Next generation Advanced Packaging using innovative laser assisted assembly processes

New key technologies in advanced packaging and interconnection technology like µLEDs, heterogenous integration, cubing, ultra-thin flex, embedded packaging, optical packaging etc. dominate not only the contents of podium discussions at conferences and exhibitions, they also impact the growth projections and analyses of technical rating agencies.

The goal of many companies concerned with chip size packaging (CSP) is to develop and offer process solutions fitting the highly complex demands of these new technologies for an efficient bonding technology.

As a world leader in wafer bumping & advanced packaging including an own machine production, PacTech, since 1995, deals with the development of innovative laser enabled process technologies as well as the provision of the respective machine system solutions.

The main problem in conventional bonding techniques, like the thermo compression bonding (TCB), the thermosonic wire bonding (TS) or the bonding via an oven reflow, lies in the introduction of high thermal loads and in the case of the TCB and TS-Bonding mechanical loads during the bonding process. Common to all of them is the risk for creating mechanical stresses in the bonds as well as the whole package, which can be primarily identified via global and local warpage, positional offsets of the bonding pads, micro cracks in the intermetallic compound layers and delamination effects of the redistribution layer (RDL), as well as bonding fails at the contacts and the contact interfaces to the substrate.

These lead to performance losses, reduced usability and reduced life cycle times of the finished product.

Machine producers undertake great efforts to solve or compensate for this problem via procedural means. For example, many conventional bonders are equipped with heated substrate holders or heated process gases, which on the one hand are to minimize the temperature difference when joining the components and on the other hand should reduce the thermal load using heated active process gases.

These approaches, however, reach their limits when it comes to new material combinations and the ongoing miniaturization. Especially the bonding of ultra-thin organic and inorganic materials paired with simultaneous reduction of the contact pad geometries down to few µm or the bonding of pure metal pads such as Cu on Cu are problematic.

All of the above justifies the call for a thermally and mechanically minimally interactive principle for the bonding process.

As the leading capacity in the area of laser enabled bonding of solder spheres and semiconductor elements, PacTech holds the key to a localized, low stress and selective bonding process by introducing the necessary energy optically via a laser.

The main advantage, apart from interaction times of less than 1s, is that the optical energy can be coupled right into the bonding position by taking the absorption coefficients of the respective elements into account and choosing the optimal wavelength.

This way, thermal loads can be omitted, mechanical stresses avoided and diffusion effects at the interfaces reduced to a minimum, which is paramount in very small bonding pads of less than 1µm as found in opto-electronic packages.

Figure **A1** shows a characteristic laser reflow profile, while figure **A2** shows the respective modulated power density distribution of the laser beam for a force free bonding of a 1.1mm x 1.1mm x 150µm blue light InGaN LED with a 3µm Sn20Au80 solder layer onto a Ag plated Cu lead frame. The bonding takes place within a timeframe of 250ms.

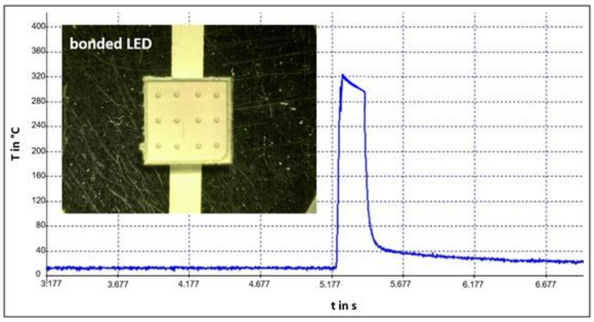

Fig. A1: Laser reflow profile for an LED assembly

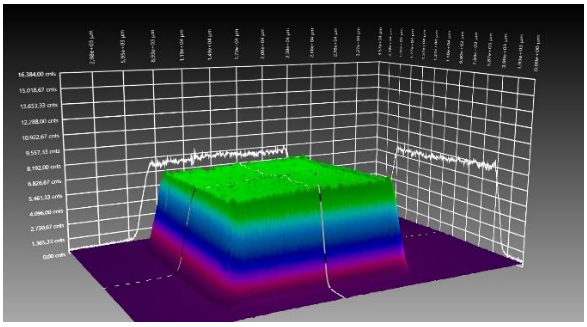

Fig. A2: Laser power distribution for an LED assembly.

