Laser-Assisted Bonding Approach for Photonic Integration Processes

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***Abstract*—Current development trends concerning miniaturizing of electronics and photonics systems are aiming at assembly and 3D co-integration of a broad range of technologies including MEMS, microfluidics, wafer level optics, and silicon photonics. To this end, on-chip integration using silicon-photonics platform offers a wide range of possibilities addressing passive optics functionality, active optoelectronic devices, and compatibility with CMOS fabrication. On the other hand, the hybrid technology enabling volume manufacturing of such system-on-chip components it is still in an early development stage. In this work, the original LAB setup with a coaxial bottom irradiation architecture was developed. The setup allows a rapid and energy-effective process with the ability to produce successful electrical bonds with negligible thermal-induced stress and warpage to bonded surfaces. The proposed machine-vision based temperature sensor is validated for photonic integration assembly processes.**

Keywords—assembly processes, laser-assisted bonding, photonic integration, silicon devices, silicon photonics, through-silicon vision, infrared imaging, infrared microscopy.

I. INTRODUCTION

Photonic integrated circuits (PICs) have gained growing attention motivated by their ability to combine an increasing variety of optical functions on a chip-level, allowing to reduce cost, and drastically miniaturize optical systems [1]. PICs will inevitably introduce a paradigm shift in the use of photonics in applications such as wearable electronics, low-dissipation power datacom, and advanced sensing. Despite many important advances, photonic integration technology requires significant development to attain the yield, the throughput, and versatility required to engage with emerging applications. To this end, one of the most promising solutions to co-integrate complimentary photonic chips is laser-assisted bonding (LAB), owing to low thermal-induced stress and warpage to bonded surfaces [2].

In LAB processes, used in microelectronic integration, silicon chips are usually bonded to printed-circuit boards (PCBs), so the laser usually is placed above the assembly (Fig. 1, a), and could be combined with vacuum pick-up-tool [3]. As for photonic integration processes, where semiconductor components are bonded to silicon photonic integration circuits or wafers, laser is usually placed below the assembly (Fig. 1, b) [4]. Laser beam delivery system is usually combined with a through-silicon microscope, but it does not allow the simultaneous observation, alignment, and irradiation, requiring switching between projecting and imaging optical channels [4].

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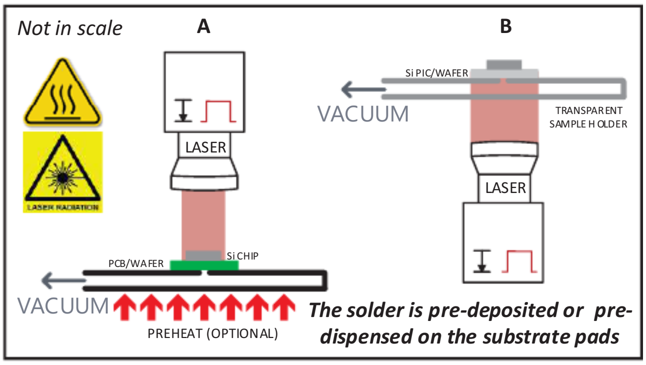

Fig. 1. LAB processes: a – uniform beam profile (top irradiation), b – uniform beam profile (bottom irradiation).

For temperature (t^o) control and feedback, a thermocouple [5] - [6], a pyrometer [7] - [8], or an IR camera (so-called thermal imager) [9] - [11] could be used. Thermal imager allows to control the temperature distribution among several points or the whole bonding surface.

In this work, we introduce the developed LAB setup with a bottom coaxial irradiation architecture [12], combined with through-silicon machine vision system [12], for obtaining an electrical interconnects (bonds) between pads on a silicon PIC, using pre-dispensed solder paste.

II. EXPERIMENTAL SETUP AND METHOD

The experimental setup consists of a through-silicon machine vision system [12], optically combined with LAB 980 nm laser bottom irradiation beam delivery system (Fig. 2). Both systems have common optical path and objective/projector, whereas vision and irradiation optical signals are divided using Wavelength Division Multiplexing (WDM) principle (Fig. 2). This design allows simultaneous observation, alignment, and irradiation of the silicon sample, placed on the custom transparent sample holder [13] during LAB process, which is highly beneficial for scientific and R&D applications. To suppress the environmental noise and vibrations impacts, the sample holder and the setup itself are mounted on a solid rigid basis with the use of properly designed vibration isolation system [14].

