Metamaterial antenna array fed by distributed Bragg deflector for beam steering on SOI platform

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***Abstract*—The capability to radiate collimated steerable beams of light is crucial for many applications, such as remote sensing and free-space optical communications. Here we experimentally demonstrate a novel 1D-antenna array architecture that exhibits a far-field Gaussian profile with an angular divergence of 1.8° × 0.2°.**

Keywords*—Silicon photonics, optical antennas, optical phased array, subwavelength grating metamaterials, Fourier optics, Bragg structures

I. INTRODUCTION

The design of nanophotonic devices capable of generating off-chip highly collimated light beams is of great interest in many research areas, including quantum photonics [1], biology [2], metrology [3], telecommunications [4], remote sensing [5] and light detection and ranging (LIDAR) [6]. The generation of this type of beams from a photonic chip employing large-aperture light emitters and without using external optics is an outstanding challenge.

Silicon-On-Insulator (SOI) is one of the most widely used platforms for photonic integrated circuits (PIC) due to the high integration it provides as well as its low mass fabrication cost. However, the implementation of large-scale radiating apertures to achieve highly collimated beams off-chip is difficult, requiring the use of weakly radiating perturbations. Typically, to obtain weak perturbations, radiative structures are designed with specific fabrication processes which permit minimum feature sizes (MFS) below tens of nanometers [7]. Nevertheless, it has been demonstrated a new topology for weakly radiating integrated optical antennas to achieve a larger MFS in SOI compatible with standard fabrication processes [8]. Alternative platforms such as silicon nitride (Si_3N_4) have been explored to perform the radiation of collimated beam using conventional gratings [9], at the expense of sacrificing integration.

In this talk, we report the experimental demonstration of a new integrated antenna array architecture that uses a compact light feeding circuit. The device has been fabricated on a 220-nm silicon-on-insulator platform using a single etch process with a minimum feature size of 80 nm. The far-field beam presents an angular divergence of 1.8° x 0.2° with a Gaussian profile in one dimension and a beam steering is achieved in both azimuthal (ϕ) and vertical (θ) directions using wavelength tuning of the input light.

II. DESCRIPTION OF THE DEVICE

The proposed device, shown schematically in Fig. 1(a), comprises two main parts: (1) an on-chip distributed Bragg deflector (DBD) to convert the fundamental mode of a conventional Si-wire waveguide into a slab free-propagating collimated Gaussian beam and (2) a one-dimensional optical phased array (OPA) of weak, millimeter-long radiating antennas that are fed with the wide Gaussian beam.

The DBD, based on the topology reported in [10], is formed by a sidewall grating waveguide that radiates the TE-polarized mode field from a conventional waveguide into a silicon slab. The DBD apodization gives the slab coupled mode a Gaussian amplitude profile with a mode field diameter (MFD) of 40 µm, around the central wavelength λ = 1540 nm. The SWG adaptation between the DBD and the slab is optimized to minimize losses, which are below 0.3 dB. The DBD is a dispersive device, thus the diffraction angle of the beam into the slab changes with respect the operation wavelength $\phi_{slab}(\lambda)$. The on-chip Gaussian beam travels through a 30-µm-long tapered adiabatic adaption zone before reaching

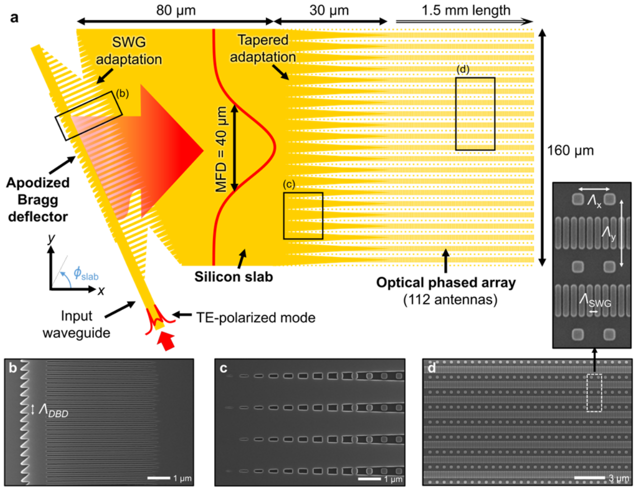

Fig. 1. a) Top-view schematic of the device converting a Si-wire waveguide mode into a silicon slab Gaussian beam to illuminate the OPA. b) SEM image of a section of the apodized DBD and the SWG adaptation region. c) SEM image of the tapered adaptation region between the silicon slab and the OPA. d) SEM image of an OPA section, with the long antennas arrayed in transversal direction (y).

