SAND2019-5045C

Phase Optimization of a Silicon Photonic Two-Dimensional Electro-Optic Phased Array

Michael Gehl, Galen Hoffman, Paul Davids, Andrew Starbuck, Christina Dallo, and Christopher Long
Sandia National Laboratories, Albuquerque, NM
cmlong@sandia.gov

Emil Kadlec, Zeb Barber, R. Krishna Mohan and Stephen Crouch,
Blackmore Sensors and Analytics, Bozeman, MT
crouch@blackmoreinc.com

Introduction

Optical phased arrays (OPAs) have received much attention recently as a solution for scanning an optical beam [1-6], with applications in LIDAR, freespace optical communications, and stand-off optical sensing. Compared to traditional mechanical beam scanners, OPAs offer advantages in manufacturing, size, speed, and durability.

Creating the array presents difficult technical challenges, requiring dense, low-loss optical routing, an ability to manipulate phase, and an efficient output coupler element. We present a two dimensional silicon photonic OPA using vertically coupled Ta gratings to scatter the light outward from waveguides. This work advances our earlier work [6] and demonstrates scanning of near-diffraction limited beams across wider angles and utilizing more radiating elements.

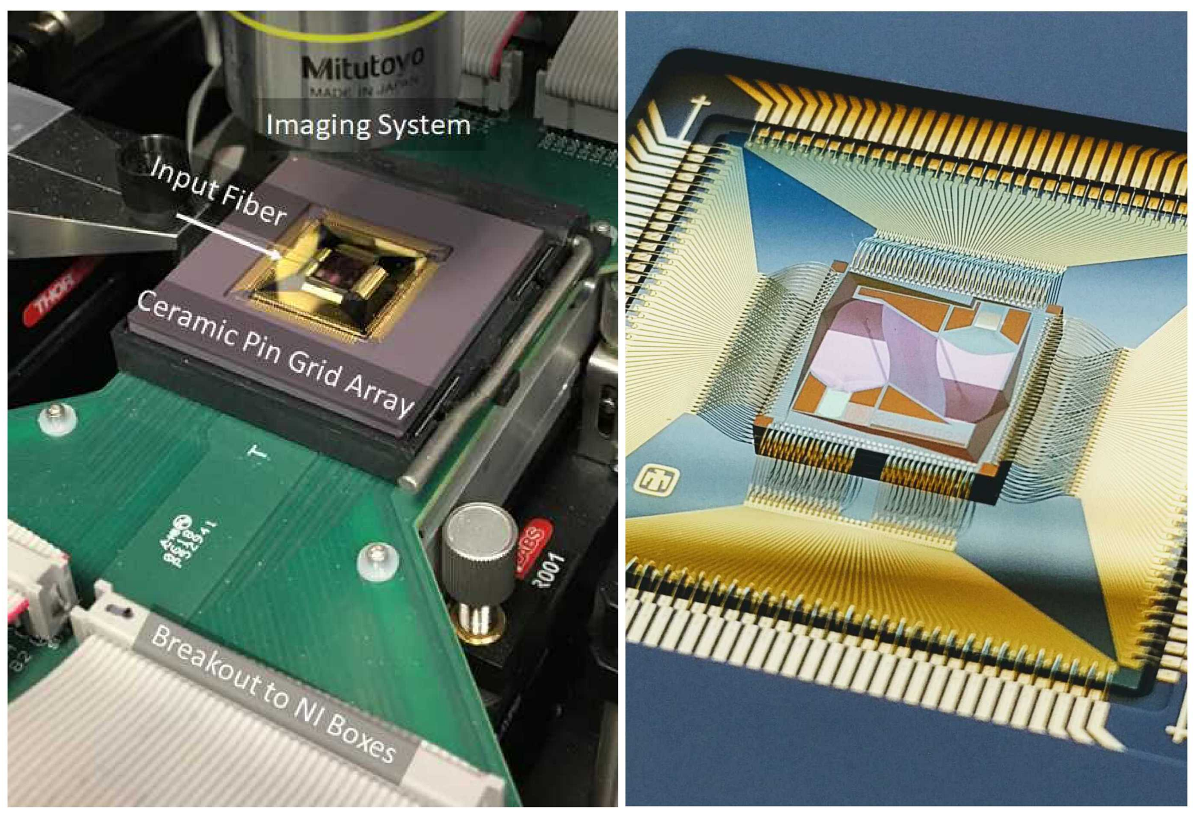

Fig. 1 | Experimental setup showing 2D OPA chip mounted on a Si interposer wirebonded to a 256 PIN mount driven by a National Instruments DAC box.

