Integrated optical phased arrays with circular architecture on a silicon platform

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Abstract. Optical phased arrays (OPAs) are now at the forefront of photonic research as a key beam steering technology for myriad of photonic applications, including in light detection and ranging (LIDAR), communications, and metrology, among others. Integrated OPAs with narrow beam widths and wide-angle steering are in critical need, especially for LIDARs in autonomous vehicle, drone and airplane navigation, or satellites. In this work, we numerically study the performances of OPAs having a circular layout arrangement. Compared to recently available solutions with 1D linear or 2D rectangular arrays, the proposed circular OPAs are poised to deliver effective suppression of the grating sidelobes, while improving beam steering range and obtaining narrower beamwidths. We demonstrate 110-element circular arrays with sidelobe suppression better than 10 dB and an angular beamwidth of 0.5°. Under a monochromatic operation at a 1550 nm wavelength, such array provides a solid angle steering range of 0.21π-sr, with a perspective for performance improvement by using large number of OPA elements and operating under broader spectral range.

1 INTRODUCTION

Chip-scale optical phased arrays (OPAs), which vary the angle of an optical beam by alternating its phase profile, are promising new technology for many applications. Compared to the well-established OPA systems working in fields of imaging and displays, integrated OPAs avoid bulky mechanical mirrors or other spinning and rotating parts. In turn, this helps the system to be more tolerant and insensitive to external vibrations. Thus, on-chip OPAs possess the advantages to be stable, fast, and precise in their functionality, paving the way for next-generation dynamic beam steering and shaping [1,2]. Silicon photonics is a platform of conscious choice for dense integration. Silicon photonics enables realization of compact, low-cost, and high-performance components on a single chip, potentially in large volumes. Leveraging the compatibility with well-mastered tools and processes of complementary metal-oxide-semiconductor (CMOS) fabrication infrastructure, silicon photonics is seen as future technology for scalable product deployment.

Silicon photonics OPAs are realized as one-dimensional (1-D) linear and two-dimensional (2-D) arrays, having either rectangular or circular layouts [1-6]. To steer the light beam, such approaches typically adopt wavelength-controlled antennas or antennas with associated phased shifters [1-3]. OPAs call upon narrow beam widths and large field-of-views, in both azimuthal and elevation angles. Narrow beams can be formed using large number of OPA antennas. On the other hand, large FOV can be assured either by shrinking the element footprint or by reducing the spacing between individual elements within the OPA. It is required to have element separation on a sub-wavelength scale, i.e. separation at a distance that is shorter than a half of a wavelength [1]. Otherwise, grating sidelobes in the far-field become too dominant, which restricts beam steering range and makes phased arrays impractical.

In this work, we report a numerical study on 2-D OPA with circular geometry. Circular OPAs are competitive alternatives to 1-D and 2-D arrays, enabling effective sidelobe suppression, enhanced beam steering spans, and having narrower beamwidths, yet with increased element separation well-beyond the sub-wavelength scale. Under

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a single-wavelength (monochromatic) operation, we design a 110-element phased array with sidelobe suppression larger than 10 dB, narrow angle divergences of only 0.5°, and solid angle steering range of 0.21π-sr.

2 OPA layout and steering performance

Figure 1(a) shows a schematic view of the proposed circular OPA. OPA system is designed for 220 nm / 2 µm (silicon / buried oxide layers) using silicon-on-insulator substrate. Circular array comprises N concentric rings, M grating antennas, with ring radius R_n and element distance dr. Those parameters are optimized and comprehensively studied to obtain reliable performance outputs. For the OPA, antennas are key devices. Optical antennas have subwavelength-assisted L-shaped profile, schematically shown in the inset of Fig. 1(a), enabling superior radiation performance over wide wavelength range [6]. Radiation efficiency as a function of a wavelength is shown in Fig. 1(b).

