A photonic MEMS interposer to solve electronic and optical assembly challenges

Li, J.; Sielecki, Andrzej; Beletkaia, Elena

DOI
10.1002/phvs.202200027

Publication date
2022

Document Version
Final published version

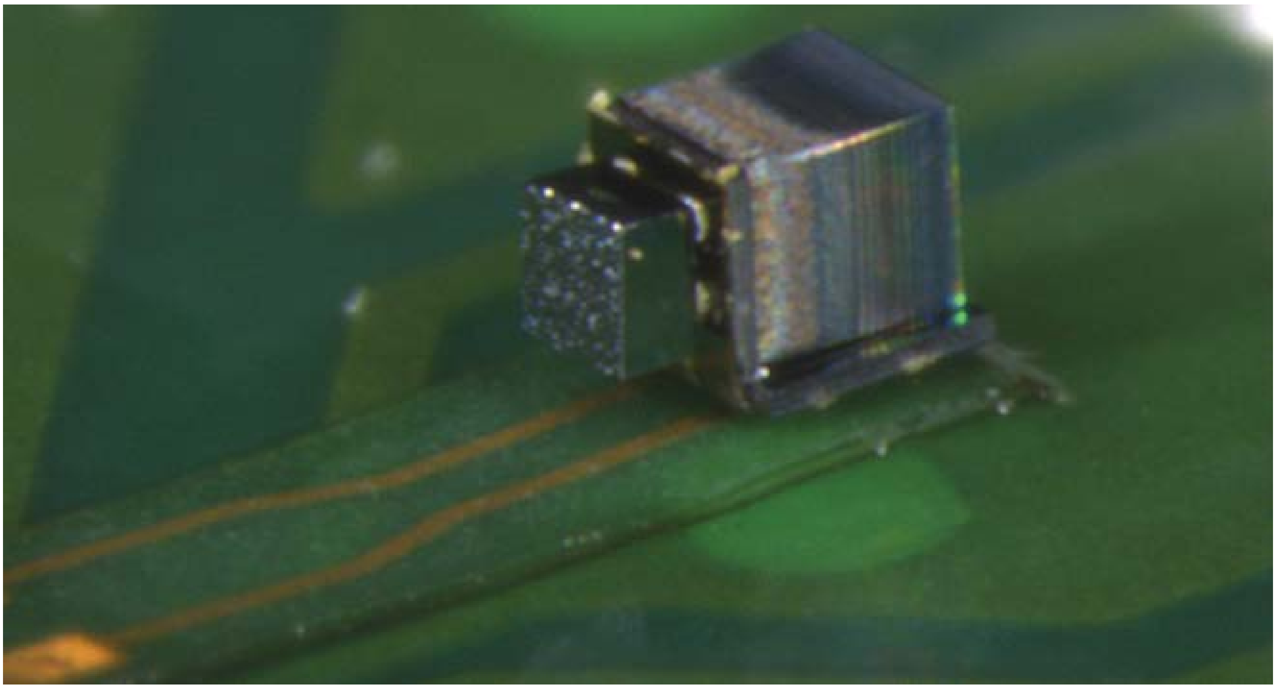
Published in
PhotonicsViews

Citation (APA)
Li, J., Sielecki, A., & Beletkaia, E. (2022). A photonic MEMS interposer to solve electronic and optical assembly challenges. *PhotonicsViews*, *19*(3), 28-31. https://doi.org/10.1002/phvs.202200027

A photonic MEMS interposer to solve electronic and optical assembly challenges

Scalable production, enabling miniaturization and function combination

Jian Li, Andrzej Sielecki, and Elena Beletkaia



Source all images: Philips

Photonic applications often face industry-specific assembly requirements that can be challenging to overcome. There is a need for micron-accurate alignment, device miniaturization and integration in challenging form factors. Special materials and packaging must be developed for the best performance of the devices in exacting environmental conditions. In the medical field, these requirements are additionally complicated by the demanding ISO 13485 regulations. The article demonstrates how solutions are found in a combination of new and existing technology in microelectronics packaging and now made suitable for photonics.

