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Paper

2D Asymmetric Silicon Micro-Mirrors for Electrostatic Field Distribution Measurement Using Optical Level Method

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Abstract We developed silicon micro-mirrors with two asymmetric axes for electrostatic field distribution measurements using a single external piezoelectric ceramic vibrating element. The 2D asymmetric silicon micro-mirrors were fabricated by using an SOI-MEMS process. The vibration transmissibility of the proposed mirror under a vacuum atmosphere was evaluated by dynamic analysis. We obtained the resonant frequency in the low-speed axis of 23.3 Hz and in the high-speed axis of 556.8 Hz respectively. To prevent a reduction in the amplitude width, we induced a 90° phase shift between the low- and high-speed axes at the resonance frequency. The ratio of the deformation between the low-speed axis of 30 Hz and the high-speed axis of 604 Hz was simulated to be 4.04. In measurement, the ratio of the deformation between the low-speed axis of 23.3 Hz and the high-speed axis of 556.8 Hz was 6.48. The difference between the calculated and experiment values were apparently due to the fabrication errors and frequency characteristics of piezoelectric ceramic vibrating element. A Lissajous pattern projected onto the screen. The scanning angle was a degree of 7.6 (total angle) in the low- and high-speed axis. We subsequently measured the electrostatic field distribution using the 2D asymmetric silicon micro-mirrors by means of the optical level method.

Keywords : 2D asymmetric silicon micro-mirror, SOI-MEMS, vacuum sealing package, electrostatic field distribution measurement

1. Introduction

Microelectromechanical system (MEMS) scanning mirrors are used in laser projectors, laser scanners, collision-prevention sensors, wearable displays with retinal scan recognition, and electrostatic field distribution measurement [1-4]. In the case of 2D silicon scanning micro-mirrors, the resonance frequencies in the low- and high-speed axes have been reported to exceed 500 Hz and 10,000 Hz, respectively [5].

Silicon scanning micro-mirrors have characteristics such as miniaturization, high reliability, and high-speed scanning. In the case of a micro-mirror driven by electrostatic force, the rotation angle of the optical scanner driven by conventional electrostatic force is limited to the gap between the mirror and substrate, and changing this angle requires a high voltage [1]. In the case of a micro-mirror driven by electromagnetic force, although the electromagnetic MEMS optical scanner operates at a low voltage and with a large rotation angle, a magnet and a yoke must be mounted [6]. In the case of a micro-mirror driven by piezoelectric force, because the stiffness of torsion increases as the piezoelectric film thickness evaporated due to torsion is increased, the piezoelectric ceramic vibrations are not efficiently transmitted to the torsion. Thus, the magnitude of a vibration turns out to be a small [7]. Moreover, the mode of vibration becomes complex. In general, the low-speed axis is driven in non-resonance mode and the high-speed axis is driven in resonance mode. Therefore, the operating current must be high [8].

Recently, an optical beam was scanned using a simple asymmetric micro-mirror excited by an external piezoelectric ceramic vibrating element irrespective of the rotation angle and high voltage [9, 10]. 2D asymmetric silicon micro-mirrors can be controlled via the independent resonance frequency of each rotation axis through the use of a single external piezoelectric ceramic vibrating element. The merits of 2D asymmetric silicon micro-mirrors allow the resonance frequencies of the low- and high-speed axes to be controlled via the mode design of the micro-mirrors for vibration.

In the previous study, asymmetric silicon micro-mirrors are fabricated by the anodic bonding of an ultra-thin silicon film on a glass substrate, followed by the fabrication of ultra-thin silicon MEMS mirror structures by a picosecond-laser micromachining system [10]. By vibrating the asymmetric silicon micro-mirror with an external vibrating element, we obtained a horizontal operation of 118 Hz and a vertical operation of 11040 Hz at the resonance frequency.