This compares to a conventional TCB process, which takes place in a time frame of 8s at 280°C and under a force corresponding to the weight of 1kg.

The carrier substrate is also pre-heated to above 200°C to reduce the losses due to thermal conduction.

The thermal energy is not introduced directly at the bonding interface but conducted through the element to be bonded, which is practically repurposed as a thermode.

The described process parameters and procedures demonstrate the advantages of the optical insertion of energy compared to the conventional thermal conduction through the whole element.

Additionally, a much more beneficial IMC formation can be observed (Figure **A3**). Studies show, that this laser reflow characteristic IMC has higher life cycle times because it experiences lower phase growth.

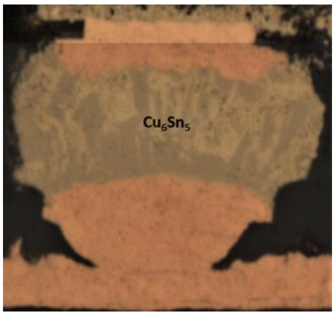

Fig. A3: IMC structure of a 40µm Cu-Pillar LAB bond

These advantages of the thermal and dynamic interaction during the bonding of the laser assisted bonding (LAB) process, paired with the increased life cycle time, find a broad range of applications in PacTech's process portfolio.

Several of the newer applications will be presented in the following sections:

<u>LAPLACE LAdB → Laser Assisted de-Bonding</u>

By reversing the process sequence of our established laser enabled bonding process for microchips (LAPLACE LAB), innovative solutions for removing faulty elements and packages (like SoP, SiP, PoP etc.) could be developed.

The process principle of laser enabled removal (LAPLACE LAdB) of faulty semiconductor elements and packages is sketched in Figure **B1**.

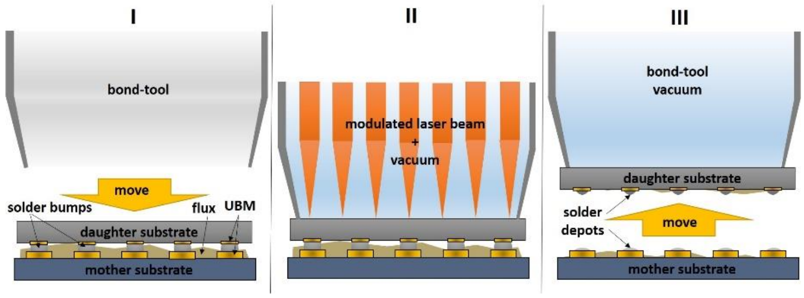

Fig. B1: Process principle of laser enabled removal of faulty elements

To perform the process, one starts by placing the bond tool onto the faulty semiconductor element (daughter substrate) and applying a vacuum inside the tool.

Next, the laser, which is adapted to the package to be processed in its wavelength and power density distribution, is activated and shot at the bonding interface.

Within just a few ms, the solder liquefies and is separated via a vertical axis movement of the bond tool. The instantaneous supply of nitrogen prevents any oxidation during the liquid phase.

The advantages compared to conventional repair solutions, which are based on mechanically abrasive processes like grinding and polishing or thermode processes introducing massive thermal loads, are obvious because the minimally invasive introduction of heat energy damages neither neighboring functional chip layers nor passivation or metallization layers.

Our investigations show, that using flux or special process gases, the residual solder assumes a quality, which allows for the direct bonding of a new chip (Figure **B2**).