The possibility to fold or roll electronic modules in a tightly confined form factor using flexible interconnects is already widely exploited in the electronics industry, in mobile phones for example. It enables the integration of multiple cameras while keeping a slim design; it allows a tighter density of functionality while maintaining a high level of reliability and more form factor degrees of freedom; it makes the next generation of foldable or deformable phones possible. And this fold or roll approach can be adopted and extended to provide benefits in photonic innovations such as opto-acoustic or spectroscopic imaging integration on the tip of a catheter or a guidewire.

Philips MEMS Foundry-developed flex-to-rigid (F2R) technology allows multiple silicon elements to be flexibly combined that can be folded [2] or rolled [3] as a result. But for the successful integration of electronics in a guidewire, size is not the only concern; the quality and the speed of data transfer requirements must be considered too. In addition, consideration must be given to minimizing the effect of cabling on the mechanical properties of the guidewire, the ease of integration during the assembly process and the direct electrical connection to other components.

The solution to this complex challenge involved the combination of F2R technology and an optical data link that removes interference issues and is able to transfer high speed digital data in a very small diameter. The microelectromechanical system (MEMS) building block based on the Philips MEMS Foundry F2R platform allowed the miniaturization of an optical data link module (ODLM), resolving form factor requirements to fit into the tip of a guidewire [1]. This MEMS interposer enabled the integration challenges to be overcome while simplifying the assembly and maintaining the high performance of the ODLM. In this way, high-speed and disturbance-free communication between, for example, an ultrasound imaging head and the analysis electronics can be realized.

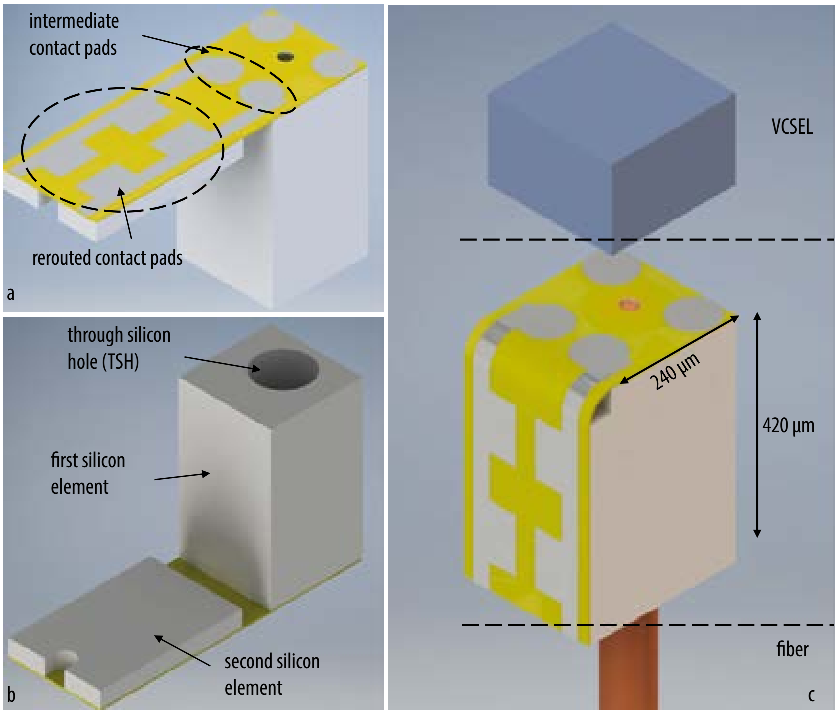


Fig. 1 ODLM design: (a) unassembled F2R interposer, (b) rear view of unassembled F2R interposer, (c) assembled F2R interposer with flip-chipped VCSEL and inserted optical fiber