Implementation

Silicon photonics platform

- Mature technology based on CMOS processes [7]
- High-density integrated optical circuits
- Full library of functional devices available to route, modulate, and detect light
- Radiator elements from nanostructures patterned in a Ta layer, placed above waveguides

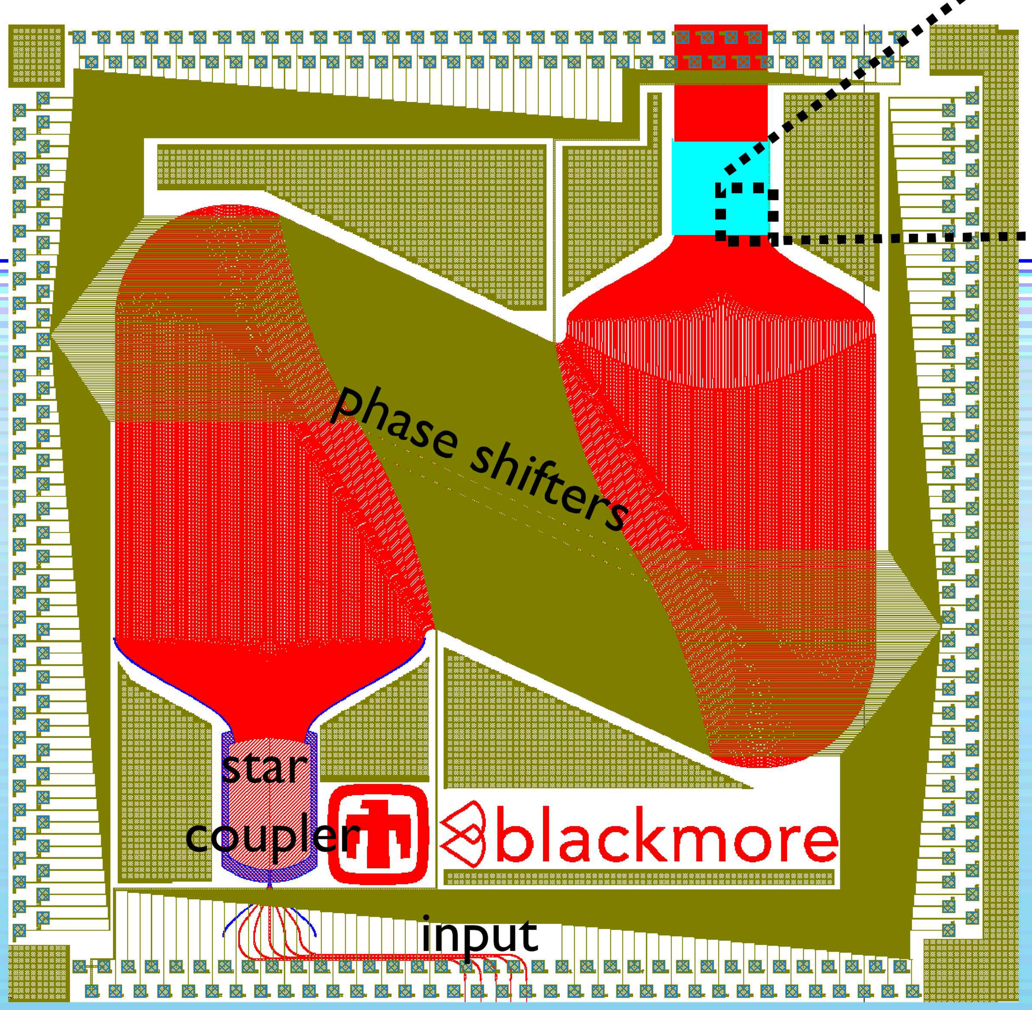

Fig. 2 | Mask layout for the 2D optical phased array.

