

# Placement and reflow of solder balls for FC, BGA, Wafer-Level-CSP, Optoelectronic Components and MEMS by using a new solder jetting method

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## Abstract

Today the requirements for the packaging of optoelectronics and MEMS devices 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 requires *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 SnPb and other lead-based solder alloys are not applicable. Instead AuSn 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 **Solder Ball Bumper Jet (SB<sup>2</sup>-Jet)** process, many potential applications have been elaborated using the **Solder Ball Bumping (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 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 1.

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.

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

Figure 1a shows the new developed SB<sup>2</sup>-Jet Machine, in figure 1b a system with a smaller working area and a Low Footprint, can be seen (SB<sup>2</sup>-Jet LF). Figure 2 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 balls from 80µm up to 760µm can be placed.

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.

	<b>Electroplating</b>	<b>Stencil Printing</b>	<b>SB<sup>2</sup>-Jet</b>
<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 1: Comparison of different Technologies

Corresponding shear forces as a function of different laser powers are shown in Figure 3.

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.



Figure 1a: SB<sup>2</sup>-Jet



Figure 1b: SB<sup>2</sup>-Jet LF

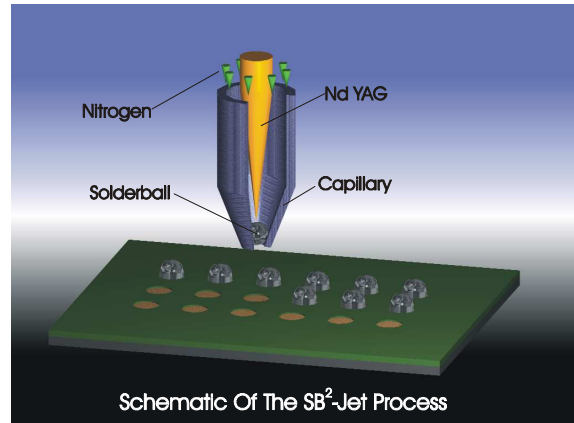


Figure 2: Principle of SB<sup>2</sup>-Jet Operation

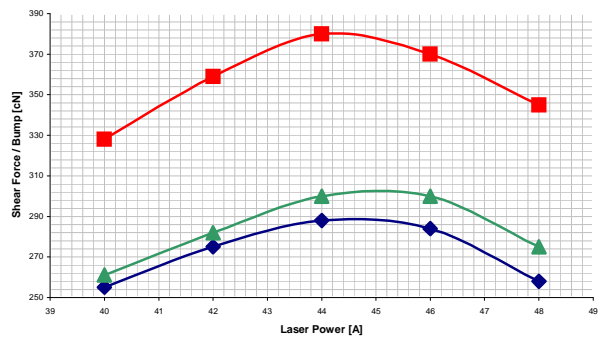


Figure 3: Shear Strength versus Laser Energy – Solder Ball Diameter: 300µm

Figure 4 shows the shear mode for an optimal bond diameter. In this case, the solder ball parameter was 300 µm for an optoelectronic CSP application

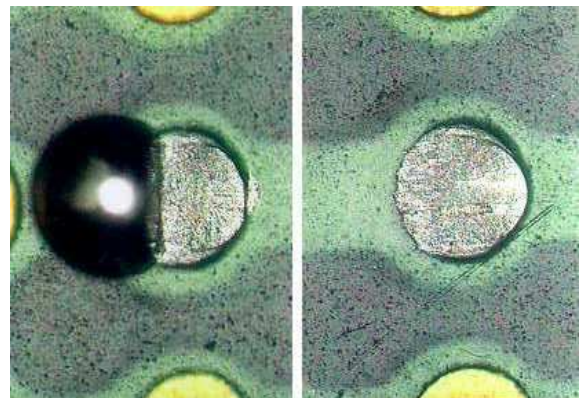


Figure 4: Shear Mode-100% Balls Shear with Optimal Parameters

Figure 5 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.

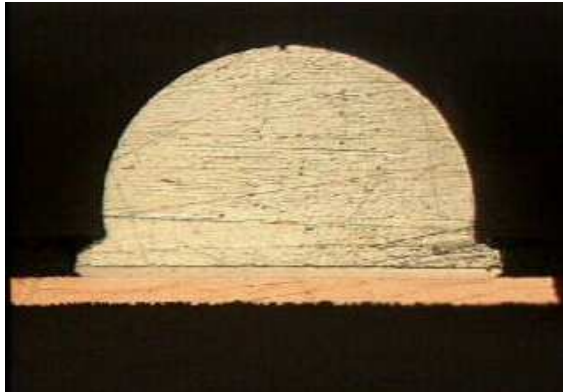


Figure 5: SB<sup>2</sup>-Jet Wettability

Figure 6 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.

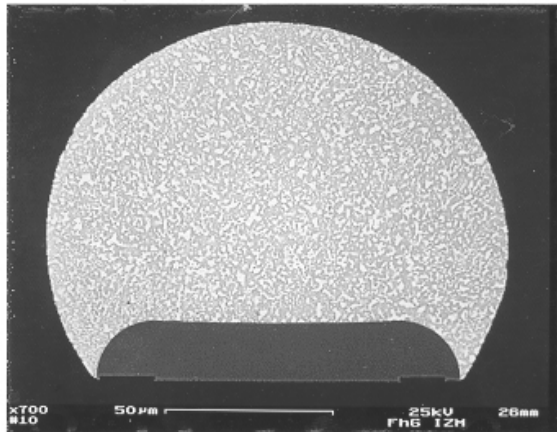


Figure 6: Cross Section of Flip Chip Solder Bump

Figure 7 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.

