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Novel Design for Optical Scanner with Piezoelectric Film by MOCVD

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1. Introduction

Scanned LASER beam can be used for wide variety of applications such as a LASER display and a LASER range finder. Optical two dimensional micro mirror scanner is a key device for these applications. The conventional 2D micro mirror scanner can be realized by a combination of orthogonal inner and outer gimbal-structures, which are supported by the torsion bars [1]. This kind of design is required larger footprint comparing with one- dimensional scanner.

We developed a novel design of piezoelectric 2D resonant optical scanner, which consists of mirror plate, a pair of torsional bars and a pair of bending mode rotational actuators, to realize a small footprint compared with mirror size. The piezoelectric material for actuator is Lead Zirconate Titanate (PZT). The PZT film must be thicker than 1μm to achieve sufficient power to actuate a mirror. we could show the ability of MOCVD-deposited 1.6μm film enough to actuate MEMS device like scanning mirror.

2. Device structure and fabrication

Figure.1 shows the device structure from top view. Overall device size is 2.5mm x 2.5mm and mirror diameter is 1mm. Four PZT unimorph actuators are located around the mirror with Pt upper and lower electrodes. The device has the layered structure of SOI/SiO_2/Ti/Pt/PZT/Pt. SOI wafer with 20 μm-thick Si device layer, 1μm-thick buried SiO_2 box layer and 400μm-thick Si handling layer is utilized as substrate. PZT films were deposited by Liquid Delivery type Metal Organic Chemical Vapor Deposition (LD-MOCVD) method using semi-homemade apparatus. Precursors are $Pb(DPM)_2$ for Pb, $Zr(IBPM)_4$ for Zr and $Ti(Oi\text{-}Pr)_2DPM$ for Ti. Each precursor are mixed into solvent in each bottles and delivered to vaporizer. Vaporized gas is introduced to reaction chamber with carrier and crystallized PZT film is deposited on the substrate. Thickness of PZT film and Pt electrodes are 1.6μm and 0.24μm. Upper and lower electrode are formed by reactive ion etch (RIE) with CF_4 and Ar. PZT and SiO_2 are etched by RIE with CHF_3 and Ar. Then, the handle layer of the SOI is etched from backside to release the scanner from the substrate by Deep-RIE with SF_6/C_4F_8. Figure.2 shows the fabricated device. Brighter areas on the surface in picture are PZT actuators with Pt electrodes. The mirror is supported with connecting narrow beam by four arc shaped PZT actuators.

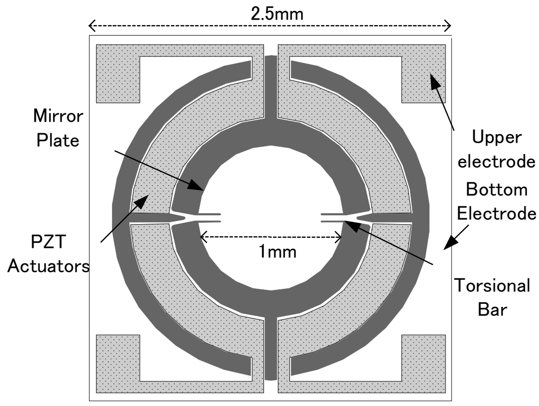
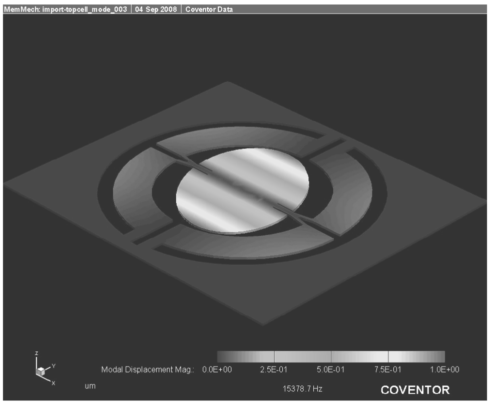


