Automating Photonic Systems-in-Package Assembly for High Performance Glass Interposers

Kevin Shortiss(1), How Yuan Hwang(2), Josue Parra(1), Sharon Butler(2), Hsiang-Chu Wang(3), Mohammadamin Ghomashi(4), Yanlu Li(4), Wilfried Noell(3), Moritz Seyfried(5), Peter O' Brien(2)

(1) ficonTEC Ireland, Tyndall National Institute, Cork, T12 R5CP, Ireland, kevin.shortiss@ficontec.com
(2) Photonics Packaging Group, Tyndall National Institute, University College Cork, T12 R5CP, Ireland.
(3) Focuslight, Rouges-Terres 61, CH-2068 Hauterive, Switzerland.
(4) Center for Nano- and Biophotonics, Ghent University, Technologiepark-Zwijnaarde 126, 9052, Ghent, Belgium.
(5) ficonTEC Service GmbH, Im Finigen 3, 28832 Achim, Germany.

Abstract *Interest in high performance glass interposers has been growing, due to the advantages which have been demonstrated over standard silicon interposers. In this paper, we demonstrate fully automated micro-optics and laser sub-assembly alignment and laser-assisted bonding processes which are compatible with glass interposers. ©2024 The Author(s)*

Introduction.

Chip-on-board (CoB) assembly has been a popular approach in the silicon photonics industries for the past few decades, owing to readily available assembly processes from outsourced semiconductor assembly and test (OSAT) companies. The typical assembly begins with thermal processes such as electrical assembly of components (photonic ICs, electronic ICs, and lasers) onto organic PCBs at panel level, followed by non-thermal processes for optical assembly involving lenses, isolators, and fibres. The process flow ends by breaking the PCB panel and inserting individual PCB assemblies into a metal housing, before being subjected to various tests. This approach can be easily found in commercial pluggable optical modules used in data centres [1, 2].

However, the increasing demand for miniaturization and power consumption is driving the need to have components packed together as close as possible. One possible solution is to substitute CoB assembly with chip-on-wafer (CoW) assembly, by using silicon or glass interposers. Within the PhotonicLEAP project [3], the authors propose the use of copper through-glass vias in a glass interposer [4-6], which has integrated cavities for laser and micro-optics assembly (Fig. 1). Aside from functioning as an electrical conduit (connecting components on the top surface to the system-level board at the bottom surface), the copper vias also improve the thermal dissipation of the glass [6], and the via positions can be chosen to reduce thermal crosstalk between neighbouring chips.

The glass interposer proposed is designed with wafer-level assembly processes in mind, consisting of probe pads for signal monitoring during laser and micro-optics assembly and a glass lid for hermetically sealing the package, to protect components during dicing and the finished assemblies during their use cases. The probe pads on the top surface of the interposer eliminate the need of an intermediate PCB at the bottom or having a vacuum chuck/socket with integrated pogo-pins. Moreover, the package is designed to be compatible with standard surface-mounting technology (SMT), following JEDEC standards used in microelectronics industries.

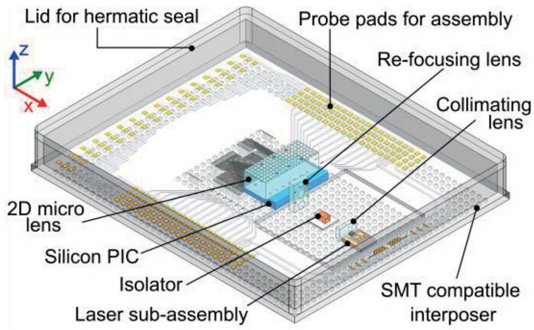

Fig. 1: 3D model of the glass interposer package proposed in Photonic LEAP [3] with through-glass vias and ball grid array (BGA) pads for board level assembly.

In the following sections, we demonstrate some of the process steps required to assemble a “System-in-Package” module on a glass interposer which is SMT compatible. The processes have been automated on ficonTEC GmbH machines to further validify the commercial feasibility of such assemblies.

Silicon Photonic IC.

The silicon photonic ICs (PIC) used to demonstrate this packaging technology were developed by UGhent-IMEC. The PIC uses back-reflecting grating couplers [7], allowing the PIC to be flip-chip compatible. This approach enables signals to travel through the bulk silicon and exit from the polished backside of the PIC, which is then collimated by a two-dimensional micro-lens attached to the PIC, allowing fibre pluggability at system level if required by the application [8,9]. The PIC has dimensions of 4.2 mm x 2.7 mm x 0.65 mm, with 107 aluminium (Al) bond pads, 1 edge coupler for laser input (with a MFD of approximately 6 µm), 24 back-reflected grating couplers for out-of-plane coupling, and 6 pairs of reference photodetectors (PD). The backside of the PIC was polished to have a peak-valley surface roughness of 20 nm and was finished with an anti-reflection coating. Alignment markers are patterned on the backside of the PIC to assist with the automated assembly.

