Circularly Polarized OAM Multiplexing Using an Integrated Phased Array

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***Abstract*— We characterize an integrated tunable optical phased array that directly generates multiplexed circularly polarized Orbital Angular Momentum (OAM) modes with highest mode counts demonstrated. We measured -12.7dB worst-case crosstalk for both modes examined and expect a uniformed performance among all supported modes.**

I. INTRODUCTION

Spatial division multiplexing (SDM) is a crucial technology for scaling data transmission [1]. Ring core fibers supporting orbital angular momentum (OAM) modes can provide tens of parallel data channels in a cost-effective manner by relieving the burden of Multiple-input and multiple-output digital signal processing [2]. Exciting fiber OAM modes with free-space setups involves a phase modulator (usually spatial light modulator or vortex plate), mode size converter and polarization management optics (half wave-plate and quarter wave-plate). These setups are often bulky. Integrated devices based on ring-resonators [3], waveguide surface holographic gratings [4] and star couplers [5] demonstrated compact OAM multiplexing in non-circular polarization. These devices require off-chip polarization management to achieve a circularly polarized mode for OAM fiber. Our previous work demonstrated a OAM multiplexer using an optical phased array with 2-dimensional (2D) antennas for on-chip circularly polarized OAM generation [6].

In [7], we improved our design [6] by adding an intensity tuning circuit and increasing the number of antennas and demonstrated record crosstalk performance of the calibrated mode (-16.4dB) and most simultaneous modes (24 modes). Here, we characterize this device as a multiplexer by examining the crosstalk of two supported modes in the same tuning condition. The device achieves -12dB worst-case crosstalk for both +5 order OAM and Gaussian (OAM0) with the same set of tuning signals after calibration.

II. DESIGN PRINCIPLE AND EXPERIMENTAL RESULT

A. Design and fabrication

In Fig. 1a, we present the schematic of our OAM generator and multiplexer. A fiber array inputs data signals to the fiber-to-chip couplers on the left side of the OAM MUX circuit. The star couplers create, for each input, a distinct phase distribution for each targeted OAM state. Each path after the star coupler has a thermally controlled phase shifter and a variable optical attenuator (VOA) in a p-i-n silicon waveguide. We use the phase shifters, in this experiment, to compensate for phase errors. In the SEM image Fig. 1b, the array of 2D antennas are evenly-spaced with central axis pointing toward the center of the circumference. Each 2D antenna is connected to a 2×2 multi-mode interferometer (MMI) through 5µm bends. The 2×2 MMI creates ±90 degree phase difference between two linear polarization inputs (quasi-TE modes in our design), enabling on-chip circularly polarized beam generation. A magnified view at 50◦ tilt of one 2D antenna is shown in Fig. 1c, where the square around the grating region is the shallow etched silicon layer at 150µm thickness. More details about the design parameters can be found in [7]. The chip was fabricated at Advanced Micro Foundry Inc.

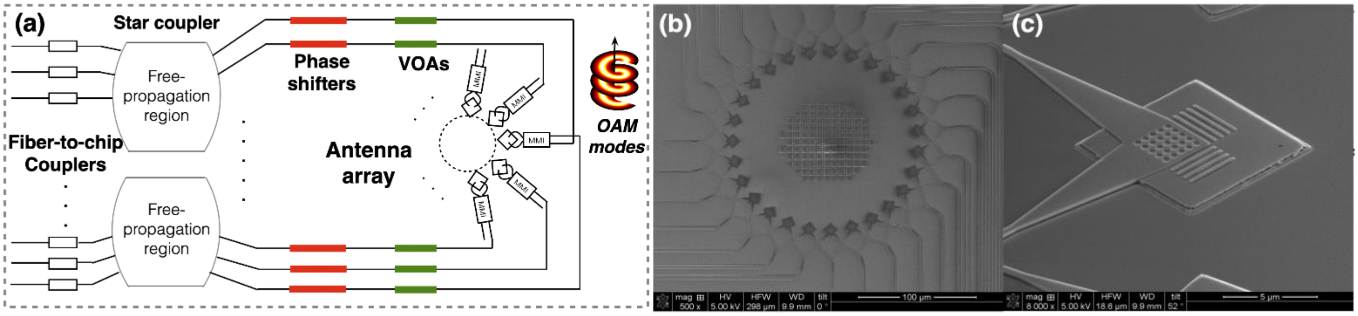

Fig. 1. (a) Schematic of the OAM generator and multiplexer, (b) SEM image of the antenna array, and (c) SEM image of one 2D antenna.

