OSA Advanced Photonics Congress (virtual event), July 14, 2020, Paper PsM2F.1 https://www.osapublishing.org/DirectPDFAccess/0FB20565-0C3D-F9E5-5F0044C2EAF48F8A_so3409874.pdf?da=1&idso=3409874&uri=&seq=0&mobile=no

Control of programmable photonic integrated meshes for free-space optics applications

M. Milanizadeh[1], T. Jonuzi[1], P. Borga[1], F. Toso[1], G. Ferrari[1], M. Sampietro[1], D.A.B. Miller[2], A. Melloni[1], and F. Morichetti[1]

[1]Dipartimento di Elettronica, Informazione e Bioingegneria - Politecnico di Milano, Milano, 20133 Italy.
[2]Ginzton Laboratory, Stanford University, Spilker Building, Stanford, CA 94305, USA
mail: francesco.morichetti@polimi.it

ABSTRACT

We report on the automated control of self-configuring programmable photonics meshes employed for the manipulation of free-space optical beams. Applications include optical beam coupling and identification, phase front correction and transmission through scattering media.

Keywords: photonic integrated circuits, programmable photonics, free space optics

INTRODUCTION

Integrated meshes of Mach Zehnder Interferometers (MZIs) are being exploited as programmable photonic platforms in many different application fields, like microwave photonics [1], optical mode manipulation [2], quantum information processing [3], and artificial neural networks [4]. By using the optical I/Os of the mesh as radiating antennas, beamforming applications can be also envisioned, enabling to use MZI meshes as transmitter/receiver reconfigurable architectures for free space optical communications [5].
In this work, we show how a silicon photonic MZI mesh can be used to manipulate free-space optical beams so as to implement several optical functions like identification and coupling of free space beams coming from arbitrary directions, phase front corrections and transmission through scattering media. We also show strategies for automated self-configuration of the mesh, investigating the impact of the control and calibration system on the optical performance of the mesh.

PROGRAMMABLE PHOTONIC INTEGRATED MESHES

As a simple example of mesh architecture, let's consider the 4x1 diagonal MZI mesh of Fig. 1a, where four ports labelled as radiating elements (RP_i) are used to couple a free-space optical beam into the photonic chip (rightward propagation) or to radiate a guided-wave signal out to the free space (leftward). Two phase shifters are integrated in each MZI to implement amplitude- and phase-tuneable couplers. An on-chip integrated photodetector is used to locally monitor the switching state of each MZI so as to realize automatic self-configuration of the mesh by means of independent local feedback loop [2]. To this aim, orthogonal dithering signals are added to the phase shifters of each MZI in order to simultaneously monitor and optimize their working point. Numerical simulations were carried out to evaluate the impact of the dithering signals on the optical performance of the mesh. Figure 1(b) shows the radiation pattern of the 4x1 mesh used as a transmitter (leftward propagation) when random uncorrelated

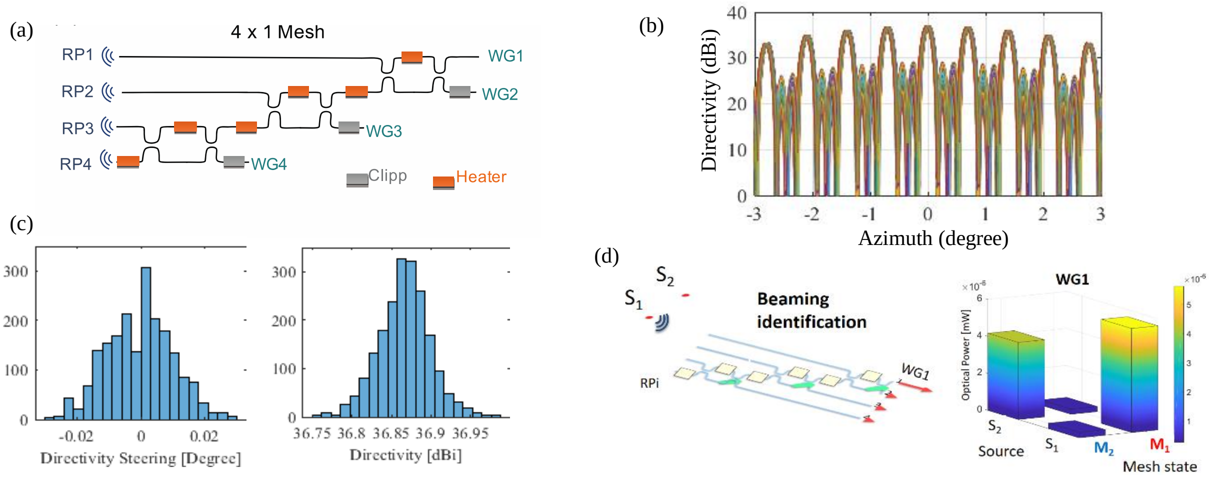

Figure 1: (a) Schematic representation of a 4x1 diagonal mesh; (b) Simulated radiation pattern of the mesh when uncorrelated phase perturbations are added to the phase shifters (normal distribution, $\pi/12.5$ std) and (c) corresponding histograms of the deviation from the direction of max directivity (left) and directivity value (right). (d) Beam identification experiment: optical power coupled at port WG1 when the mesh automatically self-configures to maximize the power coming from an unknown source (S_1 or S_2).

