Cascaded Micromirror Pair Driven by Angular Vertical Combs for Two-Axis Scanning

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ABSTRACT

Monolithically cascaded one-axis micromirrors driven by angular vertical combs are designed and fabricated. Using "W"-shape ray optics, we demonstrate two-axis scanning covering ±6.0° two-dimensional area at resonant modes: 7.5kHz, ±17V in fast-scanning mirror, 1.2kHz, ±7V in slow-scanning mirror.

INTRODUCTION

Because of their independently controllable scanning directions, cascaded one-axis light-beam deflector pairs have provided light-beam two-axis scanning for many kinds of optical instruments [1]. We present cascaded one-axis micromirror pairs driven by angular vertical combs (AVCs) for two-axis scanning.

AVC drives have been proposed for inherently self-aligned comb fingers and large rotation angle at low voltage [2-4]. Micromirrors driven by AVCs with thermally-reflow polymer hinges have an advantage of simple fabrication process [2,3].

DESIGN

The schematic of the two-axis scanning optical system is illustrated in Fig. 1. The system is composed of a fixed mirror and the combination of fast-scanning mirror and slow-scanning mirror, shown in Fig. 2. The rotational axes of the mirror pair are perpendicular to each other. The "W"-shape ray geometry allows two-axis raster scanning.

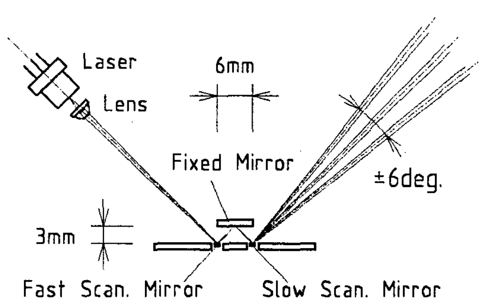

Fig.1 Optical system of the two-axis scanner

Each one-axis scanning mirror is designed separately for the system to achieve raster scanning. The fast-scanning mirror has a stiff spring and is driven at its resonant frequency. The long mirror plate in the slow-axis covers the entire walk-off distance of the light beam caused by the first scanner.

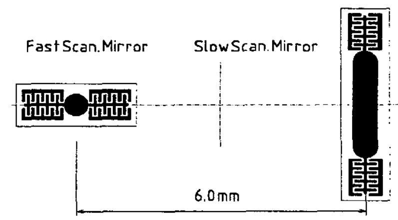

Fig.2 The schematics of the chip design

FABRICATION PROCESS

We fabricated both mirrors simultaneously using a silicon-on-insulator wafer with 25µm-thick device layer. The fabrication process of the mirrors is outlined in Fig. 3.

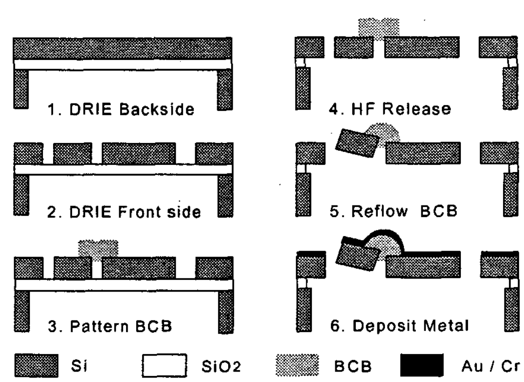

Fig.3 Fabrication process

First, windows were opened by deep reactive ion etching (DRIE) in the 400µm-thick substrate. Aligning to the backside openings, we simultaneously etched out the front-side patterns, including mirror plates, torsion springs, movable combs and fixed combs by DRIE. Photodefinable benzocyclobutene (BCB) film were coated and patterned as the hinges of the AVCs. The device was released in hydrofluoric acid and dried with a supercritical dryer. The chip was heated to 400°C in a furnace. During the thermal reflow, the BCB hinge lifted up the movable combs. Finally, 5nm chromium and 100nm gold films were deposited by an e-beam evaporator for high reflectance coating on the mirrors and electrical connection to the movable comb fingers.

EXPERIMENTAL RESULTS

Fig. 4 shows the DC transfer curves of the mirrors. The fast and slow scanning mirrors tilted by ±0.74° and ±3.2° at 50V, respectively.