B. Experimental results

We examine the performance of the device as a multiplexer by measuring the crosstalk of +5 order OAM with the tuning signals acquired from OAM0 (Gaussian) calibration. Tuners are used to correct fabrication errors; achieving the target design means these

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errors will have no impact on any mode. Experimentally, we only calibrate the device on one mode, adjusting tuners to minimize crosstalk to all unlaunched modes. This calibration should ensure that all other modes cause similarly low crosstalk.

We first inject circularly polarized OAM0 following the dashed-line path 1 in Fig. 2a and run a gradient descent algorithm to minimize the worst-case crosstalk through optimizing tuning signals. We then removed the OAM0 beam and inject an OAM5 produced by a circularly polarized Gaussian passing through a vortex plate, m=5 on the solid-line path 2. A lens of 25mm focus is used to match both OAM0 and OAM5 to the antenna array. During the calibration, the worst-case crosstalk with OAM0 input is improved from an as-fabricated -7.6 dB to a calibrated 12.7 dB (Fig. 2b). The measured worst-case crosstalk for OAM5, with the tuning signals inherited from previous calibration, is -12.9 dB (dashed line Fig. 2b). This is the first step to demonstrating uniform crosstalk performance among all the supported modes of this device. Note that the crosstalk can be further improved by exploiting the intensity tuning circuit [7].

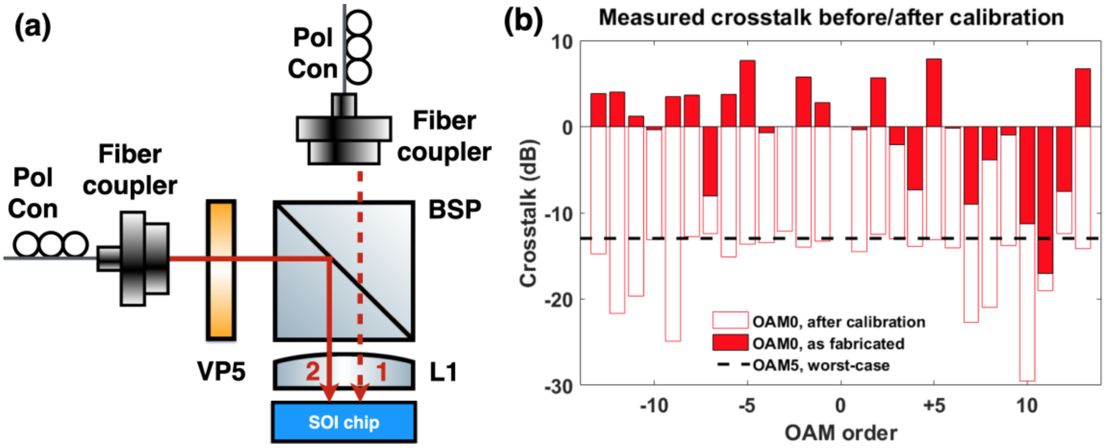

Fig. 2. (a) Setup for phase calibration with Gaussian (dashed path 1) and crosstalk measurement with OAM5 (solid path 2), and (b) Measured crosstalk for Gaussian and OAM5. Pol.con: polarization controller, VP5: vortex plate with m=5, BSP: non-polarization beam splitter, L1: 25mm focus lens.

III. CONCLUSION

We characterized an optical phased array on a silicon-on-insulator platform that multiplexes circularly polarized OAM modes. We verified its ability to provide similar performance across two supported modes (-12.7 dB worst-case crosstalk for both modes examined). The characterized device supports a highest-ever-demonstrated 24 modes [7] and can significantly extend the capacity of previous wavelength division multiplexing compatible silicon-based OAM multiplexers. The device provides a scalable, integrated solution for OAM generation and multiplexing in ultra-high capacity SDM systems.

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