Vacuum Soldering Technologies – Many Facets with a Single Goal

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1 Introduction

Where the soldering of electronic PCBs is concerned, the use of vacuum is focused primarily on removing volatile substances from the solder joints and the associated reduction of voids. Reasons for this include increasingly strict requirements with regard to the quality and reliability of electronic products, as well as higher current densities (e.g. in power modules) and the larger power losses resulting therefrom. Some modules have already reached power loss levels of greater than 200 W per square cm. Voids are highly obstructive for heat dissipation and are thus undesirable in power applications.

Voids are gas bubbles which occur due to outgassing from, for example, flux residues and by-products of chemical interactions. Experience gained during the course of process development has shown that underpressure of less than 50 mbar in proximity to the molten solder is sufficient for a significant reduction in the number of voids.

Figure 1 shows high-brightness LED solder joints after soldering without vacuum. A comparison of the two images makes it plainly apparent that with a vacuum of 10 mbar the number of pores and their surface area has been drastically minimized. In the event of solder joints with large surface areas, as is the case for instance with LEDs, QFNs and Si chips, a smaller number of voids results in improved thermal performance as well as less tilting of the component.

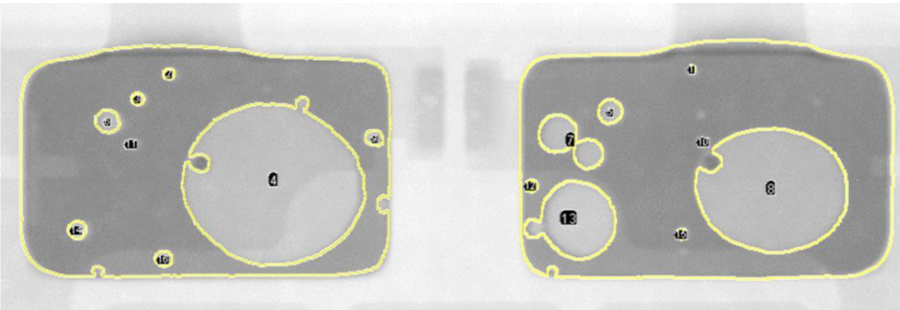
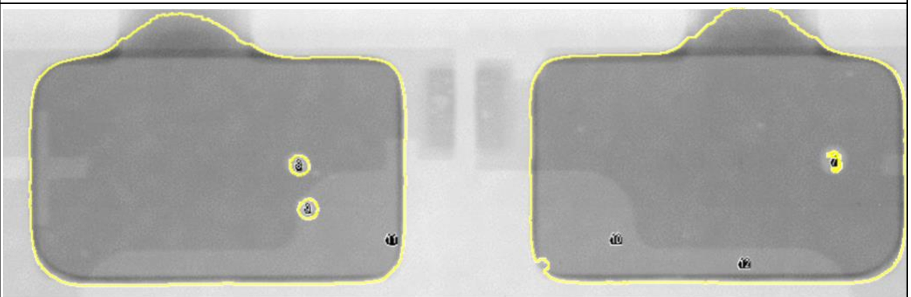
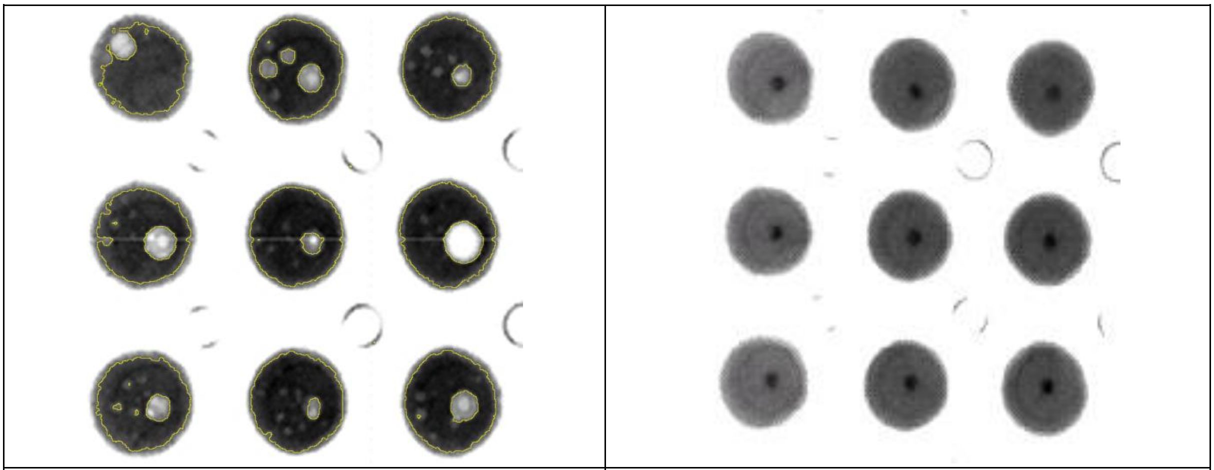
(a) Without vacuum Void surface area ~28% Number of voids: 21	
(b) With10 mbar vacuum Void surface area < 1% Number of voids: 6	

