A 2-D MEMS Scanning Mirror Using Piezoelectric PZT Beam Actuators

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Abstract

A silicon micromirror driven by a piezoelectric Pb(Zr,Ti)O\textsubscript{3} beam actuator has been demonstrated for two-dimensional scanning mirror applications. The mirror is micromachined from the device layer of an SOI wafer, while the piezoelectric beam actuator contains multilayers of Pt/Ti/PZT/Pt/Ti/SiO\textsubscript{2}/Si which is deposited and released from a SOI wafer. A 1x10 PZT arrayed actuator are separately arranged in parallel on a Si beam. Bending mode is measured at 34Hz while the torsional mode is measured at 197Hz. We demonstrated 2-D raster scanning patterns by applying AC bias of 34Hz on half of the 10 actuators and 197Hz on the other half actuators.

Keywords: Microelectromechanical Systems (MEMS), Optical MEMS, Scanning mirror, Piezoelectric actuator, PZT

1. Introduction

Scanning micromirrors based optical MEMS devices have been conceptualized for a large range of image display applications such as projection display [1], biomedical imaging [2], barcode scanner [3]. A wide variety of designs for 2-D microscanners have also been reported in the literature, with most of them deploying more than one set of actuators at different portion of the mirror for 2-D actuation. Examples of such scanning devices include actuators fabricated all round the circular micromirror [4,5] or actuators attached on 2 opposite sides of the square micromirror [6,7]. However, these devices often have complicated designs which have to be realized by complex, time consuming fabrication processes, often accompanied by bulky packaging. Hence, it is important to create simpler single mirror design so that the device is able to achieve 2-D scanning pattern under resonant condition.

A simple and compact mirror design has been demonstrated by S. Schweizer et. al. [8]. This design allows for orthogonal angular motions to be actuated by the same thermal bimorph, making 2-D scanning possible through the simultaneous thermo-mechanical excitation of the “L”-shaped cantilever at non-resonance and resonance states. Another similar mirror design concept was developed by H, Urey et. al. in 2007 [9]. A magnetic permalloy film was electrodeposited on the mirror plate to aid vertical actuation while a composite polymer actuator connecting the mirror was used for out of plane actuation. Hence, 2-D scanning can be achieved by using only one actuation coil. However, the presence of the external coil makes compact packaging highly demanding.

Briefing speaking, the ease of fabrication of a MEMS microscanner and compactness of the overall package are often dominated by the complexity of the mirror design and actuation mechanism. In this paper, we reported a novel 2-D scanning mirror driven by 1x10 PZT actuator array integrated on a silicon beam.
2. Design of micromirror

A schematic diagram of the microscanner demonstrated in this paper is shown in Fig.1(a). Ten patterned PZT thin films are arranged in parallel, along one of the sides of the micromirror. Individual contacts to the actuators were made, with bond wires connecting the contacts to the metal package to allow for external biasing. All the ground electrodes of the PZT actuators electrically connected and a common ground contact is shared among all the actuators. The mirror has a size of 5mm x 5mm, with the Si substrate beneath the mirror being 5mm long x 5mm wide x 0.4mm thick. The cantilever is 3mm long x 5mm wide x 5µm thick while the individual PZT actuator being 3mm long x 0.24mm wide x 3µm thick. Fig. 1(b) shows an optical photo of the device bonded onto a metal package and the pads connected by Au wire to the metal pins of the package.

