Advanced Photonics Congress (IPR, Networks, NOMA, PVLED, SPPCom) © OSA 2021

Programmable Photonic Circuits using Silicon Photonic MEMS

Wim Bogaerts[a], Alain Yuji Takabayashi[b], Pierre Edinger[c], Iman Zand[a], Gaehun Jo[c], Hamed Sattari[b], Peter Verheyen[g], Moises A. Jezzini[d], Cleitus Antony [d], Giuseppe Talli[d], Mehrdad Saei[d], Saurav Kumar[f], Cristina Lerma Arce[f], Marco Garcia Porcel[e], 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: We present a silicon photonics technology extended with low-power MEMS scalable to large circuits. This enables us to make photonic waveguide meshes that can be reconfigured using electronics and software.

1. Introduction

The popularity of Silicon can be attributed to two key features: Compatibility with large-volume CMOS manufacturing processes, and the high index contrast, enabling submicrometer waveguides. This makes it possible to scale up circuit complexity, and as a result we are seeing the emergence of programmable photonic circuits [1, 2].

These new photonic circuits consist of waveguide meshes interconnected with electronically tunable couplers and phase shifters. That way, the paths of light can be effectively controlled through a software layer. This provides a path for fast development of new photonic applications [3], but there are still many challenges to address.

A key challenge is the need for hundreds or thousands of electro-optic actuators, (tunable couplers and phase shifters). The traditional implementation using integrated heaters is easy but requires a constant power consumption. In the European project H2020-MORPHIC we develop actuators based on Micro-electromechanical systems (MEMS) [4, 5]: by embedding movable waveguide elements in a silicon photonics platform we can electrostatically control the coupling or phase shift, which does not require static power consumption. To enable large-scale programmable photonic circuits, the photonic chip needs multi-channel driver electronics and software layers. In this paper, we give an overview of the MORPHIC technology under development.

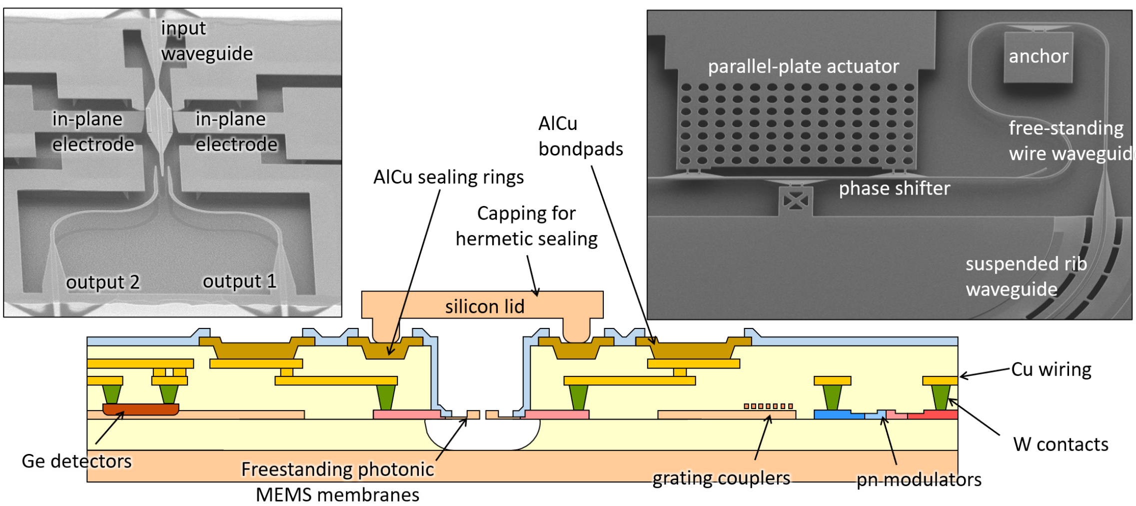

Fig. 1. MORPHIC silicon Photonic MEMS technology. Left: 1x2 switch [6], Right: Phase shifter. Bottom: cross section of the sealed silicon photonic MEMS platform [7].