Figure 1: X-Ray Penetration Images of High-Brightness-LED Solder Joints after Soldering Without Vacuum (a) and With 10 mbar Vacuum (b)

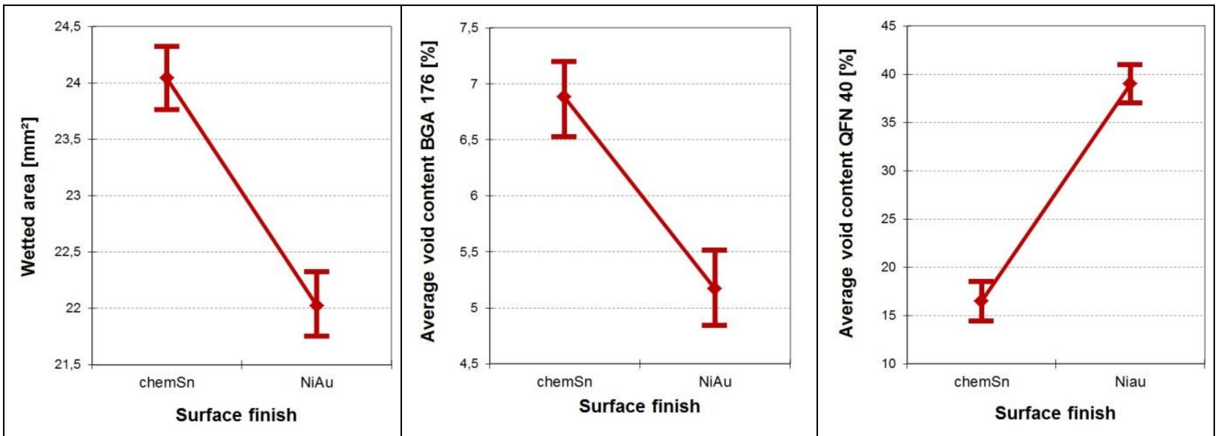


(a) (b)

Figure 2: X-Ray Penetration Images of BGA256 Solder Joints after Soldering Without Vacuum (a) and With Vacuum (b)

The permissible surface area portion occupied by voids in solder joints for ball grid arrays (BGAs) is the focal point of many research activities. Generally speaking, voids do not have any significant effect on the reliability of solder joints. This point is also made in various standards, for example IPC-A-610E: “25% or less voiding of any ball in the x-ray image area”. Figure 2 shows comparative X-rays of the solder joints of a BGA256 after soldering without vacuum and with vacuum. The use of vacuum soldering demonstrates a distinctly reduced void ratio in the case of microvias in the BGA pads as well, which may lead to the increased formation of voids for design-related reasons and which are excluded from the 25% rule.

Conflicting interactions are one of the essential reasons for the fact that process and material optimizations targeted at reducing the formation of voids result in local improvement only (e.g. pertinent to only one type of component). As shown in Figure 3, improved wetting of the immersion tin surface causes an increase in the void content of the BGA, as opposed to a reduction in the void content of the QFN. The two types of solder joints differ from each other in particular with regard to their geometry and the surface area to volume ratio before and after soldering.



(a) Solder Spreading (b) BGA176 (c) QFN40

Figure 3: Wetting Characteristics of a Solder Paste (a) and the Contrasting Effects of this Solder Paste with regard to the Formation of Voids in the Solder Joints of a BGA176 (b) and a QFN40 (c) on Immersion Sn and NiAu Surface Layers [1]

Research results obtained thus far lead to the essential conclusion that void formation mechanisms depend on many factors and that any lasting reduction of voids in solder joints can only be achieved with the help of a vacuum process. In addition to its primary objective of reducing voids, the use of vacuum also offers other advantages which depend decisively on the technology of the utilized system. The contact, vapor phase and convection soldering processes will be discussed comparatively in the following pages.