Laser sub-assembly with collimating lens.
To couple light into the flip-chipped PIC on the interposer, a sub-assembly with an expanded and collimated light source is lowered into a cavity in the glass. We have previously demonstrated this laser to PIC coupling with this expanded beam approach [10], and based on the results, we present here a further improvement in the laser sub-assembly design. The revised design has larger sidewall metal pads for gripping, as well as a more compact laser sub-assembly size. The laser on the sub-assembly is now flip-chipped, lowering the optical axis of the laser sub-assembly by 80 µm. As a result, a shallower cavity in the glass interposer can be used to match the optical axis of the sub-assembly with that of the PIC, improving the durability of the glass interposer.

The new laser sub-assembly design allows the collimating lens to be attached to the edge facet of the aluminium nitride (AlN) sub-mount instead of sitting on a thin ledge, simplifying the assembly process. A slot opening is implemented on the sub-mount to prevent structural epoxy flowing and blocking the laser beam path. The AlN sub-mount was fabricated through maskless patterning and has 18 µm electroplated copper (Cu) and direct immersion gold (DIG) surface finishing. The maskless approach allows for cheaper and more rapid prototyping of future sub-assemblies. Fig. 3 (a) shows a 3D render of the proposed sub-mount, and Fig. 3 (b) shows an

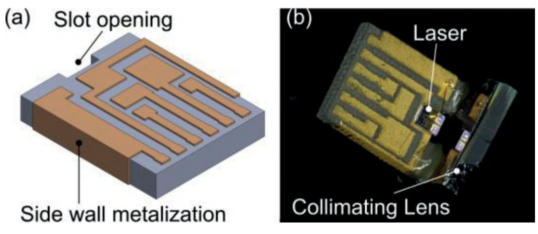

Fig. 3: (a) 3D render of the ceramic sub-mount, and (b) laser sub-assembly with collimating lens attached to the side of the sub-mount.

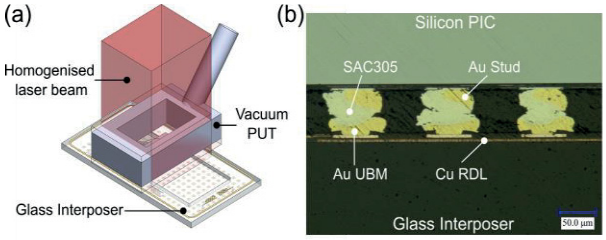

Fig. 4: (a) 3D render of the LAB process with beam shaping. A stainless-steel vacuum pick-up tool (PUT) (b) cross-sectional image of an assembled PIC on a glass interposer.

initial laser sub-assembly (non-flip-chip) with collimating lens attached to the edge of the sub-mount. The collimated beam sizes from the sub-assemblies have $1/e^2$ diameters of approximately 250 µm.

Automated laser-assisted bonding.
Laser-assisted bonding (LAB) is a process in which parts are bonded together with solder using a high-power laser [11-12]. LAB is faster than conventional hotplate reflow processes, and allows heat delivery to be targeted, allowing different reflow temperatures for different components. We have implemented our LAB process with the laser incident on the back side of the PIC, which removes constraints on the electrical routing and design of the glass interposer. This approach requires a transparent pick-up tool (PUT) [12], shown in Fig. 4 (a). Prior to the LAB process, Au-stud bumps were deposited on all 107 Al bond pads of the Si PIC and then flattened. Meanwhile, 50 µm SAC305 solder balls were laser-jetted onto the Au bond pads on the interposer.

The LAB process was fully automated on a ficonTEC CL1500 machine. The automation process involves accurately measuring the planes of the interposer and the PIC for precise co-planarity control. Cameras with microscope optics are used for machine vision, and a confocal distance sensor is used to find the yaw and roll of the parts. The coordinates of the PIC are matched with that of the interposer by placing both on a soldering station. The process is flux-less, with N2 gas used to create an inert atmosphere on the soldering station. For the SAC305 solder and bond pad density in this application, an 808 nm homogenous laser beam with an intensity of 1.5 W/mm^2 was incident on the transparent PUT for 5 s. Approximately 1 N of force was applied by the PUT throughout the LAB process. Exemplary cross-sectional results of the flip-chip assembly are shown in Fig 4 (b).

