Antenna for a two-dimensional integrated Optical Phased Array designed for Optical Wireless Communications

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Abstract

We report on the design, fabrication and characterization of a silicon photonics based optical antenna producing a low divergence Gaussian beam. We measured a full width at half maximum (FWHM) of 1.40° along both directions. This antenna will be implemented as a unitary emitter in a two-dimensional optical phased array (2D-OPA) designed for directional optical wireless communications.

Introduction

The demand for large-capacity and high-speed communication is continuously increasing while existing radio-frequency (RF) communications, with relatively low bandwidths, are becoming saturated. A potential solution is to implement free-space optical (FSO) communications, which can transmit at higher bandwidths thanks to their higher frequencies, over unlicensed spectra. Yet, two main challenges remain. First, FSO links are vulnerable to atmospheric turbulence. Second, the use of discrete elements such as lenses and detectors limit the system's size, weight, power and cost (SWaP-C) optimization [1]. To overcome these challenges, integrated optical phased arrays (OPAs), which are non-mechanical beam forming devices, are a promising solution. Lens-free FSO links with OPAs have been demonstrated [2] and active phase control in OPAs could compensate the phase front distortion caused by atmospheric turbulence. In addition to this, the OPA should also produce a single low divergence beam, with suppressed secondary lobes. One way is to set the OPA pitch, Λ, below half the wavelength, λ. This strategy will yield a large continuous scanning range, but it is practically unfeasible to implement as λ is small. However, for point-to-point communications, a relatively small scanning range is acceptable. In our work, we will present a 4x4 OPA with $\Lambda > \lambda$ in which we strongly attenuate the secondary lobes by optimizing the array fill factor, defined as the effective aperture size per unit OPA pitch. To illustrate this, we consider a 1D system. Fig. 1(a),(b) shows two OPA far field profiles for two different fill factors. The underlying analytical model can be found in [3]. As the fill factor is increased, the angular emission profile of a single emitter, known as the element factor, is narrowed and the higher lobes can be attenuated (see Fig. 1(c)). A fill factor of 0.75 is

targeted, as this will yield a high lobe suppression of -10 dB while leaving the necessary space for input waveguides to the antennas. However, designing an antenna with such a high fill factor is not trivial. Indeed, the mode, which is a few hundreds of nm wide in the input waveguide, needs to be increased to several tens of microns over a very limited surface area.
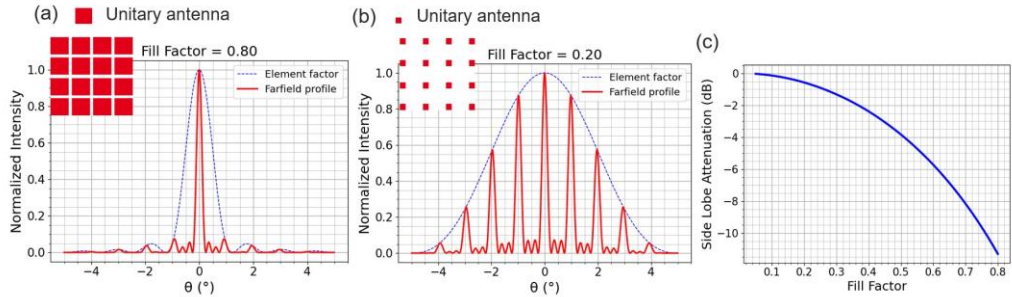

Fig. 1. OPA Far field profile with fill factor = (a) 0.80 and (b) 0.20. Insets show the 4x4 OPA schematically (c) Side lobe level variation with fill factor

