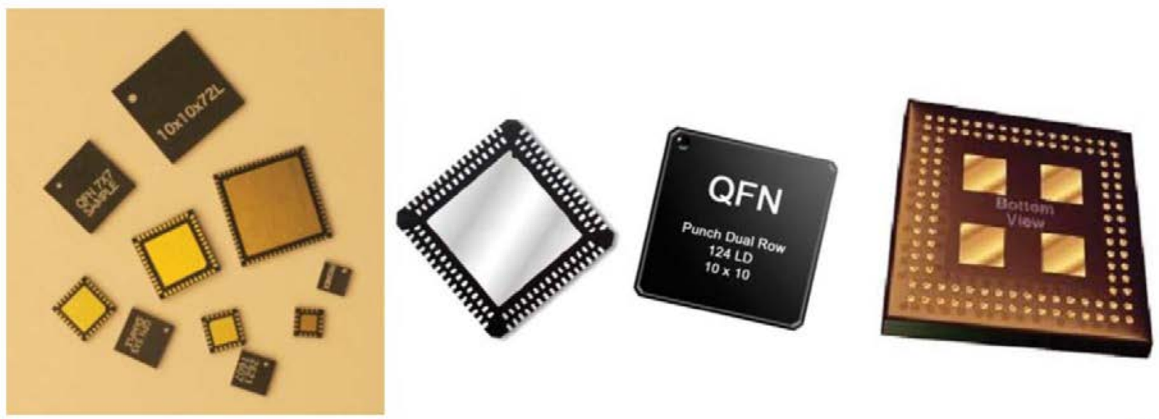
What are the benefits of soldering with vacuum profiles? – Part 1

Helmut Öttl, Head of Application and Product Management, Rehm Thermal Systems

Introduction

Requirements for void-free solder joints are continuously increasing in the field of electronics manufacturing, i.e. the reduction or elimination of cavities in the connection technology used between component connectors and connector pads. New challenges evolve on a daily basis due to the relentless introduction of new variants of so-called bottom terminated components (BTCs), a few of which are shown in figure 1. Connector geometries alone are not decisive – numerous pitfalls are of greater significance. Incentives and several fundamentals will be elucidated in the first part, which will then be supplemented in part 2 with results and perspectives.



IPC-7093-4-1

Figure 1: BTCs (source: IPC7093)

The formation of solder joints is PCB manufacturing, and thus their quality, is influenced by an unmanageably large number of parameters which are becoming more and more difficult to master and keep under control. A voids workgroup prepared the overview of factors shown in figure 2, which provide an initial insight into the complexity of the problem. However, it only includes two factors which can be taken advantage of shortly before production of the affected PCBs in order to reduce or eliminate the formation of voids. These are the stencil and the layout of the aperture on the one hand, and the use of vacuum technology during the soldering process itself on the other hand. Vacuum soldering can even be used during the production processes as a sort of “fire brigade” when a short-term increase in the number of voids occurs. And thus nothing stands in the way of using standard processes and standard profiles for series production, and it’s possible to react flexibly to any fluctuation in the quality of purchased components, PCB surfaces and solder paste batches.

In addition to series production, PCBs can also be repaired in modern vacuum soldering systems like the CondensoX in the event that excessively large voids have occurred during the initial soldering process in a conventional soldering system, which would otherwise have to be scrapped because they do not fulfill the criteria of the applicable IEC standards or IPC directives.