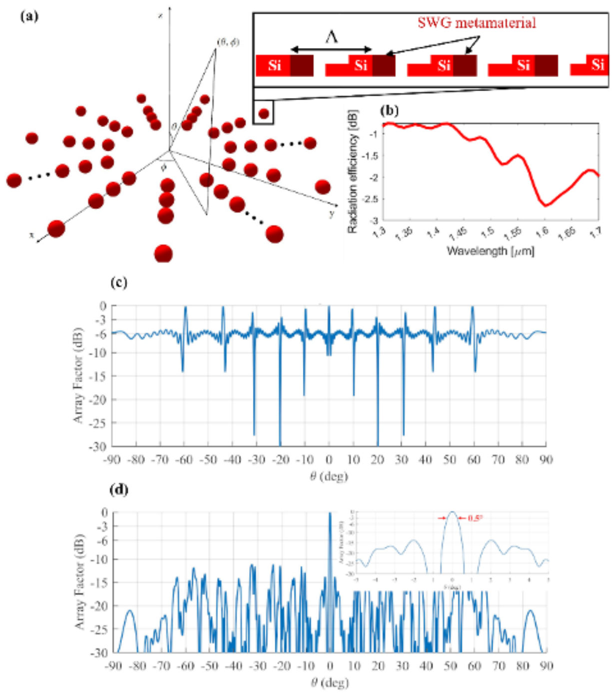

Fig. 1. (a) Schematics of circular array with silicon antennas. Inset: 2D schematics of the L-shaped grating antenna. (b) Antenna radiation efficiency versus wavelength. Elevation cut of array factor amplitudes for (c) $M = 4$ and (d) $M = 11$.

Figures 1(c) and 1(d) show simulated array factor amplitudes for different array configurations, with varying number of antennas. We observed that both sidelobe suppression as well as angular beamwidth are substantially improved. For OPA with $N = 10$; $M = 11$; $R_n = 20$ µm; and $dr = 9$ µm, the main-to-sidelobe grating suppression is -11.1 dB. For this array configuration, the angular beamwidth of about 0.5° was obtained. It is also expected that enhanced performance can be achieved by employing more elements into a circular OPA.

The steering range of proposed circular array was systematically studied by simulating array far-field pattern at different steering angles over the entire hemisphere. The steering range is defined as the set of all steerable $\{\theta, \phi\}$ angles, for which the main-to-sidelobe ratio is larger than 10 dB. All steerable angles are projected on a uv plane. Figure 2 shows the projection of steering range onto a hemisphere under single-wavelength operation at 1550 nm. We estimated a solid angle steering range of 0.21π-sr.

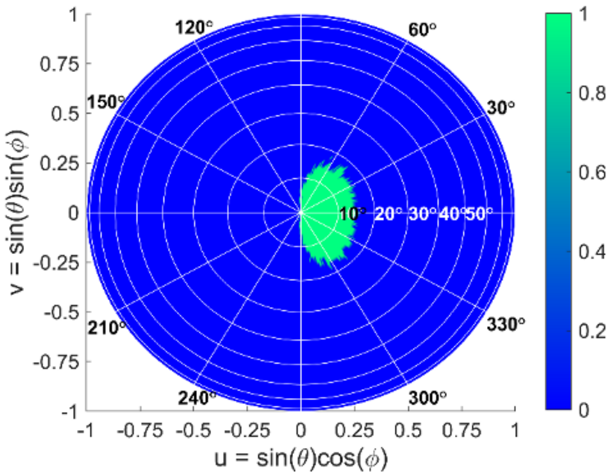

Fig. 2. The steering range projection onto a hemisphere for a circular array operating at 1550 nm wavelength. The bright green area corresponds to the set of all steerable angles with the sidelobe suppression larger than 10 dB, and the dark blue area represents non-steerable angles.

3 Conclusions

We report circular OPAs with efficient antennas that offer effective sidelobe suppression, while improving beam steering range and obtaining narrower beamwidths. We designed a 110-element OPA with sidelobe suppression better than 10 dB and an angular beamwidth of 0.5°. At a 1550 nm wavelength, proposed OPA provided a solid angle steering range of 0.21π-sr. The on-chip circular OPA is a promising technology for practical applications such as LIDARs or communications.

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