2 Contact Soldering with Vacuum

System Technology

Innovative inline vacuum soldering systems, such as budatec's VS320i shown in Figure 4, offer high levels of flexibility in the soldering process. Up to 6 chambers arranged in series can be automatically loaded and unloaded. In this way, various cleaning and soldering processes can be run simultaneously within a single system. A continuous process sequence can be implemented by buffering workpiece carriers despite synchronization. The fact that the heating, cooling and vacuum process steps take place in the same process chamber without having to move the goods to be soldered in the molten phase is a big advantage of this system concept. Processes are possible with lot sizes of down to 1 piece.

Figure 4: VS320i Automated Contact Soldering System with Vacuum for Inline Operation
Source: budatec GmbH

Profiling

Figure 5 depicts a reflow soldering profile with two vacuum process steps. The option of making special atmospheres like hydrogen or formic acid available predestines these systems for flux-free soldering with preforms. The characteristic pressure curve (pressure level and dwell time) as well as the characteristic temperature curve (precisely adjustable heat-up and cool-down ramps) can be reproducibly controlled. A minimum vacuum pressure of 0.1 mbar is possible. The heating plate is laid out for temperatures of up to 450° C, which permits the use of solders which melt at higher temperatures. The process chamber can be equipped with a microwave plasma module, e.g. in order to clean special goods to be soldered before the soldering process.

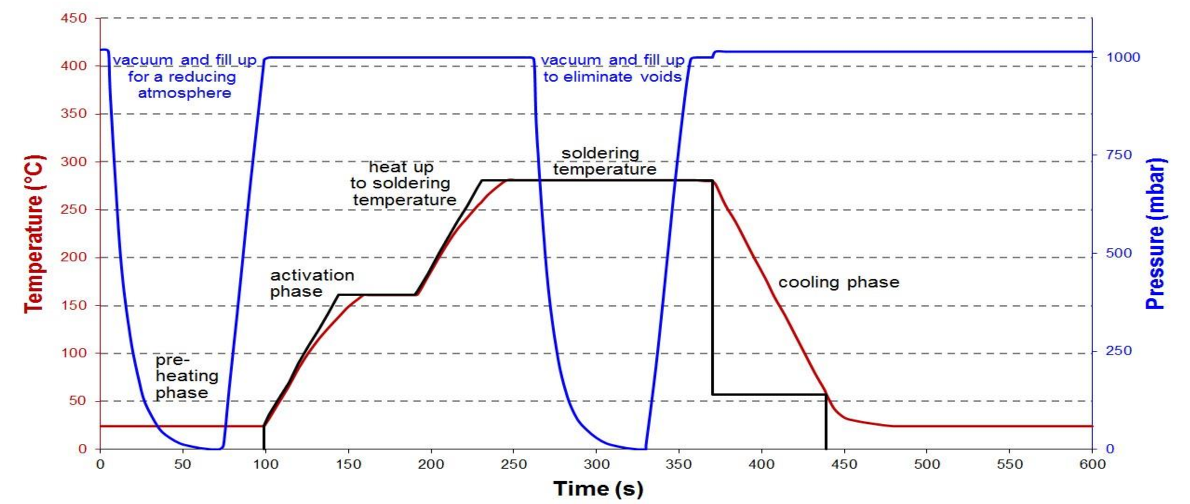


Figure 5: Temperature Profile with Pre-Vacuum and Main Vacuum from a Soldering Process using the VS320i Inline Vacuum Soldering System

3 Vapor Phase Soldering with Vacuum

System Technology

Vapor phase soldering system technology is based on the principle of phase transformation (vapor ↔ liquid) and technical handling of the PCBs. Roughly speaking, we can differentiate between two principles in this respect: continuous boiling (vaporization) of the medium and injection of the medium into a thermally sealed process chamber with subsequent vaporization. In the case of injection, the vacuum option is integrated into the already existing process chamber.

Figure 6: A Condenso Soldering System based on the Injection Principle with Process Chamber including Workpiece Carrier

The heatable chamber of the Condenso vapor phase system shown in Figure 6 is hermetically sealed by means of a bulkhead after the workpiece carrier has been moved into place. A specific quantity of Galden®, which has been matched to the PCBs, is then injected. After vaporization and heat transfer to/into the PCBs, the Galden® process medium is exhausted from the chamber and reused. Vacuum can be generated in the process chamber during any desired process step. As a final step, the PCBs are cooled down outside of the process chamber.

