Mid-infrared 2D optical phased array with mirror emitters in InP

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Abstract: A 2D beam steering optical phased array operating at a single mid-infrared wavelength is demonstrated. The device relies on a sparse aperiodic distribution of small-area mirror emitters to achieve ~1000 resolvable points.

In recent years, chip-based optical phased array (OPA) technology has progressed with great strides, motivated by the size, weight, and power gains of photonic integration for rapidly growing applications such as lidar and free-space optical communications. In particular, two-dimensional (2D) beam steering OPAs operating at a single wavelength, driven by their unparalleled utility, have experienced the most recent surge of advances.

In general, the principal figures of metric for OPA devices are steering range (also known as field-of-view), beam size, optical transmission efficiency, and phase tuning efficiency. The steering range and beam size are highly linked, described by the far-field pattern (FFP), and determined by the types of antennas and their arrangement. The FFP of a single antenna dictates the envelope function of the far-field, possibly limiting the steering range if too narrow. Likewise, the antenna arrangement may limit the (unambiguous) steering range if the spacing is large enough to produce grating lobes in the FFP (also known as aliasing). The beam size, on the other hand, is mainly dependent on the aperture size—the full size of the array—and therefore favored by larger sizes.

Innovative approaches have been developed to contend with these opposing dependencies. Most notably, 2D sparse aperiodic arrays have been demonstrated to provide both extended steering ranges and reduced beam sizes. Through judicious arrangement of antenna locations, even up to spacings of several wavelengths, grating lobes can be suppressed thereby increasing the unambiguous steering range. At the same time, the enlarged aperture gives rise to a smaller beam width. Together, the expanded steering range and reduced beam width provide a greater number of resolvable points. Seen another way, a sparse aperiodic array can achieve the same number of resolvable points as a periodic array with vastly fewer antenna elements, hence providing the additional advantage of a corresponding reduction in the number of phase shifters, reducing both control complexity and power consumption. The tradeoff for these gains is an elevated side lobe level (SLL), but which can typically be tolerated in most applications.

The determination of antenna locations is typically carried out through an optimization algorithm, iteratively adjusting antenna positions and calculating a figure-of-merit (FOM) until reaching a designated threshold. FOMs typically include SLLs, beam widths, and sparsity. A so-called genetic algorithm, which mimics the mutation and survival features of natural selection, has been used with a 128-antenna sparse array to produce >400 resolvable points [1]. Another work optimized an 81-antenna array to give >900 resolvable points with a denominated genetic deep learning algorithm [2]. Alternatively, a mathematically non-redundant arrangement of a 127-antenna array produced a record count of ~19,000 resolvable points [3].

The abovementioned works have been carried out in near-infrared silicon photonics. The development of OPA technology at longer wavelengths or on non-silicon-based platforms has been scarce and to the best of the author's knowledge limited to 1D arrays. In this work, we develop a 2D OPA for single-wavelength operation at $\lambda = 4.6\ \mu m$ in an InGaAs/InP material platform. The platform is intended to be compatible with future monolithic integration with InP-based quantum cascade lasers. Integrated beam formation and steering are expected to play important roles in various emerging applications taking advantage of the unique characteristics of this spectral region. For instance, with the low background solar noise averting the typical SNR degradation of a sunny day, around-the-clock long distance lidar and point-to-point communications operations are expected.

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The OPA device is built upon an $In_{0.53}Ga_{0.47}As/InP$ core/cladding ridge waveguide structure. A 5-level multi-mode interferometer power distribution tree divides the input power into multiple parallel channels. Thermo-optic phase shifters are used to adjust the phase of each channel. The antennas are total-internal-reflection mirrors whose small area benefits both versatility in 2D positioning as well as a broad far-field envelope [4]. The mirror facets are created with a crystallographic wet etch. The sparse aperiodic array of emitters lies on a grid of spacing 2.0λ = 9.2 μm, and their positions were optimized through a particle swarm algorithm to minimize the far-field beam size, in effect yielding a non-redundant array. Fig 1. shows the fabricated emitter array along with a scanning electron microscope (SEM) image of a single emitter.

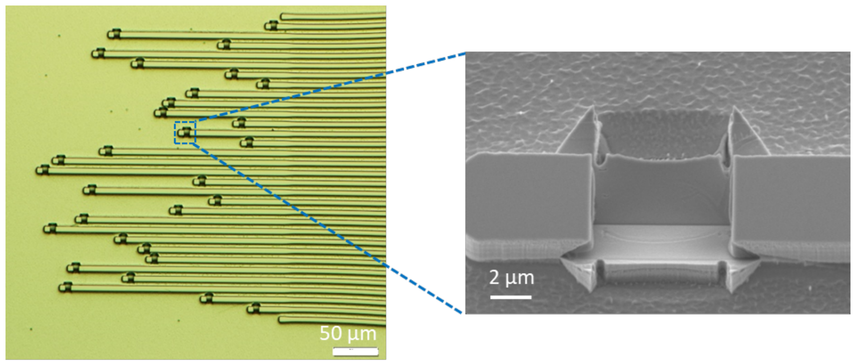

Fig. 1. Fabricated 2D sparse aperiodic array of mirror emitters terminating 2.0λ-spaced access waveguides, with a SEM image of one emitter.

A hill-climbing algorithm was used to calibrate and form the beams at arbitrary far-field locations. The far-field pattern was observed through a Fourier-imaging lens system and a mid-infrared camera. Fig. 2 shows beam steering to three different arbitrary points, within a ±11.5° imaging-system-limited field-of-view. With the device's full ±14° × ±14° field-of-view and ~0.9° × 0.8° beam size, a resolvable point count of ~1000 was achieved, while sustaining an SLL down to ~-5 dB.

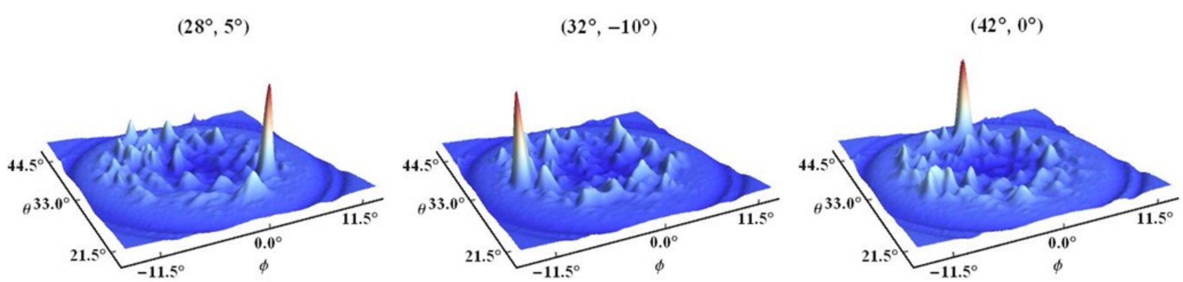

Fig. 2. 2D beam steering far-field patterns at three arbitrary points.

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