2. Silicon Photonic MEMS Technology Stack for Programmable Photonics

For programmable photonic circuits, it is not enough to make an efficient electro-optic phase shifter and/or tunable coupler. These essential functions should be combined with all other functionality of a photonic chip platform, such as high-speed modulators and photodetectors. That is why we started from the existing iSiPP50G silicon photonics technology of IMEC [8]. The freestanding movable waveguides are post-processed by locally opening the back-end-of-line (BEOL) dielectric stack and selectively underetching the buried oxide using vapor-phase hydrofluoric acid (HF).

The result is a silicon photonics circuit with local 'cavities' with free-standing movable waveguides. These MEMS devices are both optically and electrically connected to the standard silicon photonic waveguides and metallization of the iSiPP50G platform. With this technology we implemented efficient phase shifters [9] and tunable coupling and switching structures [6].

Because the MEMS areas are exposed to air, they need to be protected to avoid damage or drift due to external conditions. This is accomplished through a wafer-scale capping process where a silicon lid is bonded on top of every MEMS cavity, hermetically sealing it in a vacuum or a controlled atmosphere [7].

When many actuators are integrated on s circuit, a new bottleneck emerges: interfacing the photonic chip to the driver electronics. We have devised a prototyping workflow using electrical interposers to wire up to 3300 electrical connections, while still allowing for high-frequency connections and optical fiber array attachment. Through this interposer, the many MEMS devices can be connected to the 50V driver electronics.

The programmable circuits themselves consist of a recirculating waveguide mesh with a hexagonal unit cell [10]. These need to be configured for by adjusting the individual phase shifters and couplers. For this, we have developed a software framework and configuration algorithms have been developed. These include routing algorithms [11], but also configuration of interferometric wavelength filters.

3. Demonstrations

To demonstrate the capabilities of the technology, we have designed different programmable photonic circuits and also application-specific circuits for switching, beamforming and microwave filtering. These circuits are currently being assembled for testing.

4. Summary

In the MORPHIC project we are developing the essential technology stack to enable large-scale programmable silicon photonic circuits enhanced with MEMS functionality. This not only requires the MEMS technology, but also the packaging, driver electronics and software layers.

Acknowledgements

This work is supported by the European Union grants 780283 (MORPHIC) and 725555 (PhotonicSWARM).

References

1. W. Bogaerts *et al.*, "Programmable photonic circuits," Nature **586**, 207–216 (2020).
2. D. Pérez *et al.*, "Principles, fundamentals, and applications of programmable integrated photonics," Adv. Opt. Photonics **12**, 709 (2020).
3. W. Bogaerts *et al.*, "Programmable Photonics: An Opportunity for an Accessible Large-Volume PIC Ecosystem," IEEE J. Sel. Top. Quantum Electron. **26**, 1 (2020).
4. W. Bogaerts *et al.*, "MORPHIC : Programmable photonic circuits enabled by silicon photonic MEMS," Proc. SPIE **11285**, 11285–1 (2020).
5. C. Errando-Herranz *et al.*, "MEMS for Photonic Integrated Circuits," IEEE J. Sel. Top. Quantum Electron. **26**, 1–1 (2019).
6. A. Y. Takabayashi *et al.*, "Broadband Compact Single-Pole Double-Throw Silicon Photonic MEMS Switch," J. Microelectromechanical Syst. **30**, 322–329 (2021).
7. G. Jo *et al.*, "Wafer-level vacuum sealing for packaging of silicon photonic MEMS," in *Silicon Photonics XVI,* G. T. Reed *et al.*, eds. (SPIE, 2021), p. 11.
8. M. Pantouvaki *et al.*, "Active Components for 50 Gb/s NRZ-OOK Optical Interconnects in a Silicon Photonics Platform," J. Light. Technol. **35**, 631–638 (2017).
9. P. Edinger *et al.*, "Compact low loss MEMS phase shifters for scalable field-programmable silicon photonics," in *Conference on Lasers and Electro-Optics,* (OSA, Washington, D.C., 2020), p. SM3J.2.
10. J. Capmany *et al.*, "Microwave photonics: The programmable processor," Nat. Photonics **10**, 6–8 (2016).
11. X. Chen *et al.*, "Graph Representations for Programmable Photonic Circuits," J. Light. Technol. **38** (2020).