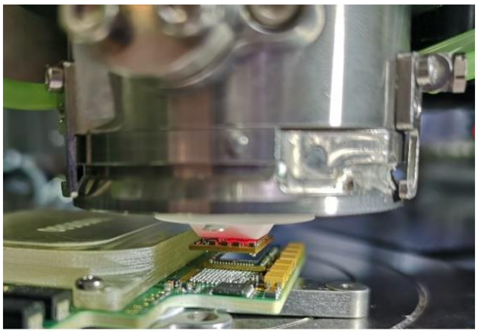

Fig. B2: Removal of a faulty PoP via LAPLACE LAdB

Using PacTech's technology even chips with a Cu-Pillar interface can be repaired up to four times before a deviation in quality, reliability and life cycle is to be expected.

Figure **B3** shows the residual solder on the flex board of a chip on board application with 40µm Cu pillar bonds.

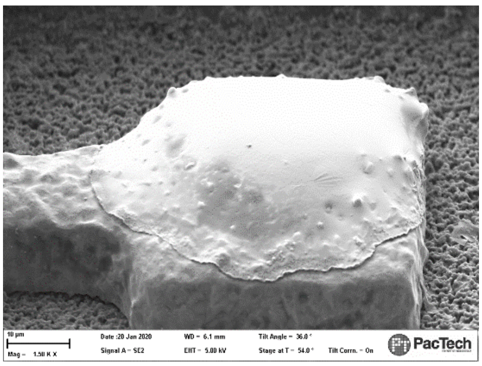

Fig. B3: Residual solder on a 40µm contact pad

This also requires a sufficient precision of the bond system. PacTech offers, among other systems, the multi-functional bond platform LAPLACE "Genesis", which reaches positioning accuracies in the sub-µm regime using a combination of highly precise axis systems, a unique recognition mechanism and a nano positioning system (Figure **B4**).

Fig. B4: LAPLACE-GENESIS bond platform

SB²-WB → Laser Soldered Wire Bonding

All conventional wire bond processes like thermosonic (TS), ultrasonic (US) or thermo compression (TC) bonding have the introduction of strong mechanical forces (30-90cN) or large thermal loads (100°C-250°C) at the bonding interface in common.

Applications on brittle materials such as GaAs, PZT-ceramics, organic thin films (<20µm) like an MCM-D-type package or vibration sensitive pins cannot be equipped with a conventional wire bond in a reliable and reproducible manner.

Additionally, the material structure of the wire is being transformed during the electric flame off (EFO) or the ultrasonic welding.

A characteristic property of this is the so called "neck-break" failure mode on wire pull tests.

To overcome this problem, PacTech developed the SB²-WB wire bond process. At the core of this innovative solution for the creation of alternative low stress wire bonds on the chip level or substrate level sits a combination of the unique SB²-Jet solder jetting principle with a wire feeding unit.

The simplified working principle is illustrated in Figure **C1**.

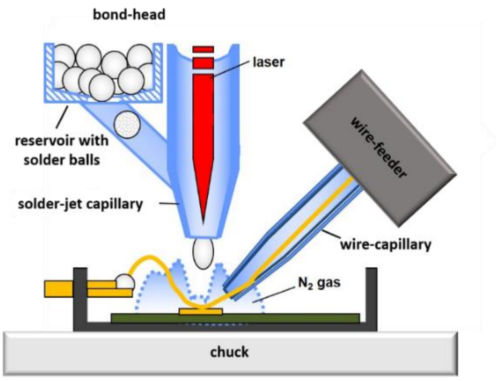

Fig. C1: Principle of the SB²-WB process

The wire is fed onto the contact pad underneath the solder jet capillary. Almost simultaneously to the feeding and positioning of the wire, a molten solder sphere is applied to the wire. Compared to competing processes, this process can be regarded as mechanically contactless as the force created by the solder lies in the µN regime.

The bonding process itself happens within a time regime of less than 10ms as it is performed using laser. Next, the wire is pulled over to the corresponding contact, forming a loop if needed, and bonded using a solder ball analogous to the first contact. Finally, the wire is cut using a blade, pulling force or well-proportioned laser pulse. Alternatively, to the conventional processes, the wire can be continued to further contact pads and bonded to them without intermission or change to the wire profile.