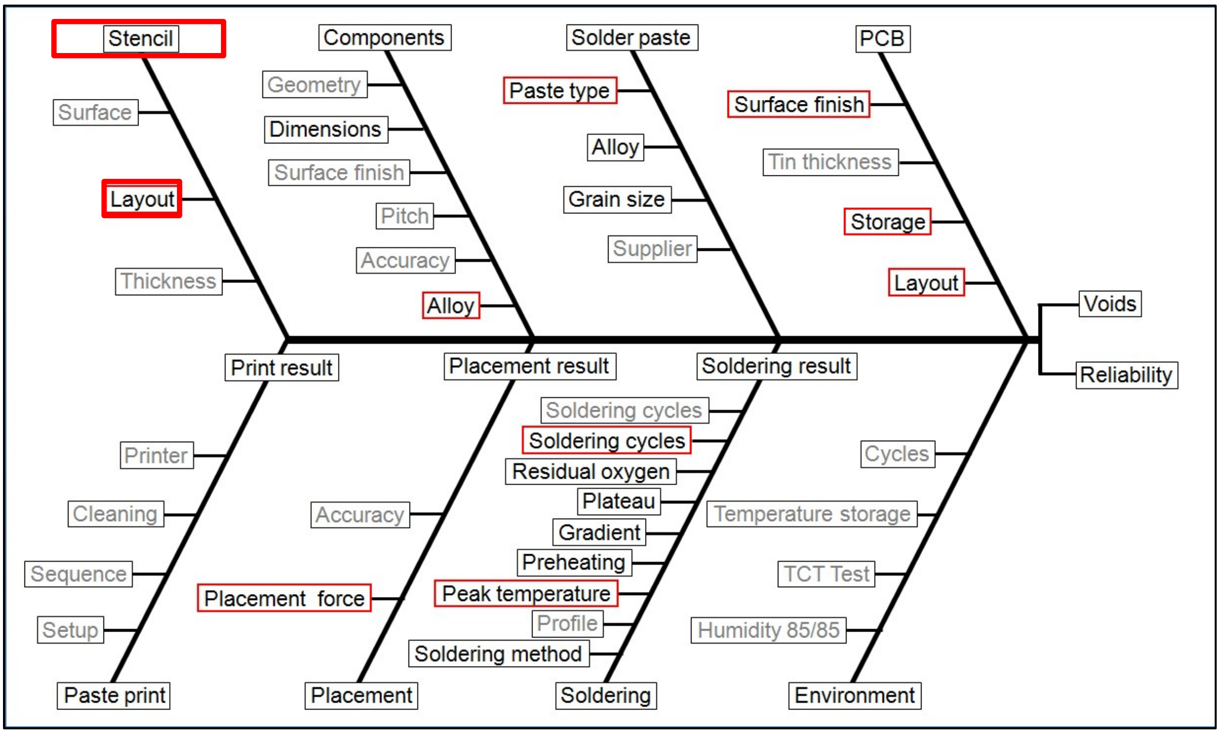


Figure 2: Factors which Influence Voids and Reliability (source: Voids Workgroup, Dr. Wohlrabe, TU Dresden)

Vacuum is defined as follows in DIN 28400 (in agreement with ISO 3529-1): “Vacuum is the state of a gas when the pressure of the gas, and thus the particle-number density, is lower within than it is outside of its container, or when the pressure of the gas is less than 300 mbar, i.e. lower than the smallest atmospheric pressure which occurs on the surface of the Earth.”

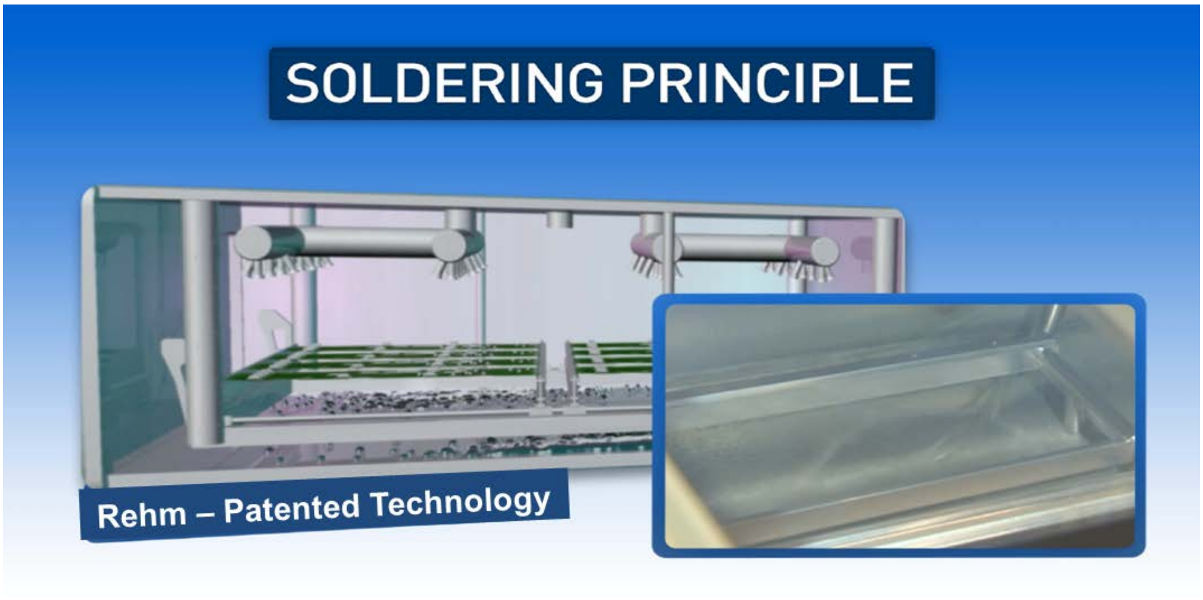


Figure 3: Process Chamber of the CondensoX for Soldering of Stationary PCB Assemblies with Vacuum

