21.6 Microelectromechanical Scanning Devices for Optical Networking Applications

Ming C. Wu, Dooyoung Hah, Pamela R. Patterson, Hiroshi Toshiyoshi[1]

Electrical Engineering Department, University of California, Los Angeles, CA
[1]Institute of Industrial Science, University of Tokyo, Tokyo, Japan

The emergence of optical layer networking creates demand of all-optical photonic devices. Microelectromechanical systems (MEMS) are key enabling technology for many of these new devices. This paper reviews the state-of-the-art of optical MEMS technologies. In particular, a new scanning micromirror with angular vertical comb (AVC) drive actuators offers large scan angles and low actuation voltages.

MEMS optical switches offer many advantages over other types of switches. They have low insertion loss and low crosstalk, and are independent of polarization, wavelength, bit rate, and data format. There are two basic architectures for MEMS optical switches. A 2-D switch consists of a matrix of N^2 movable micromirrors between N input fibers to N output fibers. It can be monolithically integrated on a silicon chip. Since each of the movable micromirror is a digital ON-OFF switch, control of the 2-D switch is straightforward. The maximum port count is limited by optical diffraction loss to 32x32. Using surface-micromachining technology, a low voltage (<20V) 2-D switch using curled cantilever actuators is demonstrated [1]. Excellent optical performance is achieved. For larger switches (e.g., 16x16 or 32x32), the optical performance depends critically on the angular accuracy and uniformity of the micromirrors. Tight control of MEMS manufacturing and packaging processes are essential to achieve good performance and high yield. Currently, monolithic 16x16 switches with <6dB loss are now commercially available [2].

In a 3-D switch, optical beams are steered from a two-dimensional array of input fibers to a matching array of output fibers. The 3-D architecture can achieve port counts >1000x1000 with low optical insertion loss [3]. However, each beamsteering mirror is an analog device and requires close-loop control to maintain optical alignment in practical environment.

The key enabling devices for 3-D switches are 2-axis scanning micromirrors with large, flat mirrors and large scan angles. Such scanning mirrors are realized with double gimbal support and parallel-plate actuators [4]. Vertical comb drive actuators have higher force density and perimt lower operating voltage [5]. Recently, scanners with staggered vertical comb (SVC) drives are demonstrated by patterning the fixed and moving combs in distinct layers of Si separated by sacrificial oxide [6]. The fabrication process is complicated, however, and critical alignment is required.

An angular vertical comb (AVC) drive can be fabricated on a single-layer silicon-on-insulator (SOI) wafer. The self-aligned comb fingers are patterned in a single etching process and no critical alignment is needed. The schematic of an AVC-actuated micromirror is shown in Figure 21.6.1. The movable comb is tilted upward while the stationary comb remains in the substrate plane. The angular comb drive offers several advantages over the SVC drive. First, the maximum scan angle of AVC drive is equal to the initial tilt angle of the movable comb, and is 50% larger than that achievable by SVC drives. Second, the self-aligned process minimizes the asymmetry of comb fingers and increases the threshold of lateral instability.

A prototype AVC-actuated micromirror is fabricated on an SOI wafer with 25μm-thick device layer. Both moveable and fixed combs are patterned and etched simultaneously by deep reaction ion etching. Photoresist hinges are patterned to connect the movable combs to the mirror. After release etch, the photoresist is heated until reflow. The surface tension force of molten photoresist causes the movable comb to tilt upward until stopped by a vertical limiter [7]. The scanning electron micrograph (SEM) of the fabricated scanner is shown in Figure 21.6.2. A close-up view of the AVC is shown in Figure 21.6.3. The tilting angle of the moveable comb is measured at 20°

The maximum scan angle of AVC depends on several factors, including the finger thickness, length, gap spacing, and the number of fingers. Figure 21.6.4 shows the measured and calculated scan angles at 100V versus finger length for various number of fingers. The finger thickness is kept constant at 25μm. The current device has a total of 40 fingers, each finger is 40μm long, and gap spacing is 3μm. The measured scan angle at 100V is 1.5°, which agrees well with the calculated value. The calculation shows that the scan angle is enhanced by increasing the number of fingers and the finger length. With 100 fingers, scan angles of >10° are achieved. The measured frequency response of the AVC scanner with 1mm-diameter micromirror is shown in Figure 21.6.5. The resonant frequency of 1.4kHz agrees well with the theoretical value. Resonant scan angle of ±18° is achieved at 1.4kHz (Figure 21.6.6). More detailed characterization of the AVC actuators and their optical performance are to be reported at conference.

