Silicon-Based On-Chip Micromirrors for DWDM Wavelength-Selective Crossconnects

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Abstract

We report on a silicon-based on-chip micromirror array for monolithic wavelength-selective crossconnects. The 75-μm mirror pitch matches to the DWDM grids with 100 GHz spacing. A maximum mechanical scan angle of 6.5 degree has been achieved.

Keywords: MEMS, on-chip micromirror, planar lightwave circuits, PLC, comb-drive, WDM.

1 INTRODUCTION

Integration of planar lightwave circuits (PLC) and MEMS micromirrors can greatly reduce the size of optical MEMS systems [1-6]. Silicon-based PLC is particularly attractive for this application because the PLC and the MEMS micromirrors can be monolithically integrated on silicon-on-insulator (SOI) platform. Recently, we have reported a monolithic 1x4 wavelength-selective switch (WSS) [5] and a 4x4 wavelength-selective cross connect (WSXC) [6] with 400-μm-pitched micromirrors for coarse wavelength-division multiplexing (CWDM) with 20-nm channel spacing. Scaling to dense WDM (DWDM) grids with 0.8-nm (100 GHz) spacing needs 25 times higher spectral resolution. This can be accomplished by either a longer propagation distance after grating (L), or a smaller pitch (P_M) of micromirror array, as shown by the following relation:

$$\frac{P_M}{L} \approx D_\lambda \cdot \Delta\lambda$$

where D_λ is the angular dispersion of the grating and $\Delta\lambda$ is the channel spacing. The propagation distance L is limited by the wafer size. For a DWDM 4x4 WSXC to fit in a 6-inch wafer, a micromirror array with a pitch of 75 μm is thus required. The rotary comb-drive reported previously [5, 6] cannot fit in the required footprint.

In this paper, we report on a novel micromirror structure for a pitch of 75 μm and a fill factor of 90%. The micromirrors are fabricated on SOI and are compatible with monolithic DWDM WSS and WSXC.

2 DESIGN

The schematic of the micromirror is shown in Figure 1. It is actuated by a linear comb-drive. The micromirror is attached through an L-shaped arm to the middle of the flexure spring, which has the largest angular deflection as the comb moves laterally (Fig. 1(b)). The mirror angle is proportional to the displacement, and inversely proportional to the spring length. Short spring length is desired to achieve large mirror angle since the displacement is usually limited by the small pitch. To reduce the operating voltage, we employed a serpentine design, as shown in Fig. 1(c).

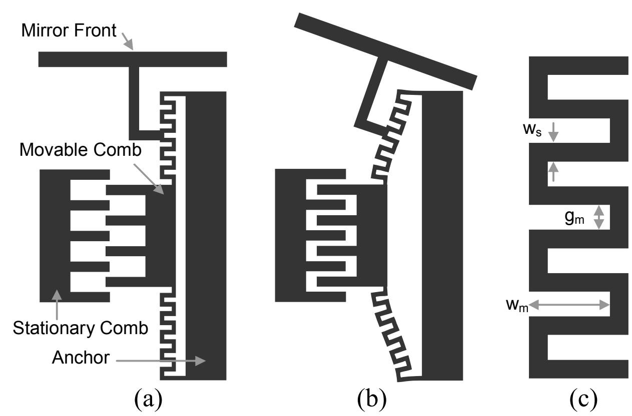

Figure 1. Schematic of the small-pitch micromirror with lateral comb-drive actuator (a) without bias, and (b) with non-zero bias. (c) The serpentine spring design.

Figure 2 shows the layout of the micromirror. The serpentine spring has a length of 174 μm, a width (w_s) of 2 μm, a meandering gap (g_m) of 2 μm, and a meandering width (w_m) of 6 μm. The 27-finger comb-drive has a finger gap of 2 μm, a finger width of 3 μm, a finger length of 25 μm, and an initial finger overlap of 1 μm. The total suspension length is 621 μm. A resonant frequency of 18 kHz is simulated by finite element method (FEM).

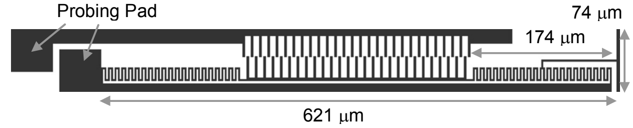

Figure 2. Layout of the 75-μm-pitch micromirror with lateral comb-drive actuator. The mirror is attached to the middle of the serpentine spring.

3 FABRICATION

The micromirror was fabricated on a 6-inch SOI wafer with a 5μm-thick device layer. A 500-nm-thick thermal oxide was grown as the hard mask for silicon etching. The micromirror was patterned with i-line optical lithography. The oxide and the silicon were etched by inductively coupled plasma reactive ion etcher (ICP-RIE, Applied Materials Centura) using CHF_3/CF_4 and HBr/Cl_2 chemistry, respectively. The moveable structures were released with vapor HF at 40°C. The scanning electron micrograph (SEM) of fabricated devices is shown in Figure 3.