MEMS interposer design to manufacture an ODLM in a miniaturized form factor

In order to align with the overall standard guidewire assembly protocol, the optical link should be mass-producible, designed for high speed and high yield assembly steps, and preferably on wafer level. It must also be a stand-alone device that can be easily connected to other parts in the guidewire. To accomplish this, the optical link design comprised three parts: a microfabricated F2R silicon interposer; a commercially available vertical cavity surface emitting laser (VCSEL) with its electrical contacts and laser emitting spot on the same surface; a 125 µm diameter optical fiber. The F2R silicon interposer incorporated flexible interconnects to reroute the VCSEL electrical contacts to a plane perpendicular to the surface of the VCSEL. This design enabled the optical link module to be mounted on a flex-PCB within the limited space available in the catheter or guidewire. At the same time, the VCSEL is optically self-aligned and connected to a fiber (Fig. 1c) that can be mounted in the catheter shaft leading up to the proximal end of the catheter. This design allows the interposer to be made using high-volume, compatible assembly processes.

Interposer fabrication and assembly into the ODLM

The silicon interposer fabrication was based on the F2R process module available from Philips MEMS Foundry and described in detail elsewhere [4]. Some critical points of the F2R process include tight control over the etching process, leading to the required alignment accuracy, and well controlled deposition of the polyimide layers containing the electrical tracks. Importantly, the metal layer in the flexible interconnect is in the stress-neutral plane, and as a result can achieve a very small bending radius of 10 µm that allows tight packaging.

For the first assembly step of the interposer into the ODLM, solder spheres can be placed on the contact pads of the ODLMs at a wafer/die level and the VCSEL can be flip-chipped on top of four reflowed solder spheres. The use of four solder spheres provided two electrical contacts, with the other two being used for mechanical support to prevent tilting during the second reflow step. While all assembly steps were executed piece by piece for the prototype, for high volume assembly solder ball application and reflow on wafer level,

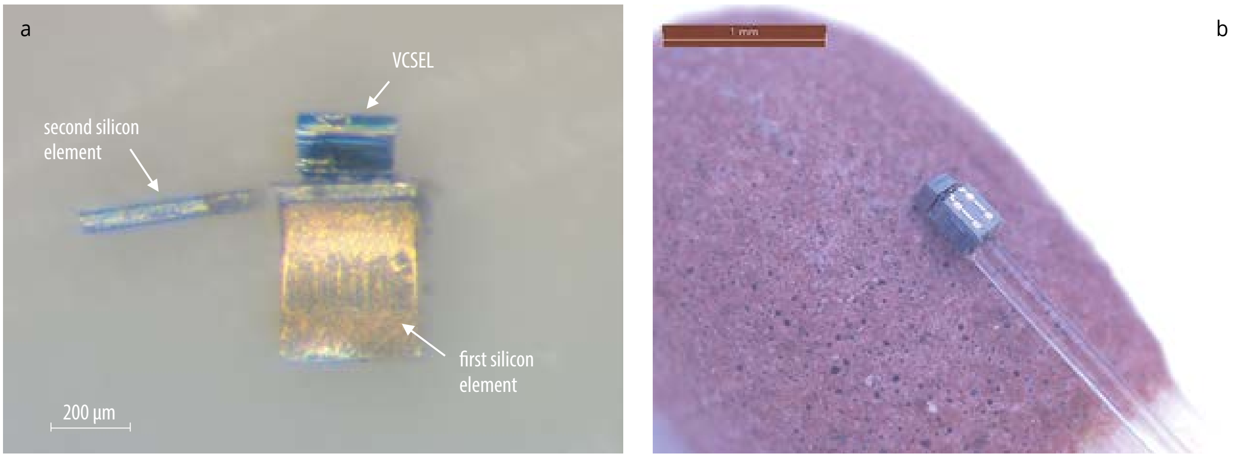


Fig. 2 (a) Side view of an ODLM F2R interposer with assembled VCSEL, released from the Si frame. The two silicon elements are connected by flexible interconnects. (b) An assembled ODLM, with the VCSEL and an inserted 125 µm diameter optical fiber, placed on a match head. The optical fiber was fixed with biocompatible glue.

