Programmable Photonic Circuits powered by Silicon Photonic MEMS Technology

Wim Bogaerts[a], Alain Yuji Takabayashi[b], Pierre Edinger[c], Gaehun Jo[c], Arun Kumar Mallik[d], Cleituis Antony[d], Iman Zand[a], Tigers Jonuzi[e], Xiangfeng Chen[a], Hamed Sattari[b], Junsu Lee[d], Moises A. Jezzini[d], Giuseppe Talli[d], Cristina Lerma Arce[f], Saurav Kumar[f], Peter Verheyen[g], Niels Quack[b], Kristinn B. Gylfason[c], Frank Niklaus[c], Umar Khan[a]

[a] *Ghent University - IMEC, Photonics Research Group, Department of Information Technology, Belgium*
[b] *École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland*
[c] *KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden*
[d] *Tyndall National Institute, Lee Maltings Complex Dyke Parade, T12 R5CP Cork, Ireland*
[e] *VLC Photonics S.L., Ed. 9B, D2, UPV, Camino de vera sn, 46022 Valencia, Spain*
[f] *Commscope Connectivity Belgium, Diestsesteenweg 692, 3010 Kessel LO, Belgium*
[g] *imec vzw. 3DSIP Department, Si Photonics Group, Kapeldreef 75, 3001 Leuven, Belgium*

wim.bogaerts@ugent.be

Abstract: Programmable photonic chips allow flexible reconfiguration of on-chip optical connections, controlled through electronics and software. We will present the recent progress of such complex photonic circuits powered by silicon photonic MEMS actuators.
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1. Introduction

The past few years has seen a growing interest in so-called *programmable photonic circuits* [1]. The idea behind this new class of photonic integrated circuits (PICs) is that the paths of light can be fully configured in software, by electronically controlling the coupling coefficients and phase delays in a network of connected waveguides. The advantage of such programmable circuits can be significant: flexibility to configure multiple functions, adaptive tuning of performance to compensate drift and variability, and redundancy in case of failure. Like flexible programmable electronics, these chips could also accelerate the prototyping of new applications, without the need to fabricate a custom-designed photonic circuit.

Today, programmable photonic chips are still in an immature state, and there are many challenges to overcome before they can find their way in the many applications for PICs. The main challenge is one of scale: generic programmable circuits will by definition be larger and more complex than custom-designed application-specific PICs. Because every light path needs to be configurable, a programmable PIC will have many electrically controlled tunable couplers and phase shifters, which will all take up floor space, introduce optical propagation losses, consume power and require an electrical driver. On top of that, the need to control the chip will require additional monitors integrated on chip, which can also contribute to optical losses and packaging complexity.

Silicon Photonics technology is considered the most promising technology for programmable PICs, because it supports very compact building blocks and large integration density, including high-speed modulators and photodetectors. However, its primary mechanism for electrical control is a heater integrated close to the optical waveguides. Even with the high thermo-optic coefficient of silicon, these heaters consume multiple mW of power for a π phase shift, and if hundreds or even thousands of such heaters are needed, the large programmable photonic circuits will have an excessive heat dissipation problem, which can lead to uncontrollable thermal crosstalk.

In the European project MORPHIC, we have been developing MEMS-based tunable couplers and phase shifters that can be integrated together with the other building blocks of IMEC's iSiPP50G silicon photonics platform, and we combined this with large-scale packaging techniques that make it possible to interface a large number of these MEMS actuators with dedicated electronic driver circuits [2].

2. MEMS in Silicon Photonics

Micro-electromechanical systems (MEMS) present an interesting method for manipulating light on chip: by actually moving the waveguides, it is possible to directly change the coupling of two waveguides or induce a phase shift [3]. The movement can be driven electrostatically using parallel-plate capacitors or comb drives, which consume virtually no static power. MEMS devices can also be faster than heaters by engineering the stiffness. We have demonstrated phase shifters [4] and tunable couplers [5], shown in Fig. 1.

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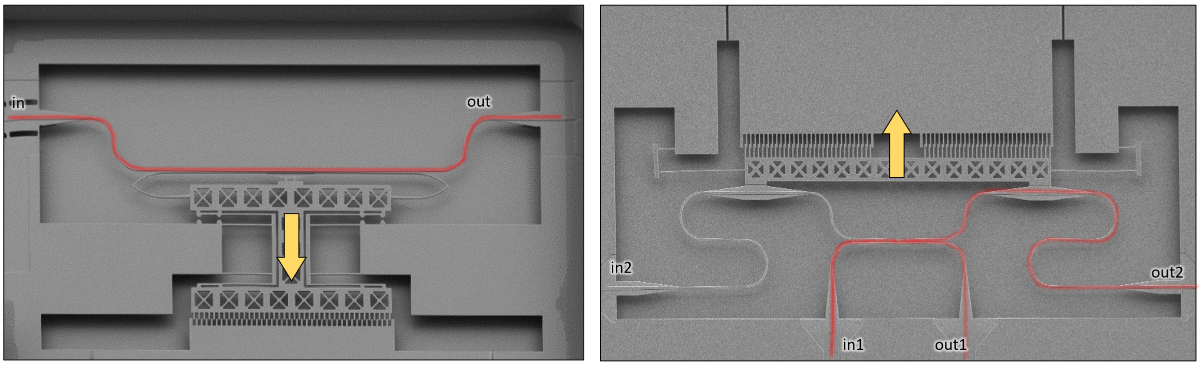

Fig. 1. Silicon Photonic MEMS actuators for programmable photonic circuits. Left: Phase shifter using a thin beam of silicon that is pulled way from the main waveguide [4]. Right: Tunable coupler where the distance between two waveguides can be controlled [5].

The fabrication of these MEMS devices is performed as a post-processing step in IMEC's iSiPP50G silicon photonics platform. The MEMS are designed into the waveguide layer which supports 3 etch depths. After the silicon photonics chips have been fully fabricated, including 2 layers of Cu metallization, the back-end-of-line dielectric stack is locally etched back until the silicon waveguides are exposed. After a protective deposition of Aluminium oxide, the buried oxide underneath the waveguides is selectively removed with a vapor-phase HF etch.

After this release process, the fragile MEMS devices are exposed to the open air. The recessed cavities with the MEMS are then sealed with a silicon lid using a wafer-scale thermocompression bonding [6].

3. Packaging, Electronics and Software

The MEMS devices are electrostatically actuated with a 0-30V DC drive. In larger circuits, hundreds of these MEMS actuators need to be controlled simultaneously, so a packaging approach is needed that can interface these to the driver electronics. The long-term approach would be to flip-chip or 3D stack a custom-designed electronic driver circuit, but this does not allow for rapid and flexible prototyping. Instead, a large-scale ceramic interposer was designed that can interface ¿3000 electrical bondpads arranged in a regular grid [2]. The silicon photonics chip is then flip-chipped on this interposer, which in turn is mounted on a carrier printed circuit board (PCB) that connects to the driver electronics.

For the drivers we have designed a modular driver board with 64 DAC channels, and an additional 32 readout channels for photodetectors. Multiple boards can be controlled in parallel, scaling to 100s-1000s of channels. The boards are connected to the carrier PCB using flex cables.

The many electronic controls and the complex photonic chip layouts are managed using a python-based software framework that keeps track of the many driver and readout channels, and that allows us to visualize the elements being controlled on the chip.

4. Summary

We have developed MEMS-based silicon photonics circuits, together with a packaging method and driver electronics, to enable large-scale programmable photonic circuits.

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