Electrostatic field distribution measurements using a silicon micro-mirror array fabricated by the MEMS process have been presented [11]. The deflection angle of each silicon micro-mirror, which was placed on a spherical surface and was deflected by an electrostatic field, was measured optically using a 2D optical scanner and position-sensitive detector (PSD). The optical scanner is composed of a computer-controlled stepping motor and single-axis MEMS optical scanner. However the angle accuracy of the stepping motor was found sufficient. The rotation of the stepping motor required a certain amount of time. The measurement time was 30 seconds or more in spite of the goal for 1 second. However low speed 2D silicon micro-mirrors such as

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resonant frequencies in the low-speed and high-speed axes of 30Hz and 600 Hz has not yet been reported.

This study aims to develop silicon micro-mirrors with two asymmetrical axes for electrostatic field distribution measurements using a single external piezoelectric ceramic vibrating element. The vibration transmissibility of the proposed mirror under a vacuum atmosphere was evaluated by dynamic analysis. We measured an electrostatic field distribution using the 2D asymmetric silicon micro-mirrors by means of the optical level method.

2. Design and vacuum-sealing package

2.1 2D asymmetric silicon micro-mirror design

To evaluate the absolute deformational displacement of the characteristic mode, we conducted simulated modal analysis of the resonance frequency and dynamic analysis. The resonance frequency of the 2D asymmetric silicon micro-mirror was evaluated using the IntelliSuite software (IntelliSuite, ver. 8.7).

We designed 2D asymmetric silicon micro-mirrors, as shown in Fig. 1. The 2D asymmetric silicon micro-mirrors were designed to be 5.8 mm long × 5.8 mm wide × 15 μm thick. The torsion mirror was 1.7 mm long × 2.0 mm wide.

First, we used Blueprint, which is a physical design tool. The 3D model was constructed in IntelliSuite's 3D builder, which is a 3D mesh generator. The frequency analysis was performed by using the ThermoElectroMechanical analysis module. The minimum mesh was 46 μm long × 2.5 μm wide × 7.5 μm thick at torsion. The parameters used in the analysis are summarized in Table 1.

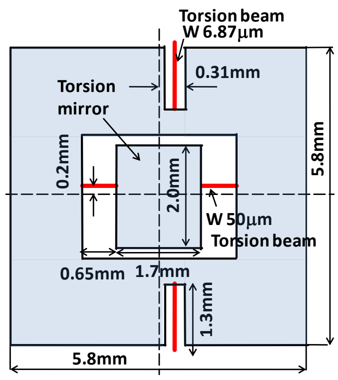
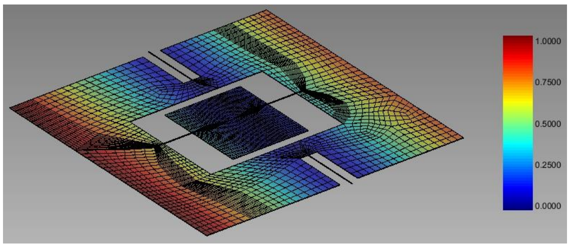


Fig. 1. Layout of a 2D asymmetric silicon micro-mirror.

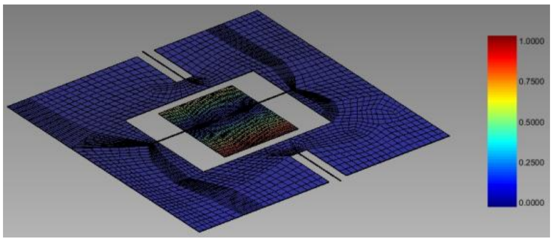
Table 1. Parameters used for analysis with the IntelliSuite software

Material	Silicon
Young's modulus	160 GPa
Density	2.30 g/cm^3
Poisson's ratio	0.226

In the first stage, we performed the modal analysis using the IntelliSuite software. Fig. 2 shows the results of the modal analysis of the 2D asymmetric silicon micro-mirrors. The resonance frequencies in the low- and high-speed axes, as calculated by the ThermoElectroMechanical module of the IntelliSuite software package, were 30 Hz and 604 Hz, respectively. The results indicate the eigenvalue and mode shape. However, dynamic analysis is necessary to evaluate the absolute deformational displacement of the characteristic mode. The dynamic analysis can indicate the absolute amount of modification although the modal analysis can evaluate the relative spatial relationship of modification.