Where modern vacuum systems are concerned, we no longer speak of simply evacuating the atmosphere, but rather the user is provided with the option of influencing the gradient at which the vacuum is generated and adjusting dwell time at a specified pressure. This provides above all sensitive components and volatile flux ingredients with the opportunity of adapting to prevailing ambient conditions. Damage to components or solder splashing may otherwise occur. However, this type of vacuum profiling must not be seen a separate step – it's available for the entire duration of the soldering process. As a result, pressure can be adjusted in addition to the temperature profile, making it possible to fulfill various requirements. Moisture absorbed by the solder paste can be removed before soldering, or all of the process gas can be exchanged, for example at 160° C, in order to remove residues which have evaporated out of either the PCB material or the solder paste, in order to assure that they don't condense onto sensitive components (e.g. optics) during the cooling process. The CondensoX provides users with greatest possible flexibility in this respect, allowing them to respond to a vast variety of tasks and to influence the PCB assembly manufacturing process in a targeted and reproducible fashion.

As a preview to part 2, the utilized vacuum and temperature profile is shown in figure 4, with which BGA and QFN (BTC) components were soldered in the CondensoX during the course of the case study. Not only were the PCBs soldered with and without vacuum for the study – stencil apertures were varied as well. The goal was to demonstrate the extent to which void results can be influenced for both soldering processes.

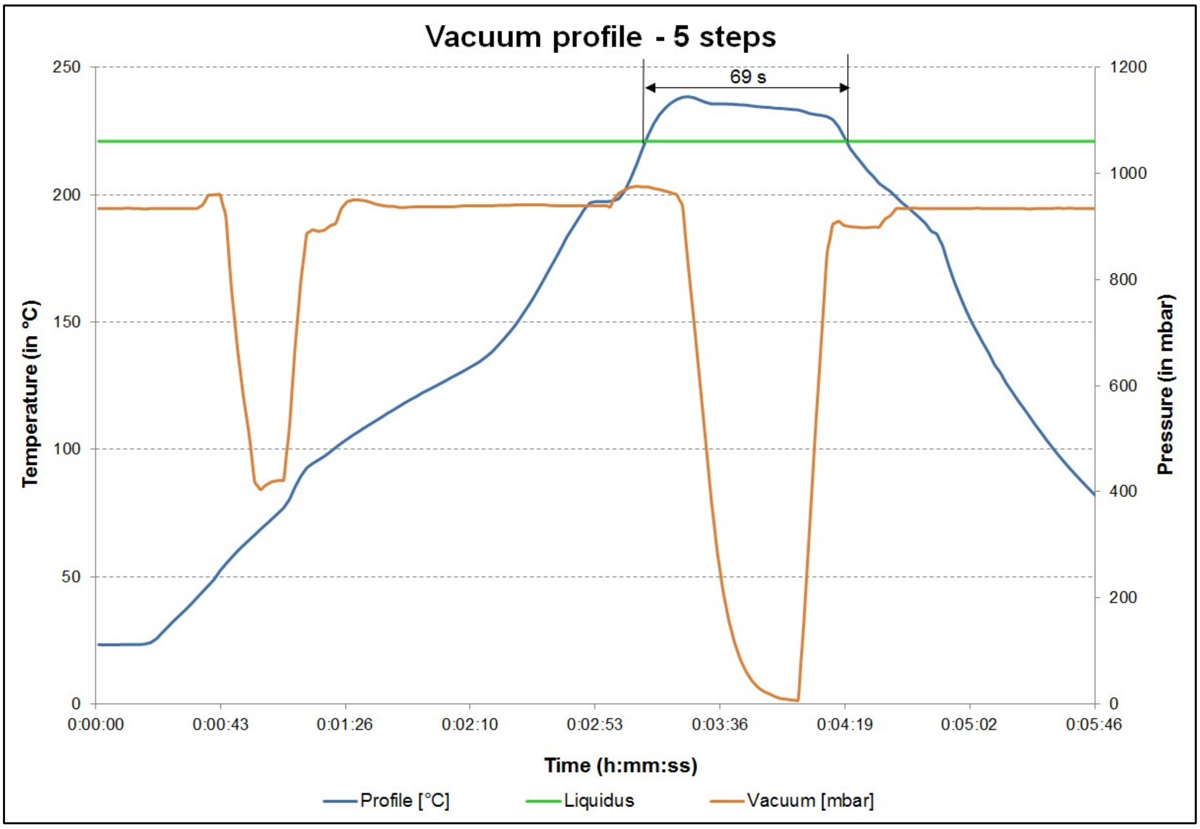


Figure 4: Selected Vacuum Profile for the Soldering Task

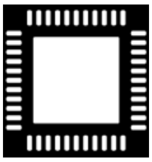
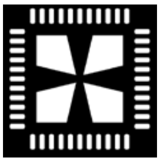
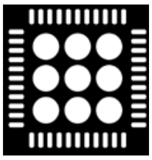
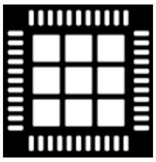
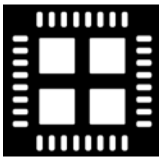
Rectangle	Polygon	Circle	9 button matrix	Squares
				