Profiling

Figure 7 shows, in a representative fashion, how pressure in the chamber can be influenced by so-called pre-vacuum and main vacuum. With the help of pre-vacuum, outgassing which has already been released during the heat-up phase can be removed from the process chamber, making it possible to avoid contamination of the surfaces [2]. Main vacuum is generated when the solder is in the molten state in order to reduce voids. Time above liquidus is increased by roughly 20 to 30 seconds. With the CondensoXS, the vacuum option is available for the entire duration of the soldering process, making it possible to fulfill highly specific process requirements for soldering. For example, more uniform distribution of the gas (vapor) can be achieved by injecting the Galden® into the pre-vacuum, so that a more homogenous temperature distribution can be ensured over the entire height of a product. Furthermore, PCBs with large thermal masses can be uniformly heated up to soldering temperature thanks to the very high heat transfer coefficient of up to 150 to 300 W/m²K that are typical for the vapor phase soldering process.

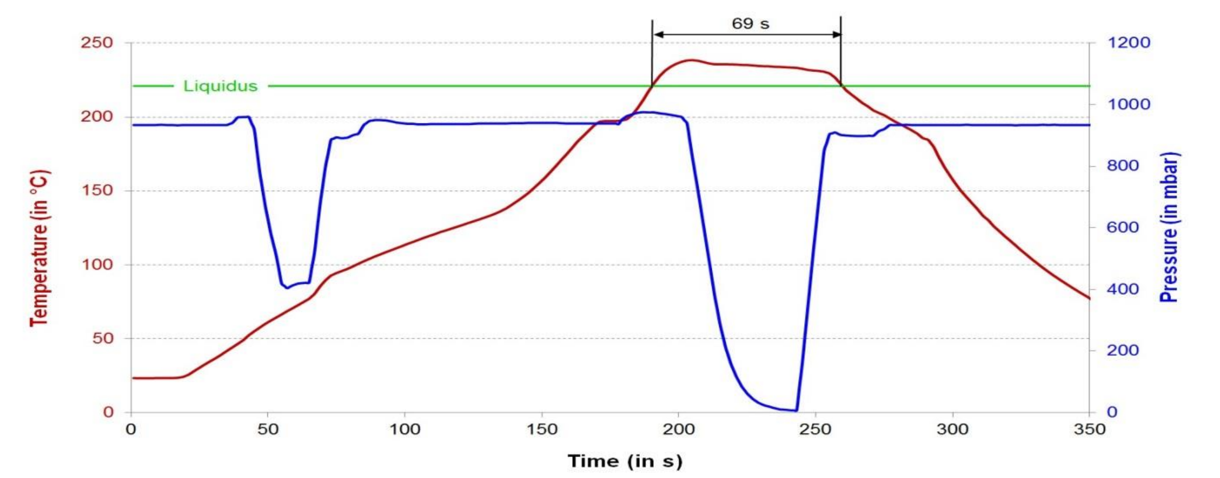


Figure 7: Temperature Profile with Pre-Vacuum and Main Vacuum from a Soldering Process using the Condenso Soldering System

4 Convection Soldering with Vacuum

System Technology

Convection soldering is the most widely used soldering process in the field of electronics manufacturing. In the case of convection, the air or nitrogen atmosphere is heated up and fed to the process chamber with the help of fans. In order to heat the PCBs up to their preheating and soldering temperatures, and to cool them back down again, both temperature and volumetric flow are regulated in the preheating, peak and cooling zones, which can be adjusted independently of each other, and conveyor speed is controlled as well.

Figure 8: VXP+ Vac Convection System with Vacuum Chamber

As shown in Figure 8, the vacuum chamber is installed as a supplement to already existing peak zones for the VXP+ Vac convection reflow soldering system. The system's mechanical layout offers the option of either using the vacuum feature or operating the VXP as a conventional convection soldering system. Adequately sized displacement of the vacuum chamber into the servicing position ensures easy access to the internal mechanism during regularly scheduled maintenance. The system's throughput can be significantly increased by expanding the conveyor system with a second lane (Figure 8, right), because the time for the vacuum operation stays exactly the same. Using the same proven vacuum technology as in the Condenso product family, underpressure and dwell time can be flexibly adjusted to the product needs on the VXP+ Vac series. The difference between VXP+ Vac and Condenso involve the availability and flexibility of vacuum operation during the complete soldering cycle. Whereas convection soldering is concerned, vacuum can only be generated for the process step during where the solder joint temperature is above liquidus.