The AVC scanner has several impacts on 3-D switches: (1) larger scan angle allows the switch to scale up to higher port count; (2) lower operating voltage significantly reduces the power consumption of the switching systems; (3) simplified fabrication and the self-aligned process increase the yield and reduce the cost of the switch.

References:

[1] R. T. Chen, et al., "A high-speed low-voltage stress-induced micromachined 2x2 optical switch," IEEE Photonics Technol. Lett., Vol. 11, pp.1396-8, November 1999.

[2] A. Husain, "MEMS-Based Photonic Switching in Communications Networks," Proc. Optical Fiber Communications (OFC) Conf., Paper WX1, 2001.

[3] R. Ryf, et al., "1296-port MEMS Transparent Optical Crossconnect with 2.07 Petabit/s Switch Capacity," Optical Fiber Communications (OFC) Conf., Postdeadline paper PD28, 2001.

[4] L. Fan, M. C. Wu, "Two-Dimensional Optical Scanner with Large Angular Rotation Realized by Self-Assembled Micro-Elevator," Proc. IEEE LEOS Summer Topical Meeting on Optical MEMS, Paper WB4, Monterey, California, August 20-22, 1998.

[5] A. Selvakumar, et al., "Vertical comb array microactuators," Proc. IEEE Micro Electro Mechanical Systems, pp. 43-48, 1995, Amsterdam, The Netherlands.

[6] R. A. Conant, et al., "A Flat High-Frequency Scanning Micromirror", 2000 Solid-State Sensor and Actuator Workshop, Hilton Head, SC, pp. 6-9.

[7] R. R. A. Syms, et al., "Improving Yield, Accuracy and Complexity in Surface Tension Self-Assembled MOEMS", Sensors and Actuators A 88 (2001) 273-283.

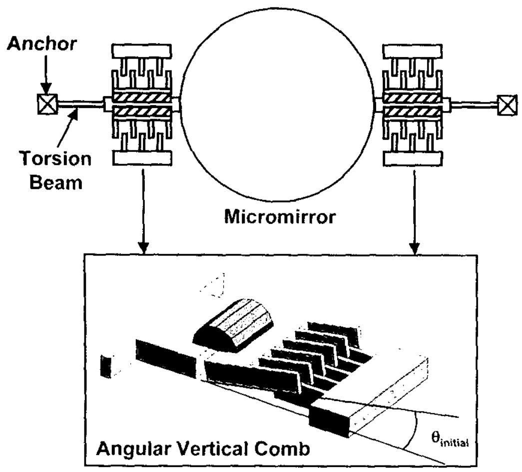

Figure 21.6.1: Schematic of AVC scanner.

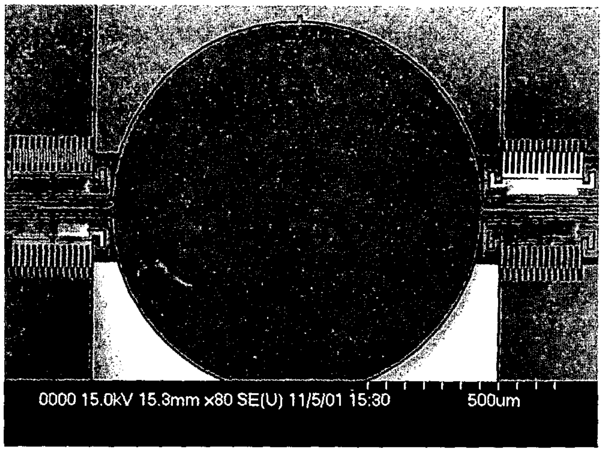

Figure 21.6.2: SEM of AVC scanner.