(a) Low-speed axis (Normalized modal displacement of Mode 1:30.708Hz)



(b) High-speed axis (Normalized modal displacement of Mode 6:604.48Hz)

Fig. 2. Modal analysis of 2D asymmetric silicon micro-mirrors.

Fig. 3 shows the model for dynamic analysis of the 2D symmetric silicon micro-mirrors. The sine wave amplitude was generated by a pressure of 0.1 MPa as a function of frequency, although the mesh size differs from that used in the modal analysis. Fig. 4 shows a plot of the amplitude–frequency characteristics calculated by dynamic analysis. The ratio of the deformation between the low-speed axis of 30 Hz and the high-speed axis of 604 Hz was simulated to be 4.04.

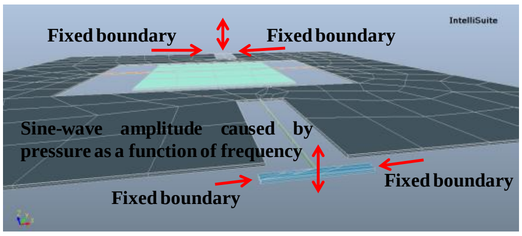


Fig. 3. Model for dynamic analysis of 2D asymmetric silicon micro-mirrors.

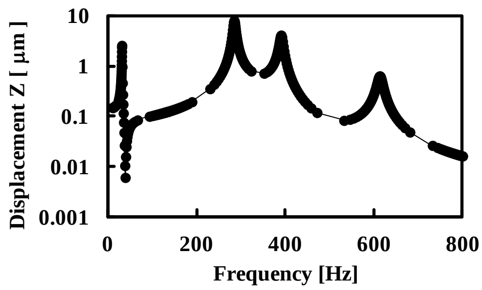


Fig. 4. Vibration transmissibility characteristics calculated by dynamic analysis.

2.2 Vacuum-sealing packaging

2D asymmetric silicon micro-mirrors were fabricated by SOI-MEMS process [11]; a photograph of one of the resulting micro-mirrors is shown in Fig. 5 (MEMS CORE). The torsion beam was cut with a picosecond-laser micromachining system (Japan Laser and Time-Bandwidth, Duettino-SHG). For micromachining with a picosecond laser, the 2D asymmetric silicon micro-mirror was placed on a 2D nano-motion stage (Aerotech, ANT130-160), which was driven by motion controlled software (Aerotech, Automation 3200).

After the 2D asymmetric silicon micro-mirror was placed on the piezoelectric ceramic vibrating element, we adhered the 2D asymmetric silicon micro-mirror to the piezoelectric ceramic vibrating element and vacuum-sealing package (KYOCERA) which was vacuumed to the degree of 5×10^{-3} Pa. Fig. 6 shows a photograph of the vacuum-sealed package with the embedded 2D asymmetric silicon micro-mirror.

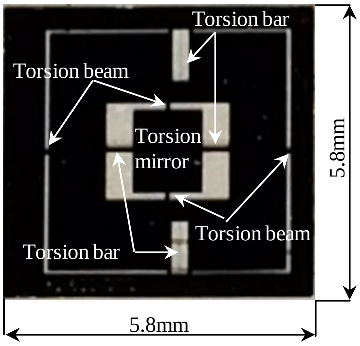


Fig. 5. Photograph of the asymmetric silicon micro-mirror fabricated by the SOI-MEMS process, which is made from the silicon-on-insulator by the semiconductor process.

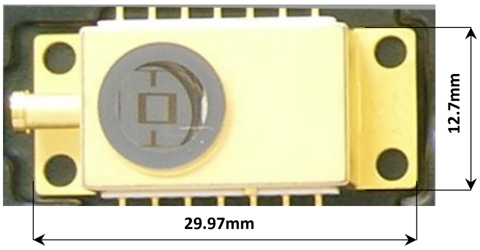


Fig. 6. Photograph of the vacuum-sealed 2D asymmetric silicon micro-mirror.