Surface area = 21,1 mm² 100 %	Surface area = 13,37 mm² 63 %	Surface area = 14,11 mm² 67 %	Surface area = 18,3 mm² 87 %	Surface area = 14,4 mm² 68 %

Table 1: Utilized Apertures for BTC Soldering

What are the benefits of soldering with vacuum profiles? – Part 2

Helmut Öttl, Head of Application and Product Management, Rehm Thermal Systems

Introduction

Now that the issue of soldering with vacuum profiles has been introduced in part 1, we'll take a closer look at the process and discuss the obtained soldering results in part 2.

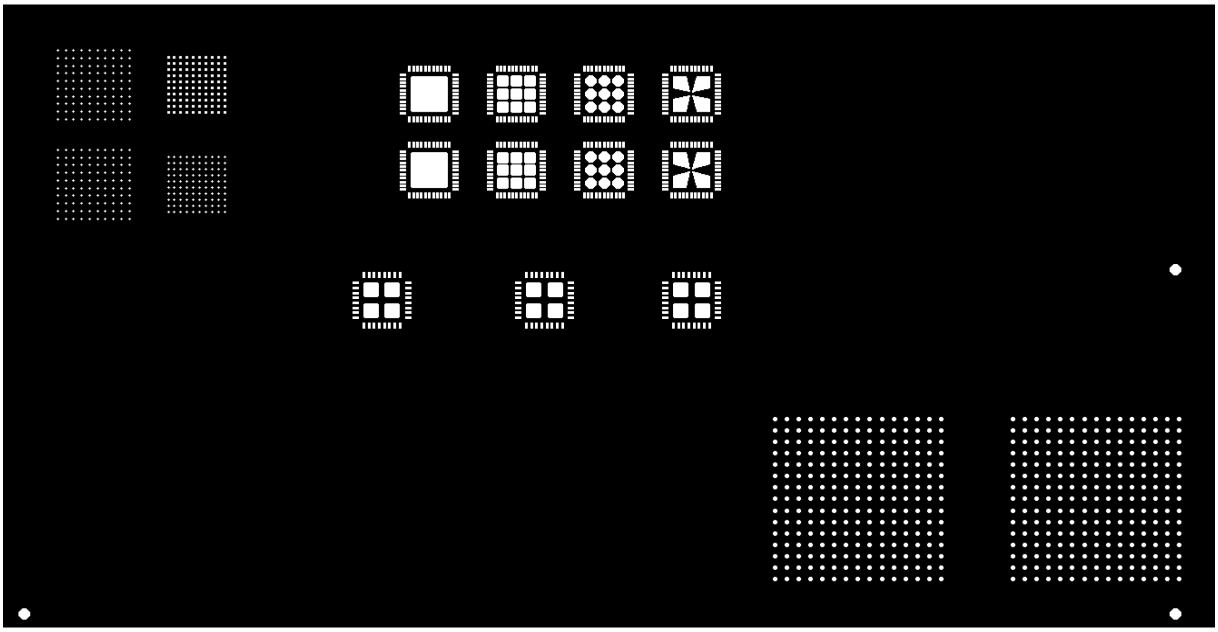


Figure 1: Layout of the Test Board with Five Different Apertures for BTC Components

Figure 1 shows the overall layout of the test board, although only the components with ground connection will be considered for this evaluation. Two identical apertures per variation are also included on each PCB.

The two stencils vary with regard to thickness and utilized manufacturing process. One stencil was used without any additional "finishing steps" and has a thickness of 120 µm. As opposed to this, the other half of the boards were printed with the plasma coated, electro-polished variant and a stencil thickness of 110 µm.

The difference between the soldering profiles is made apparent by figure 2 and results from the use of the controlled vacuum profile depicted in the graphic at the right. A so-called pre-vacuum was used in the preheating zone, which stabilizes the test procedure because the soldering tests were distributed over an entire day and thus, for example, absorption of moisture into the solder paste flux chemistry might lead to distorted results.

Stable conditions can be assured by reducing pressure, which lowers the boiling point of liquids, and therefore promoting ease of evaporation of volatile compounds like water etc.