The test vehicle consists of a 15x10x0.65 mm silicon PIC [15] - [16] with 100x100 µm *Au*-plated pads, covered with a pre-dispensed type 619D solder paste (Sn62/Pb36/Ag2, metal content 86%, mesh type 3), (Fig. 3). The target temperature of 300^oC was chosen to ensure the melting of solder and the

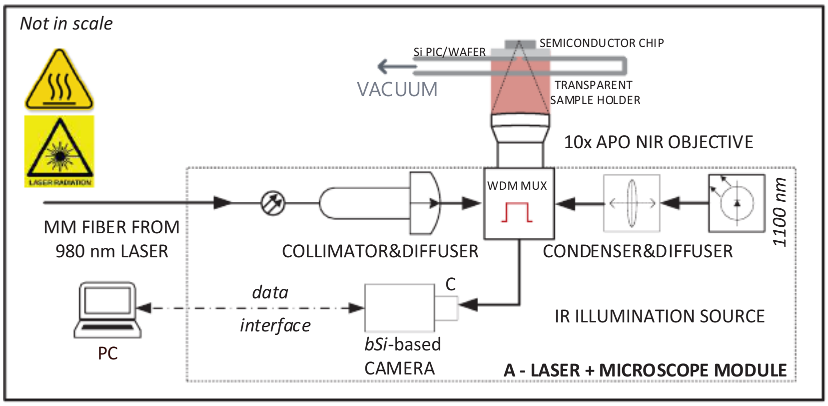

Fig. 2. The proposed design of the developed LAB setup, combined with through-silicon machine vision system [12].

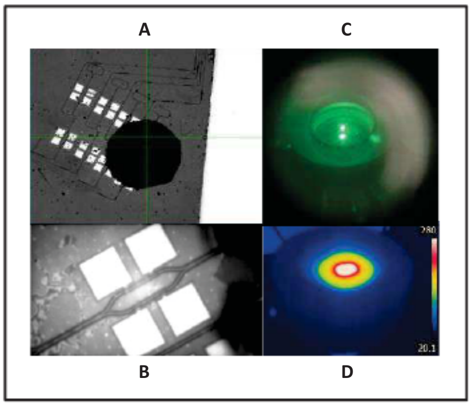

Fig. 3. Test vehicle: A and B – top and bottom through-silicon [12] view of a PIC with dispensed solder paste, respectively; C and D – IR visualizer and thermal imager pictures taken during LAB process, respectively.

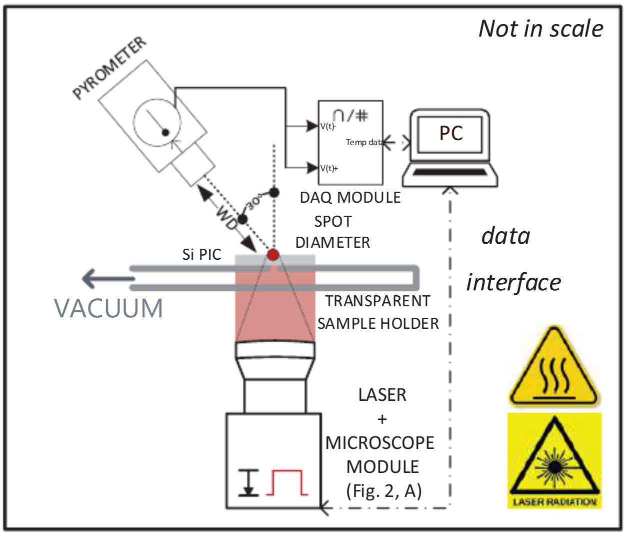

Fig. 4. Simultaneous thermal measurements using the machine-vision based sensor and a pyrometer sensor.

wetting of a bonding surfaces. Depending on an assembly process requirements (e.g., to satisfy *RoHS* directives), a *Pb*-free soldering materials could be used (with necessary temperature adjustments).