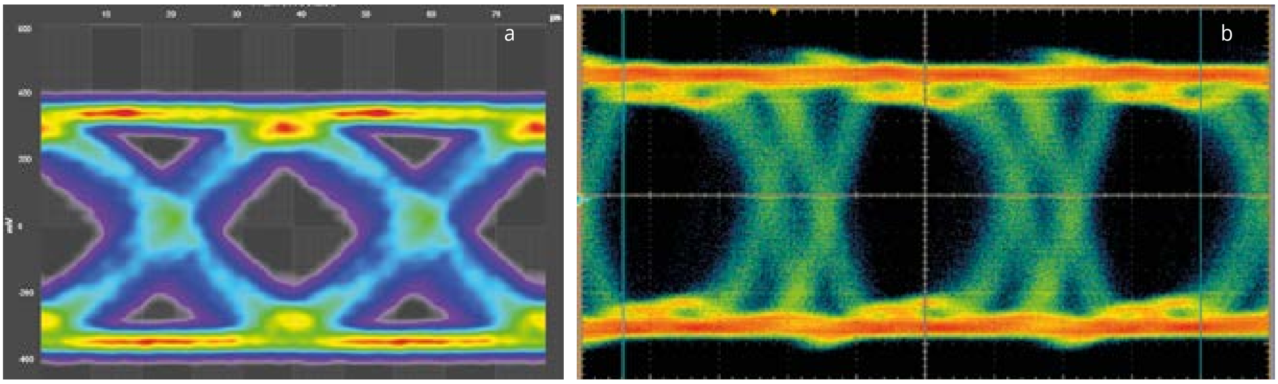


Fig. 3 Eye diagrams of (a) standalone ODLM with 25.8 Gb/s and (b) ODLM and laser driving testing board with 7 Gb/s

automatic flip-chip and wafer level soldering techniques would be possible to use, confirming a design for high-volume manufacturing.

After the electrical integration of the VCSEL on the F2R interposer, the interposer was released from the Si wafer and the free-hanging second thin silicon element was connected to the first silicon element by the flexible interconnect (Fig. 2a). The second thin silicon element was folded by ninety degrees and fixed to the side of the first element with a transparent, biocompatible, UV-cured glue. Subsequently, a 125 µm diameter OM1 multimode optical fiber was stripped and dipped in the same glue, inserted into the 135 µm diameter through-silicon hole, and pushed into the assembled VCSEL on the other side. Fig. 2b shows the final assembled standalone ODLM, including the VCSEL, the F2R interposer, and an inserted 125 µm diameter optical fiber. The interposer geometries attained match the designed geometries shown in Fig. 1. This is strong evidence that the Philips MEMS Foundry F2R processing has reached a maturity level that allows accurate fabrication according to the design with good process control, and creates a good basis for solving assembly challenges in the development of custom devices for different applications.

ODLM performance testing

Miniaturization often comes at the cost of performance. The assembled ODLM was characterized by high-speed data transmission measurements with an external laser driver through high speed probes using a time-domain analyzer and tested to a maximum speed of 25.8 Gb/s. This speed was limited by the analysis system used, not by the ODLM.

A bias voltage of 1.91 V was applied to obtain the best performance of the VCSEL. An optical output power P_{opt} = 1.1 mW was detected at the end of the 1 m long optical fiber. Compared with the specifications of the VCSEL where P_{opt} = 1.45 mW is achieved at 1.91 V bias voltage, the ODLM delivers over 75 % of the optical intensity generated by the VCSEL. This optical intensity was satisfactory for the application and could still be optimized by improving VCSEL positioning.

A 25.8 Gb/s differential signal with PRBS 2^{31}-1 sequence was fed into the ODLM device through high-speed probes. The eye diagram without clock data recovery (CDR) in Fig. 3a proves the capability of the stand-alone ODLM to support data rates up to 25.8 Gb/s. The ODLM was also tested with a custom laser driver with a power dissipation below 10 mW in order to prevent a temperature increase in the tip of the catheter to over 40 °C. The result was a maximum data rate of 7 Gb/s, well above the data rate of 1.6 Gb/s required for the application. Using the low power miniaturized laser driver, 7 Gb/s differential signals with 2^{15}-1 sequence were fed into the ODLM with the resulting eye diagram shown in Fig. 3b.