An example for an application is shown in Figure **C2**, the wire bond is realized between vibrationally sensitive pins and a LTTC carrier substrate.

Fig. C2: SB²-WB wire bonds in a plug module

Figure **C3**, shows a lateral SB²-WB wire bond on a sensor housing.

Fig. C3: SB²-WB wire bond on a sensor housing

The SB²-WB process allows for the formation of the typical loop forms in the bond wire. Another advantage is, that the SB²-WB process can be geometrically tailored such that the wire exits the solder bond in a direct lateral fashion without any vertical component. Thus, the height of this variant is lower than that of ultra-low loop (ULL) or stand-off stitch bond (SSB) solutions in conventional wire bonding processes.

Our studies show that the expected stability and life cycle durations match or even exceed those of conventional wire bonding techniques for soft solders and in dependence of the chosen wire diameter and solder sphere volume.

For example, performing a current load capability test a more advantageous heat distribution could be identified (Figure **C4**).

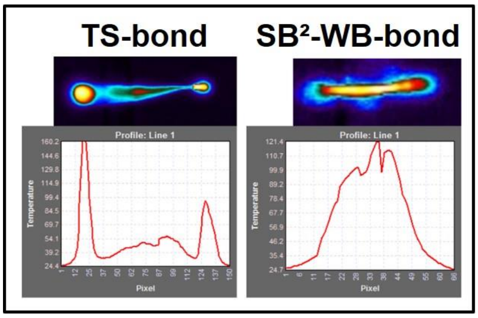

Fig. C4: Optical temperature measurement under current load (FHG-ENAS)

The above result is mainly caused by the advantageous property of the SB²-WB process of not changing the material structure of the wire through thermo mechanical effects.

Another advantage lies in the simple repairability of faulty contacts, as these can easily be de- and rebonded.

Because of the intermetallic compounds, which are characteristic for the short laser reflow, this process can be repeated several times without a loss in performance arising.

The newly developed SB²-WB process can process and bond wires in the range of 15µm-500µm. The smallest processable pitch lies around 40µm. All common solderable wire materials can be processed reliably with a speed of up to 6 bonds per second.

<u>SB²-Jet Macro Solder Ball Bumping</u>

The classic area of placement technology of wired elements via through hole technology (THT) also calls for alternative solutions to overcome the technical disadvantages of wave, selective and hand soldering for future generations of circuit boards for certain applications.

PacTech focuses on the omission of flux and the resulting reduction of subsequent cleaning steps as well as the bonding of smaller wire distances resulting in higher package densities and the soldering of hardly accessible contacts.

This is why PacTech has broadened its spectrum of processable solder ball sizes of 30µm-760µm and now offers support for sizes of up to 2000µm to serve the volume needs of the through hole technology assembly.

The overall process principle of the SB²-Jet process stays the same even with these very large solder balls (Figure **D1**).

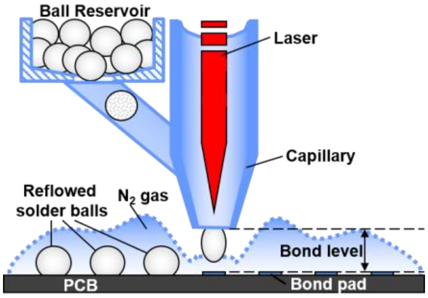

Fig. D1: Principle of the SB²-Jet process

The solder spheres are singulated in a specialized bond head and enter a capillary. The diameter of the capillary’s lower opening is smaller than that of the solder ball, which forces the ball to a halt at the tip of the capillary.

Via a laser pulse, the solder ball is molten and applied to the bond contact by nitrogen pressure. Upon arrival on the contact pad, the solder assumes a spherical shape (solder bump) again, due to its surface tension.

The advantageous process characteristic is conserved unconditionally even in very large solder ball sizes. The local, selective and flux free bonding from a distance of up to five times the solder ball diameter provides manufacturers of circuit board based products with new perspectives.

