Photonic Integrated Circuits for LiDAR: Solid-State 2D Beamsteering

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Abstract: In this work, we summarize our recent advances in 2D beamsteering using optical phased arrays operating in NIR and SWIR wavelengths, covering different architectures and steering techniques based on active phase shifting and wavelength tuning.

1. Introduction

Light detection and ranging (LiDAR) has drawn significant attention over the last decade, mainly driven by applications in the automotive industry, with increasing interest from the consumer and industrial sectors. Emerging LiDAR architectures focus on reducing their dependency on mechanical scanning devices, with optical phased arrays (OPAs) gaining significant visibility for solid-state beamforming. Size, weight, power and cost (SWaP-C) criteria are major driving forces in the adoption of photonic integrated circuits (PICs) for developing LiDAR, where most key photonic building blocks can be densely packed on Si/SiN platforms and manufactured using CMOS-compatible foundry processes [1, 2]. In this paper, we summarize our recent work in demonstrating 2D beamsteering using PIC-based OPAs operating in NIR (∼905 nm) and SWIR (∼1550 nm) wavelengths, implementing different architectures and steering techniques based on active phase shifting and wavelength tuning.

2. OPA-based 2D beamsteering

In optical phased arrays, light is typically emitted off-chip through grating-based optical antennas. Full 2D beamsteering of a single far-field spot (or pattern) can be achieved with a 2D array of optical emitters with active phase shift control of each element [2, 3], as illustrated in Fig. 1(a). This architecture has a straightforward design and uses a fixed wavelength laser source; however, it results in complex waveguide and electrical routing, and requires a large number of phase shifters and optical elements. An alternative approach for achieving 2D beamsteering is to use a 1D OPA, where active phase shifting can be combined with wavelength tuning of the laser source [4, 5], as illustrated in Fig. 1(b). The emission angle of each antenna is wavelength-dependent, which allows 1D steering in the direction along the antenna, while steering in the second direction is achieved by active phase shifting. Finally, 2D beamsteering can also be achieved using fully dispersive architectures [6–8], where both steering directions are controlled by the wavelength of the laser source, as illustrated in Fig. 1(c). The architecture shown here uses an arrayed waveguide grating (AWG) approach, where light is split in a star coupler or splitter tree and then routed with incremental delay lines that deliver the required phase shift to each antenna. Additional solid-state steering methods include liquid-crystal leaky antennas [9] and focal plane arrays [10].

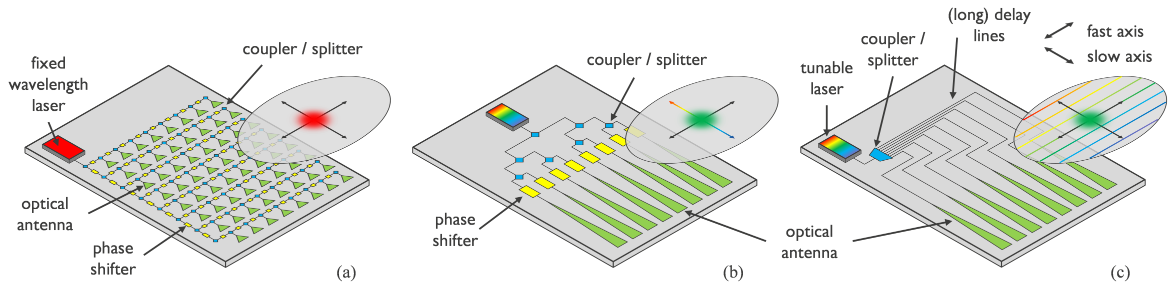

Fig. 1: OPA architectures for 2D beamsteering: (a) 2D array with active phase shifting; (b) 1D array with phase shifting and wavelength tuning; and (c) 1D dispersive array (full wavelength tuning) using an AWG approach.

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3. Discretized dispersive OPAs

Dispersive OPAs work well for small arrays (up to $\sim$100 emitters) but become impractical when scaling up to thousands of emitters, which is normally required in long-range LiDAR systems (with large apertures and therefore low diverging spots in the far field). The total length of the required delay lines results in significant chip area, optical loss, and phase errors. To overcome this scaling problem, we recently explored different types of discretized dispersive OPAs [8]. The approach consists in dividing large arrays into smaller blocks that, when combined, produce a pixelated far-field pattern with the required angular resolution of the large array. The concept is illustrated in Fig. 2(a).