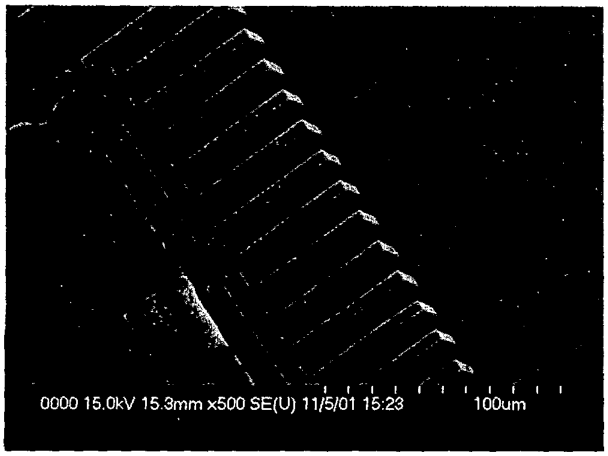

Figure 21.6.3: SEM of AVC comb.

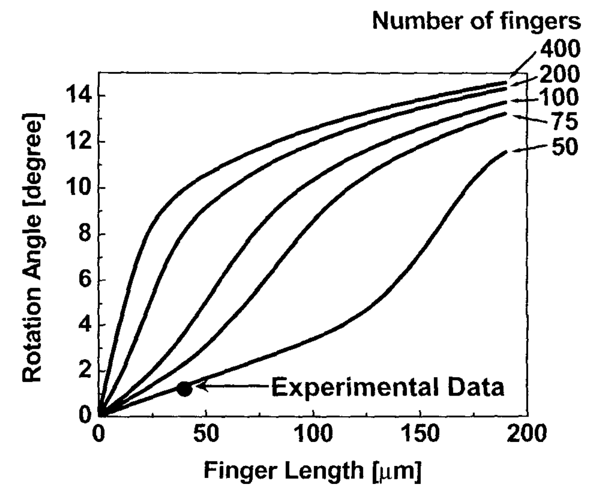

Figure 21.6.4: Measured and calculated sccan angle versus finger length.

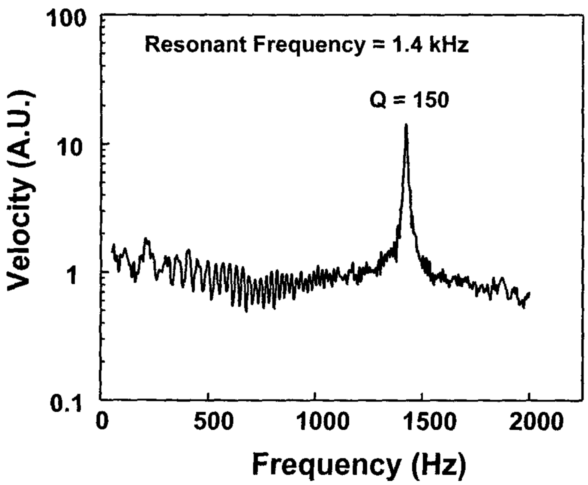

Figure 21.6.5: Frequency response of AVC scanner.

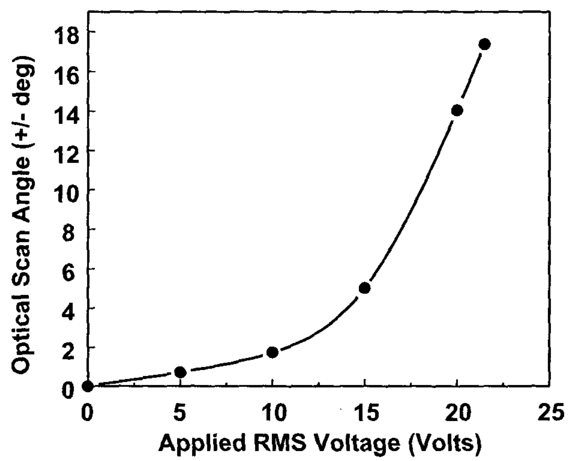

Figure 21.6.6: Resonant opticcal scan angle versus voltage.