Scalable Optical Phased Array with Sparse 2D Aperture

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Abstract: A scalable OPA with sparse 2D aperture is presented, achieving the highest reported grating-lobe-free FOV-to-beamwidth ratio (16°/0.8°). A PWM generator chip is designed to drive compact phase shifters with row-column layout to reduce power consumption.
OCIS codes: (130.0130) Integrated optics; (130.6750) Systems; (110.5100) Phased-array imaging systems; (280.3640) Lidar; (060.2605) Free-space optical communication; (130.4815) Optical switching devices; (130.0250) Optoelectronics.

1. Introduction

Integrated optical phased arrays (OPAs) with full electronic steering enable many applications such as LiDAR, free-space point-to-point communication, lens-less projection, and holographic display. OPA performance improves as the number of radiating elements in the aperture increases. While there have been some efforts to make scalable OPAs with 1D apertures [1-3], large-scale electronically-steerable 2D OPAs with a large grating-lobe-free steering range have not been demonstrated. Scalability of 2D apertures is hampered by the 2D planar routing of the element-feeding optical waveguides [4,5]. Additionally, incorporating a larger number of elements in the OPA aperture increases the number of required phase shifter drivers. Therefore, the overall power consumption of the system increases linearly with the size of apertures and poses a challenge to the scalability of the system.

In this work, we present a scalable 2D OPA architecture based on a sparse array of radiators which also provides additional degrees of freedom to enhance beamforming performance. This proof-of-concept design with 128 elements is equivalent to a 484-element uniform array with an element spacing of 5.6µm, which is not feasible to implement in a planar process due to routing limitations. The implemented OPA system has the highest reported grating-lobe-free steering range over beamwidth with a 2D aperture. Furthermore, to address the issue of power consumption in a large-scale OPA, compact spiral phase shifters are designed with electrical row-column access. In this scheme, the required number of phase shifter drivers scales with the *square root* of the number of phase shifters. The row-column array of phase shifters is driven by an integrated pulse-width modulated (PWM) electrical driver instead of digital-to-analog converters (DACs) to further reduce power consumption, complexity, and area of the system.

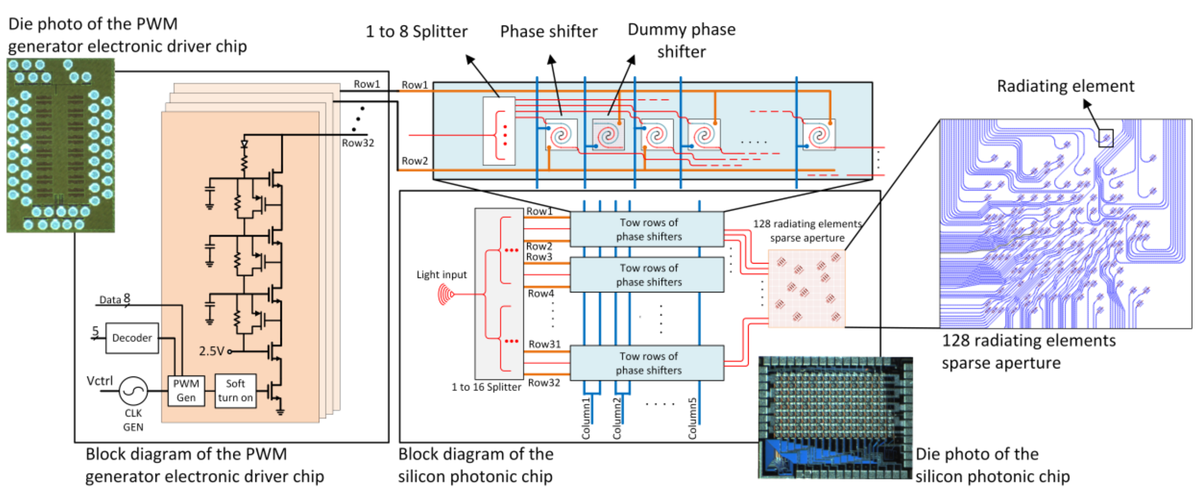

Fig. 1. The OPA system with PWM electronic driver chip and silicon photonic chip with row-column modulator routing and sparse aperture.