Automating laser sub-assembly and micro-optics integration.
Using a glass interposer with electrical probe

pads provides many advantages, as described in the introduction. The use of probe cards is ubiquitous in the automated assembly of electrical and optical components, and we use it in this application to power up the laser diode and monitor photodiodes (PD) on the PIC during assembly. A ficonTEC FL300 with two axis aligners with 6 degrees of freedom (DOF) was used for the active alignment of micro-optical components.

The glass interposer is fixed on the chuck which is on top of a linear stage. The probe card is connected to a transimpedance amplifier (TIA), which is monitored by the FL300 during alignment. Piezo grippers are mounted to the 6-axis stages, which together can handle and align a pair of optical components at a time. For this application, the gripper which holds the sub-assembly also provides current to drive the sub-assembly's laser (enabled by the conductive sidewalls on the sub-assembly). The second piezo gripper is designed to handle optical lenses with dimensions between 0.3 mm to 30 mm. Fig. 5 shows the grippers during the alignment process.

Cameras on the machine are used to measure the position of the components in the package, using machine vision tools. The positions of the optical components are used to reference and planarize each subsequent component to be placed, followed by active alignment processes using the PDs on PIC to optimise the coupling.

Fig. 6 shows an exemplary optical power distribution obtained when performing an area scan of the refocusing lens in the plane parallel to the facet of the PIC (coordinate axis illustrated in Fig. 1). The silicon refocusing lens has a radius of curvature of 1.1 mm, with a diameter of 245 µm, and a working distance of 300 µm. The alignment tolerances of the refocusing lens with respect to the PIC are improved due to the collimated beam, with 1 dB tolerances in Y, Z, Rx, Ry, Rz of +/- 1.79 um, +/- 1.11 um, +/- 250 arcsec, +/- 500 arcsec and +/- 700 arcsec, respectively. The expanded beam approach with micro-optics has been

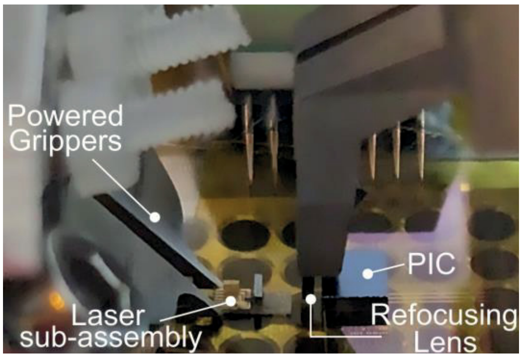

Fig. 5: Side view of the laser sub-assembly and refocusing lens to PIC alignment process with probe card needles in the background.

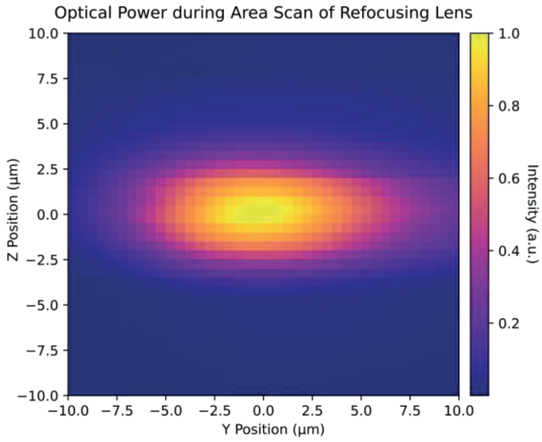

Fig. 6: Optical power distribution in the PD of the PIC while scanning the refocusing lens in Y and Z axes. See Fig. 1 for the orientation of Y and Z axes.

proven to relax the alignment tolerances between laser sub-assembly and refocusing lens and has the potential to improve the optical coupling efficiency in comparison to butt coupling a laser to the PIC [8-10].

Conclusions

In this paper, we demonstrated automated packaging processes by integrating various components on a glass interposer. Laser assisted bonding (LAB) was used to flip-chip attach a silicon PIC to a glass interposer, instead of the more commonly used mass reflow or thermo-compression bonding.

In addition, we demonstrated the integration of laser sub-assemblies and micro-optics using electrical probe pads for active alignment with relaxed optical coupling tolerances. This automated assembly was achieved using a new laser sub-assembly design with a smaller footprint, allowing for shallower cavities in the glass interposer. While we have demonstrated the automated assembly on a single interposer, the concept is valid and can easily be transferred to operate on a wafer. At the point of writing, the final automation processes for the 2D micro lens attachment onto the silicon PIC and the lid sealing (Fig. 1) are being optimised and will be demonstrated in the future.

