Demonstration of a 4 × 4-port Universal Coupler

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***Abstract*—We present a working implementation of a 4 × 4-port universal coupler circuit using a thermally tuned silicon photonics platform. The coupler circuit can couple any configuration of input power distribution to any of 4 outputs, or a linear combination thereof. We demonstrate the operation of the different optimization algorithms originally proposed by Miller using both fiber and camera detection.**

***Keywords*—Silicon photonics, Universal coupler.**

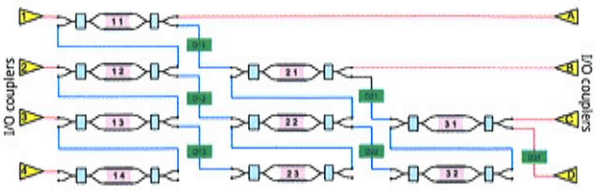

Fig. 1. Schematic diagram of the circuit.

I. Introduction

Photonic integrated circuits today resemble the very specialized application specific integrated circuits (ASICs) rather than general-purpose CPUs or highly flexible field-programmable gate arrays (FPGA). Still, reconfigurable optical circuits could dramatically reduce the time to application or prototype a new optical chip. A concept of a general-purpose reconfigurable optical circuit, that can implement any linear function or coupling between inputs and outputs, was proposed by David Miller in [1].

We implemented such a *universal coupler* in a silicon photonics platform. Silicon photonics is especially attractive for such reconfigurable circuits because it allows potentially very dense integration of circuit elements., and a potential for mass fabrication. We used off-the-shelf PDK building blocks (grating couplers, waveguides and MMI couplers) to implement a 4-port universal coupler and demonstrate different reconfiguration algorithms.

II. Design

We designed our device as a network of 2 × 2 symmetric Mach-Zehnder interferometers. Both arms of the MZI can be thermally tuned. A differential drive will induce an amplitude modulation at the output, while common-mode driving of the heaters will introduce a simple phase shift. This way, we implement the unit cell described by Miller [1].

Within the circuit we also introduced small power taps to monitor the power in specific branches. Grating couplers were used for all inputs and outputs. Figure 1 shows a schematic of the circuit. For a 4 × 4-port circuit 9 MZIs were used. To enable broadband operation, we designed all paths to have identical length. The circuit was designed using the IPKISS EDA toolset from Luceda Photonics. The MZI and the circuit were simulated using Caphe, integrated with IPKISS.

III. Fabrication

The optical circuit is realized in the passive SOI platform of IMEC, Belgium, through the Europractice MPW service. The silicon waveguides are 220nm thick, and an additional 2 μm of oxide is deposited as a top cladding. On these, we processed simple titanium heaters with gold wiring using a liftoff process. A microscope image is shown in Fig. 2.

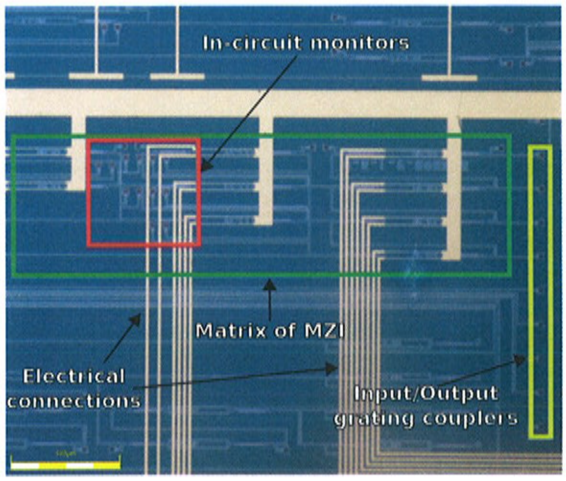

Fig. 2. Device microscope image.

IV. Measurement

To operate the circuit as a beam coupler we illuminated the input of the circuit and monitor the power at the output while the algorithm adjusts the balance and the phase shift of the MZIs in the circuit. We used a laser source at 1550nm coupled through the grating couplers. The light collected from the output of the circuit is then redirected to a power meter. The implemented setup is represented in Fig. 3.