3. Results

3.1 Scanning characteristics of the 2D asymmetric silicon micro-mirror

Fig. 7 shows a photograph of the experimental setup of the vacuum-sealing package. We obtained the resonant frequency in the low-speed axis of 23.3 Hz and in the high-speed axis of 556.8 Hz respectively. To prevent a reduction in the amplitude width, we induced a 90° phase shift between the low- and high-speed axes at the resonance frequency, as shown in Fig. 8. In measurement, the ratio of the deformation between the low-speed axis of 23.3 Hz and the high-speed axis of 556.8 Hz was 6.48. A photograph of the Lissajous pattern projected onto a screen of 300 mm away from the vacuum-sealing package is shown in Fig. 9. We measured the scanning range from the Lissajous pattern with scale. The scanning angle was 7.6° (total angle) in the low- and high-speed axes and was limited by the output voltage saturation of the excited instrument in the vacuum-sealing mount.

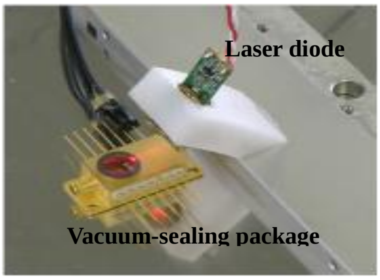


Fig. 7. Experimental setup of the vacuum-sealing package.

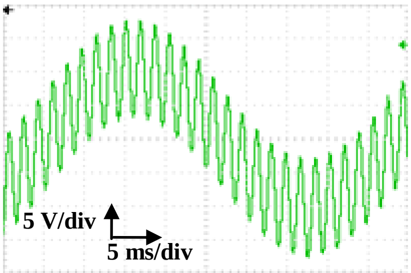


Fig. 8. Digital oscilloscope recording of the drive voltage for the asymmetric silicon micro-mirror shown in Fig. 5 (low frequency: 23.3 Hz, AC 21 Vp-p; high frequency: 556.8 Hz, AC 15 Vp-p).

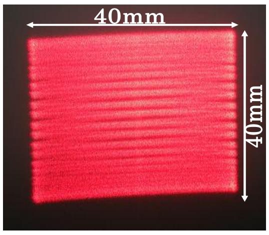


Fig. 9. Photograph of the Lissajous pattern projected onto a screen.

3.2 Electrostatic field distribution measurements

Electrostatic field distribution measurement using a silicon micro-mirror array by SOI-MEMS processes has been reported [11]. Fig. 10 shows the schematic of a silicon micro-mirror for electrostatic field distribution measurement.

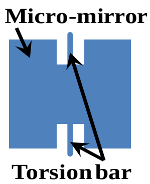


Fig. 10. Schematic of a silicon micro-mirror for electrostatic field distribution measurement

Fig. 11 shows the schematic of electrostatic field distribution measurement using optical level method. When the micro-mirror is moved by electrode, the deflection angle of the torsion mirror by electrostatic force was determined by the method of Peterson [12]. The deflection angle of the silicon micro-mirror is given by (1)

$$\phi = \frac{\varepsilon_0 V^2 l b^3 (1+\nu)}{16 K E d^2 t^4} A, \tag{1}$$

where ϕ is the deflection angle of the silicon micro-mirror, ε_0 is dielectric constant of vacuum, V is applied voltage, l is torsion bar length, b is mirror width, ν is Poisson's ratio, K is a constant defined by the shape of the torsion bar. In the case of the torsion bar with a rectangular cross section, K is 0.141. E is Young's modulus, d is distance between the mirror and voltage-applying electrode, t is torsion bar width and thickness, and A is a correction factor determined using the effective electrode area. By substituting the material constant and sizes of the torsion mirror into eq. (1), the relationship between the deflection angle ϕ and applied voltage at the electrostatic field is given.

Fig. 11 shows the schematic of electrostatic field distribution measurement using optical level method. When θ is measured using the optical level method, the electrostatic voltage can be calculated from eqs. (1). θ can be calculated by measuring displacement Δd.

