

## Laser Solder Attach for Optoelectronics Packages

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### Abstract

The packaging of optoelectronics and MEMS devices is placing challenging requirements for the interconnection and soldering technology. These requirements can no longer be met with standard flux-based processes which use a long temperature reflow profile and are implementing a lot of mechanical handling steps and processes. Basically, the packaging of these new devices is requiring *fluxless soldering*, no thermal stress by localized heating, low respectively *no mechanical contact* and damage on sensitive membranes in MEMS or optical components (like lenses, etc.). Some of these applications even require 3D-packaging and *selective solder application in 3D-structures*, like cavity, vertical assembly, etc. An additional, very challenging requirement is a *high flexibility in solder alloys* because eutectic tin lead and other lead-based solder alloys are not applicable. Instead Gold/Tin and Indium-based solder alloys are required.

In order to fulfill the specific needs in these applications, a new laser-based solder jetting technology has been developed. This technology fulfills all the needs of fluxless soldering, local heating and reflow, no mechanical contact and stress during soldering, high solder alloy flexibility and capability of 3D-packaging. Prior to developing the **S**older **B**all **B**umper Jet (SB<sup>2</sup>-Jet) process, many potential applications have been elaborated using the **S**older **B**all **B**umping (SB<sup>2</sup>)-technology. The advantage of SB<sup>2</sup>-Jet is basically the higher throughput which the jet process. With a throughput of 10 balls/s, it fulfills most of the requirements for today's packaging of optoelectronics and MEMS devices in production. A further increase in speed to 20 and 30 balls/s is in progress for the next generation. An additional feature of the SB<sup>2</sup> and SB<sup>2</sup>-Jet-technology is the repair option and repair capability. This permits individual removal and replacement of solder balls and solder contacts and allows to increase the yield and productivity of cost-intensive high end devices.

### I. Introduction

The use of lasers for soldering/microwelding is offering technological many advantages compared to the standard oven reflow or thermode soldering/ bonding methods. The advantages by the use of lasers in the laser physics which offers the possibility of localized heat and short laser

pulses. Localized heat means that no or minimal thermal stresses applied on the area outside of the bonding interface.

A short pulse means that a low thermal stress is applied on chip and substrate, respectively on the interconnections because the amount of thermal energy provided in one laser pulse is transferred in

a short periode of time. By laser, the heat is localized and the temperature can be applied selectively in the interconnection areas. It is not necessary to heat up a whole substrate to a reflow temperature in order to melt and reflow a small interconnection of a few Micron.

The technical advantages deducted from the use of laser physics is one side the compatibility with soldering and adhesive processes for flip chip attach. Laser can be used for both – soldering, but also adhesive curing. This allows shorter soldering times and shorter adhesive curing times, significantly below than one second.

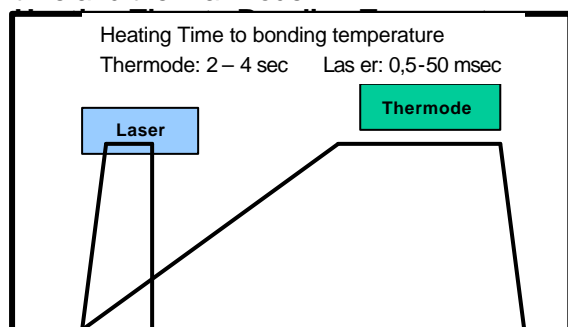
Laser soldering and interconnection technology can also be applied for flip chip and resistor attach, as well as for solder attach. Lasers permit a high flexibility on substrate selections, especially allow bonding and soldering on low cost  $T_G$ -substrates which can be organic or anorganic material, ridgid or flexible material.

In comparison of the soldering times and soldering temperatures between SMT – oven reflow, thermode reflow and laser soldering is given in **table 1**.

FLIP CHIP ASSEMBLY PROCESSES		
•Soldering processes		
•SMT/ reflow	230-250 °C	60-180 sec (min)
• Thermode	250-300 °C	1-10 sec (sec)
•Laser soldering	250-300 °C	0.01-0.2 sec (ms)

**Table 1**

**Figure 1** shows the schematics of the pulse time and thermal mode.



**Figure1: Thermode Bonding vs. Laser Bonding**

The available technologies for solder bumping are based on vapor deposition, electroplating, stencil printing and ball placement. For cost reasons, the main technologies applied in packaging of flip chip devices are electroplating and wafer level printing.

