A 20×20 Focal Plane Switch Array for Optical Beam Steering

Xiaosheng Zhang†, Kyungmok Kwon†, Johannes Henriksson, Jianheng Luo, and Ming C. Wu*

Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA 94720, USA

†These authors contributed equally to this work.

*wu@eecs.berkeley.edu

Abstract: We present a two-dimensional random-access optical beam steering system composed of a 20×20 focal plane switch array integrated on a silicon photonics chip with microelectromechanical-system (MEMS) optical switches. 32°×32° field-of-view is demonstrated.

1. Introduction

Optical beam steering devices are the key components for many applications such as light detection and ranging (LiDAR) and free-space optical communications. Integrated beam steering devices with fast steering speed, low power consumption and large field-of-view (FoV) are highly demanded to address the drawbacks of their bulky mechanical counterparts. Optical phased arrays have been demonstrated for 2D beam steering, however, they require precise control of thousands of phase shifting elements at the same time [1,2].

In contrast, the imaging-based beam steering system that combines an imaging lens with a programmable array of emitters at the focal plane is simple and highly scalable. The optics is similar to that of a camera except the light travels in the reverse direction. Large FoV is achieved simply by using a short focal length lens with a large-size array. Control is simple since only one element is turned on at a time. Several integrated 1D or small-scale 2D focal plane switch arrays with thermally tuned Mach-Zehnder (MZ) or microring resonator-based optical switches have been demonstrated recently [3–6]. However, their array sizes (or densities) were limited by the footprint of the switch and the high power consumption. The MEMS-actuated silicon photonics switches we demonstrated previously for large matrix switches offer many advantages for focal plane array beam steering, including small footprint, low loss, low crosstalk, and digital switching with low power consumption [7]. Here we demonstrate a 20×20 focal plane switch array with row-column addressing. Random-access 2D beam steering with a FoV of 32°×32° and a beam divergence of 0.080°×0.086° has been demonstrated with microsecond reconfiguration time.

2. System design and beam steering principle

A schematic of the beam steering system with the focal plane switch array is shown in Fig. 1(a). An N×N grating coupler array with 135 μm pitch in both directions is fabricated on the device layer of a silicon-on-insulator wafer. Light at 1550 nm wavelength is delivered to the selected grating coupler by turning on the corresponding row- and column-selection switches. The optical switches are similar to those reported in [7], where the two tips of a polysilicon waveguide coupler are pulled down vertically by MEMS actuators to switch the light propagation direction. The switches in the same column are actuated together so the total number of electrical connections is only 2N. The selected grating coupler directs light into free space, pointing towards the lens that is placed at one focal length 𝐹 = 4.5 mm above the chip. Each grating is mapped to a distinctive far-field angle corresponding to a straight line from the grating to the center of the lens. The FoV is 32°×32° (= 2tan⁻¹(D/2)) where D is the array length and f is the focal length. The grating periods and orientations are designed such that the light is emitted towards the center of the lens to increase the transmitted power and reduce aberration. The overall chip size is 3.8×3.8 mm² (Fig. 1(b)).

Fig. 1. (a) Schematic of the proposed beam steering system at two different steering angles. The actuated switches are in red color. For clarity, the MEMS actuators are not shown here. (b) Microscope image of the fabricated 20×20 focal plane switch array on a 3.8×3.8 mm² chip.
3. Experiment results

Figure 2 shows the transfer curve and switching time of the MEMS optical switches. The sub-μs actuation time enables agile beam steering suitable for high frame rate LiDAR with more than 10⁶ points per second.

Fig. 2. (a) Transfer curve and (b) switching time measurement results of the MEMS optical switch.

To characterize the far-field beam quality of the system, the output light from the f = 4.5 mm lens in the beam steering system is collected by a second lens with f = 30 mm and then focused on an infrared image sensor. The intensity distribution on the sensor corresponds to the far-field angular distribution of the output beam from the system. Figure 3(a) shows the intensity distribution at one of the output angles, and the measured beam divergence (full width half maximum) is 0.080°×0.086°.

To demonstrate the beam steering capability, the far-field image of the light emitted from each of the gratings in the 20×20 array is recorded, and Fig. 3(b) shows an overlap of all the 400 images. Here the f = 4.5 mm lens in the system is replaced by an f = 30 mm lens to reduce the magnification of the system due to the limited image sensor area, but this also results in larger beam divergence due to increased aberrations. Figure 3(b) shows that light in some of the row waveguides propagating from the left side in the image to the right side is blocked halfway by a defective switch, resulting in dark spots in the remainder of the row. We believe an improved fabrication process will solve this issue and remove the dark spots in our future experiments. The proposed system can be extended to larger arrays by shrinking the pitch of the array and increasing the chip size.

Fig. 3. (a) Far-field beam divergence measurement results. (b) Overlap of 400 far-field images captured by the infrared image sensor.

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5. References