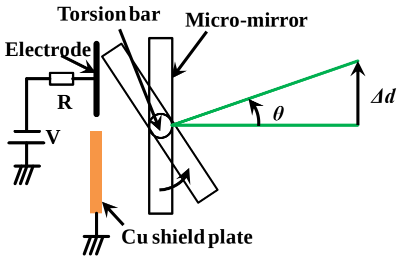


Fig. 11. Schematic of electrostatic field distribution measurement using optical level method

Fig. 12 shows the schematic of the optical measurement setup. The deflection angle of each silicon micro-mirror, which was placed on a spherical surface such as Fresnel lens and was deflected by an electrostatic field, was measured optically using a 2D optical scanner and position-sensitive detector (PSD). A laser beam (λ = 532 nm, output power 5 mow, Shimadzu, BEAM MATE) was focused on the silicon micro-mirror and scanned two-dimensionally; the beam then irradiated each micro-mirror through a beam splitter and a convex lens. The reflected laser was reflected by the beam splitter and was focused on the PSD (Hamamatsu Photonics, S1880) surface to allow measurement of the spot position. The horizontal and vertical operations of 23.3 Hz and 556.8 Hz signals, respectively, at the resonance frequency of the asymmetric silicon micro-mirror were driven by the piezoelectric ceramic vibrating element.

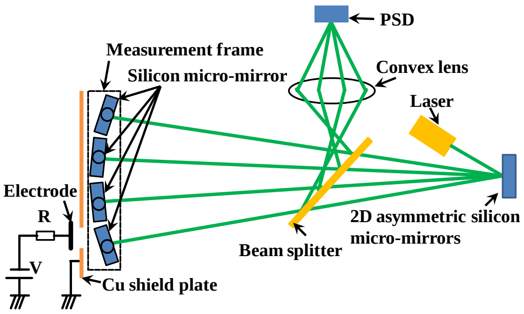
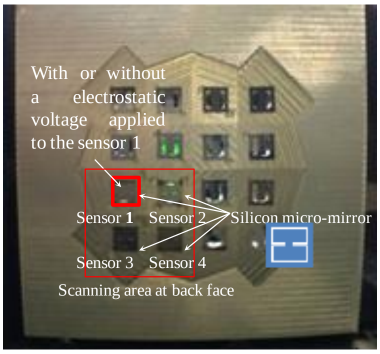
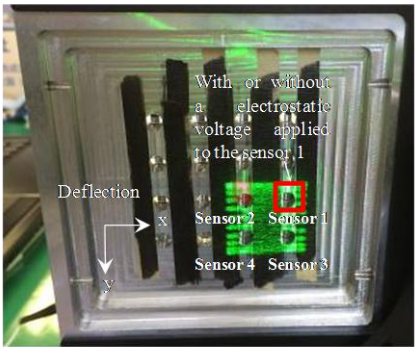


Fig. 12. Schematic of the optical measurement setup.

Fig. 13 shows the photograph of the measurement frame incorporating a silicon micro-mirror array. Sixteen silicon micro-mirrors were attached to the measurement frame. Four silicon micro-mirrors were scanned by a laser beam. The deflection direction was limited to the y-axis. Sensor 1 was with or without an electrostatic voltage applied.



(a) Front



(b) Back

Fig. 13. Measurement frame incorporating a silicon micro-mirror array.

Fig. 14 shows the PSD output signal (Y), which was measured by scanning a laser beam across a silicon micro-mirror array at Sensor 1 under an applied electrostatic voltage of 1000 V. The repetition time of 42.9 ms corresponded to the 23.3Hz vertical operation frequency of the 2D asymmetric silicon micro-mirrors. Four spike-like waveforms were observed in the 42.9 ms period. We observed the change in the waveform of the PSD output signal (Y) with or without an applied electrostatic voltage of 1000 V by the deflection of the silicon micro-mirrors of Sensor 1, as shown in Fig. 15. Fig. 15(a) shows the waveform at 23.3 Hz. Fig. 15(b) shows the change in waveform under an applied electrostatic voltage of 1000 V applied. Nine peaks were observed.