The evaporation technology based on C4 is still in use in high end devices, however, for cost-driven applications it is too expensive.

Electroplating is requiring a lot of costly equipment, like sputtering, mask aligner, special cup-platers for individual wafer plating and reflow oven. The solder printing process requires a lower capital cost, basically stencil printing equipment, reflow oven and flux cleaning equipment.

On the other hand, the SB<sup>2</sup>-Jet is requiring only one system: the ball placement and jet system. No additional reflow oven is necessary because the laser is used internally for the local reflow. The special features of the three technologies regarding tooling requirements and flexibility, flux requirements, capital cost, total equipment list, local reflow capability, mechanical contact, 3D-packaging and solder alloy flexibility are summarized in **Table 2**.

These data show that the SB<sup>2</sup>-Jet technology can fulfill some very unique needs for the optoelectronics and MEMS packaging.

The throughput of the processes is very high for the stencil printing process, high for electroplating. For the SB<sup>2</sup>-Jet, the throughput is medium and is depending on the number of bumps per wafer. However, for the applications in MEMS and optoelectronics, the needs of the productivity requirements combined with the total cost of the equipment and cost of ownership, can easily be met.

	Electroplating	Stencil Printing	SB <sup>2</sup> -Jet
<b>Tooling Requirement</b>	Mask	Stencil	None
<b>Capital Cost</b>	Very high	Medium	Low
<b>Equipment</b>	1. Sputtering 2. Mask aligner 3. Plating tool 4. Reflow oven	1. Printer 2. Reflow oven 3. Flux cleaning	1.a. SB <sup>2</sup> -SM or 1.b. SB <sup>2</sup> -Jet
<b>Throughput</b>	High	Very high	Medium
<b>Flux</b>	No	Yes	No
<b>Local Reflow</b>	No	No	Yes
<b>Mechanical Contact</b>	Yes	Yes	No
<b>3D-Packaging</b>	No	No	Yes
<b>Solder Alloy Flexibility</b>	Low	Medium	High

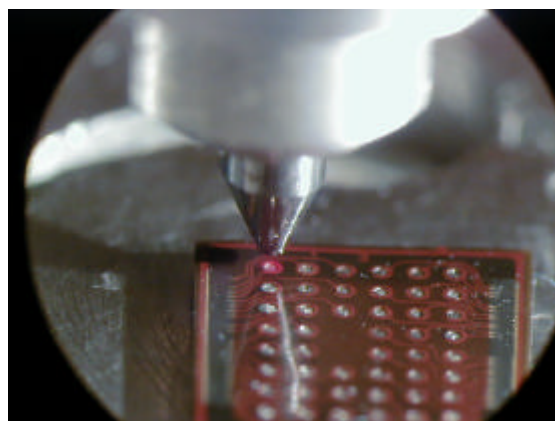
**Table 2: Special Features of the three Technologies**

## II. System Concept for the SB<sup>2</sup>-Jet

**Figure 2** shows the new developed SB<sup>2</sup>-Jet machine. **Figure 3** shows the principle of the jet solder ball singulation and laser reflow. In contrast to the conventional jet machines, the Laser Jet is using preformed solder balls which are singulated and jetted via a capillary onto the substrate. The singulation process is very fast and guarantees a designed shape of the solder balls. Solder ball diameters from 80  $\mu\text{m}$  up to 760  $\mu\text{m}$  can be achieved.

During the jetting process, the solder ball is melted via a laser which is integrated in the bond head of the system. With this laser energy, the solder ball has sufficient thermal energy in order to wet the substrate and to provide an intermetallic good interface. Corresponding shear forces as a function of different laser powers are shown in **Figure3**.

At the optimal set of laser parameter, the intermetallic contact between the solder ball and the substrate can be: Wafer PCB with bumps/pads as wettable metallization: Copper, Nickel/ Gold or others). As criterion for shear test with SB<sup>2</sup>-Jet, 100% shear in the solder ball is only acceptable.



