Delft University of Technology

Photonic Motherboard
A Scalable Approach for Building Complex Photonic Systems

Magalhães, Letícia S.; Witt, Donald; Shams-Ansari, Amirhassan; Rajabali, Shima; Assumpcao, Daniel; Zhu, Xinrui; Warner, Hana K.; Yeh, Matthew; Hu, Yaowen; More Authors

Publication date
2025

Document Version
Final published version

Published in
2025 Conference on Lasers and Electro-Optics, CLEO 2025

Citation (APA)
Magalhães, L. S., Witt, D., Shams-Ansari, A., Rajabali, S., Assumpcao, D., Zhu, X., Warner, H. K., Yeh, M., Hu, Y., & More Authors (2025). Photonic Motherboard: A Scalable Approach for Building Complex Photonic Systems. In *2025 Conference on Lasers and Electro-Optics, CLEO 2025* Article AA127-5 (2025 Conference on Lasers and Electro-Optics, CLEO 2025). IEEE.

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.
For technical reasons the number of authors shown on this cover page is limited to a maximum of 10.

Green Open Access added to TU Delft Institutional Repository
as part of the Taverne amendment.

More information about this copyright law amendment
can be found at https://www.openaccess.nl.

Otherwise as indicated in the copyright section:
the publisher is the copyright holder of this work and the
author uses the Dutch legislation to make this work public.

Photonic Motherboard: A Scalable Approach for Building Complex Photonic Systems

Letícia S Magalhães,[1,†] Donald Witt,[1,†] Amirhassan Shams-Ansari,[1,2,†] Shima Rajabali,[1,4] Daniel Assumpcao,[1] Xinrui Zhu,[1] Hana K Warner,[1] Matthew Yeh,[1] Yaowen Hu,[1,5] Juergen Musolf,[3] Victoria Roseborough,[2] Leif Johansson,[3] and Marko Lončar[1,*]

[1] *John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138*
[2] *DRS Daylight Solutions, 16465 Via Esprillo, San Diego, CA, USA* [3] *Freedom Photonics, 41 Aero Camino, Goleta CA, USA* [4] *Department of Quantum and Computer Engineering, Delft University of Technology, Netherlands* [5] *State Key Laboratory for Mesoscopic Physics and Frontiers Science Center for Nano-optoelectronics, School of Physics, Peking University, Beijing 100871, China*

[*] *lmagalhaes@g.harvard.edu*

[†] *These authors contributed equally to this work.*

Abstract: We present a photonic integration method combining flip-chip bonding and photonic wirebonding. This approach enables a "mother" substrate to host "child" chips from diverse platforms, fostering seamless integration for multi-functional photonic architectures. © 2024 The Author(s)

A motherboard is an essential component in electronics, facilitating communication between various elements and enabling them to collaborate on tasks far more complex than those achievable by individual parts. In contrast, photonics research has historically excelled at developing highly specialized, material-dependent functionalities. Recently, however, there has been a significant shift toward system-level architectures capable of advanced applications such as artificial intelligence (AI) processing, high-speed communication, and quantum computing [1]. Despite this progress, integrating an arbitrary number of photonic platforms into a cohesive system remains a challenge. The photonic motherboard concept addresses this issue by extending the principles of a traditional electronic motherboard to photonics. It aims to integrate diverse photonic platforms, overcoming material and functional constraints to enable new architectures and applications.

Various strategies have been developed to enable multi-platform photonic systems, each with its trade-offs [2]. Hybrid integration preserves material properties and allows for the pre-selection of devices but faces challenges with alignment, interface losses, and low throughput. Heterogeneous integration provides scalability but suffers from low yield and requires complex material co-processing. Microtransfer printing, which relies on the pick-and-place assembly of membranes, offers potential scalability but suffers from poor thermal performance due to the use of adhesives between the coupons and the substrate.

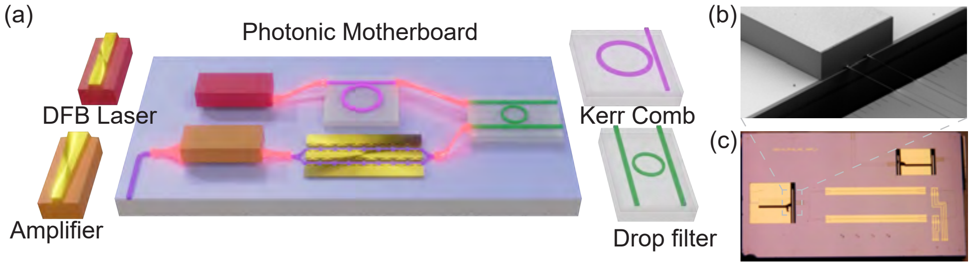

Fig. 1. **(a)** Conceptual Representation of Photonic-Mother Board. In this representation, the mother platform (in this case TFLN) contains an EO modulator while hosting functionalities such as laser source, amplifier, Kerr comb, and a drop filter from different photonic material platforms. The integration occurs via the photonic wirebonding. **(b)** Scanning Electron Microscopy of Distributed Feedback Laser (DFB) connected to a Lithium Niobate waveguide. The photonic wirebonding was done using the Vanguard Sonata 1000. **(c)** Example of a complex multi-platform system featuring a DFB, TFLN mother with travelling wave EO modulators and heaters, and a Semiconductor Optical Amplifier (SOA).

The complexity of these integration challenges suggests a need for an intermediate approach that balances the scalability of heterogeneous stacks with the flexibility of hybrid methods. Such an approach would ideally allow for more straightforward integration while preserving the specialized properties of each material. Inspired by the versatility of wirebonding in electronics, photonic wirebonding provides precise, low-loss, and broadband optical

Authorized licensed use limited to: TU Delft Library. Downloaded on November 27,2025 at 13:51:25 UTC from IEEE Xplore. Restrictions apply.

interconnects between photonic chips and fibers [3]. However, its application has been constrained by reliance on adhesives and custom-made shims, and the challenges of manually aligning chips with varying substrate thicknesses [4].

