Development of 808 nm Laser-Assisted-Bonding (LAB) for Photonic System-in-Package Integration

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Abstract: We describe a versatile laser-assisted bonding (LAB) system for photonic system-in-package integration using an 808 nm laser. This paper details the LAB process for flip chip bonding of Si and InP PICs onto glass interposers.

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1. Introduction

Silicon photonic integrated circuits (Si PIC) have come a long way since Soref et al. [1] first proposed the use of silicon waveguides in the mid-1980s. As photonic systems and applications continue to grow, so do the challenges in packaging and integration. For instance, 1) the change of package form-factor from die-attach and wire-bonding on butterfly packages to flip-chip assembly on silicon or glass interposers, 2) the increased number of components within a package and 3) the integration of various materials within a package. Together these changes necessitate a paradigm shift in package design, material choices, process flow and equipment.

Laser-assisted-bonding (LAB) [2,3] can address many of the challenges facing state-of-the photonic packaging, as it offers highly localised heating, short soldering times, and causes less thermal stress on components than standard oven reflow [4]. Within the Photonic LEAP project [5], an assembly design kit (ADK) for a photonic system-in-package is under development, which combines PICs, lasers, micro-optics, and electronic components on a glass interposer (Fig. 1 (a) and (b)). To support this goal, an automated and flexible LAB process was developed to attach Si PICs and InP PICs to glass interposers.

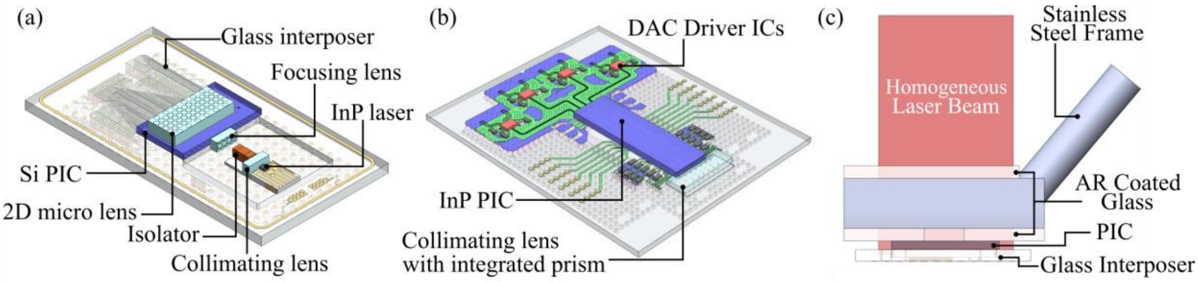

Fig. 1: (a) 3D render of Photonic LEAP's system-in-package demonstrator [5]. The laser-assisted-bonding process described here is used to attach the Si PIC and (b) the InP PIC to the glass interposers shown. (c) Illustration of the LAB process, with the laser beam from the top passing through ficonTEC's novel vacuum pick-up tool.

2. Design of the Laser-Assisted-Bonding System

For the LAB process, a ficonTEC CL1500 machine was equipped with a 100 W 808 nm laser diode (Aerodiode), as both Si and InP have strong absorption at 808 nm. The following subsections describe the materials, optical beam shaping, and the pick-up tool (PUT) configurations used for our LAB system.

2.1 Description of PICs and Interposers

The components used in this work are as follows. The Si PICs were 2.6 mm × 4.2 mm × 0.65 mm, with Al bond pad thickness of 1 µm and pad size of 55 µm × 75 µm. The InP PICs were 10.15 mm × 3.03 mm × 0.5 mm, with Au bond pad thickness of 1 µm and pad size of 70 µm × 70 µm. The glass interposers (13 mm × 7 mm × 0.46 mm) for the Si PICs were fabricated by Fraunhofer IZM [6] with 16 µm thick Au bond pads above 3 µm thick Cu metallization. Dummy glass interposers were used for the InP PICs, of size 10.15 mm × 5.15 mm × 0.5 mm, with 1 µm thick Au bond pads. Prior to laser-assisted-bonding, Au stud bumps were deposited on all 107 Al bond pads of the Si PIC. These were then flattened before 50 µm solder balls (either SAC305 solder or eutectic AuSn solder) were laser-jetted onto these Au studs. For the InP PIC, SAC305 solder balls were directly deposited onto the 194 Au bond pads without the need of additional Au stud bumps.