Fig. 1 Device structure

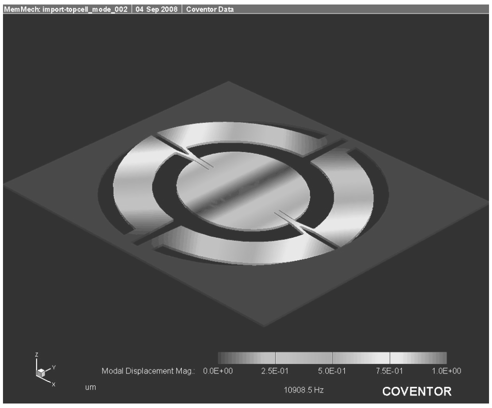
Fig. 2 Fabricated device

3. Actuation mechanism and Simulation

The mirror scanner is driven at resonant frequency of torsional and bending mode for 2D actuation. The torsional rotation of mirror can be used for horizontal scanning and the bending rotation of mirror can be used for vertical scanning. Figure.3 shows the numerical simulation results using finite element method for (a) torsional mode rotation at 15.3 kHz and (b) bending mode rotation at 10.9 kHz by CoventorWare™. This result shows that 15kHz vibration of this structure makes the mirror rotate to torsional rotating actuation and 10kHz vibration makes the mirror rotate to bending actuation. We can get 2D beam scanning with both 15kHz and 10kHz vibrations at the same time.

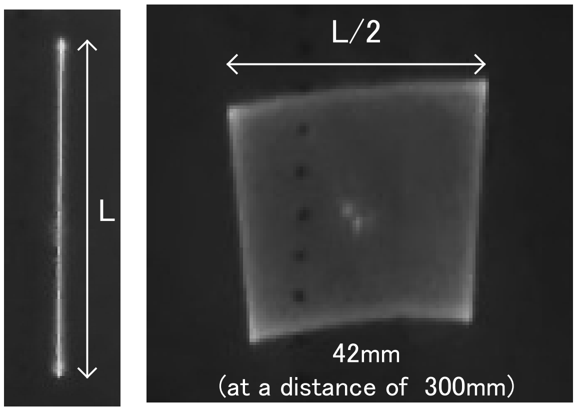


(a) Torsional mode at 15.3kHz



(b) Bending mode at 10.9kHz

Fig. 3 Modal analysis



(a) 1-D scan (b) 2-D scan

Fig.4 Scanned laser beam

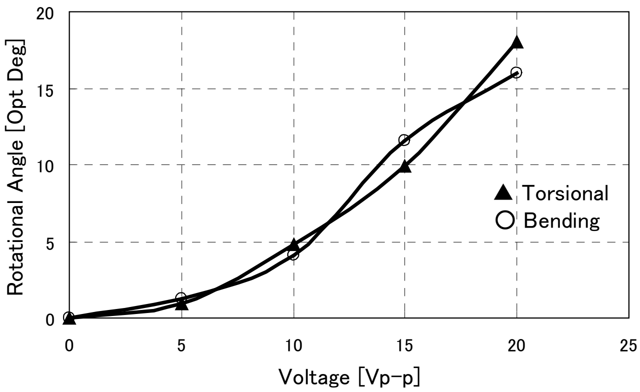


Fig. 5 Rotational angle (optical) against Voltage

Some of applications do not require raster like scanning. For instance, laser range finder does not care of order of pixels to capture. Further more, even laser display can be realized with relatively complex laser beam control by advanced electronics on non-raster-scanning [2].

The scan image by this device is not raster-type but Lissajous figure. When the ratio of vertical frequency to horizontal frequency is irrational, Lissajous figure does not close. Unclosed-Lissajous figure shifts the position gradually. The shifted Lissajous figure makes scan all the pixel points on 2-D image frame within a certain time interval.

4. Experimental results

Torsional rotation occurs on appling driving voltage to one of the four electrodes at around 15kHz. Fig. 4 (a) shows the scanned laser beam in resonant mode. In addition, bending rotation are integrated on appling driving voltage to another one of the rest three electrodes at around 10kHz. We can get the un-closed Lissajous scanning image by adjusting the frequency. Fig. 4 (b) shows 2D un-closed Lissajous scanning image.

Figure.5 shows optical scanning rotational angle against actuation voltage at resonant frequency.

5. Conclusion

An optical scanner with piezoelectric film by MOCVD was designed, fabricated and evaluated. Overall device size is 2.5mm x 2.5mm and the mirror diameter is 1mm. Scan angle of torsional and bending rotation are 17 deg and 16 deg at 20 V in atmospheric ambient. The angle in 2-D is about the half of 1-D. Resonant frequency of torsional rotation and bending rotation are 15kHz and 10kHz.

Acknowledgments

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References

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