For example, the bonding can take place deep inside a casing or at a moment in time, when further cleaning steps are already prohibited.

Figure **D2** shows an example for an application on a LTCC carrier for a head light module.

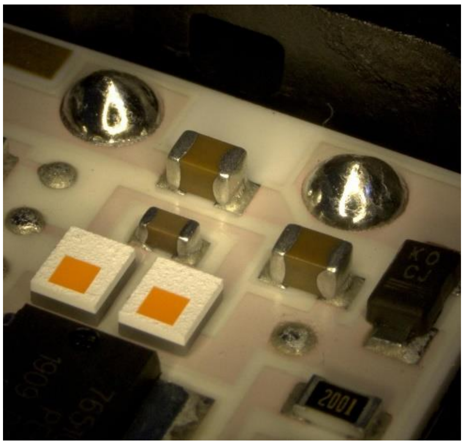

Fig. D2: THT contact pin soldering in the casing of a head light module

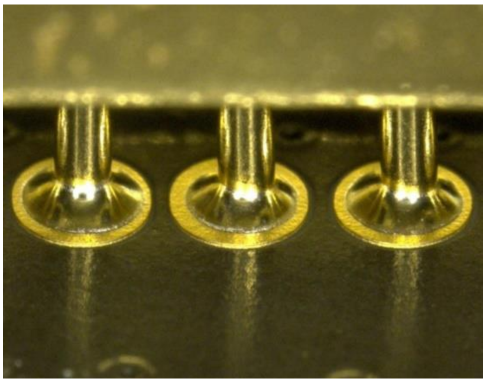

Fig. D3: THT plug casing contacting through circuit board

Again, PacTech offers a broad spectrum of machine solutions. Figure D4 shows an exemplary available machine platform.

Fig. D4: SB²-Jet dual bonder

Inside the system either several universal 3D axis systems or PacTech's robotic solution with a bond head effector can be integrated. The system contains a loading, transfer and unloading unit to allow for a fully automated operation. Universal interfaces for data communication, RFID or code reader come as part of the standard.

In conclusion, PacTech's state-of-the-art laser-assisted bonding/de-bonding technologies offer compelling benefits in the form of low optical interaction times (<1s), topical/local interaction with ultra-high precision (µm), high-quality IMCs, and ultra-low thermal and mechanical stresses (µN). A wide range of solder sphere (wire) sizes and compositions could be used. In addition to robust processes and specialized machine systems outlined above for solder- and wire-bonding applications, PacTech offers a multitude of other innovative and alternate solutions (e.g. cantilever, capacitor, LED) tailored for each respective application to fulfill complex demands while simultaneously offering high productivity and yield. PacTech strives to be at the forefront of offering agile solutions for sophisticated problems in relation to applications involving flip-chips, probe cards, MOSFETs, diodes, µLEDs, RF, etc. Our goal is to actively shape the bonding technologies of tomorrow and beyond.

About PacTech

Pac Tech – Packaging Technologies GmbH is a world leading provider of advanced wafer bumping, packaging and solder ball placement equipment. As an innovator in the area of Laser Assisted Solder Jetting and Laser Chip Bonding, PacTech provides high accuracy high speed high flexibility solder bonding solutions for semiconductors and additional electronic components, alongside with its unique turnkey solution for wafer level electroless plating including process, equipment and chemical supplies from a single source.

For more than 25 years and with great success, PacTech supports besides equipment manufacturing, subcontracting services for high volume production and engineering projects on wafer, substrate and chip level at the sites in Germany, the U.S. & Malaysia with by now nearly 400 employees.

From electroless Ni/Au or Ni/Pd Under Bump Metallization (UBM) for Flip Chip or WLCSP, electroless Ni/Pd/Au OPM for Au or Cu wire bonding, electroplated Cu Pillars, solder balling via Single Jetting (SB^2), Ball Drop Stencil Technology (Ultra-SB^2) and wire soldering to a multitude of back-end services, PacTech provides a broad range of highly specialized technology solutions.

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