structure is constrained by the gap $d$, the angular orientation of position B is obtained by using the following relation:

$$\alpha = \sin^{-1} \frac{d}{L_A} \quad (3)$$

### 2.2 Actuator

To actuate proposed lever structure, a digital/analog electrostatically-driven actuator mechanism is used here. As shown in Fig. 2, the actuating mechanism is composed of electrostatic actuators with nails and clamped torsion beams. Instead of actuating MEMS device to move in a horizontal direction [6], the actuators are designed as a clamp-clamp actuating mechanism. While *Lin* [7] had demonstrated the clamp-clamp actuating mechanism could reach digital/analog states, we utilize the digital characteristic of the actuator to generate lever contact force.

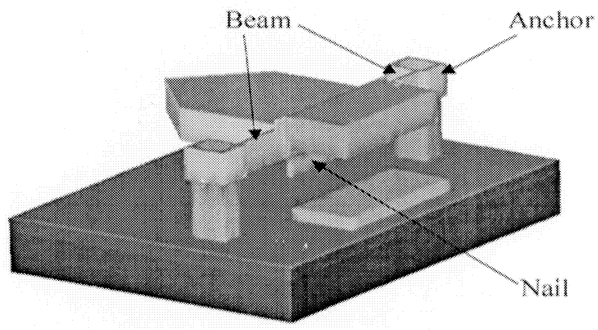


Fig. 2: The digital/analog electrostatic actuating mechanism

Fig. 3 shows the characteristics of the actuator simulated by using CoventorWave [8]. It is clearly to see that the pull-in of the actuator could be obtained when the applied voltage is increased to 60V. As a result, the actuator could be used to drive the lever structure in one side of the lever structure such that mirror plate could be lifted accordingly.

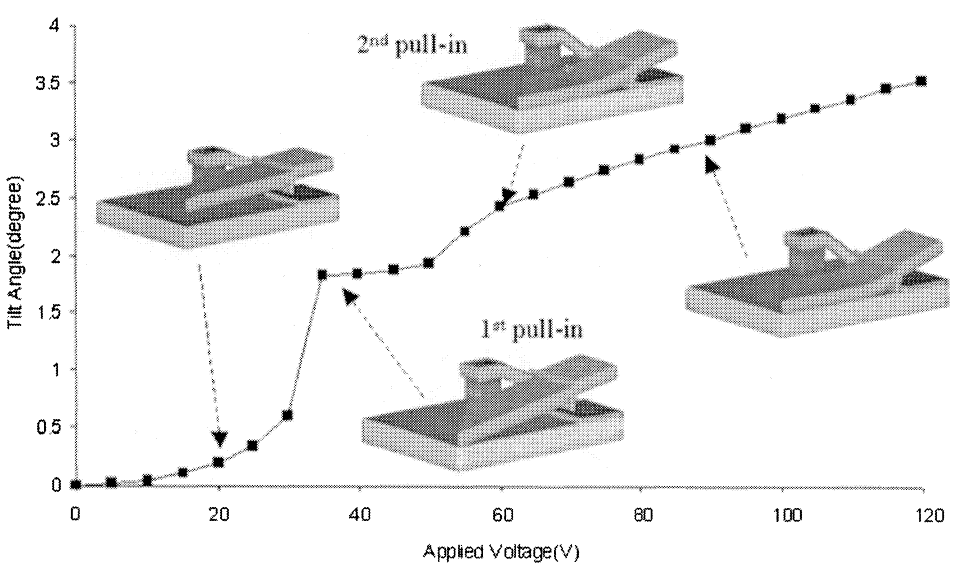


Fig. 3: Simulation of the actuator

### 2.3 Layout Design

By utilizing the proposed lever structure and actuating mechanism, micromirror with precise rotating angle could be designed here. Fig. 4 shows the layout design of the proposed micromirror device. The device was fabricated through Cronos/MEMSCAP PolyMUMPs process [9]. It consists of a micromirror, lever structure and two electrostatically-driven pushing actuators. The diameter of the mirror is 200μm. The actuators are fixed on the nitride and provide force to actuator lever structure once the electrostatic force is applied. The torsion beam is designed as rotation joint of the lever. An anchor plate is designed to support the torsion beam. Several dimples and etching holes were designed on the mirror surface to avoid the sticking problem, and ease the release procedure. A 0.75μm oxide layer (PSG2) was trapped between two polysilicon layers to enhance the surface flatness of the mirror. Note that the nails are located on the top of the driving (position A) end of the lever.