**Figure2: Photo of the SB<sup>2</sup>-Jet System**

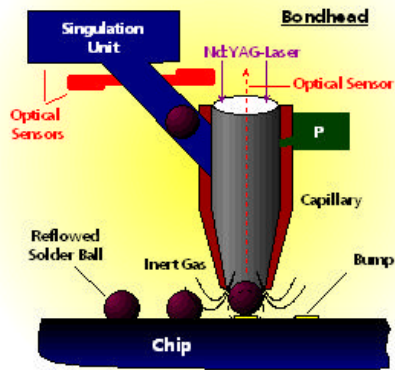


Figure 3: Principle of SB<sup>2</sup>-Jet Operation

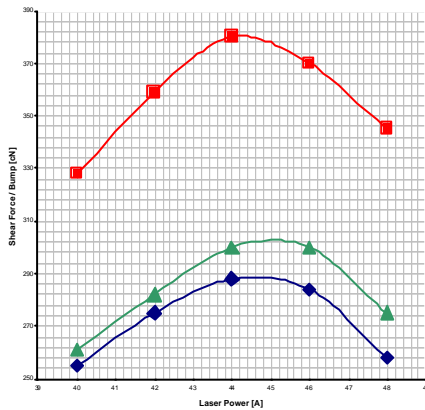


Figure 4a: Shear Force/Bump  
 Solder Ball Diameter: 300µm  
 Average Shearforce, 368g, standard dev. = 16,8 g  
 Cpk: 2,33 Solder Ball diameter: 300µm  
 Solder Alloy – Eutectic SnPb 63/37  
 Fracture Mode: Solder Shear

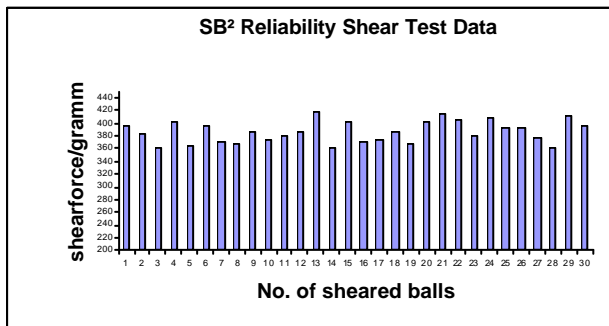


Figure 4b: Shear Force Distribution

Figure 5 shows the shear mode for an optimal bond diameter. In this case, the solder ball parameter was 300 µm for an optoelectronic CSP application.

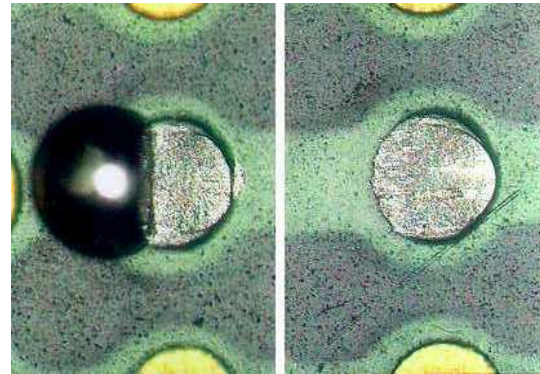


Figure 5: Shear Mode-100% Balls  
 Shear with Optimal Parameters

Figure 6 shows a cross section of the corresponding interconnection between solder ball and CSP pad. The ideal wettability is evident and corresponds to the shear mode shown prior.

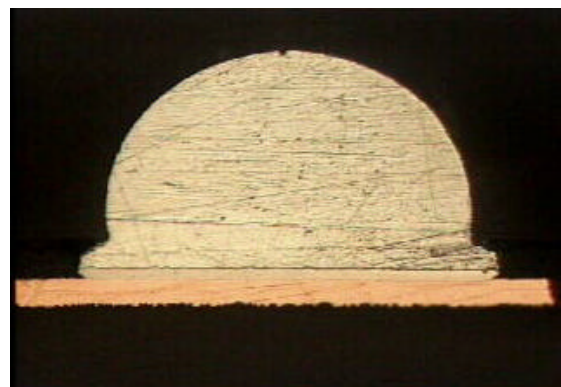
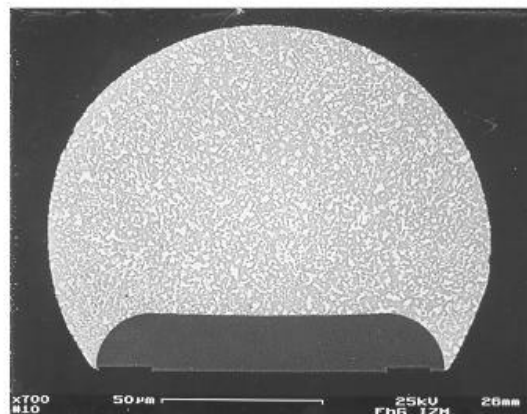