Two irradiation modes with the power densities of 110 and 240 W/cm^2 at 980 nm are investigated. A machine vision-based sensor is employed for non-contact temperature control of the silicon substrate. The temperature data obtained using a through-silicon vision system [12] is compared with data obtained with a pyrometer. For the best temporal resolution, the measurements are taken using a power density of 40 W/cm^2. The operation principle of the vision-based temperature control system relies on the transparency vs temperature dependence of silicon, due to which a through-silicon image undergoes darkening with temperature increase; thus, the change in image brightness carries information about temperature change [17] - [19]. For the temperature measurements validation, the setup is equipped with a pyrometer with a 300 mm working distance (WD, Fig. 4).

III. Results And Discussion

The time-temperature diagrams (so-called "shark fins") of a Ø3mm central spot on the PIC top surface and a photo of bonds are given in Fig. 5. Both LAB operation modes resulted in the heating of the PIC above the solder melting temperature, which in turns led to the successful bond formation with electrical impedance in the range of hundredths of an Ohm, which is consistent with the published data [20]. The Pearson correlation coefficient (PCC) of the developed vision-based temperature sensor and pyrometer signals was 0.9522, which demonstrates their high mutual correlation. The vision-based approach to temperature measurements is highly beneficial as a non-contact threshold sensor for *in situ* LAB photonic integration assembly process control.

The results obtained are of great interest for the needs of heterogeneous photonics integration.

IV. Conclusion

The original LAB setup with a coaxial bottom irradiation architecture was developed. The setup allows a rapid and energy-effective process with the ability to produce successful electrical bonds with negligible thermal-induced stress and warpage to bonded surfaces. The proposed machine-vision based temperature sensor is validated for photonic integration assembly processes. The detailed review on LAB in the fields of microelectronics and photonics is presented in [13].

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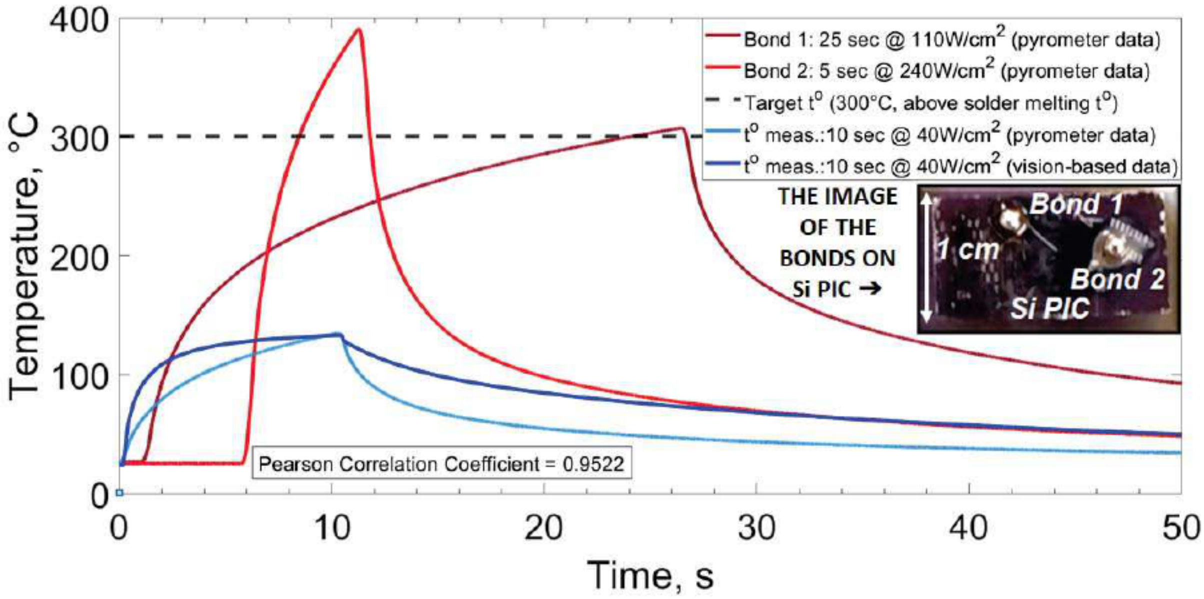

Fig. 5. The LAB processes research results: time-temperature diagrams ("shark fins") and a photo of obtained solder joints (bonds).

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