A 2D Scanner by Surface and Bulk Micromachined Angular Vertical Comb Actuators

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ABSTRACT

We present the design, fabrication, and demonstration of a fully decoupled 2D gimbal scanner with angular vertical comb (AVC) actuators. The device is realized by combining a foundry surface-micromachining process (MUMPs) with a 3-mask deep-reactive-ion-etching (DRIE) post process. Surface-micromachining provides versatile mechanical design and electrical interconnect while bulk micromachining offers flat micromirrors and high-force actuators. The scanner achieves DC mechanical scanning ranges of ±6.2° (at 55 Vdc) and ±4.1° (at 50 Vdc) for the inner and outer gimbals, respectively. The 1-mm mirror has a radius of curvature of 40 cm.

INTRODUCTION

Two-dimensional (2D) scanners with large mirror and wide scan range are keyed enabling elements for high-resolution endoscopic imaging [1], scanning display, and optical crossconnects. There have been increasing interests in electrostatically actuated 2D scanners with vertical combdrive actuators [2,3]. Previously, we have reported 1D scanners with angular vertical combdrive (AVC) actuators [4,5], which offers self-aligned comb fingers with single etching step and larger scan angles for the same comb dimensions.

Bulk micromachining offers advantages for fabricating flat micromirrors, however, tight control of spring constant and electrical interconnect/isolation are difficult to achieve. Surface micromachining, on the other hand, provides flexible mechanical and electrical structures. The combination of polysilicon layers and single-crystalline silicon (SCS) substrate enable high actuation force, large flat micromirrors, flexible electrical interconnect, and tightly-controlled spring constants [5,6]. In this paper, we report on the first experimental demonstration of 2D AVC scanners with fully decoupled x and y scanning.

DEVICE DESIGN

The schematic of the 2D scanner is illustrated in Fig. 1. An SCS micromirror is suspended inside a gimbal frame by a pair of polysilicon torsion springs. The gimbal frame is supported by two pairs of polysilicon torsion springs. The four electrically isolated torsion beams also provide three independent voltages (V_1 to V_3) to inner gimbals and mirrors. The torsion spring is 400 µm long, 10 µm wide, and 4.5 µm thick. The scanner has 8 comb banks with 10 movable fingers each. The finger is 5 µm wide, 150 µm long, and 35 µm thick. The gap spacing between comb fingers is 4 µm. The mirror is 1000 µm in diameter and 35 µm thick. The AVC banks are fabricated on SCS. The movable and fixed comb banks are completely self-aligned [4,5].

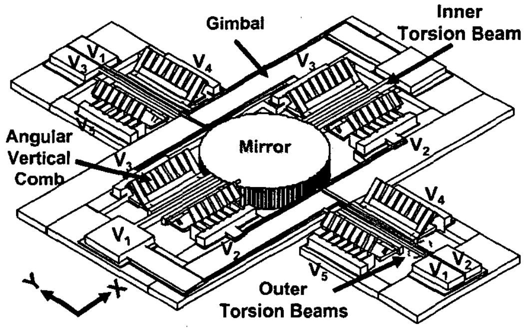

Fig. 1 : Schematic of 2D AVC gimbal scanner.

FABRICATION PROCESSES

The surface micromachining part was realized by foundry process (MUMPs). The 3-mask bulk-micromachining post process (Fig. 2) was performed at UCLA's Nanofabrication Facility. The MUMPs chip is first thinned down to 300 µm. The comb fingers are etched by DRIE using the MUMPs gold patterns as the etching mask. The mirror, polysilicon hinges, and latches are protected by photoresist (PR) during the front-side etching (Mask 1). Next, a 2-µm-thick SiO_2 is

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deposited on the backside. The front side is protected by a 5-µm-thick PR. The oxide underneath the mirror and the combs is opened using a double-side aligner (Mask 2). The third mask defines the SCS islands. A timed DRIE is performed to delineate the SCS areas. Then, the PR is removed from both sides. A 1-µm-thick parylene is deposited on the front side as a mechanical support during the releasing step. The third DRIE completely removes the substrate between the SCS islands and the islands themselves. The etching stops at the MUMPs nitride layer. That exposed nitride layer is selectively removed by dry etching until the lower phosphorous silicate glass (PSG1) layer of the MUMPS chip is revealed. The device is released in 49% HF for 40 minutes and dried in a supercritical dryer. Then, the parylene layer is removed by oxygen plasma. The comb banks are manually assembled to a pre-defined angle (10°) and locked in place by polysilicon latches.

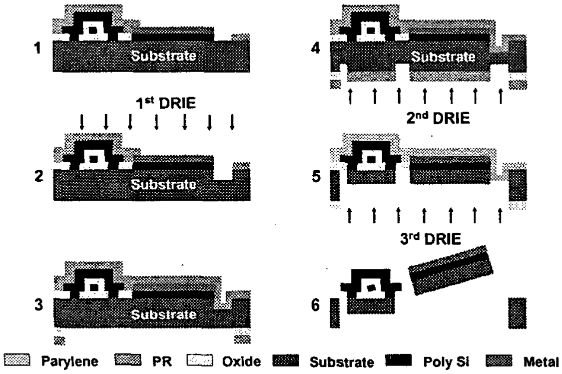

Fig. 2 : Post fabrication process of the scanner

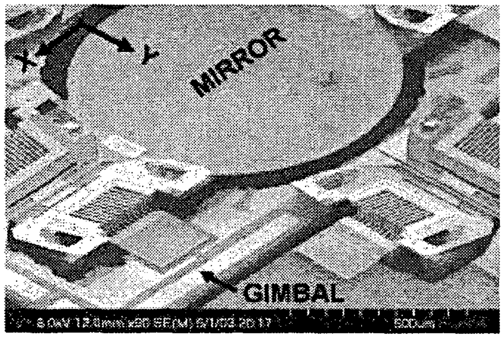

Fig. 3 : SEM of a 2D AVC scanner

EXPERIMENTAL RESULTS

The scanning electron micrograph (SEM) in Fig. 3 shows the 2D AVC scanner. The optical, electrical, and mechanical performance of the scanner was characterized in detail. Table 1 summarizes the experimental results of the AVC 2D gimbal scanner. The surface roughness and the radius of curvature of the mirror were characterized by a WYKO RST 500 Optical Profiler. The dynamic responses were measured with a Polytec Microscan Laser Doppler Vibrometer.

Table 1: The summary of the experimental results

	x-axis	y-axis
Mirror size	1 mm in diameter	
Mirror flatness	40 cm	
Mirror surface roughness (Ra)	11 nm	
Resonant freq.	315 Hz	144 Hz
Max. scan angle (Mechanical)	± 6.2°	± 4.1°
Voltage at Max. angle	55 Vdc	50 Vdc

CONCLUSION

We have successfully demonstrated a high performance 2D scanner with angular vertical comb (AVC) actuators by combined surface/bulk micromachining techniques. The scanner achieves fully decoupled x and y scanning movements. Large DC mechanical scan ranges (±6.2° and ±4.1°) and low actuation voltages (55 Vdc) have been achieved.

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