The use of the main vacuum extended the time above liquidus by 30 seconds in order to reduce the number and the formation of voids. Because the void reduction process has to be conducted for the most part in the molten state and must not be run too quickly, a longer period in the melting phase of the solder alloy has to be accepted. A final pressure of 10 mbar and a dwell time of 10 seconds were selected to achieve the following results.

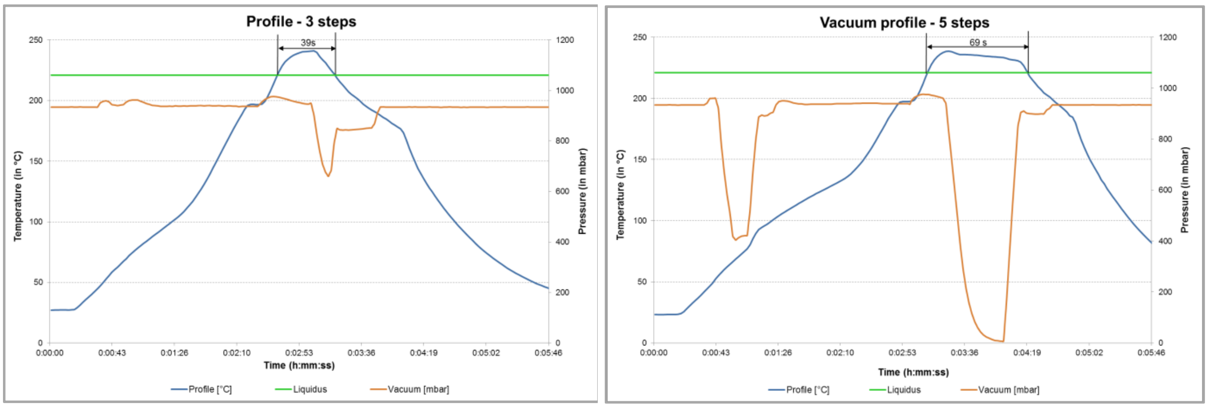


Figure 2: Soldering Profile without Vacuum on the Left as Opposed to a Vacuum Profile with 10 mbar and a Dwell Time of 10 s on the Right

A comparison of the soldering results for these two profiles is depicted in figure 3. Minor differences between aperture-related results can be detected here, although they cannot be classified as significant. The results obtained with a vacuum pressure of 10 mbar are significant, with which all solder joints were produced with a void content of less than 2 %.