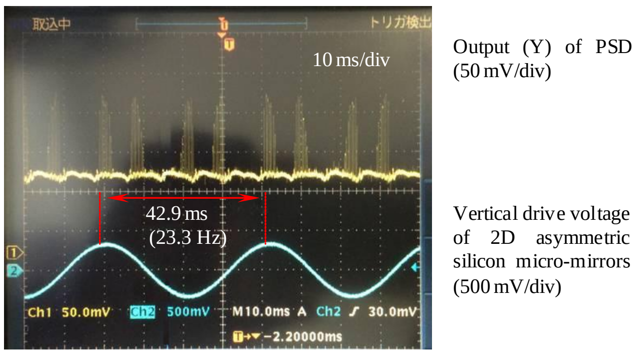
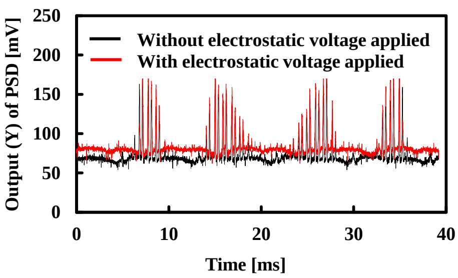
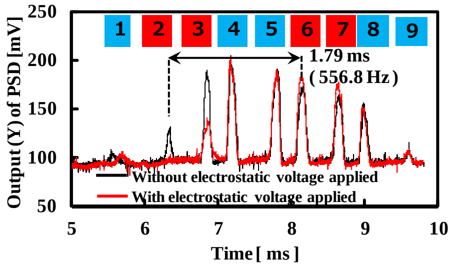


Fig. 14. Photograph of the output signal of the position-sensitive detector (PSD).



(a) Waveform at 23.3 Hz



(b) Change in waveform

Fig. 15. Measurement output (Y) of the position-sensitive detector (PSD) with or without the electrostatic voltage applied.

4. Discussion

In this study, we developed silicon micro-mirrors with two asymmetric axes for electrostatic field distribution measurements. The vibration transmissibility of the proposed mirror under a vacuum atmosphere was evaluated by dynamic analysis. We measured the electrostatic field distribution using our fabricated 2D asymmetric silicon micro-mirrors.

The ratio of the deformation between the low-speed axis of 30 Hz and the high-speed axis of 604 Hz was simulated to be 4.04. In measurement, the ratio of the deformation between the low-speed axis of 23.3 Hz and the high-speed axis of 556.8 Hz was 6.48. The difference between the calculated and experimental values was apparently due to fabrication errors and the frequency characteristics of external piezoelectric ceramic vibrating element.

In the case of the 2D silicon scanning micro-mirrors, to prevent a reduction in the amplitude width, which is caused by interference between the vibrations of the low- and high-speed axes, these axes oscillated in and out of phase with the resonant frequency, respectively [13].

We measured the electrostatic field distribution using the 2D asymmetric silicon micro-mirrors (Figs. 14 and 15). Fig. 16 shows a schematic of the line scan on the measurement frame. The laser beam was scanned in the direction of the arrow from the starting point to the turning point and then returned from the turning point to the starting point. The laser beam scanned Sensors 1 and 2 four and five times, respectively. The turns are labeled with the notation of 1 to 9 in Fig. 16. When the electrostatic voltage of 1000 V was applied at Sensor 1, the output of the PSD (Y) changed. The measurement outputs (Y) of the PSD with the notations of 2 and 3 decreased, whereas those of 6 and 7 increased.

The PSD can be used to measure the position of the light spot on its surface from each current of four electrodes [14]. The signal was amplified using an operational amplifier and showed a good S/D ratio. Displacement p is calculated according to eq. (2) using each electrode current output X_1, X_2, Y_1, and Y_2:

$$p = \frac{X_2 - X_1 + Y_2 - Y_1}{X_2 + X_1 + Y_2 + Y_1} \bullet \frac{L}{2}, \tag{2}$$

where L is the lateral length of the PSD surface.

