160×160 MEMS-Based 2-D Optical Phased Array

Youmin Wang[1], Guangya Zhou[2], Xiaosheng Zhang[1], Kyoungsik Yu[3], and Ming C Wu[1]
[1]*University of California, Berkeley, Berkeley, USA*
[2]*National University of Singapore, Singapore*
[3]*Korea Advanced Institute of Science & Technology (KAIST), Korea*
wu@eecs.berkeley.edu

Abstract: We present a two-dimensional ultra large aperture optical phase array (OPA) with 160×160 elements enabled with optical microelectromechanical system (MEMS). The random access beamsteering up to 4.4°×4.6° scanning range at 1550nm is demonstrated.
OCIS codes: (120.5060) Phase modulation; (230.4685) Optical microelectromechanical devices (110.5100) Phased-array imaging systems

1. Introduction

Two-dimensional (2-D) optical phased arrays (OPA's) have many applications such as solid-state LiDAR (light detection and ranging), computational imaging/microscope, 3-D display and 3-D brain imaging. Silicon photonics provide only 1-D OPA, with the other axis scanned by wavelength tuning. Liquid crystal OPA's are commercially available but they are too slow for LiDAR and some other applications. Micro-electro-mechanical-system (MEMS) offers many advantages for OPA, including fast response time and low power consumption. Previous demonstrations of MEMS OPA include 1-D micromirrors with piston [1] and tilt motion [2], 2-D OPA with piston mirrors operating at infrared (1550nm) [3] and UV [4]. Most MEMS OPA's use piston mirrors with parallel-plate actuators. However, large vertical displacement (> 0.5 wavelength) is difficult to realize due to the pull-in effect, especially for longer wavelength operations. Recently, a novel dispersion-free optical phase shifter was reported using a lateral-moving grating element [5]. This grating phase shifter is particularly suitable for 2-D MEMS OPA because the array is completely flat and the phase shift is independent of wavelength. Large displacement can be realized by combdrive actuators. Here we report on a 2-D MEMS phased array with 160×160 individually addressable pixels. The MEMS actuators are hidden underneath the grating phase shifters to achieve high fill factor (91.8%). Random access beam pointing in two directions have been demonstrated, with a field of view of 4.4°×4.6°.

2. Grating based MEMS Optical Phase Array

The fabricated 2-D MEMS optical phased array has 160×160 elements, covering an aperture of 3.2×3.1mm^2. The photograph of the fabricated OPA is shown in Fig. 1(a). The schematic and the principle of the 2-D grating OPA is shown in Fig. 1(b). An optical beam is incident at 65° from the surface normal, and the main output beam at -1 diffraction order emits at 40° for 955nm-pitch grating. Moving the grating along the grating vector direction creates an optical phase shift in the -1st order beam. The phase shift is equal to $\Delta x/p$, where Δx is the lateral displacement and p is the grating pitch. Note that the phase shift is independent of wavelength (hence dispersion-free).

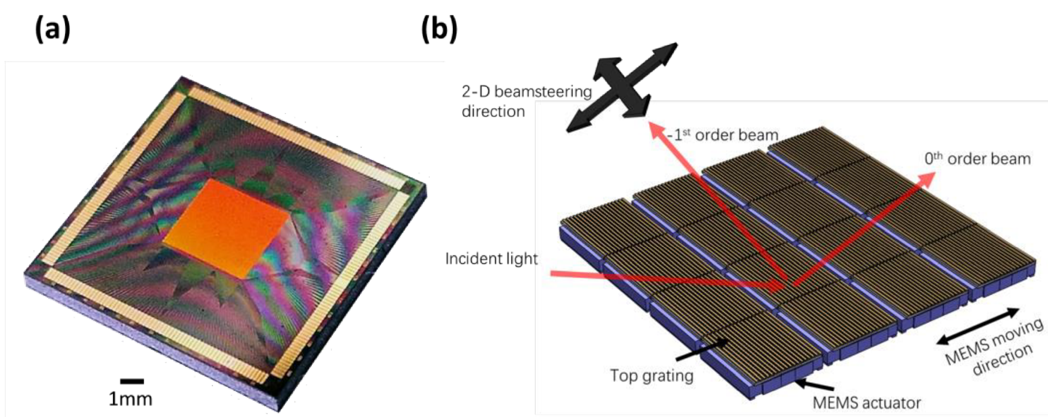

Fig. 1. (a) Photograph of the fabricated 2-D MEMS OPA (b) Schematic of the grating-based 2-D optical phase array.

The scanning electron micrographs (SEMs) of the OPA are shown in Fig. 2. It consists of a 2-D array of grating pixels, each pixel is 20×19.1μm^2. The field of view (FOV) is 4.4°×4.6° at 1550nm wavelength. Larger scan angle can be obtained using 4-*f* or holographic optics while maintaining the number of resolvable spots. The area of the grating phase shifter is $19.7\times17.8\mu m^2$, correspondign to a fill factor of 91.8% . A travel range of ±0.475µm is needed to achieve 2pi phase shift. This is achieved at ±16V bias to the combdrive actuators. The close-up view of the pixel in Fig. 2(b) clearly shows the gratings as well as the release holes to facilitate wet HF release.