Results and Discussion

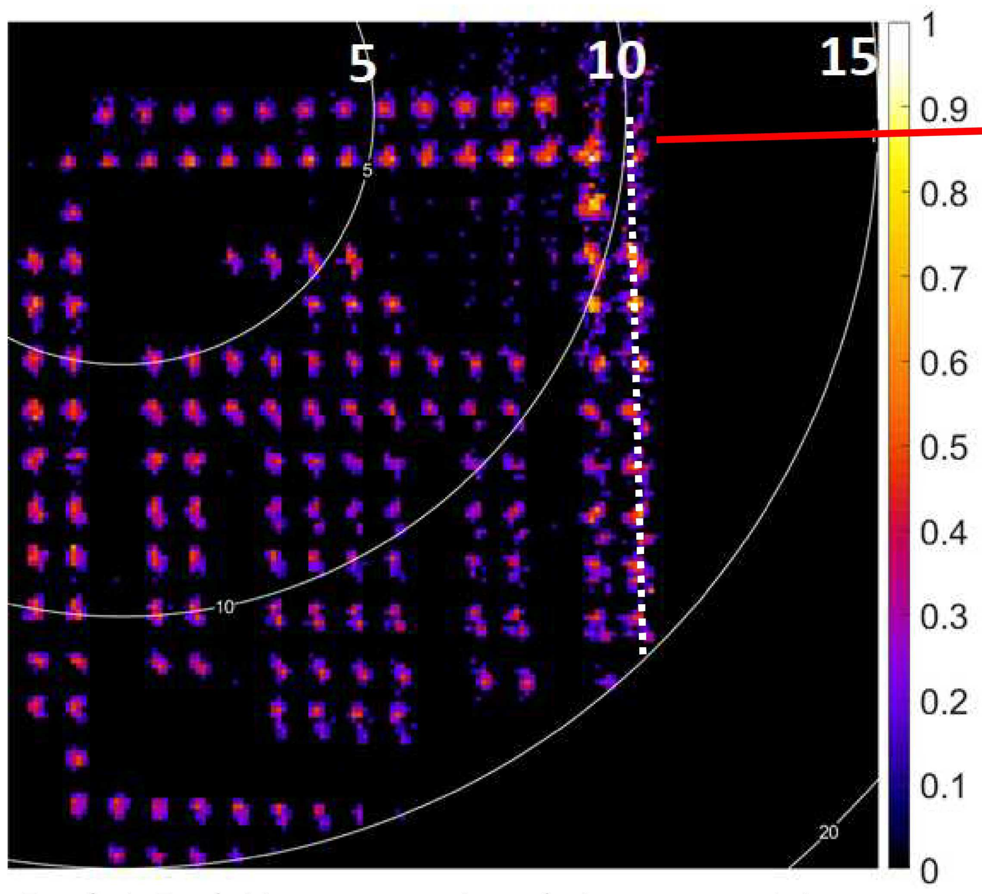

Fig. 3 | Far-field image overlay of the optimized beam at various angles. The phases were optimized at a single wavelength. Pathlength matching in the device ensures phases remain optimized from 1500nm to 1600nm.