Both eye diagrams show a big opening, indicating room for a speed increase in both the stand-alone and the integrated case with the low power laser driver. This also means that the 75 % optical intensity transmission through the MEMS interposer is not a limiting factor to the optical link performance.

Photonic MEMS interposer beyond ODLM

The photonic MEMS interposer was also adjusted to be compatible with a four-fold VCSEL component (Fig. 4a), showing the potential to further increase the data transmission density with this technology. It also shows that further miniaturization, scale-up and acceleration in assembly is possible. Using the same F2R technology to redirect the electrical connections to the side of the module, the assembled module can be directly flip-chipped on an ASIC or flex PCB to reduce the length of the interconnect. The example assembly with four fibers in one larger interposer on a flexible PCB is shown in Fig. 4b.

The integrated electronic connection points in the photonics MEMS interposer can also be extended to include mounting pads for ASICs, passive components, or cables. The big benefit of the MEMS interposer is the ability to make a flip chip connection to these ASIC or PIC chips, allowing a route to high volume manufacturing.

In addition, the combination of the passive alignment of optical components and integrated electronics in the MEMS interposer can also be extended with other processing modules from the Philips MEMS Foundry, like the capacitive ultrasound transducers in different frequency ranges and apertures. Furthermore, this technology building block can be combined with the technology and capability of other research and industry partners of MedPhab. Europe's first pilot line for photonics-based med-

Company

Philips MEMS Foundry

With almost 200 experts working at the MEMS Foundry and Micro Devices Facility, a phase gated approach is followed to demonstrate the feasibility and provide proof of concept, develop the process to the required maturity level and manufacture your devices with the required quality certifications – such as ISO 13485 and 9001. From small series to high volume, inquiries are approached with a manufacturing mindset. Philips MEMS Foundry is your reliable partner in creating your MEMS and Micro Devices. Making innovation work.

engineeringsolutions.philips.com/mems

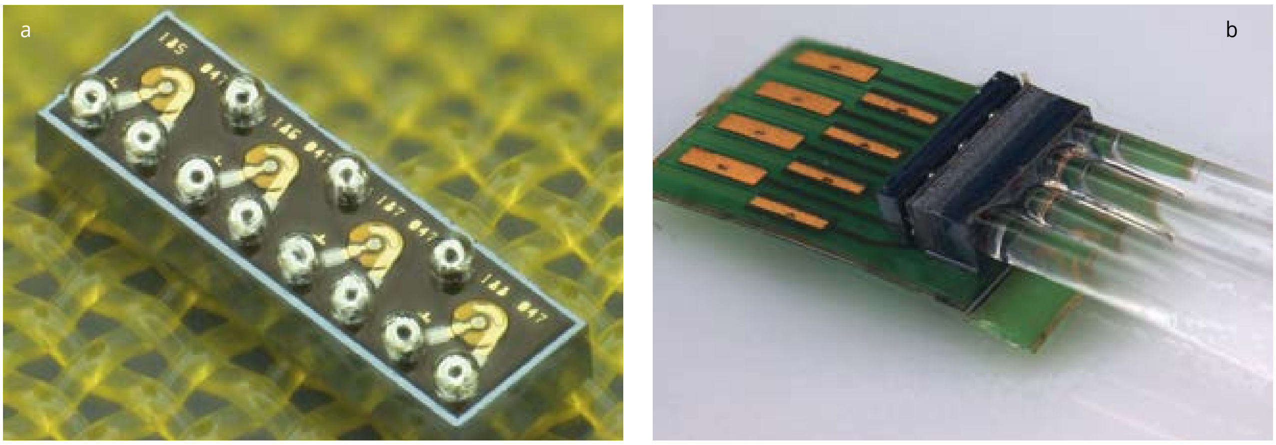


Fig. 4 Four-fold VCSEL a) as a bare chip package with re-flowed solder balls and b) 1 × 4 version of an ODLM with VCSEL interfaced to four fibers and electrically connected to a flexible PCB board using the MEMS interposer

ical devices, MedPhab is dedicated to accelerating their development and commercialization by improving the technology transfer from research and technology organizations to high(er) volume medical applications.