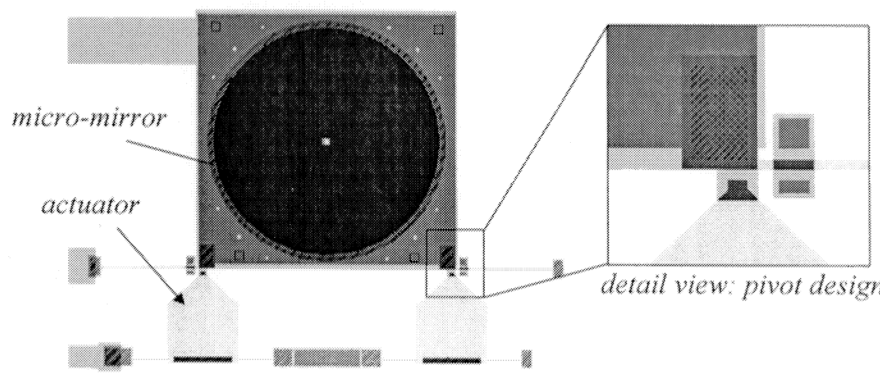


Fig. 4: Layout of the micromirror with lever structure

To realize a lever structure in PolyMUMPs, the sacrificial layer is used to obtain an accurate gap $d$ such that the precise angle of the mirror could be obtained. The cross section view of actuating lever structure is shown in Fig. 5.

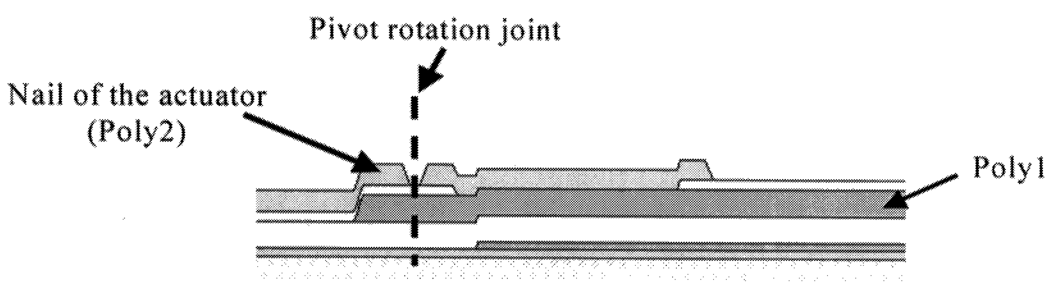


Fig. 5: The cross section view of actuating lever structure

Finally, Fig. 6 shows the SEM picture of the fabricated micromirror device after using the standard release process in releasing the sacrificial layers. When a voltage is applied to the actuator (poly2) and substrate, the nail of the actuator will make contact with the lever so that the micromirror in the other side of the lever can be tilted to the designed angle $\alpha$.

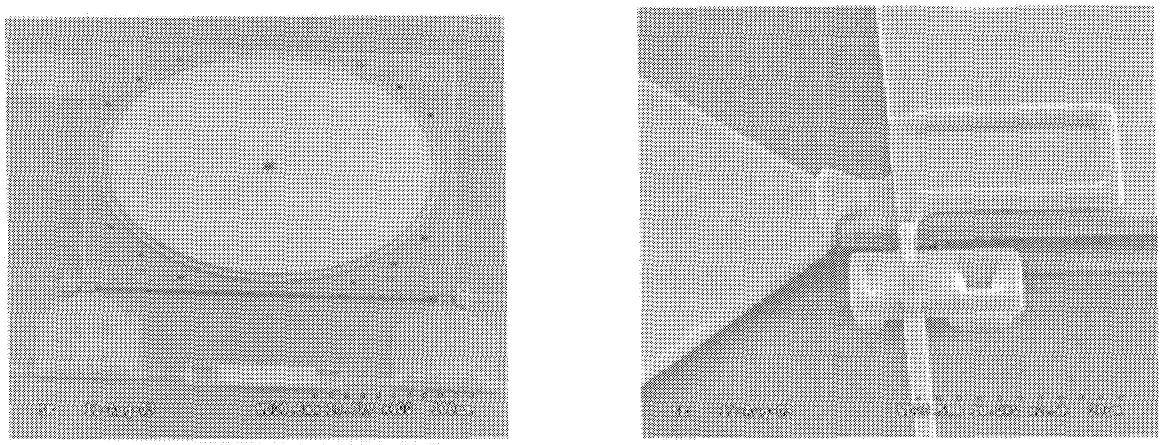

Fig. 6: Overview of fabricated micromirror device (left), and detail of lever structure (right)