Because the deflection direction was limited to the y-axis in our experiments, $X_2 = X_1 = 0$. Therefore, eq. (2) becomes eq. (3):

$$p = \frac{Y_2 - Y_1}{Y_2 + Y_1} \bullet \frac{L}{2}. \tag{3}$$

Fig. 17 shows a schematic of the output of the PSD (Y) change with or without an applied electrostatic voltage. When the micro-mirror was deflected with an electrostatic voltage, the laser spot on the surface of the PSD moved from its initial point without an electrostatic voltage. The displacement changed as shown in eq. (3). In the case of the measurement output (Y) of the PSD with the notations of 2 and 3 (Figs. 15 and 16), the displacement becomes negative from the initial position. In the case of the measurement output (Y) of PSD with the notations of 6 and 7, the displacement becomes positive from the initial position.

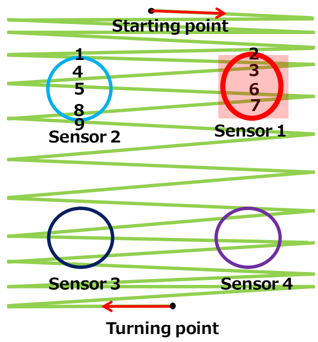


Fig. 16. Schematic of the line scan on the measurement frame.

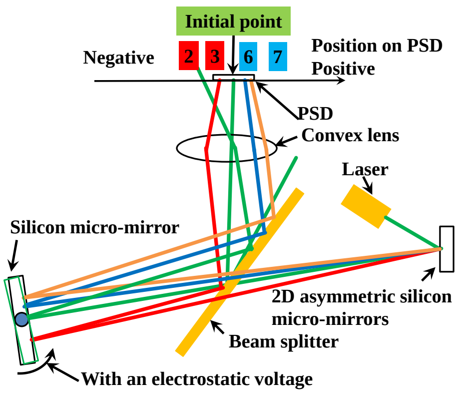


Fig. 17. Schematic of the output of the PSD (Y) change with or without an electrostatic voltage.

5. Conclusions

We developed silicon micro-mirrors with two asymmetric axes for electrostatic field distribution measurements using a single external piezoelectric ceramic vibrating element. 2D asymmetric silicon micro-mirrors were fabricated using an SOI-MEMS process. The vibration transmissibility of the proposed mirror under a vacuum atmosphere was evaluated by dynamic analysis. We obtained the resonant frequency in the low-speed axis of 23.3 Hz and in the high-speed axis of 556.8 Hz respectively. To prevent a reduction in the amplitude width, we induced a 90° phase shift between the low- and high-speed axes at the resonance frequency. The ratio of the deformation between the low-speed axis of 30 Hz and the high-speed axis of 604 Hz was simulated to be 4.04. In measurement, the ratio of the deformation between the low-speed axis of 23.3 Hz and the high-speed axis of 556.8 Hz was 6.48. The difference between the calculated and experiment values was apparently due to the fabrication errors and frequency characteristics of external vibrating element piezoelectric ceramic vibrating element. A Lissajous pattern projected onto the screen. The scanning angle was a degree of 7.6 (total angle) in the low- and high-speed axis. We subsequently measured the electrostatic field distribution using the 2D asymmetric silicon micro-mirrors.

