Multi-Transverse-Mode Optical Processors: Towards On-chip Programming and Calibration

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***Abstract*— We design a Multi-Transverse-Mode Optical Processor (MTMOP) exploiting the first two quasi-transverse electric modes (TE0 and TE1). This design enables the on-chip measurement of optical phase required for programming the optical processors.**

Keywords—Optical computing, programmable optical processors, Silicon photonics.

I. INTRODUCTION

Programmable optical processors are promising structures for performing fast and energy efficient vector matrix multiplication [1]. Calibration and programming the optical processors require sensing both the optical power and optical phase [2]. Although sensing the optical power is feasible in Silicon Photonics (SiPh) using on-chip photodetectors, sensing the optical phase requires more elaborate hardware and complex techniques such as coherent detection. In the Multi-Transverse-Mode Optical Processor (MTMOP) design, we overcome this challenge by introducing a new but simple building block enabling on-chip optical phase monitoring without the need for coherent detection.

II. DESIGN AND DISCUSSION

The proposed MTMOP is designed for fabrication on a silicon-on-insulator (SOI) chip with a device thickness of 220 nm. Figure 1 (a) presents the 2 × 2 building block schematic of the MTMOP. The fundamental quasi-transverse electric (TE0) mode carries the main optical signal, and the first quasi-transverse electric (TE1) mode is dedicated to on-chip phase measurement. The internal phase shifter (PS) θ is a mode-insensitive PS applying the same phase shift to the TE0 and TE1 modes. In the MTMOP, the external PS is replaced by an MZI composed of two multimode interferometers (MMIs) as beam splitter and combiner, and two PSs (ϕ and δ). PS δ is mode sensitive with different thermo-optic coefficient for TE0 and TE1, while PS ϕ is mode insensitive as internal PS θ.

For programming the MTMOP, we start by θ. Programming θ is more straightforward since it sets the output optical power detectable by a photodetector. We sweep the PS θ voltage bias and measure the TE0 optical power at the bottom outputs (O_1 in Fig. 1 (a)). The optical power is minimized and maximized at $\theta = \pi$ and $\theta = 0$, respectively. Programming the external PS is more challenging as it sets the output phase. We start with setting a bias to ϕ as an initial point for the desired TE0 phase shift. We then sweep the PS δ voltage bias until the TE0 signal power at O_0 is maximized meaning the TE0 signal passing through the PSs ϕ and δ constructively interferes. The total phase shift applied to TE0 by the external PS (ψ_{TE0}) is equal to ϕ_{TE0} and δ_{TE0} . However, this would not be the case for TE1 owing to the mode sensitive nature of δ. In conventional optical processors, once we set the external PS bias, we need coherent detection to monitor the applied phase shift. In MTMOP, knowing the different thermo-optic coefficient for TE0 and TE1, we monitor ψ_{TE0} by measuring the output amplitude of TE1. Monitoring ψ_{TE0}, we iterate the process until achieving the desired value. Figure 1 (b) plots the simulated TE0 output power (flat black dashed line), ψ_{TE0} (red dotted line), and TE1 output power (blue dash-dotted line) at O_0 versus PS ϕ bias voltages. While the optical output power of the TE0 mode remains constant (due to constructive interference of TE0 going through ϕ and δ), ψ_{TE0} changes with PS ϕ. By monitoring the optical power change of TE1, ψ_{TE0} can be inferred.

The proposed MTMOP building block includes an additional MZI compared to the conventional optical processors leading to higher insertion loss. We can compensate for this extra insertion loss by hybrid integration of a gain block [3]. Considering the developing trend in SiPh multi-mode components [4], MTMOP provides a viable solution to advance towards scalable self-programming optical processors.

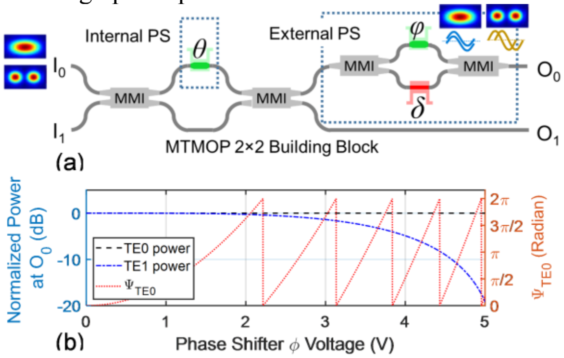

Fig. 1. (a) The 2 × 2 building block of the MTMOP. (b) Output power of TE0 and TE1 at O_0, and phase shift applied to TE0 as a function of the PS ϕ voltage bias.

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