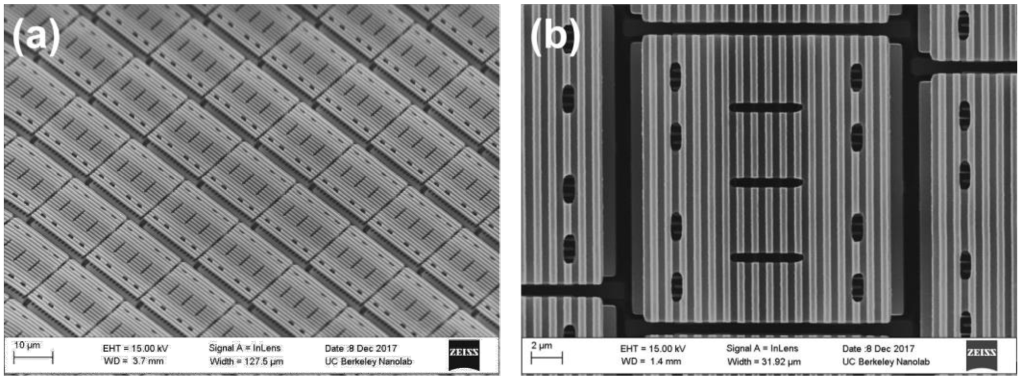

Fig. 2. SEMs of the High fill-factor 2-D grating based MEMS OPA. (a) Top view of the pixel array, (b) Close-up view of the individual phase shifter element.

3. Beamsteering Results

We have performed beamsteering experiments with various phase maps using a laser source at 1550nm wavelength. A diffraction-limited beam is observed when there is no bias on the OPA (Fig. 3(a)). This indicate the starting phase and height of the OPA are very uniform across the array. No compensation is needed. Fig. 3(b) shows the measured far-field pattern when the OPA is programmed to have alternating 0/pi phase shifts in the X-direction. Two beams at ±2.3° are observed. Fig. 3(c) shows 4 steered beams from alternating 0/pi phase shifts in both directions. The separations are 4.6° and 4° in the X and Y directions, respectively. The beam patterns agree very well with theoretical prediction. This shows the capability of the OPA for 2-D beamforming.

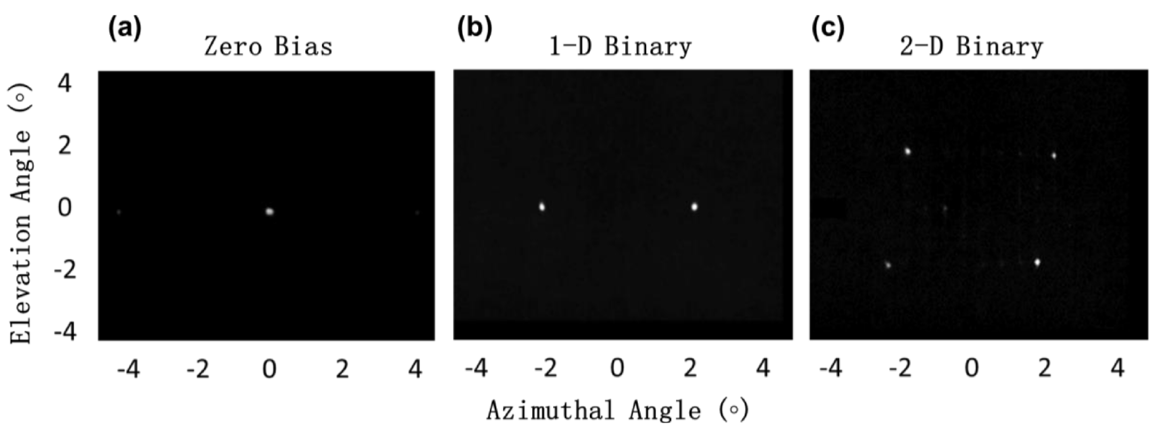

Fig. 3. Experimental measurement of the MEMS OPA beamsteering. From left to right: (a) diffraction pattern when the OPA is at zero bias. Only the main lobe is visible. (b) Diffraction pattern when OPA has alternating 0/pi phases in X direction. Two lobes at ±2.3° are visble. (c) Diffraction pattern when OPA has alternating 0/pi phases in both X and Y direction. Four lobes are observed.

4. Acknowledgement

This project is funded in part by Texas Instruments (TI), Huawei (USA), Berkeley Sensor and Actuator Center (BSAC), and the NSF PFI: AIR program.

5. References

[1] Y. Wang, et al., "Micromirror based optical phased array for wide-angle beamsteering." Micro Electro Mechanical Systems (MEMS), 2017 IEEE 30th International Conference on. IEEE, 2017.

[2] U. Krishnamoorthy et. al., "Dual-mode micromirrors for optical phased array applications" Sensors and Actuators, 97-98 (2002)

[3] B.W. Yoo, et. al., "A 32 × 32 optical phased array using polysilicon sub-wavelength high-contrast-grating mirrors," Optics Express 22 (2014)

[4] M. Hacker et al., "Micromirror SLM for femtosecond pulse shaping in the ultraviolet," Applied Physics B, vol. 76, no. 6, pp. 711–714, Jun. 2003

[5] G. Zhou, et al, "Nondispersive optical phase shifter array using microelectromechanical systems based gratings," Optics express, vol. 15, no. 17, pp. 10958–10963, 2007