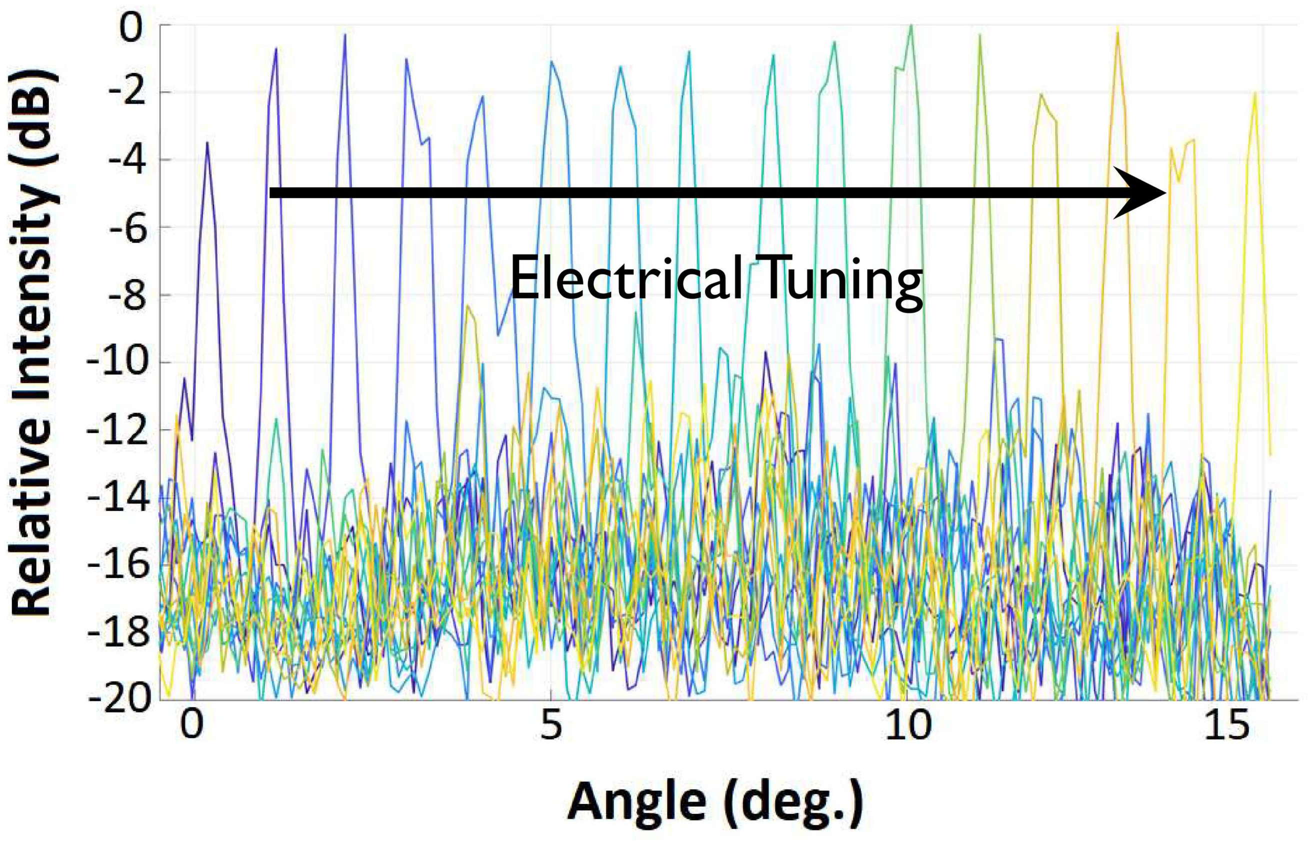

Fig. 5 | Far field beam scanning with applied DC voltage at 1550 nm.

Beam Phase Optimization

- Voltage bias was used to optimize the longitudinal array phase at 1500 nm wavelength for 16 different spot positions, yielding a lookup table for beam position
- The voltage ranged from: -7V to 2V
- For each phase shifter the voltage bias was chosen to maximize the figure of merit defined by the scalar overlap integral between the measured far field beam profile and the desired profile