To overcome these limitations, we introduce a novel integration technique combining flip-chip bonding with photonic wirebonding. A “mother” substrate serves as the host for “child” chips, supporting integration across diverse material platforms. The mother substrate can incorporate functional elements or act as an optical interposer, with trenches enabling automatic photonic wirebonding to the flipped “child” chips. By leveraging the established reliability of flip-chip technology, our approach offers a versatile framework for integrating photonic platforms with diverse geometries and stack thicknesses, paving the way for high performance multi-platform systems.

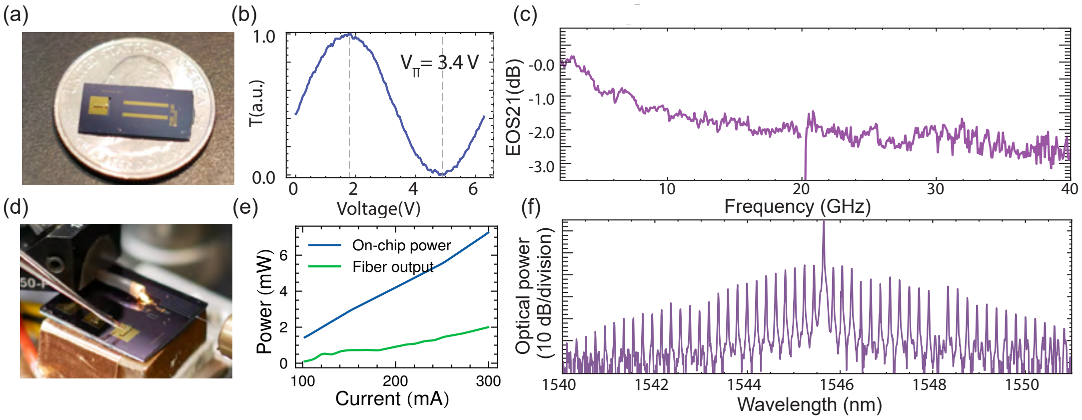

Fig. 2. (a) EO transmitter: DFB laser flip-chip bonded to a TFLN motherboard with an amplitude modulator, connected via photonic wirebond. (b) Voltage-dependent transmission (T) curve of the modulator with V_π = 3.4 V. (c) EO bandwidth (S21) of the transmitter, confirming high-frequency performance. (d) EO frequency combs: Three DFB laser bars flip-chip bonded to the same chip, each connected to a separate resonant comb source with a 27 GHz FSR. (e) Power-current (P-I) characteristics showing on-chip and fiber output power of the lasers. (f) Optical spectrum from the frequency comb, demonstrating compact and portable functionality.

We validated this approach through two key demonstrations leveraging distributed feedback (DFB) laser integration with thin-film lithium niobate (TFLN): an electro-optic (EO) transmitter and a battery-powered laser source for a EO frequency comb. In the first demonstration, a DFB laser chip was flip-chip bonded onto a TFLN photonic motherboard hosting an amplitude modulator. A photonic wirebond written using the Vanguard Sonata 1000 connected the DFB laser to a mode-size converter (fig 2a), creating a link between the laser and the modulator. V_π and EO bandwidth measurements confirmed the successful integration, as illustrated in Figure 2(b) and 2(c). The second demonstration showcased a DFB laser flip-chip bonded to a resonant EO frequency comb source with a 27 GHz free spectral range (FSR), as shown in Figure 2(e) and (f). Notably, three DFB laser bars were bonded to the same chip, with each bar hosting two lasers, resulting in a total of six fully operational light sources on a single die.

In conclusion, we demonstrated a platform that integrates diverse photonic chips for applications like photonic computing and optical interconnects. Its versatility supports components such as lasers, modulators, detectors, combs, and potentially chip-based electronics, offering scalable solutions for high-performance systems.

Funding: This work is supported by the Defense Advanced Research Projects Agency (HR0011-20-C-0137), Fulbright-CAPES grant 88881.625368/2021-01, and Behring Foundation Scholarship.

References

1. S. Shekhar, W. Bogaerts, L. Chrostowski, J. E. Bowers, M. Hochberg, R. Soref, and B. J. Shastri, “Roadmapping the next generation of silicon photonics,” *Nature Communications*, vol. 15, p. 751, Jan. 2024.
2. P. Kaur, A. Boes, G. Ren, T. G. Nguyen, G. Roelkens, and A. Mitchell, “Hybrid and heterogeneous photonic integration,” *APL Photonics*, vol. 6, p. 061102, June 2021.
3. N. Lindenmann, G. Balthasar, D. Hillerkuss, R. Schmogrow, M. Jordan, J. Leuthold, W. Freude, and C. Koos, “Photonic wire bonding: A novel concept for chip-scale interconnects,” *Optics Express*, vol. 20, pp. 17667–17677, July 2012.
4. S. J. Chowdhury, K. Wickremasinghe, S. M. Grist, H. Zou, M. Mitchell, M. A. Al-Qadasi, B. Lin, D. Birdi, S. Smythe, S. Shekhar, K. C. Cheung, and L. Chrostowski, “On-chip hybrid integration of swept frequency distributed-feedback laser with silicon photonic circuits using photonic wire bonding,” *Optics Express*, vol. 32, pp. 3085–3099, Jan. 2024.

Authorized licensed use limited to: TU Delft Library. Downloaded on November 27,2025 at 13:51:25 UTC from IEEE Xplore. Restrictions apply.