Figure 6: SB<sup>2</sup>-Jet Wettability

**Figure 7** shows a cross section of a flip chip application on an electroless NiAu UBM. It is evident also in this cross section that the intermetallic soldering contact is ideal. Also evident is the very low thickness of the intermetallic compounds formed during the very short laser solder pulse.

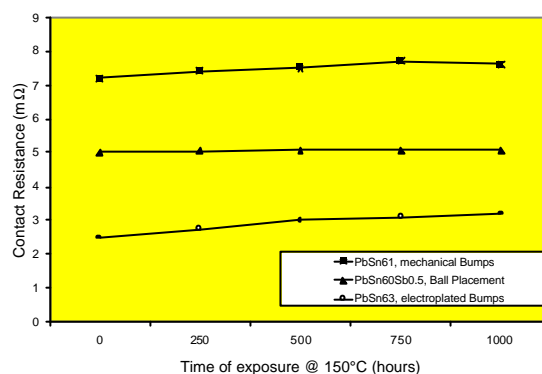
The fact that the thickness of intermetallics is significantly smaller compared to contacts made by oven reflow, it indicates that the thermal stress during the laser solder jet process is significantly smaller compared to a reflow process.



**Figure 7: Cross Section of Flip Chip Solder Bump**

**Figure 8** shows a comparison in the contact resistance between electroplated bumps and bumps made by laser solder ball jet, respectively bumps made by mechanical stud bumping.

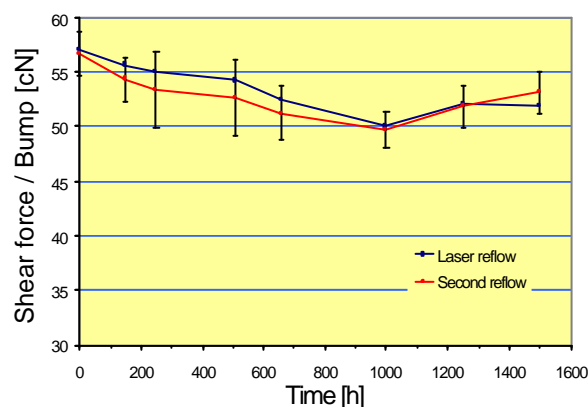
The contact resistance of solder balls for flip chip on electroless NiAu UBM is with 5 mOhms in a very good range.



**Figure8:Comparison of Contact Resistance between different Solder Bumps**

The shear strength of laser solder balls during thermal temperature storage is shown in **Figure 9**. This also gives evidence that the solder joint is reliable, even with two laser reflows. The degradation in shear test is due to the recrystallization of the solder and the grain modifications in the eutectic tinlead solder. No degradation at the interface between the solder joint and the substrate is detected.

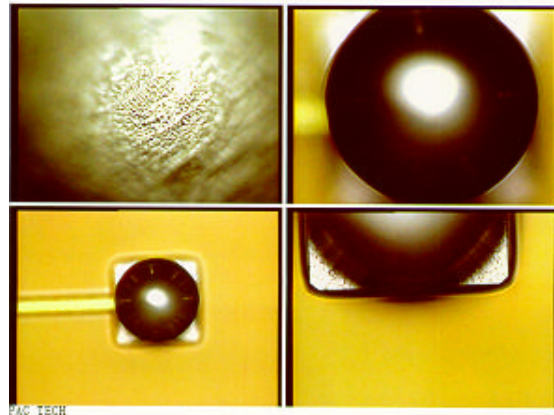
The SB<sup>2</sup>-Jet system is very well suitable for leadfree soldering based on SnAg, SnCu or SnAgCu as well as for eutectic AuSn solder bumping.