Design and fabrication of the unitary antenna

Fig. 2(a) shows the antenna architecture intended to maximize the fill factor. It consists of two separate diffraction gratings to expand the mode along the two directions. The first diffraction grating consists of blazed sidewall corrugations [4]. The input light, initially propagating along the x-axis in a 500 nm wide single mode waveguide, is diffracted parallel to the y-axis by these corrugations. The diffracting power of the corrugations has been modulated along the x-axis to produce a Gaussian-mode, which then propagates in a partially etched Silicon slab until it is diffracted by the second grating into free space. The second diffraction grating consists of subwavelength gratings (SWGs) elements that act as a metamaterial with a lower index than that of silicon [5], allowing a sufficiently weak grating strength to produce a Gaussian emission profile over the desired length. The resulting 2D-Gaussian mode was around 65 µm wide in both directions in the near field.
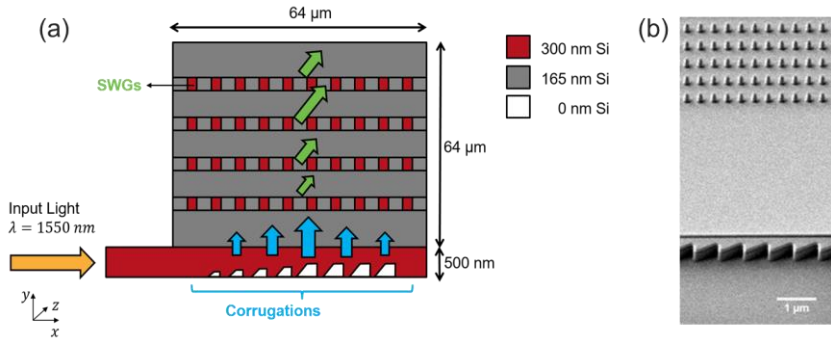

Fig. 2. (a) Top view of the antenna architecture to maximize the fill factor
(b) Scanning Electron Microscope (SEM) inspection of the fabricated antenna

The antenna was fabricated on the 300 mm wafer platform at CEA-LETI using immersion lithography. In our unitary antenna, the minimum feature sizes were 70 nm in the corrugations and 100 nm for the SWG elements (see Fig. 2(b)).

Experimental set up and Characterization

A laser with a wavelength $\lambda = 1.55\ \mu m$ was injected into a photonic waveguide

feeding a unitary antenna, which then emitted the light into free space. The far field images of the produced beam were then taken using an infrared camera placed at a height of 40 mm above the antenna surface, beyond the expected Fraunhofer distance $d_F \sim 4.5\ mm$. The far field image of the unitary antenna is shown in Fig. 3(a). Cross-sections along θ and φ axes (Fig. 3(b) and (c)) taken at the position of maximum intensity have been fitted using Gaussian functions. The measured full width at half maximum (FWHM) along both axes is $\sim 1.40°$. This value corresponds to a mode field diameter, $MFD = 2 \times \frac{1.18\,\lambda}{\pi\,FWHM}$, of around 48 µm. The antenna was placed in a 4x4 array with pitch 90 µm. The effective fill factor, which is 48/90 = 0.53, is less than the targeted 0.75. Characterization of the array is in progress.

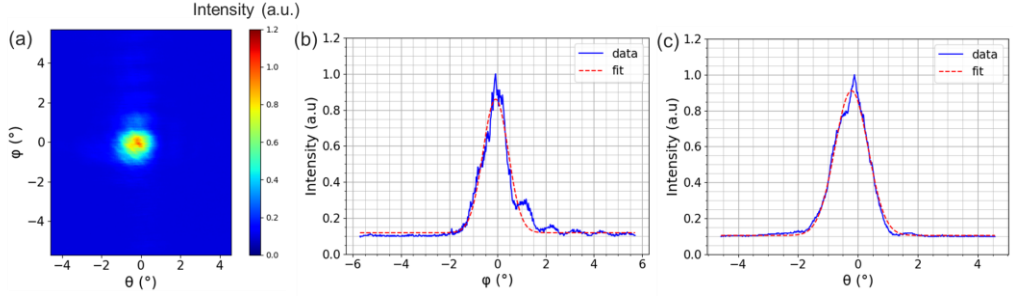**Fig. 3. (a) Far field image of the antenna. Cross-sections taken along (b) φ and (c) θ axes**

Conclusion

In this work, we have reported a low divergence 2D-OPA unitary antenna. The measured FWHM of the 2D Gaussian beam was around 1.40° in both directions. The corresponding MFD is 48 µm. Characterization of the OPA is in progress. We believe that the presented antenna architecture could be a promising solution for the implementation of 2D-OPAs for directional optical wireless communications.

References

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