Profiling

Figure 9 depicts the temperature profile of a convection soldering process with main vacuum. Despite a low pressure of just 10 mbar, it was possible to fulfill all profile specifications (≤ 3 K/s heat up, $t_L \leq 90$ s, $T_P \leq 240$ C). With the help of heating integrated into the chamber, the temperature of the PCB can be adjusted while vacuum is being applied.

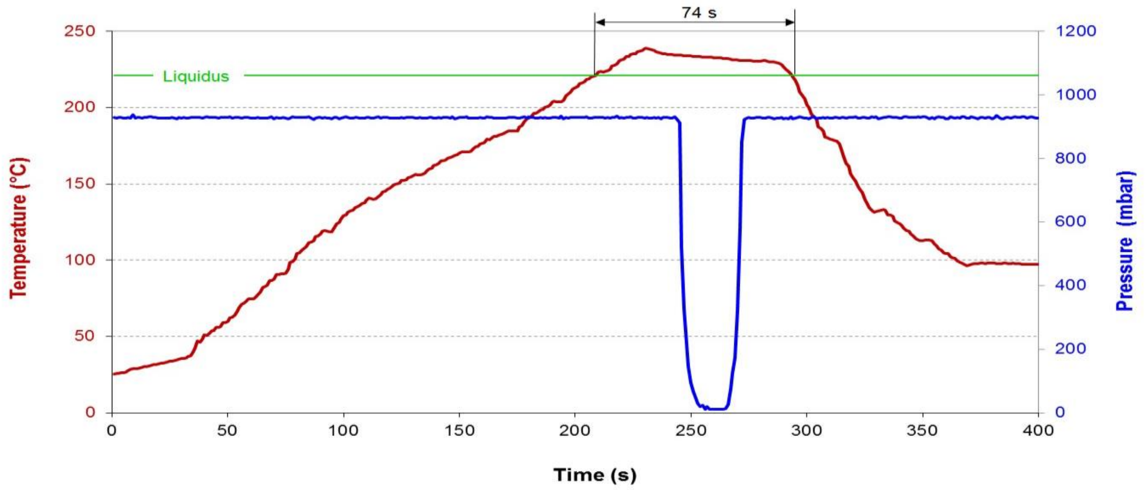


Figure 9: Temperature Profile with Main Vacuum from a Soldering Process using the VXP+ Vac Soldering System

5 Summary

All modern vacuum soldering processes provide the option of reducing the void ratio in the solder joints by means of flexible vacuum management. A list of available thermal processes reveals that possibilities and applications covered by the soldering process differ greatly despite their common goal of reducing void numbers and void size. In order to identify a suitable combination comprising a soldering process and a vacuum application, the individual goals must be precisely analyzed. The following table provides a comparison of several essential characteristics of the above discussed vacuum soldering processes. In particular the type of PCBs to be processed, maximum temperature and productivity can be classified as decisive in this respect.

Table 1: Comparison of Essential Characteristics of Contact, Convection and Vapor Phase Soldering Systems with Vacuum

	Contact Soldering with Vacuum	***Vapor Phase Soldering with Vacuum***	***Convection Soldering with Vacuum***
Reflow profiling flexibility	Good	Good	Very good
Maximum process temperature	450°C	240°C	300°C
PCB temperature difference (ΔT)	Depends on the PCB	Relatively small	Depends on number of heat zones
Goods to be soldered	Front-end applications, one-sided planar PCBs	One and two-sided PCBs with large masses	One and two-sided PCBs
Process environment	Air, nitrogen, microwave plasma, hydrogen etc.	Medium: PFPE (Galden®)	Air, nitrogen

Vacuum process	Very flexible, for the duration of the entire soldering process	Very flexible, for the duration of the entire soldering process	Only after the soldering process
Productivity	Small lot sizes	Medium lot sizes	Large lot sizes

Bibliography

[1] H. Wohlrabe, *Void-Expert Datenbank,* 2011.

[2] H. Öttl, "Was bietet Löten mit Vakuumprofilen?," *PLUS,* pp. 2412-2413, November 2014.