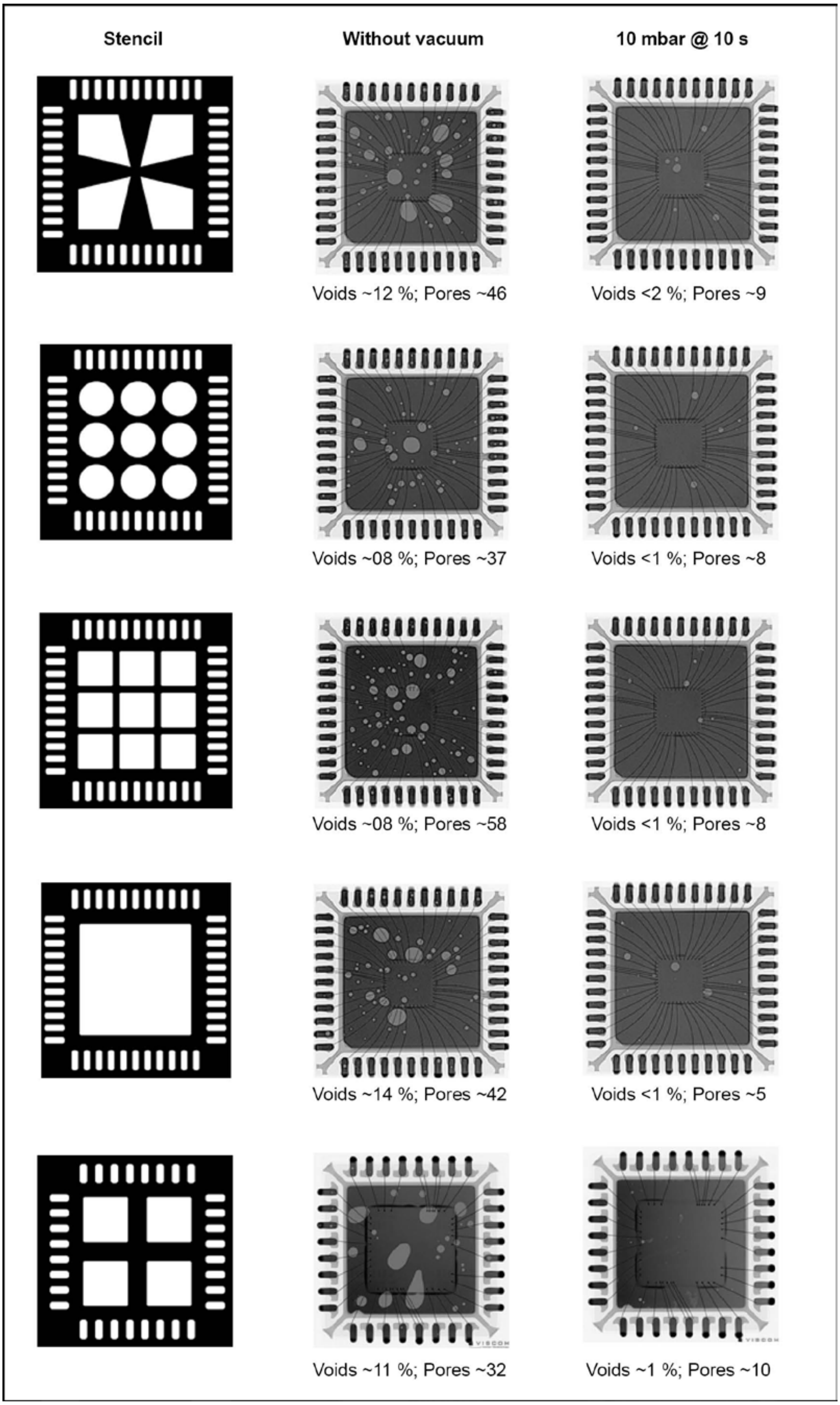


Figure 3: Comparison of Stencil Geometry with and without Vacuum Process

The results in figure 4 of the extreme comparison of soldering at ambient pressure and with a vacuum of 10 mbar are also confirmed by the test run at 100 mbar. Void content (< 3 %) and the number of voids can be significantly reduced in this case as well. Beyond this, the selection of aperture geometry and stencil type has a less significant influence on vacuum soldering results. However, one gains the subjective impression that in this case the plasma stencil has the tendency to leave somewhat less voiding, which could possibly be traced back to better release of the wet paste and the associated dimensional stability. And thus the stable, uniform paste release would have to be taken into consideration as an influencing parameter.

Summary

Soldering with targeted use of vacuum can contribute to a considerable reduction of the number of voids and void content. In order to assure that no negative effects occur such as damage to sensitive components or solder splashing, it should be possible to profile the pressure curve like a temperature profile. The use of different aperture geometries or variously coated stencils doesn’t necessarily result in significant differences during vacuum soldering. The theory involving outgassing ducts cannot be confirmed in this case, because they disappear already in the preheating zone. To a much greater extent, partitioning of a large ground pad can have a positive effect on wet paste print characteristics and wet paste print stability (e.g. see scooping etc.), which may lead to better results. Nor can any single vacuum pressure value be specified which always yields best possible results. Depending on the wet paste layer thickness, the selected solder paste and the stencil aperture, results of less than 2 % void content can be attained with vacuum pressure values ranging from 10 to 100 mbar.