The heaters are controlled using current sources equipped with voltage meters to monitor the power consumption. This allows a precise control of the power applied to each heater. All heaters can be simultaneously and individually controlled

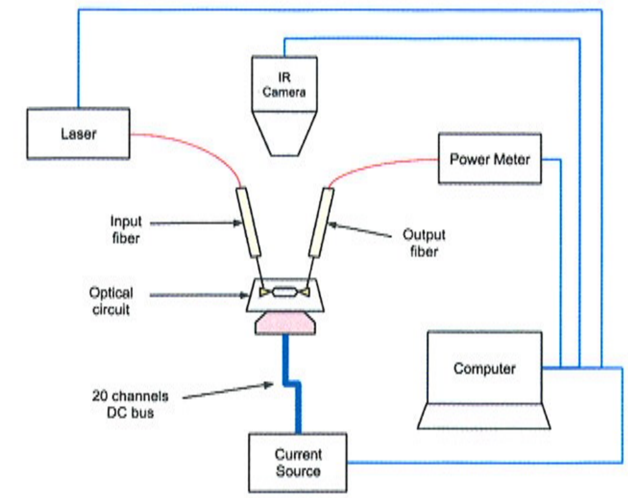

Fig. 3. Measurement setup. Fibers are used for optical input and output, while an IR camera is used to capture the in-circuit monitors. Heaters are driven through a 20-probe array.

through python automation. We also mounted an IR camera over the circuit to capture the output from the internal monitors. This information is used to implement different reconfiguration algorithms.

V. Results

A. Reconfiguration based on a single detector

To configure the circuit using a single output detector we constantly monitor the power at one output of the circuit while we illuminate one of the input ports. Then the algorithm progressively optimizes the balance and the phase of each MZI. This requires that some MZIs are set in full transmission mode as an initial condition. This makes it difficult to use this algorithm in a continuous feedback loop.

Figure 4 shows the evolution of the power at one output after each step in the optimization algorithm. The experiment was repeated for three different inputs. Notice that the number of steps to optimize port 1 is larger than for the remaining ports. This is because some MZIs are already in the correct state after the first optimization. The difference in absolute power after optimization is due to suboptimal fiber alignment.

B. Reconfiguration with in-circuit monitoring

It is also possible to tune the device by monitoring the power within the circuit. For this, power taps with directional couplers and grating couplers were placed at strategic locations within the circuit. We use a camera to monitor all outputs simultaneously. Optimization by in-circuit power monitoring allow us to use continuous feedback, since the algorithm does not require any specific initial condition.

Fig 5 shows the evolution of the optimization. Notice the decrease of brightness in most of the monitors, with exception to the ones referent to the output port.

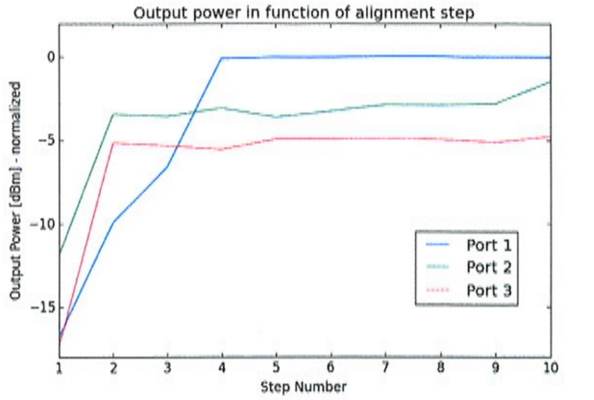

Fig. 4. Evolution of the output power at the circuit along the optimization process, when the fiber is positioned at different output.

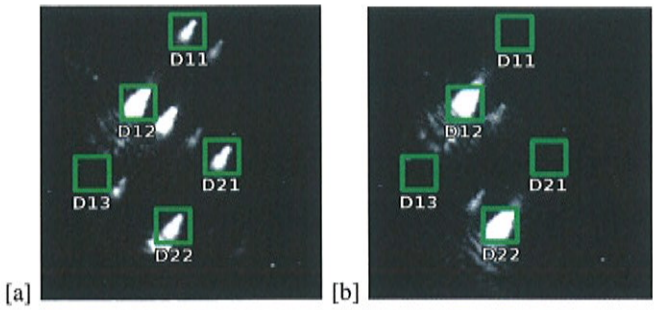

Fig. 5. Intermediate monitors ass seen from the IR camera. The grating couplers in the image that are not labeled as detectors are reflection monitors and were not used in the experiment.

C. Configurable switch

As an extension of the universal coupler application, we demonstrate the circuit operation as a 4×4-port switching device. To train the circuit to operate as a switch we first apply light at the desired output and tune the first column of MZIs to obtain maximum power at the correspondent input. We proceed by illuminating the second desired output and tuning the second column of MZI to obtain maximum power at the desired output. We do the same for the third output and the fourth output will be automatically set.

VI. Conclusion

We have demonstrated an operational 4×4-port universal coupler circuit on a silicon photonic platform. We show the circuit operating using two different feedback methods, one be monitoring directly the power at the output of the circuit and another by monitoring the power across the circuit. We also demonstrated the circuit as a 4×4 configurable switch.

Acknowledgements

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References

[1] D. A. Miller, "Self-aligning universal beam coupler," *Optics express*, vol. 21, no. 5, pp. 6360–6370, 2013.

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