Sparse Optical Phased Array Design

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Abstract: We propose a scalable, low fill factor, optical phased array design based on sparse arrays, relaxing the sub-wavelength antenna pitch requirement for sidelobe suppression, achieving significantly lower beamsteering power consumption than a uniform array.

1. Introduction

Optical Phased Array (OPA) technology has rapidly advanced in recent years, enabling CMOS-compatible arrays suitable for commercial LIDAR applications [1]. OPAs serving real-world applications require hundreds to thousands of antennas for narrow beamwidth and wide field-of-view [1]. At optical frequencies, dense arrays pose significant design challenges to achieve the ideal half-wavelength antenna pitch required to minimize sidelobes and maximize steering range [2]. The antenna pitch can be increased beyond sub-wavelength dimensions to minimize coupling between antennas, and accommodate low-loss optical routing to each antenna. Increased sidelobes due to non-ideal antenna pitch can then be actively suppressed post-fabrication. The increased circuit complexity and power consumption due to active tuning can be further relaxed using subarrays at the expense of beamsteering range [3]. As the density of OPAs continue to increase, flexible and low complexity array architectures are needed to balance these design tradeoffs.

Typically, OPAs are designed as uniform arrays for smooth spatial sampling across the array aperture [3]. The fill factor of an array can be reduced with minimal impact on the array factor by selectively removing antennas to create an aperiodic array. Thinning algorithms based on genetic and particle swarm optimizations are commonly used to determine antennas suitable for removal [4]. However, these algorithms require careful design of the cost function for meaningful convergence, and are computationally prohibitive for dense arrays due to the size of the search space of potential solutions. An alternative aperiodic technique shifts the relative antenna locations to form a sparse array [4]. By optimizing antenna locations within a sparse array aperture of low fill factor, the array factor of the sparse array can be geometrically tuned to approximate an equivalent dense, uniform array of high fill factor. In this work, we present an OPA design using sparse arrays to significantly relax the tradeoffs of dense OPA design.

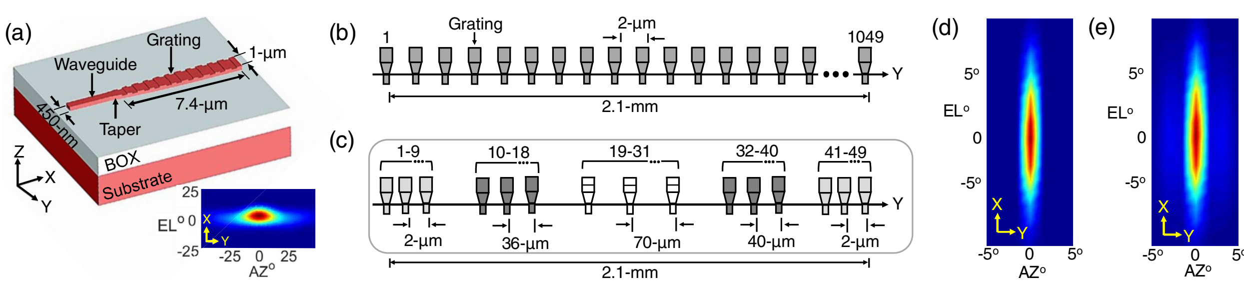

Fig. 1. (a) FDTD model of an SOI waveguide grating; (b) 1×1049 uniform grating array (synthesized model); (c) Proposed equivalent 1×49 sparse array (synthesized model); (d) 3-D far-field radiation profile of the uniform array; (e) 3-D far-field radiation profile of the sparse array.

2. Design Methodology

We propose to leverage the sparse *augmented nested array* (ANA) concept [6], to simultaneously reduce the fill factor, mutual coupling, and beamsteering power consumption of a uniform OPA. An ANA has the highest spatial resolution

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and lowest mutual coupling as compared with conventional co-prime, nested, and super-nested sparse configurations [6]. As shown in Fig. 1, for a fixed aperture length, a dense 1-D OPA array of uniformly-spaced waveguide grating antennas can be equivalently represented by a sparse ANA.