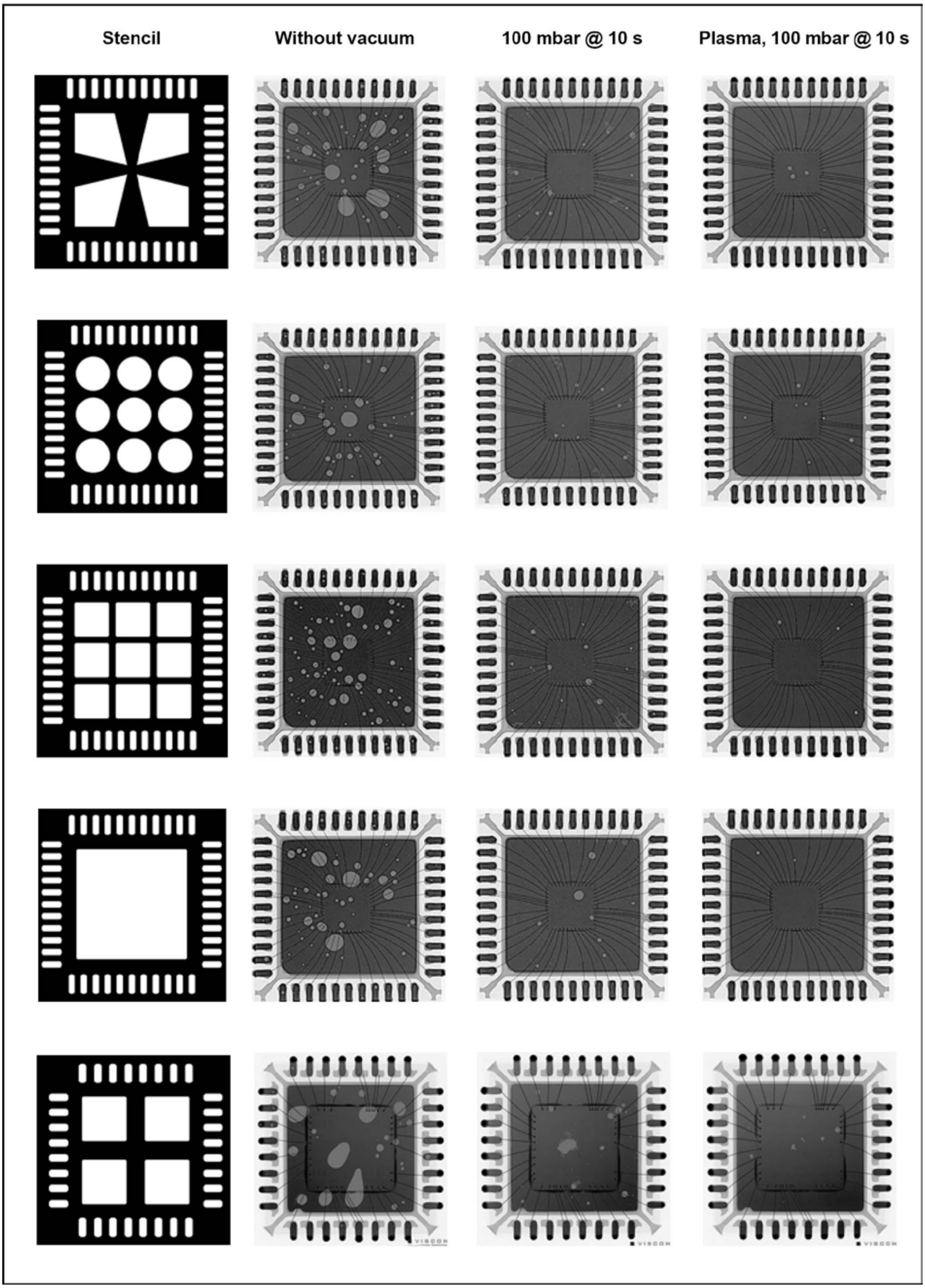


Figure 4: Comparison of Stencil Geometry, Stencil Type and Soldering Process

What are the benefits of soldering with vacuum profiles? – Part 3

Helmut Öttl and Paul Wild, Rehm Thermal Systems

Introduction

After having described the influence of aperture variations and vacuum on the number of voids and void content in BTCs (bottom terminated components) in parts 1 and 2, a further advantage of the targeted use of vacuum is shown in part 3. As a result of the uniform distribution of the vapor during the pre-vacuum phase, it was possible to significantly improve the 3-dimensional soldering process for a MID (molded interconnect device) application.

Use of MID Technology

MID technology is used in particular where significant miniaturization, freedom of design with regard to geometry and a reduced number of components for the electronics assembly is required. The electrical and mechanical features which are normally distributed to various components during conceptualization and development are combined into a single MID part. And thus an intelligent, energy-self-sufficient pressure sensor system with a MID housing was developed as part of the Joint Project for Intelligent, energy-self-sufficient couplings for fluidic systems for automotive applications of the German Federal Ministry of Education and Research (No. V3EAAS010). Figure 1 (left) shows the individual process steps required for LPKF-LDS® technology in the production of the interconnect device. Thanks to the MID housing, the sensor could be made very compact manner and with a reduced number of components.

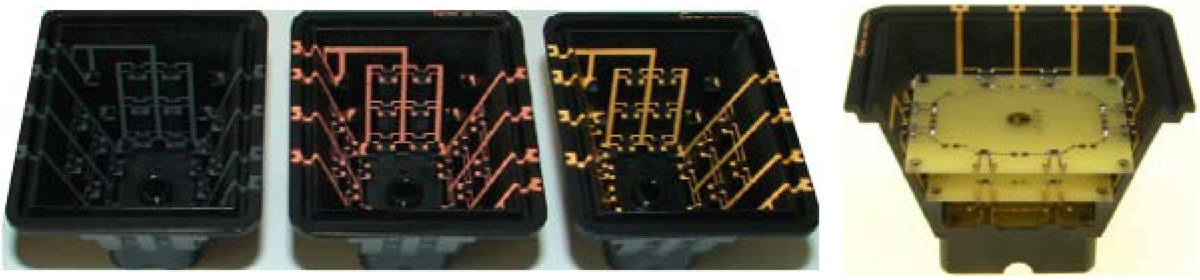


Figure 1: The MID Housing Manufactured by LPKF-LDS® Technology (left) and the Vertically Distributed Mounting Levels of an Energy-Self-Sufficient Pressure Sensor (right)
Source: Intelligent, energy-self-sufficient couplings for fluidic systems for automotive applications (IEKU, No. V3EAAS010), German Federal Ministry of Education and Research