2. Design and Fabrication

Figure 1 shows the block diagram of the designed sparse OPA system comprised of the silicon photonic and the CMOS electronic chips. An important aspect of the sparse array design is the placement of the individual radiating elements. In this design, 128 radiating elements are distributed non-uniformly across a 27 x 27 uniform grid with 5.6µm spacing. The designed sparse aperture has a simulated 16° grating-lobe-free steering range in both directions with a beamwidth of 0.64°.

Each radiating element has a dedicated tunable phase shifter. Thermal phase shifters are electrically routed in a row-column fashion (4 x 32 plus 16 dummies) to reduce the number of electrical drivers. 16 dummy heaters are placed uniformly in between thermal phase shifters to keep the substrate temperature constant and minimize the thermal cross-talk of the phase-shifters through the substrate. The row-column phase shifter layout is folded to 16 x 9 to reduce the optical path length. The rows and columns of the phase shifter grid are electrically addressed by a custom PWM CMOS electronic chip, thereby reducing the power consumption of the drivers.

3. Characterization and Measurement Results

To characterize the OPA performance of the designed OPA system, a laser light source at 1550nm is coupled to the chip via a single-mode fiber, and an IR camera is used to capture the far-field radiation pattern. The digital control signals for programming the electronic chip are provided by a microcontroller unit via a serial interface from a desktop computer (Fig. 2(a)).

Figure 2(b) shows a typical beam pattern captured by the camera. The measured side-lobe level is -12dB (Fig. 2(c)). The measured beamwidth is 0.8° with a 16° steering range as shown in Fig. 2(d). This narrow beamwidth over the large grating-lobe-free steering range is the highest reported among all reported OPAs with a two-dimensional aperture.

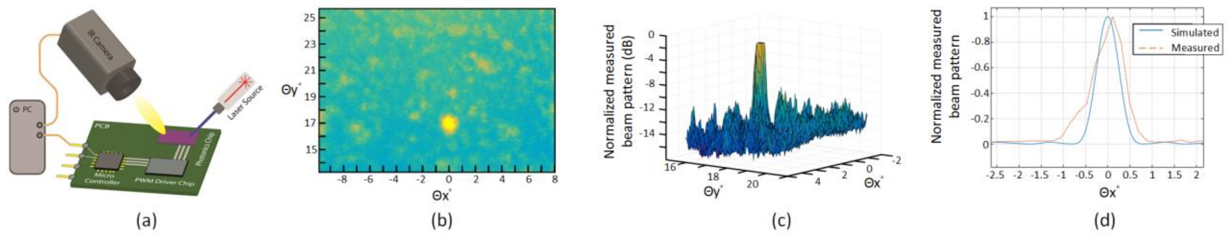

Fig. 2. (a) Schematic of the setup (b-d) Measured pattern of a formed beam

The beam steering functionality of the system is demonstrated in Fig. 3. Both the azimuthal and elevation angles of the beam are controlled electrically by adjusting the phase shifters via the electronic chip, Fig. 3(a). Fig. 3(b) shows the letter "A" projected by the 2D OPA via steering the beam.

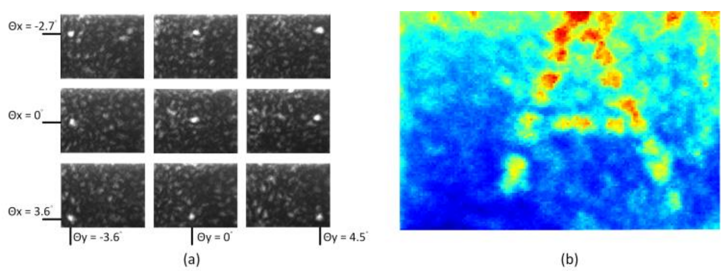

Fig. 3. (a) Measured beam pattern with IR camera for multiple angles (b) Projection of letter "A" by beam steering

4. Conclusion and Summary

In this paper, a sparse-aperture OPA with scalable structure and full phase control for both directions is demonstrated for the first time. This OPA system has the highest reported grating-lobe-free steering range over beamwidth with a 2D aperture. A row-column electrical driving method for addressing the phase shifters is devised to reduce the power consumption and electronic driver complexity. A PWM generator driver chip is used to drive the row-column phase shifters, which increases the power efficiency of the OPA system compared to DAC-based drivers.

5. References

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