Note that, the length of $L_A$ is 7μm, and gap $d$ is 1.25μm, the tilting angle $\alpha$ of the presented micromirror design is:

$$\alpha = \sin^{-1}\frac{d}{L_A} = \sin^{-1}\frac{1.25}{7} = 10.28 \quad \text{(degree)}.$$

## 3.EXPERIMENT

In order to examine the fabricated micromirrors, a simple optical testing configuration as shown in fig. 7 is used for preliminary measurement. An incident light form laser is focused on the mirror and thus reflected it onto the screen. By applying voltage to actuate the micromirror, we could record the moving displacement of the spot on the screen such that the characteristics of the tilt angle could be obtained. Fig. 8 shows fabricated device wit635Xhout applied voltages. Table 2 lists two measurement results of tilting angle of the fabricated micromirrors with 80V driving signals. In comparison to the previously predicated tilting angle, the relative errors are within 6.4%, which shows the reliability of the present design in controlling the angle of the micromirrors for precise optical switching. The error is occurred from the measurement errors and the fabrication variations.

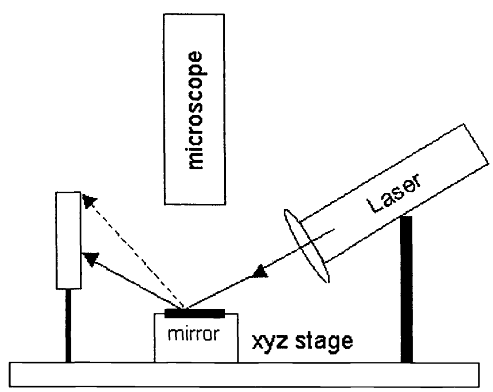


Fig. 7: Optical testing configuration

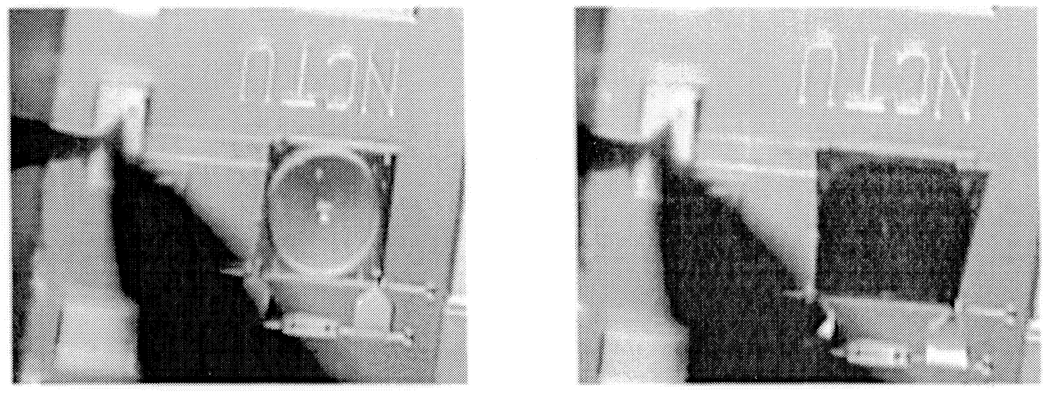

Fig. 8: (left) not actuated (right) actuated

| Device | Tilting Angle (degree) | Relative error |
|---|---|---|
| I | 9.62 | 6.4% |
| II | 9.81 | 4.6% |

Table 2: Measured results of tilting angle

## 4.CONCLUSION

In this paper, a surface-micromachined micromirror with accurate tilting angle had been designed and fabricated. The micromirror is driven by an actuated lever structure such that a large tilting angle is achieved. PolyMUMPs process was used to fabricate proposed micromirror devices. Experimental results had indicated that the micromirror device could reach 10-degree tilting angle with 80V driving signal with 6.4% relative error compared to designed model.

## 5. ACKNOWLEDGEMENT

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