Acknowledgement

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References

(1) K. Yamada and T. Kuriyama:"A Glass-Like Retinal Display Asymmetric Silicon Micro-Mirror", IEEJ Transactions on Sensors and Micromachines, Vol. 129, No. 2 pp. 35-40 (2009).
(2) T. Kuriyama, W. Takatsuji, T. Itoh, H. Maeda, T. Nakaie, J. Matsui, and Y. Miyamoto:"Electrostatic Field Distribution Measurement Using MEMS Micro-mirror array", Technical Digest of the 30th Sensor Symposium, 5PM3-PSS-061, Sendai, Nov. 2013.
(3) Light beam scanner using large electrostatic force, United State Patent 5959760
(4) W. O. Davis, R. Sprague, and J. Miller:"MEMS-based pico projector display", 2008 IEEE/LEOS International Conference on Optical MEMS and Nanophotonics, pp.31-32 (2008)
(5) E. Kawasaki, H. Yamada, and H. Hamanaka:"Application of the Optical MEMS scanner "ECOSCAN" for Pico Projector", The 16th International Display Workshops, Miyazaki, Dec. 2009.
(6) A. Ishizuka, S. Choe, J. Hashizume, Y. Itou, and R. Okada:"Development for 2-axis electromagnetic driving MEMS mirror", IEEJ Transactions on Sensors and Micromachines, Vol. 130, No. 4 pp. 113-117 (2010).
(7) Japan Patent 4982814.
(8) Japan Patent 2012-137692A.
(9) K. Yamada and T. Kuriyama: "A novel asymmetric silicon micro-mirror for optical beam scanning display", Proc. MEMS 98, IEEE, pp.110-115 (1998).
(10) T. Itoh et al. :"2D Asymmetric Siliocn Micro-Mirror Fabricated with Anodic Bonding between an Ultra-Silicon Film by laser Micro-Processing and a Glass Substrate", IEEJ Transactions on Sensors and Micromachines, Vol. 134, No. 8, pp. 247-252 (2014).
(11) T. Kuriyama, W. Takatsuji, T. Itoh, H. Maeda, T. Nakaie, J. Matsui, and Y. Miyamoto:"Electrostatic Field Distribution Measurement Using MEMS Micro-mirror array", IEEJ Transactions on Sensors and Micromachines, Vol. 134, No. 12, pp. 378-384247-252 (2014).
(12) K. E. Peterson:"Silicon as a mechanical material", Pro. IEEE, Vol 70, No. 5, pp. 420-457 (1832).
(13) H. Ra, W. Piyawattanametha, Y. Taguchi, L. Michael, and O. Solgaard:" Two-Dimensional MEMS Scanner for Dual-Axes Confocal Microscopy", J. Microelectromech. Syst, Vol. 16, No. 4, pp. 969-976 (2007).
(14) T. Kuriyama, T. Aoi, H. Maeda, T. Itoh, Y. Ueno, T. Nakaie, N. Matsui and H. Okumura:"Desing of Opical System for Electrostatic Field Distribution Measurement Using Micromirror Array", Sensors and Materials, Vol. 23, No. 7, pp. 435-448 (2011).

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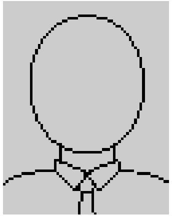
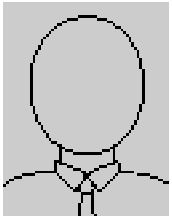
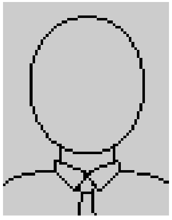


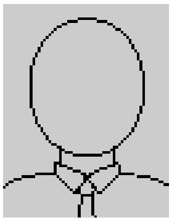
Toshihide Kuriyama (Member) Toshihide Kuriyama received his B. S. and M. S. in applied physics and his Ph. D in electronic engineering from the University of Tokyo in 1971, 1971 and 1977, respectively.
He joined NEC Corporation in 1977 and worked on high-voltage devices. From 1981 to 1982, he was on leave as a visiting scholar at the Moore School of Electrical Engineering, University of Pennsylvania, where he was involved in ion sensor research. Since 1982, he has been engaged in sensor device research. Dr. Kuriyama is a Professor of Kinki University, a member of Japan Society of Applied Physics, the Institute of Electronics, Information and Communication Engineers and the Institute of Electrical Engineers of Japan.



Toshiyuki Nakaie (Non-member) Toshiyuki Nakaie was born in Wakayama, Japan, 1955. He graduated from Osaka Institute of Technology in 1977. In April 1977, he joined the Hanwa Electronic Ind. Co., Ltd. Currently, he belongs to the ESD equipment technical group of Hanwa.



Jun Matsui (Non-member) Jun Matsui was born in Wakayama, Japan. He received his B.S. degree in Electronic Engineering from Kinki University in 2004. In 2004, he joined Hanwa Electronic Ind. Co., Ltd. Wakayama, Japan. Currently, he is with the New Business Development Department of Hanwa.



Yoshiaki Miyamoto (Non-member) Yoshiaki Miyamoto received his B.S. degree in electronic control from Shimane University in 2009. After graduation from Shimane University, he joined Hanwa Electronic Ind. Co., Ltd. He is engaging in a study of electrostatic visualization etc now.