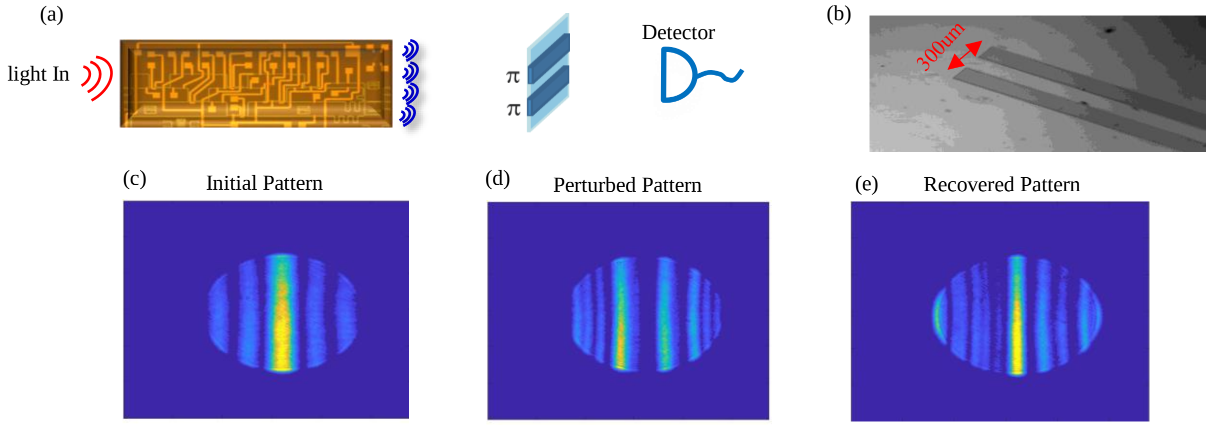

Figure 2: Phase front corrections in a free space optical link: (a) schematic of the setup, where a 1x4 diagonal mesh is used as a beam shaper for free space communications and a near-IR camera monitors the intensity profile at the detector. (b) Phase mask employed along the free space link to introduce phase front perturbations (π-shifts) across the beam profile. Radiation pattern recorded by the near-IR camera for (c) optimum free-space channel established without the phase mask in the path, (d) after the introduction of the phase mask medium and (e) after the recalibration of the mesh compensating for the phase front distortion due to the phase mask.

perturbations (normal distribution with $\pi/12.5$ std) are used, these perturbations largely exceeding the amount of phase dithering required for the control algorithm. As shown in Fig. 1(c), an absolute error of less than +/- 0.02 deg in the max directivity angle (deviation of the beam) and directivity change of less than 0.1 dB (over almost 37 dBi directivity) is recorded.

This 4x1 mesh architecture was fabricated on a standard 220 nm SiP platform, using a 1D array of grating couplers (127 µm spacing) as radiating elements, TiN heaters as thermal phase shifters and CLIPP transparent detectors as on-chip monitors. More details on the circuit design and fabrication technology can be found in [2]. The high angular resolution of the mesh was exploited to couple into a single-mode optical waveguide [WG1 in Fig 1(d)] a free-space beam coming from an arbitrary direction, while minimizing the coupling from other directions. Two free space optical beams at a wavelength of 1530 nm were simultaneously shone on the grating array by using two fibers spaced by 127 µm at a distance of 5.5 mm from the mesh [sources S_1-S_2 in Fig. (d)]. When a beam for a given fiber impinges on the grating array, the mesh automatically self-configures by following a progressive tuning scheme [2] in order to maximize the transmission to port WG1. Once convergence is achieved, the phase shifts (voltages) that are applied to the thermal tuners of the MZIs are compared to those of pre-calibrated states [M1 and M2 in Fig 1(b)] and the position of the source from where the beam is coming can be identified.

The capability of the mesh to operate as a programmable beam shaper was exploited to demonstrate free space transmission through an obstacle corrupting the phase front of the free space beam. Figure 2(a) shows the schematic of the free space setup where the 1x4 mesh is used as a transmitter while a near-IR camera is used as a detector. The mesh is initially configured in order to establish the optimum communication link, that is to maximize the light intensity at the center of the camera [Fig. 2(c)]. A planar phase mask [Fig. 2(c)] consisting of two transparent slits spaced by 300 µm and introducing local π-shifts across the phase front of the beam was introduced along the path at a distance of 10 cm from the mesh output. Upon the introduction of the phase mask, the field pattern is substantially altered and exhibits zero intensity at the center of the beam profile at the camera [Fig. 2(d)]. Figure 2(e) shows that the phase-front perturbation introduced by the phase mask can be compensated by reconfiguring in mesh, whose amplitude and phase output beams can be set to re-establish the best communication channel. Similar results were achieved by replacing the phase mask with a diffusive optical element, in which case the recovery of the link performance provided by the mesh is only limited by the number of radiating elements of the mesh itself.

This work was supported by the European Commission through the H2020 project Super Pixel (grant 829116).

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