$$FOM_{max} = \iint b_{meas} b_{target} d\theta d\varphi$$

Phased Array Architecture

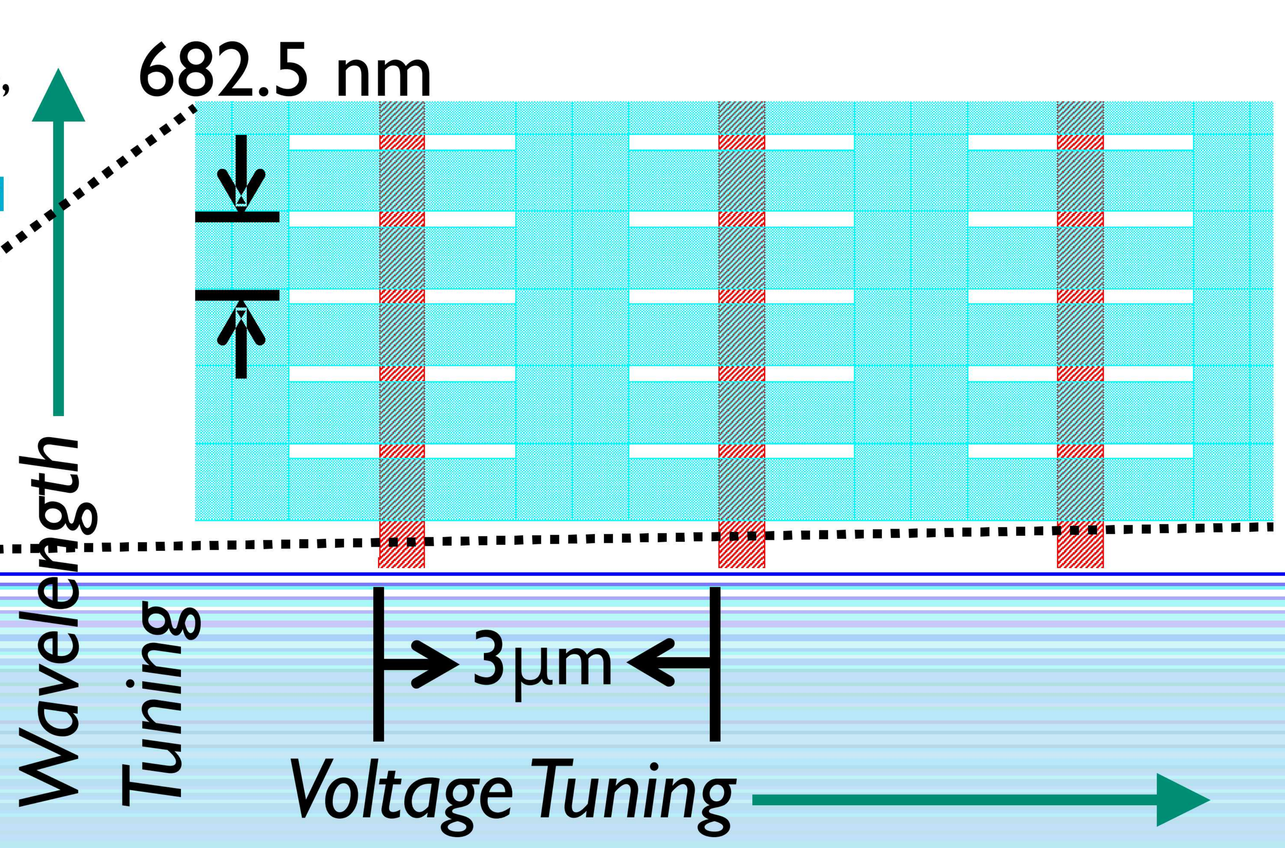

Fig. 4 | Closeup image of the Ta (light blue) over the Si (red) waveguides.

- Edge-coupled Si waveguides
- Star coupler distributes an apodized light intensity profile to 256 waveguides
- Transverse phase is modulated with 1mm long electro-optic phase shifters formed from PN junctions
- Longitudinal phase is modulated with wavelength

Electronic beam steering

- Beam steering performed by setting the voltage and wavelength according to the lookup table
- 250 deg./s steering speed (600 μs/step @ 0.15 deg. steps) limited by the NI voltage control box
- Intrinsic beam steering time is less than 1 ns
- Imaging the far field shows well-formed beams
  - 0.3° FWHM with grating lobes spaced by 31°
  - matches Array Factor calculation [8]

$$AF = \sum_{n=0}^{N-1} A_n \exp(in\psi),\ \psi = \frac{2\pi}{\lambda} d\cos(\theta) + \alpha$$

Next steps

- Replace Ta with Si gratings for lower absorption loss
- Improve fiber-to-chip coupling loss
- Longer array for to improve divergence of beams
- Integrate Ge photodetectors
- Implement faster Gerchberg-Saxton beam optimization

Summary

- Developed novel OPA designs with Ta scattering elements to achieve narrow beams, wide tuning angle, and simple electrical controls
- Demonstrated successful operation with near-diffraction limited beams and > 15° steering with +2V to -7V signal
- Demonstrated vertically-coupled Ta scattering element to provide flexibility in beam profile design

References

[1] J. Doylend, M. Heck, J. Bovington, J. Peters, L. Coldren, and J. Bowers, Optics Exp., 19(22), pp. 21595-21604, 2011.
[2] J. Sun, E. Timurdogan, A. Yaacobi, E. Hosseini, and M. Watts, Nature, 493(7431), p.195, 2013.
[3] K. Van Acoleyen, H. Rogier, R. and Baets, Optics Exp., 18(13), pp. 13655-13660, 2010.
[4] D. Hutchison, J. Sun, J. Doylend, R. Kumar, J. Heck, W. Kim, C. Phare, A. Feshali, and H. Rong, Optica, 3(8), pp.887-890, 2016.
[5] S. W. Chung, H. Abediasl, H. Hashemi, IEEE Journal of Solid-State Circuits 53.1, 275-296, 2018.
[6] C. DeRose, R. Kekatpure, D. Trotter, A. Starbuck, J. Wendt, A. Yaacobi, M. Watts, U. Chettiar, N. Engheta, and P. Davids, Optics Exp., 21(4), pp.5198-5208, 2013.
[7] A. Lentine, C. DeRose, P. Davids, N. Martinez, W. Zortman, J. Cox, A. Jones, D. Trotter, A. Pomerene, A. Starbuck, D. Savignon, T. Bauer, M. Wiwi, and P. Chu, IEEE Aerospace Conference, pp. 1-9, 2015.
[8] M. Sadiku, Elements of Electromagnetics, New York: Oxford University Press, 1995.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ____________

Visit us at the National Security Photonics Center site:
http://www.sandia.gov/mesa/nspc/