The extremely small form factor and integration of electrical interconnects brings new assembly opportunities to integrated photonics devices with the promise of a high volume manufacturing capability using standard microelectronics assembly methods. As an example, an F2R-based optical data link module (ODLM) with dimensions of 240 µm × 280 µm × 420 µm was designed, fabricated, assembled, and characterized, showing 7 and 25 Gb/s data rate performance. The technology platform described is already offered as a manufacturing service by Philips MEMS Foundry under ISO 13485, complementing customers' own innovations, potentially amplified with solutions from MedPhab partners.

*

We would like to thank all Philips Engineering Solutions colleagues that supported the design, fabrication and assembly of the devices, and TU/e for its characterization and optical measurements. This work was partly funded by the EU ECSEL JU POSITION project, grant no. Ecsel-783132-Position-II-2017-IA

DOI: 10.1002/phvs.202200027

https://medphab.eu

[1] *J. Li, C. Li, V. Henneken, M. Louwerse, J. van Rens, P. Dijkstra, O. Raz , R. Dekker:* 25.8 Gb/s Submillimeter Optical Data Link Module for Smart Catheters, Journal of Lightwave Technology, **8** (2021) 2456-2464

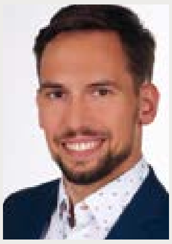
[2] *M. Kluba, B. Morana, A. Savov, H. van Zeijl, G. Pandraud, R. Dekker:* Wafer-Scale Integration for Semi-Flexible Neural Implant Miniaturization, Proceedings MDPI, **2** (2018) 941-945

[3] http://position-2.eu/wp-content/uploads/MUT2019.pdf

[4] *B. Mimoun, V. Henneken, A. Van Der Horst, R. Dekker:* Flex-to-rigid (F2R): A generic platform for the fabrication and assembly of flexible sensors for minimally invasive instruments, IEEE Sens. Journal, **10** (2013) 3873–3882

Authors

Jian Li received his MSc degree in microelectronics from the TU Delft in 2013. He is now a PhD researcher at the TU Delft, specializing in MEMS/semiconductor microfabrication and process development. He conducts his PhD project together with Philips Research, developing integration technologies for highly miniaturized systems such as smart medical instruments. His previous work includes developing the cavity-BOX SOI for monolithic MEMS fabrication and a high-speed optical data link module for smart catheters.



Andrzej Sielecki graduated from Warsaw University of Technology with an MSc in mechatronics, specialized in photonics engineering. He is process architect for photonic assembly at Philips Engineering Solutions, solving (micro) device assembly challenges for various photonic-related devices, including fiber coupling, lens alignment or laser applications for both medical and non-medical products. He has prior experience in product development and integration as well as in system design and installation.

Elena Beletkaia graduated from the Lomonosov Moscow State University and received a doctorate from Leiden University specializing in biophysics. Always focusing on understanding and using multiple microscopic and spectroscopic techniques, she worked at EPIC as a project leader with her main application areas in medical devices, biophotonics, life sciences and the agrifood industries. Currently she is focusing on bioMEMS and photonics technology as a business development manager at Philips MEMS Foundry.

Dr. Elena Beletkaia, Philips, Philips MEMS Foundry and Micro Device Facilities, High Tech Campus 4 – 5.060, 5656 AE Eindhoven, The Netherlands; phone: +31 6191 81296;
e-mail: elena.beletkaia@philips.com, Web: www.engineeringsolutions.philips.com/mems Philips-MEMS-Foundry