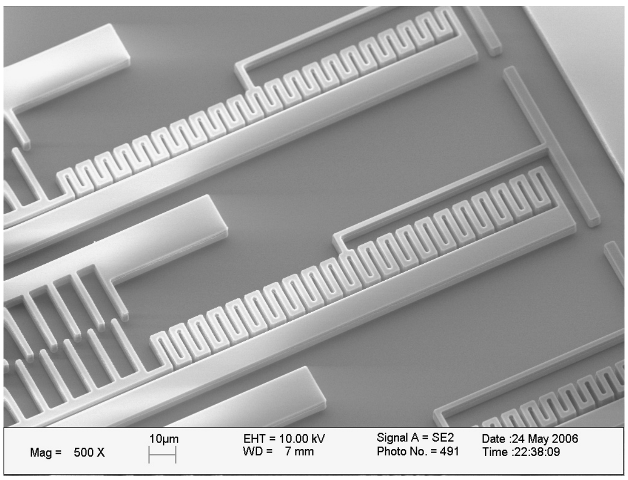

Figure 3. SEM image of the fabricated on-chip micromirror.

4 DEVICE PERFORMANCES

The fabricated device was tested by applying a DC bias across the movable and stationary combs. Figure 4(a) shows the actuation of the micromirror. The scan angle is limited by lateral instability and pull-in effect, which are shown in Figure 4(b) and (c), respectively. The lateral instability is mainly caused by the bending in the backbone of the movable comb. This can be improved by increasing its stiffness. The pull-in is due to the interaction of the fringing fields when the movable and stationary combs are too close. Figure 5 shows the simulated (by FEM) and measured DC characteristics of the micromirror. A maximum mechanical angle of 6.5° is achieved at a bias of 190 V.

5 CONLUSION

We have demonstrated a micromirror structure for a pitch of 75 μm and a fill factor of 90% on a 5-μm SOI planar lightwave circuits (PLC). This micromirror array is part of a monolithic DWDM wavelength-selective switches (WSS) and crossconnect with 100GHz channel spacing. A maximum mechanical scan angle of 6.5 degree has been achieved. This project is supported in part by DARPA CS-WDM program under MDA972-02-1-0020.

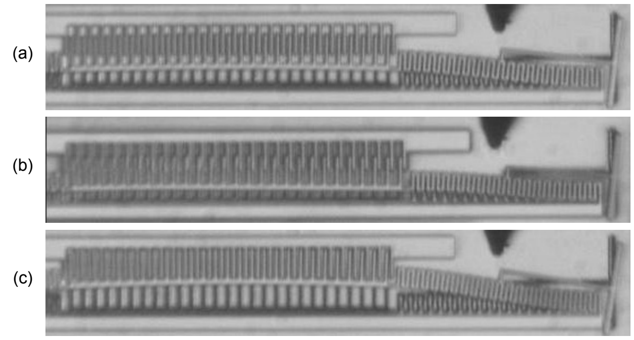

Figure 4. Photographs of the fabricated micromirror with (a) scan angle of 6.5° at 190 V (b) lateral instability (c) pull-in.

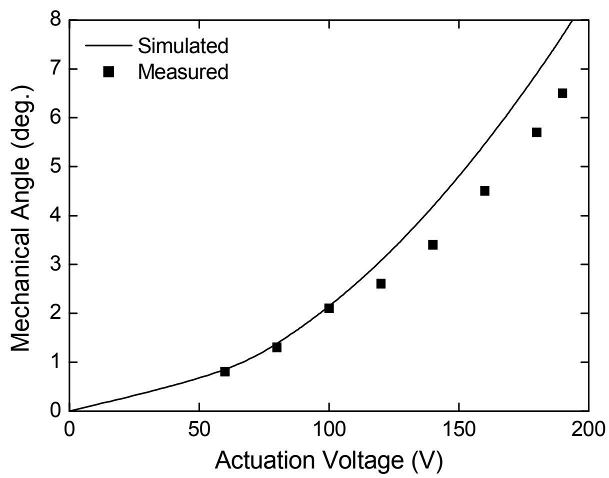

Figure 5. FEM simulated and measured DC characteristics of the micromirror with lateral comb-drive actuator.

REFERENCES

[1] C. H. Chi, *et al.*, "Compact 1x8 MEMS optical switches using planar lightwave circuits," OFC 2004, ThQ4.

[2] D. M. Marom, *et al.*, "Wavelength-selective 1x2 switch utilizing a planar lightwave circuit stack and a MEMS micromirror array," Optical MEMS 2004, C-1.

[3] T. Ducellier, *et al.*, "Novel High Performance Hybrid Waveguide-MEMS 1x9 Wavelength Selective Switch in a 32-Cascade Loop Experiment," ECOC 2004, Th4.2.2.

[4] D. T. Fuchs, *et al.*, "A Hybrid MEMS-Waveguide Wavelength Selective Cross Connect," *IEEE Photon. Technol. Lett.*, pp. 99-101, 2004.

[5] C. H. Chi, *et al.*, "Integrated 1x4 Wavelength-Selective Switch with On-Chip MEMS Micromirrors," CLEO 2005, JThE58.

[6] C. H. Chi, *et al.*, "Silicon-Based Monolithic 4x4 Wavelength-Selective Cross Connect with On-Chip Micromirrors," OFC 2006, OTuF1.