512-Element Actively Steered Silicon Phased Array for Low-Power LIDAR

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Primary CNF Tools Used: BOSCH etcher, AJA sputter deposition, CVC sputter deposition, Cu electroplating tanks, Oxford 100 ICP RIE

Abstract:

Solid-state beam steering using large-scale optical phased arrays is of great interest for LIDAR and free-space communication systems, enabling wide-angle, long distance ranging or transmission of data in a robust platform. Ideally, a widely steerable narrow output beam that can reach to long distances requires a large aperture containing a large number of independently phase-controlled elements while remaining at a reasonable total power consumption. Applications at distances of tens to hundreds of meters require element-counts of several thousands, such that independent phase control overwhelmingly dominates power consumption and has prohibited larger element-count demonstrations thus far. We demonstrate the highest yet-reported element count actively-steered optical phased array with record low array power consumption of < 1.8 W. We show 2D steering over a 70 × 14° field of view while pumped by an integrated InP/silicon laser.

Summary of Research:

Here, we demonstrate low-power 2D beam steering with a 512-element active silicon optical phased array—to our knowledge the largest independently controllable phased array to date. We achieve low power operation by using a resonance-free light recycling device to re-circulate light multiple times through a single thermo-optic phase shifter, thus multiplying its efficiency by approximately the number of circulations [1]. We place a 5-pass light recycling structure on every element (Figure 1b). Phase shifter power and voltage is sufficiently low to be directly driven by off-the-shelf digital to analog converter integrated circuits. The input laser light is split in a binary splitter tree into 512 channels, each of which then have a high-efficiency thermo-optic phase-shifter. The phase-shifters are separated by 20 μm to minimize thermal crosstalk, and are then fanned-in to a 1.3 μm emitter spacing.

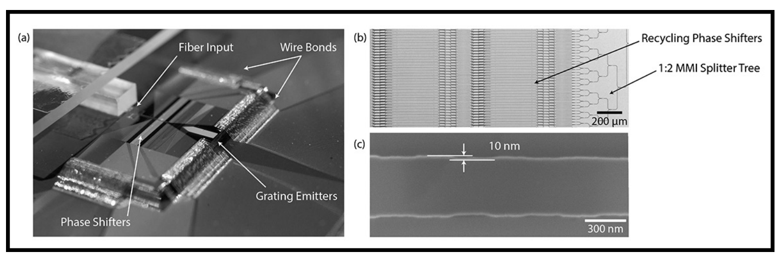

Figure 1: (a) 512-element silicon photonic array chip wire-bonded to interposer. (b) Microscope image of a section of the array of recycling phase shifters and tree of 1:2 MMI splitters (light flows right to left). (c) Scanning electron micrograph of sidewall grating on 450 nm wide emitter waveguide.

Finally, a 1D array of 1-mm-long sidewall gratings [shown in Figure 1(c)] direct the beam upwards out of the chip and allow for 2D beam steering via wavelength tuning of our integrated laser in the vertical direction due to the 0.3°/nm wavelength sensitivity of the grating emission. Two layers of aluminum metal on the photonic chip route signals and a common ground to peripheral bond pads, where they are attached to a single layer of aluminum on a silicon interposer. The interposer is then mounted and wire bonded to a standard printed circuit board and its wires routed to control circuitry. The packaged chip is shown in Figure 1(a).

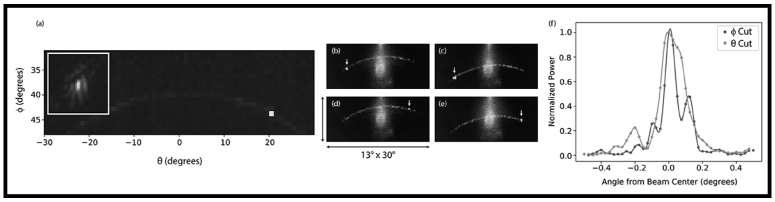

Figure 2: Measured far-field optical power for a beam steered 20° off-axis in the phase-tuned direction. (a) Widefield scan showing beam at 20° off axis. Faint arc is residual power confined by the grating, but not completely confined by the phased array. Inset is a detail 2° × 2° view of the beam. (b-e) Fourier-plane camera images of beams pointed to θ, ϕ of (b) -20°, 42°, (c) -20°, 48°, (d) +20°, 42°, (e) +20°, 48°. Sidelobe power is exaggerated due to limited camera dynamic range. (f) Cuts in ϕ and θ axes through the center of the beam in (a).

For our laser source, we fabricate an external laser cavity in silicon using vernier ring filters and couple it to an off-the-shelf facet-emitting reflective semiconductor optical amplifier (RSOA). This compact integrated laser source is both broadly tunable over tens of nanometers, while exhibiting sub-MHz narrow linewidth. For this demonstration light is coupled between separate laser and phased array chips with a single mode optical fiber.

We show a 2D-steerable phased array with a beam width of ~ 0.15° in both axes. To converge a single beam for each angle in the 2D phi-theta space and to compensate for as-fabricated phase mismatch between channels, we use a single-element photodiode placed physically in the far-field and a global optimization algorithm [3]. A far-field scan of the beam is shown Figure 2(a) as well as a fine scan in Figures 2(b) and 2(c), showing a peak-to-sidelobe ratio of 8.0 dB. Beam divergence and peak-to-sidelobe in the phase-controlled axis are slightly diminished from the theoretical values of 0.13° and 13 dB due to low phase shifter yield (63%) from a metal-layer fabrication error. The beam width of 0.15° in the grating axis confirms an effective grating length of approximately 1 mm. We demonstrate 2D beam steering of ± 35° in the phase-tuned axis (ϕ in Figure 2) and a ± 7° in the wavelength tuned axis (θ in Figure 2) grating axis by tuning the laser bandwidth over a 45 nm (controlled by microheaters on the vernier ring filters). For accessing any steering point, the phased array consumes 1.5-1.8 W.

This large size array is already adequate for application around 10m operation for ranging or communication applications. Further optimization of our beam-forming algorithm coupled with improved phase-shifter efficiency and additional phase re-circulation can yield several factors improvement to scale up toward hundreds of meters. Considering that the laser efficiency is on the order of 4% [2], for input laser light of 50 mW (corresponding to the maximum output power of typical RSOAs), we estimate total power consumption less than 3W, enabling the array to be operated by a compact battery pack.

References:

[1] You-Chia Chang, Samantha P. Roberts, Brian Stern, and Michal Lipson, "Resonance-Free Light Recycling." arXiv:1710.02891 (2017).

[2] Brian Stern, Xingchen Ji, Avik Dutt, and Michal Lipson, "Compact narrow-linewidth integrated laser based on a low-loss silicon nitride ring resonator." Opt. Letters 42, 4541-4544 (2017).

[3] Christopher T. Phare, Min Chul Shin, Steven A. Miller, Brian Stern, and Michal Lipson, "Silicon Optical Phased Array with High-Efficiency Beam Formation over 180 Degree Field of View." arXiv:1802.04624 (2018).