the OPA. The tapers minimize insertion losses and discretize the beam profile to feed each individual antenna with a specific amplitude and phase. The OPA consists of 112 antennas arrayed in the transversal direction (y) with a period $\Lambda_y = 1.45$ µm. The geometry of these antennas, shown in an inset of Figure 1(d), consists of an SWG core loaded with an array of perturbation segments based on the antenna reported in [8]. The SWG metamaterial core allows accurately adjustment of electromagnetic parameters such as modal confinement and hence the radiation strength, achieving an antenna length of 1.5 mm. The details and dimensions of the complete device are specified in our recent publication [11].

III. EXPERIMENTAL RESULTS

For the experimental characterization of the antenna array we used an Agilent 81600B tunable laser as a light source. TE-polarized light with an extinction ratio > 25 dB around the band of operation was coupled from a lensed fiber into the chip through a broadband high-efficiency metamaterial fiber-chip coupler [12]. The measured far-field intensity pattern radiated by the antenna array as the wavelength is tuned is shown in Fig. 2(a). This measurement was made using an infrared camera with an InGaAs sensor. The far-field setup includes an antireflection coated achromatic lens with a focal length $f = 35$ mm, which projects the far-field distribution into the camera sensor, i.e., two-dimensional Fourier transform of the near field of the antenna array. As the wavelength varies, it modifies the relative phases between the antennas, hence scanning the radiated beam in ϕ direction while at the same time the wavelength tuning changes the emission angle of the antennas in the θ direction. The superposition of these two effects results in diagonal beam steering. We also characterized the angular divergence of the radiated beam. In Fig. 2(b) we show the far-field intensity cross-sections for both directions (θ and ϕ) of the beam spot measured at $\lambda = 1575$ nm, which is radiating approximately at $\phi = 0°$ due to fabrication errors. The azimuthal cut has a Gaussian profile relative with the radiated beam coming from the DBD, and the elevation cut has a Lorentzian profile consistent with grating theory. In this way we can estimate the FWHM accurately, obtaining a far-field beam divergence of 1.8° × 0.2°.

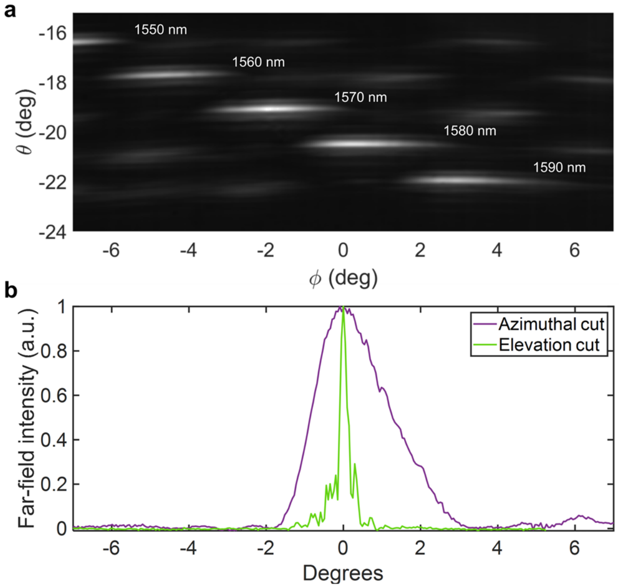

Fig. 2. (a) Measured far-field intensity distribution as a function of θ and ϕ angular coordinates for different wavelengths in the range of 1550 nm – 1590 nm. (b) Far-field intensity along the azimuthal and vertical directions at $\lambda = 1570$ nm.

IV. CONCLUSION

We have experimentally demonstrated a new topology for silicon-based 1D antenna arrays. The DBD permits a Gaussian modulation of the amplitude illumination of the OPA and allows to control the relative phase between antennas with a single control element. The device was experimentally demonstrated obtaining a highly collimated beam in the far field with an FWHM angular divergence of 1.8° × 0.2°. We believe that our results establish exceptional prospects for free-space optical interconnects and remote sensing applications leveraging established integrated silicon photonic technology.

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