The novelty of our scanner design lies in the mirror’s ability to develop an out-of-plane degree of freedom and overcome the limitations of the actuation range of the PZT cantilevers. This is made possible from the knowledge that the microsystem of bending actuators and mirror being equivalent to a harmonic oscillator with a distributed mass suspended by a mechanical spring, hence making multiple resonant modes with all six degree of freedom of 3-dimensional space to be probable

3. Device Microfabrication

As shown in Fig. 2(a), a SOI substrate of 5µm thick Si device layer and 1µm thick buried oxide (BOX) was used as the starting material for device A. A thermal oxide layer of 0.37µm was created from the Si device layer surface. Pt/Ti layers were deposited by sputtering to form the bottom electrodes, followed by deposition of 3µm of PZT thin film by sol-gel process. Finally, the top electrode is formed from multilayered deposition of Ti/Pt/Ti by sputtering. In Fig. 2(b), the top and bottom multilayered electrodes are etched away by Ar-ion while the PZT thin film were wet-etched away. In Fig. 2(c), a 0.8µm thick oxide layer were deposited by RF-magnetron sputtering to serve as insulation. Contact hole etching were done by reactive ion etching (RIE) with CHF 3 gas. In Fig. 2(d), Pt wire of 1µm with Ti adhesion was deposited by RF-magnetron sputtering and later etched by Ar ion. In Fig. 2(e), the thermal oxide, structural Si and BOX were etched by RIE using CHF 3 gas (SiO 2) and SF 6 gas (Si) to open the area of cantilever and mirror. Finally, in Fig. 2(f), the substrate Si and BOX were etched from the backside to release the mirror and the cantilever.
4. Experimental Setup

The schematic drawing of the measurement setup used in this experiment is illustrated in Fig. 4. A He/Ne laser source of wavelength 632.8nm is used in this paper. The incident light from the source located at the left hand side is reflected by the mirror and propagates toward the screen on the right side with an optical deflection angle of \( \theta \), where \( \theta \) denotes the mechanical deflection angle. The screen is placed and fixed perpendicularly to the reflected light when the mirror is initially unbiased. When the actuators are driven in ac mode, a mechanical deflection angle of \( \pm \theta \) is introduced to the mirror. The resulted reflected light will be deviated from the original light path with an angle of \( \pm 2\theta \) and the light spot on the screen will be shifted by a distance \( L \). The value of \( \theta \) can then be derived from the measured \( L \) and the known distance \( H \). To enhance the piezoelectric characteristic of the actuators, poling treatment was done prior to the experiment. A dc voltage of 25V was applied to each of the PZT plates for 5 minutes, with the poling direction from the bottom electrode to top electrode.

5. Results and discussion

![Fig. 4. Schematic drawing of measurement setup of mirror deflection angle when mirror is driven under dc or ac actuation voltage.](image)

Fig. 5. (a) Spectrum of optical deflection angle versus various ac actuation frequencies, biased at 2Vpp simultaneously applied to all ten actuators. (b) Measured optical deflection angle versus various driving ac voltage simultaneously applied to all ten actuators at first resonant mode of 34Hz.

Fig. 5 shows two resonance at 34Hz and 197Hz in the measured spectrum of deflection angle versus frequency of actuation bias of the PZT driven scanning mirror. 1-D scanning pattern at the first resonance frequency (34Hz) shows scanning pattern (Fig.6a) due to out of plane bending motion by applying the same AC bias to PZT actuators. In this bending mode, a linear curve with a slope of 1.5°/V is measured and illustrated in Fig. 5b. A large optical deflection angle of 14.7° was obtained at a low ac driving voltage of 10Vpp under the bending mode. Another 1-D scanning pattern is achieved by applying 10 Vpp bias to all actuators at 197Hz, i.e., the 2nd mode or torsional mode (Fig.6b). When the right half actuators biased at 34Hz and the left half actuators biased at 197Hz simultaneously, clear 2-D raster scanning patterns are demonstrated as shown in Fig. 6c and 6d.
6. Conclusion

Novel piezoelectric driven 2-D scanning mirrors, using single mechanical supporting beam integrated with multiple PZT actuators, have been successfully designed, fabricated and tested. The device obtained its bending resonant peak at 34Hz, having a frame scanning optical angle that can reach as high as 2.7° at 2Vpp. Torsional mode operation was also examined, with the device attaining its resonant peak at 198Hz, with raster scanning optical angle reaching up to a maximum of 0.75° at 2Vpp. Demonstrations of high speed scanning pattern for device were also made and illustrated.

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