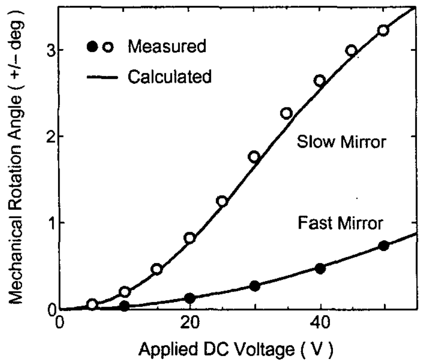

Fig.4 DC transfer curves

Using the optics shown in Fig. 1, we measured the frequency dependence of the optical deflection angles (Fig. 5). The fast-scanning mirror achieved ±6.0° scanning driven by ±17V AC at its resonant frequency 7.5kHz. The slow-scanning mirror also achieved ±6.0° resonant mode scanning at ±7V AC.

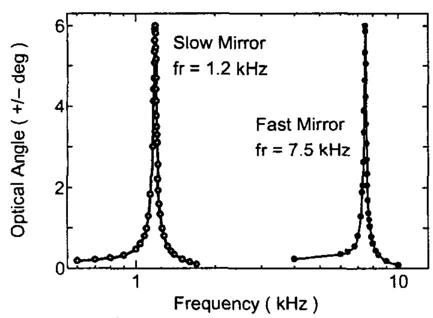

Fig.5 Frequency dependences of the optical deflection angle. The slow-scanning mirror was driven at ±7V AC voltage. The fast-mirror was driven at ±14V AC voltage.

The specification of the mirrors and the experimental results are summarized in Table 1.

Table 1 Specifications and performance of the mirrors

	Fast Scan. Mirror	Slow Scan. Mirror
Size	0.4 mm diameter	0.4mm x 2.5 mm
Flatness	R > 3m	R > 3m
Resonant freq.	7.5 kHz	1.2kHz
Max. tilt angle (Mechanical)	± 4.3 ° at 17V AC	± 3.0 ° at 45V DC or 7V AC
Max. scan angle (Optical)	± 6.0° at 17V AC	± 6.0 ° at 45V DC or 7V AC
Drive mode	Resonant	DC or Resonant

We demonstrated two-axis scanning in ±6.0° area, shown in Fig. 6, driving both mirrors at their resonant frequencies: 7.5kHz, ±17V in fast-scanning mirror, 1.2kHz, ±7V in slow-scanning mirror.

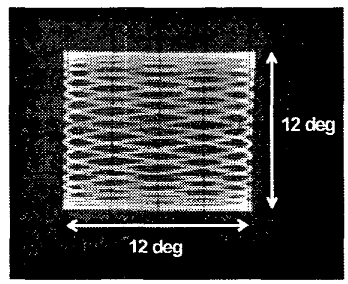

Fig.6 Lissajous figure that the scanned light beam drew on a two-dimensional position sensitive detector

CONCLUSIONS

We demonstrated two-axis resonant mode scanning ±6.0° (optical), by use of monolithically cascaded micromirror pairs actuated with AVCs. The DC property of the slow-scanning mirror, ±3.0° (mechanical) at 45V, promises raster scanning in ±6.0°(optical) area.

AKNOWLEDGMENTS

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REFERENCES

[1] D. L. Dickensheets and G. S. Kino, "Micromachined Scanning Confocal Optical Microscope," Optics Letters, Vol.21, No.10, pp.764-766 (1996)

[2] P. R. Patterson, D. Hah, H. Nguyen, R.-M. Chao, H. Toshiyoshi, Ming C. Wu, "A Scanning Micromirror with Angular Comb Drive Actuation," 15th IEEE International MEMS Conference 2002, pp.544-547

[3] H. Nguyen, D. Hah, P. R. Patterson, W. Piywattanametha, Ming C. Wu, "A Novel MEMS Tunable Capacitor Based on Angular Vertical Comb Drive Actuators," Solid-State Sensor & Actuator Workshop, Hilton Head 2002

[4] W. Piyawattanametha, P. R. Patterson, D. Hah, H. Toshiyoshi, and Ming C. Wu, "A Surface and Bulk Micromachined Angular Vertical Combdrive for Scanning Micromirrors," OFC 2003, Vol.1, pp.251-252