2.2 Transparent Pick-up Tool Design and Optical Beam Shaping

To be compatible with various package designs on a wafer level scale, a “from the top” LAB design was chosen. For the laser beam to come from above the parts, a “transparent” vacuum PUT was designed (illustrated in Fig.

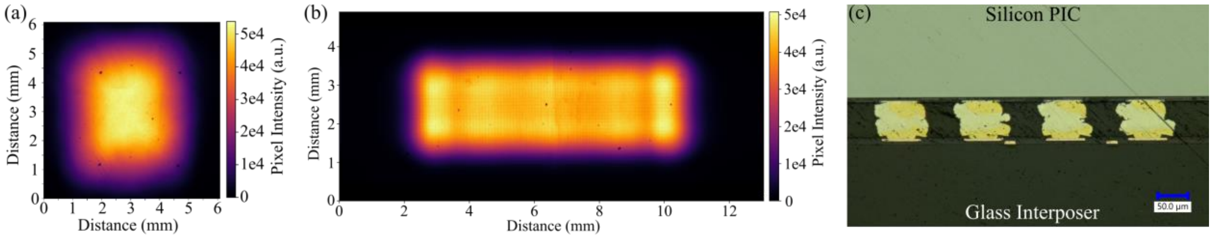

Fig. 2: (a) Spliced image of the homogenous beam used for the Si PIC and (b) for the InP PIC. (c) Cross sectional image of a Si PIC with SAC305 solder, which has been reflowed using LAB onto IZM's glass interposer [6].

1(c)). The PUT was constructed by sandwiching a metal frame between AR coated glass, with a gap in the lower glass for the vacuum. This also enabled a small force to be applied during reflow, to ensure a good bond on all pads.

To achieve uniform heating across the Si and InP PICs, separate optics setups were implemented. For the Si PICs, the multimode laser beam was collimated and then incident on a beam homogeniser (PowerPhotonic), which created an approximately square output beam. This resulted in beam with FWHM of 3.8 mm × 3.5 mm which was incident on the Si PIC, Fig. 2 (a). For the InP PIC, the multimode laser beam was instead incident on a pair of cross-orientated cylindrical micro lens arrays (SUSS MicroOptics), with 0.5 mm pitch and radii of curvatures of 1.5 mm and 5 mm. An additional AR coated lens with focal length 75 mm was positioned after the micro lenses to control the size of the beam on the InP parts. This resulted in a rectangular beam shape, with FWHM of 2.3 mm × 8.5 mm as shown in Fig. 2 (b).

2.3 LAB Process Description

The full assembly process was automated within a ficonTEC CL1500. The glass interposer is first placed on a sapphire chuck, on which N2 is used to create an inert atmosphere. The pitch, yaw and roll of the PIC are matched to that of the glass interposer, within an accuracy of 500 µrad. The PUT is then used to apply a force of 1.5 N across the PIC. A reflow time of 5 s was used for both PIC types, with a beam intensity of approximately 1.5 W/mm^2 for the SAC305 solder, and 2.45 W/mm^2 for the eutectic AuSn solder.

3. Experimental Results

Results from the laser reflow process described above were analysed using cross-sectional analysis of the solder joints, daisy chain DC connectivity tests, and shear tests. Cross sectional analysis of the Si PICs showed good contact between all metals, from the Al bond pads, Au stud bumps and solder to the Au bonds pads on the glass interposer (see Fig. 2(c)). There were no large voids, cracks, or defects observed. The planarity of the re-flowed PIC relative to the interposer was also measured using a confocal distance sensor and was found to be less than 500 µrad. Shear tests were carried out on the Si PICs and indicated that the solder joints provided greater than 10 grams-force per bond pad, which meets the MIL-STD 883-2 standards. Similarly, cross section analysis of the InP reflow process showed good contact between all the metal layers and the solder, with no voids or defects visible. Shear tests were not performed on the InP PICs due to their fragility.

4. Conclusion

We present an automated laser-assisted-bonding process for the attachment of Si and InP PICs to glass interposers, using an 808 nm laser with a transparent pick-up tool. Cross sectional analysis showed good electrical contact throughout. Shear tests on the Si PICs also indicate strong bonding was achieved.

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