Acknowledgements

The PhotonicLEAP project has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement number 10101673.

References

[1] "Intel Silicon Photonic 100G CWDM4 QFSP28 Transceiver," Yole SystemPlus, Mar. 2020. https://www.yolegroup.com/product/report/intel-silicon-

photonic-100g-cwdm4-qfsp28-transceiver/ accessed on 31st March 2024.

[2] “Innolight’s 400G QSFP-DD Optical Transceiver”, Yole SystemPlus, Jan. 2021. https://www.yolegroup.com/product/report/innolights-400g-qsfp-dd-optical-transceiver/ accessed on 31st March 2024.

[3] https://photonicleap.com, accessed on 31st March 2024.

[4] K. Kröhnert, G. Friedrich, D. Starukhin, M.Wöhrmann, M. Schiffer, M. Schneider-Ramelow, “Reliabillity of Through Glass Vias and hermetically sealing for a versatile sensor plattform," *2020 IEEE 8th Electronics System-Integration Technology Conference (ESTC)*, Tønsberg, Norway, pp. 1-6 (2020). DOI: 10.1109/ESTC48849.2020.9229834.

[5] R. Santos, N. Ambrosius, R. Ostholt, J.P. Delrue, “Bringing New Life to Glass for Wafer-Level Packaging Applications,” *IEEE 2020 International Wafer Level Packaging Conference (IWLPC)*, San Jose, CA, USA, Oct. 2020. DOI: 10.23919/IWLPC52010.2020.9375851.

[6] P. Gupta, P. E. Morrissey, P. O' Brien, K. Kröhnert, M. Wöhrmann, M. Schiffer, C. Kelb, N. Ambrosius, M. Schneider-Ramelow, "Impact of Through Glass Vias Filling on the Performance of Passive Thermal Cooling in Photonic Packages," *2022 IEEE 9th Electronics System-Integration Technology Conference (ESTC)*, Sibiu, Romania, 2022, pp. 391-397, DOI: 10.1109/ESTC55720.2022.9939531.

[7] M. Ghomashi, R. Baets and Y. Li, "Design and Optimizing Backside Grating Couplers in Si-Photonics Circuits," *2023 International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD)*, Turin, Italy, 2023, pp. 117-118, DOI: 10.1109/NUSOD59562.2023.10273523.

[8] C. Scarcella, K. Gradkowski, L. Carroll, J. S. Lee, M. Duperron, D. Fowler and P. O’ Brien, “Pluggable Single-Mode Fiber-Array-to-PIC Coupling Using Micro-Lenses,” *IEEE Photonics Technology Letters*, vol. 29, no. 22, p. 1943-1946, Nov. 2017. DOI: 10.1109/LPT.2017.2757082.

[9] K. Gradkowski, D. Stegall, D. Mackey, A. Naughton, T. Smith, and P. O'Brien, "Demonstration of a Single-Mode Expanded-Beam Connectorized Module for Photonic Integrated Circuits," *Journal of Lightwave Technology*, 41, 3470-3478 (2023). DOI: 10.1109/JLT.2023.3239138.

[10] C. M. Patil, H. Y. Hwang, M. Pfeiffer, W. Noell, P. E. Morrissey and P. O’Brien, "Microlens-Assisted Expanded Beam Technique for Coupling of Laser Source to Photonic Integrated Circuit," *2023 28th Micro-Optics Conference (MOC)*, Miyazaki, Japan, 2023, pp. 1-2, DOI: 10.23919/MOC58607.2023.10302834.

[11] W. Tian, L. Beste, A. Khachikyan, C. Mittelstädt, R. Dekker, K. Wörhoff, J. van Kerkhof, R. Santos, K. Williams, and X. Leijtens, “Flip-Chip Bonding of InP Die on SiN-Based TriPleX Carrier With Novel Laser Soldering,” *IEEE Journal of Quantum Electronics*, vol. 59, no. 3, pp. 1-7 (2023). DOI 10.1109/JQE.2022.3224794.

[12] K. Shortiss, H. Y. Hwang, J. Parra-Cetina, M. Seyfried, P. O’Brien, “Development of 808 nm Laser-Assisted-Bonding (LAB) for Photonic System-in-Package Integration,” *2024 Conference* on Lasers and Electro-Optics *Pacific* Rim, Incheon, South Korea, 2024. In-press.