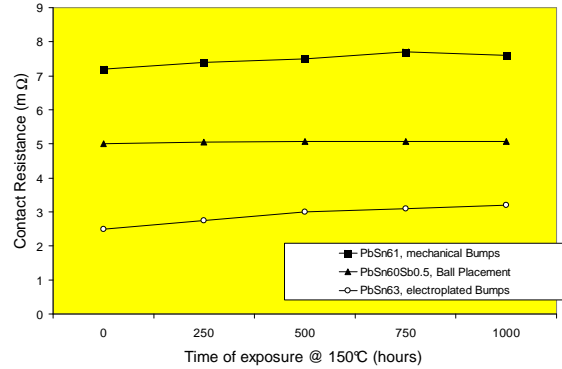


Figure 7: Comparison of Contact Resistance between different Solder Bumps

The shear strength of laser solder balls during thermal temperature storage is shown in Figure 8. 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.

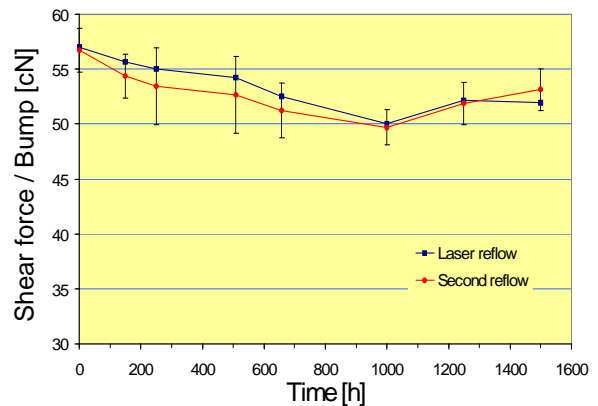


Figure 8: Shear Strength of Solder Balls during Temperature Storage

The SB<sup>2</sup>-Jet system is very well suitable for leadfree soldering and for eutectic AuSn solder bumping.

Figure 9 shows shear mode of leadfree SnAgCu solder, like CSP's with optical interfaces.

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

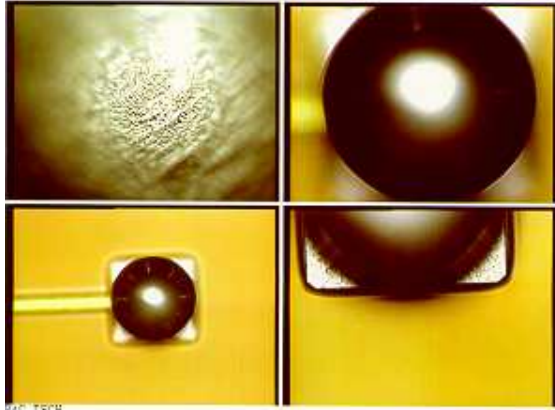


Figure 9: Leadfree Solder Bumping, SnAgCu

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 10 with 200µm Sn63Pb37 on top of 300µm Sn10Pb90 solder balls.

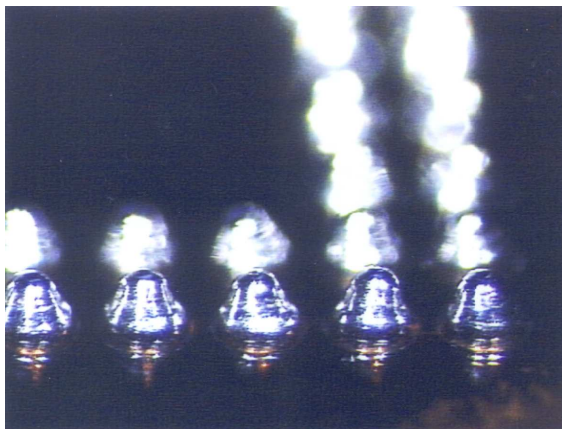


Figure 10: Stacked CSP Ball Attachment

Figure 11 shows a cross section of a 3D-interconnection between a vertical sensor chip and a horizontal sensor substrate.

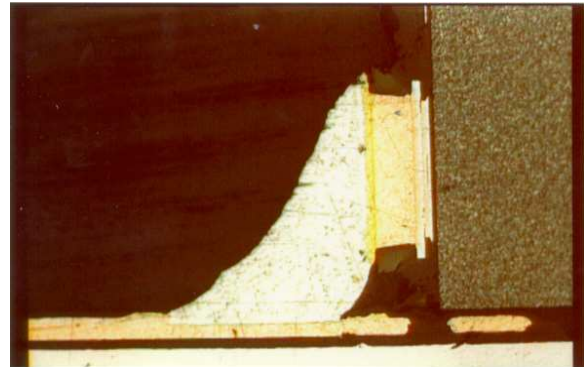


Figure 11: 3-Dimensional MEMS-Packaging

### 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 SnPb 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.

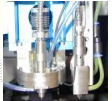
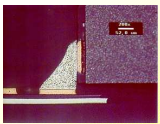
SB <sup>2</sup> - Applications		
Research	Production	
Fast Prototyping	Rework/ Repair	<ul style="list-style-type: none"> <li>• „MEMS“ Packaging</li> <li>• Optoelectronic Packaging</li> </ul> 
Wafer Bumping	Wafer Bumping	
BGA/ CSP	CSP/ BGA	
Optoelectronic Packaging	„MEMS“ Packaging	
<b>Advantages</b>		<ul style="list-style-type: none"> <li>• HDD</li> <li>• 3D Packaging</li> </ul>
<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>		

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

## References

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