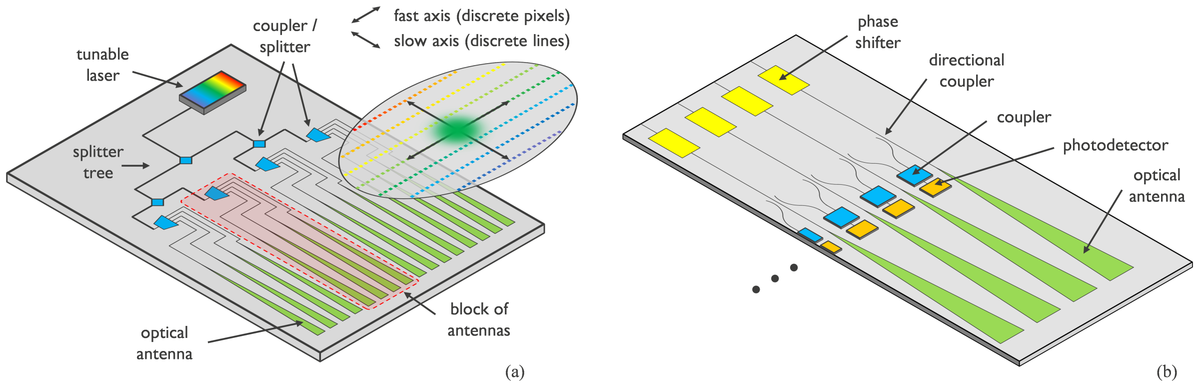

Fig. 2: OPA architectures: (a) discretized dispersive OPA for 2D beamsteering; and (b) on-chip phase interrogators for phase calibration.

4. On-chip phase calibration

For accurate beamforming, it is critical to correct for any optical phase errors that might result from fabrication non-uniformities such as local waveguide thickness or width variations. Temperature gradients within the chip or different operating wavelengths may also require phase adjustments. These issues can be mitigated with on-chip calibration schemes that use scalable integrated phase interrogators and active phase shifters, as we recently demonstrated in [11,12]. The approach allows for fast calibration with reduced computational power. The concept is illustrated in Fig. 2(b), where a small fraction of the optical signal that feeds a specific antenna is tapped off and compared to the adjacent signal (through a coupler and photodetector to determine the phase difference). Active phase shifting is then used to correct for any phase errors (and for beamsteering), typically achieved through different effects such as thermo-optic, electro-optic, liquid crystal or plasma dispersion. Here we use thermal phase shifters, which have low insertion loss, simple design and high reproducibility (despite limitations in terms of power consumption and switching speed).

5. Summary

Optical phased arrays are attractive for beamforming and solid-state beamsteering in LiDAR systems, and can be implemented in integrated photonic platforms. This paper presents our recent beamsteering demonstrations implemented in Si/SiN processes, operating at NIR and SWIR wavelengths.

References

[1] P. P. Absil *et al.*, “Silicon photonics integrated circuits: a manufacturing ... ,” Opt. Express **23**, 9369–9378 (2015).
[2] H. Abediasl and H. Hashemi, “Monolithic optical phased-array transceiver ... ,” Opt. Express **23**, 6509–6519 (2015).
[3] J. Sun *et al.*, “Large-scale nanophotonic phased array,” Nature **493**, 195–199 (2013).
[4] K. van Acoleyen *et al.*, “Off-chip beam steering with a one-dimensional optical ... ,” Opt. Lett. **34**, 1477–1479 (2009).
[5] C. V. Poulton *et al.*, “Coherent solid-state LiDAR with silicon photonic optical ... ,” Opt. Lett. **42**, 4091–4094 (2017).
[6] K. van Acoleyen *et al.*, “Two-dimensional dispersive off-chip beam scanner ... ,” IEEE PTL **23**, 1270–1272 (2011).
[7] S. Dwivedi *et al.*, “Dispersive OPA at very near-infrared wavelengths,” in IEEE Photonics Conference, WE3.3 (2021).
[8] W. Bogaerts *et al.*, “A 2D pixelated optical beam scanner controlled by ... ,” IEEE JSTQE **27**, art. no. 6100512 (2020).
[9] K. Nakamura *et al.*, in Proc. SPIE **11690**, Smart Photonic & Optoelectronic Integrated Circuits XXIII, 116900W (2021).
[10] C. Li *et al.*, “Lens-based integrated 2D beam-steering device with ... ,” Opt. Express **27**, 32970–32983 (2019).
[11] J. Kjellman *et al.*, “Densely integrated phase interrogators for low-complexity on-chip ... ,” submitted for publication.
[12] M. Prost *et al.*, “Optical phased array with on-chip phase calibration,” unpublished.

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