To demonstrate the proposed sparse OPA concept, we design a compact waveguide grating antenna on an SOI substrate (220-nm top silicon and 2-μm BOX) as shown in Fig. 1(a). The grating model was simulated in FDTD and the far-field radiation data was synthesized [5] into a 1×1049 uniform array, and its 1×49 sparse array equivalent as shown in Fig. 1(b)(c). Fig. 1(d)(e) compares the synthesized far-field beam profiles of the uniform and sparse arrays respectively. The 0.982^o Full-Width Half Maximum of the uniform array is preserved by the sparse array with a 95.21% reduction in the number of antennas, while maintaining a 2.1-mm aperture. The aperiodic pitch of the sparse array reduces near-field mutual coupling between adjacent antennas, and increases routing area for optical waveguides at the array center, benefitting application-specific 2-D sparse OPA designs requiring a symmetric array factor.

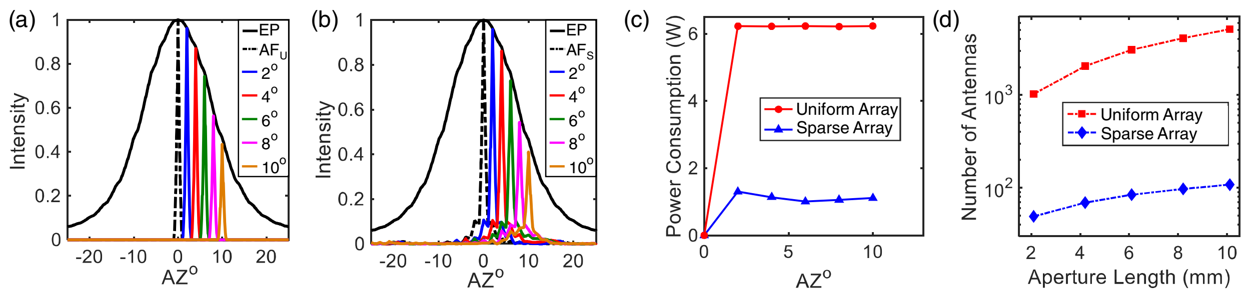

Fig. 2. Comparison of proposed sparse array with uniform array: (a) Phased array beamsteering of uniform array; (b) Phased array beamsteering of sparse array; (c) Power consumption for thermo-optic phase shifting; (d) Antenna count as aperture length is scaled.

Fig. 2(a)(b) compares the beamsteering performance of the uniform and sparse arrays. Phase coefficients are synthesized [5] to steer the array factors (AF) under the element pattern (EP) envelope of a single antenna. Good agreement in beamsteering between the two arrays is observed, with significantly reduced fill factor and minimal sidelobes in the sparse case. Fig. 2(c) compares the total power consumption to steer each array using thermo-optic phase shifters with 24-mW/π thermal efficiency [7]. A $5\times$ reduction in overall power consumption is observed in the sparse case with only a 4.79% fill factor. Fig. 1(d) compares the number of antennas required by uniformly and sparsely distributed 1-D OPAs as the aperture length is scaled. Significant reduction in fill factor is observed in the sparse case.

The low fill factor of the sparse array reduces the far-field intensity as compared with a dense uniform array and can be compensated by a higher input optical power. The sidelobe suppression capability of the sparse array is also reduced due to the low fill factor, but can be managed on the component-level by element pattern design.

3. Conclusion

We present a flexible approach to OPA design which relaxes the design tradeoffs for dense arrays with hundreds to thousands of antennas. Rather than uniformly arranging antennas over a fixed aperture length, an aperiodic distribution of antennas in a sparse array configuration is proposed. Compared with a uniform array, a sparse array significantly reduces the fill factor of the array, minimizes coupling between antennas, and lowers beamsteering power consumption with minimal impact on far-field pattern profile and sidelobes.

References

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