**Figure 9: Shear Strength of Solder Balls during Temperature Storage**

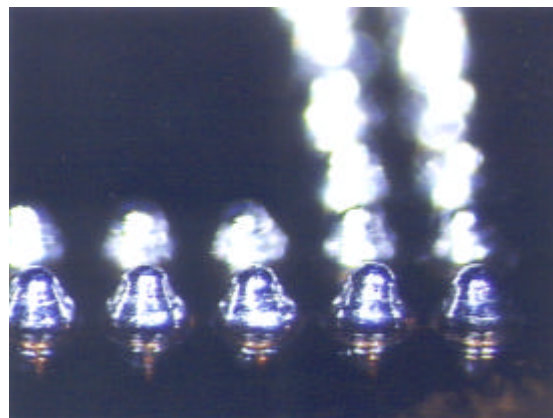
**Figure 10** shows shear mode of leadfree SnAgCu solder.

The solder jetting technology can be applied for 3D-packages with a cavity, but also for 3D-interconnection.



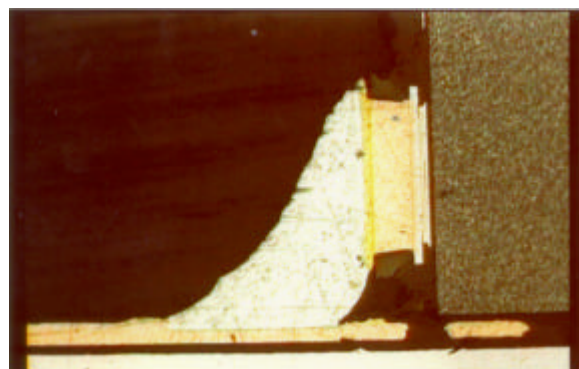
**Figure 10: Leadfree Solder Bumping, SnAgCu**

A special feature of the SB<sup>2</sup>- and SB<sup>2</sup>-Jet process is the possibility to stacked solder balls in order to achieve a higher stand-off as shown in **Figure 11**

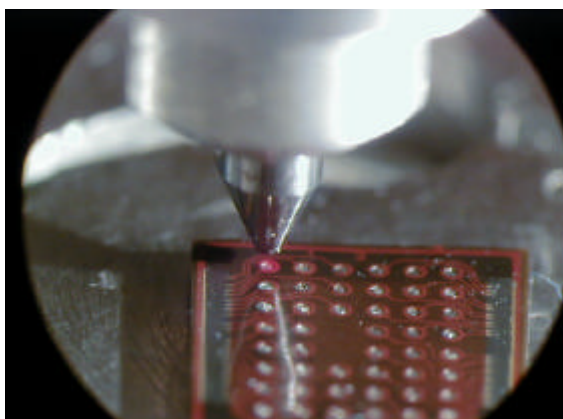


**Figure 11: Stacked CSP Ball Attachment**

**Figure 12** shows a cross section of a 3D-interconnection between a vertical sensor chip and a horizontal sensor substrate.



**Figure 12a: 3 Dimensional MEMS-Packaging**





**Figure 12b: 3D – MEMS Packaging using AuSn 80/ 20 Solder Balls**

### III. Summary

The technological feasibility of the SB<sup>2</sup>-Jet was demonstrated. In methodical investigations, the shear forces and the interfaces were studied and a reliable interconnection was achieved for a wide field of applications, including high lead solders, eutectic tinlead solder, leadfree solder alloys, based on SnAgCu and AuSn solders. An overview of possible applications and future use of this new technology is presented in **Table 2**.

The applicability to a high variety of pad metallizations and substrate types has been demonstrated.

Additional specific use of the SB<sup>2</sup>-Jet technology for 3D-packaging and fluxless optoelectronics packages could be shown.

SB <sup>2</sup> - Applications			
Research	Production		
Fast Prototyping	Rework/ Repair	• „MEMS“ Packaging	• Optoelectronic Packaging
Wafer Bumping	Wafer Bumping		
BGA/ CSP	CSP/ BGA		
Optoelectronic Packaging			
„MEMS“ Packaging			
<b>Advantages</b>			
<ul style="list-style-type: none"> <li>• No tooling</li> <li>• No flux</li> <li>• No mechanical stress/ contact</li> <li>• No thermal stress</li> <li>• 3D - assembly</li> </ul>		<ul style="list-style-type: none"> <li>• HDD</li> <li>• 3D Packaging</li> </ul>	

**Table 3 : SB<sup>2</sup> - Applications**

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