3D MID Package

Due to the three-dimensional design of the housing, the contact points between the interconnect device and the PCBs are vertically distributed (see figure 1, right). As shown in figure 2, the package was soldered in the worst possible position for vapor phase soldering, namely as a cup. In conventional systems, this type of component positioning leads to excessive carry-over of the vapor phase medium. This results in some solder joints being heated more quickly than others, loss of medium from the system due to the cup effect - and a negative influence on the soldering profile. In order to investigate this effect, a soldering test was first of all conducted using a standard vapor phase process with a lead-free temperature profile.

Soldering Test, Vapor Phase Process without Pre-Vacuum

As shown in figure 2 (left), thermocouples are attached to various internal mounting levels, as well as to the upper and lower edges of the housing. First of all, the temperature profiles were recorded on the component while injecting the Galden® at ambient pressure and followed by the main vacuum. The curves in figure 2 (right) make it apparent that the measurement results demonstrate considerable differences with regard to heat up times. The great differences observed with regard to the heat transfer on the component can be traced back to two causes: on the one hand, the vapor rising up from the bottom to top causes time-delayed heat energy input over the height of the housing and, on the other hand, the air from the lowermost areas cannot be fully displaced. These two effects influence the development of the temperature gradient over time, and thus the heat up behavior of the component as well.

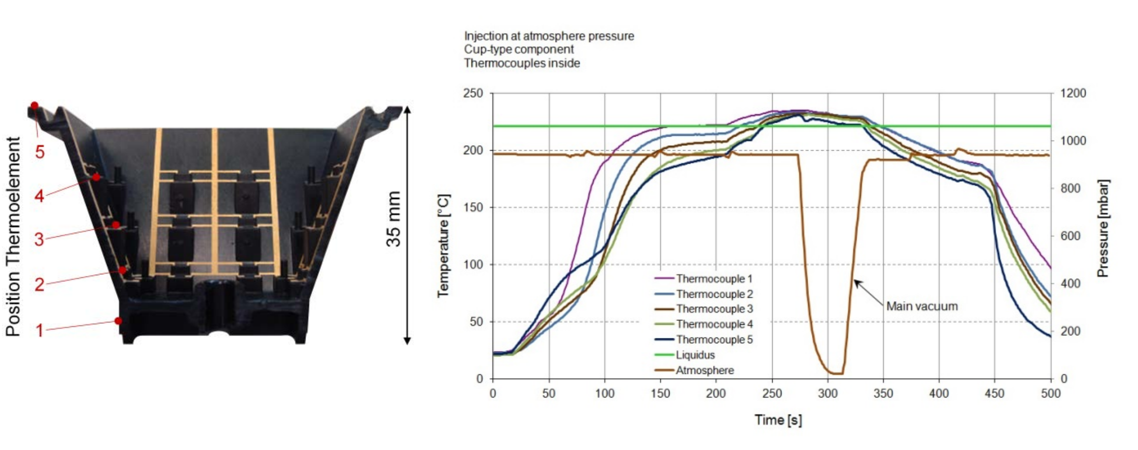


Figure 2: Positioning of the Thermocouples and Alignment of the MID Housing (left), and Measured Temperature Profiles (right) During Vapor Phase Soldering only with Main Vacuum

Soldering Test, Vapor Phase Process with Pre-Vacuum

The next step of experimental investigation involved testing with the same component alignment and thermocouples positioning and the addition of a pre-vacuum step. Right from the very beginning of the soldering process, a pre-vacuum of 100 mbar was pulled and Galden® was directly injected into the vacuum. The measurement results depicted in figure 3 reveal a much more uniform temperature rise at various locations on the component, which enable a much more uniform transition into the liquidus phase at various component mounting levels.

Distribution of Galden® Vapor inside the Process Chamber

When vacuum is used, the Galden® Vapor is distributed uniformly throughout the process chamber instead of forming an ascending vapor front during preheating and soldering. In this way, the disadvantages of the temperature gradient associated with conventional vapor phase systems (the closer to the source of heat the sooner heat up takes place) and with convection systems (the closer to the source of heat the sooner heat up takes place and the hotter it gets) are avoided. This is due to the fact that there are not any large masses of air which have to be displaced, thus permitting quick distribution of the gas molecules into the "empty room". This effect has a positive influence on the profiling of the soldering process and the temperature homogeneity during heat up, and finally on the quality of the soldering result!

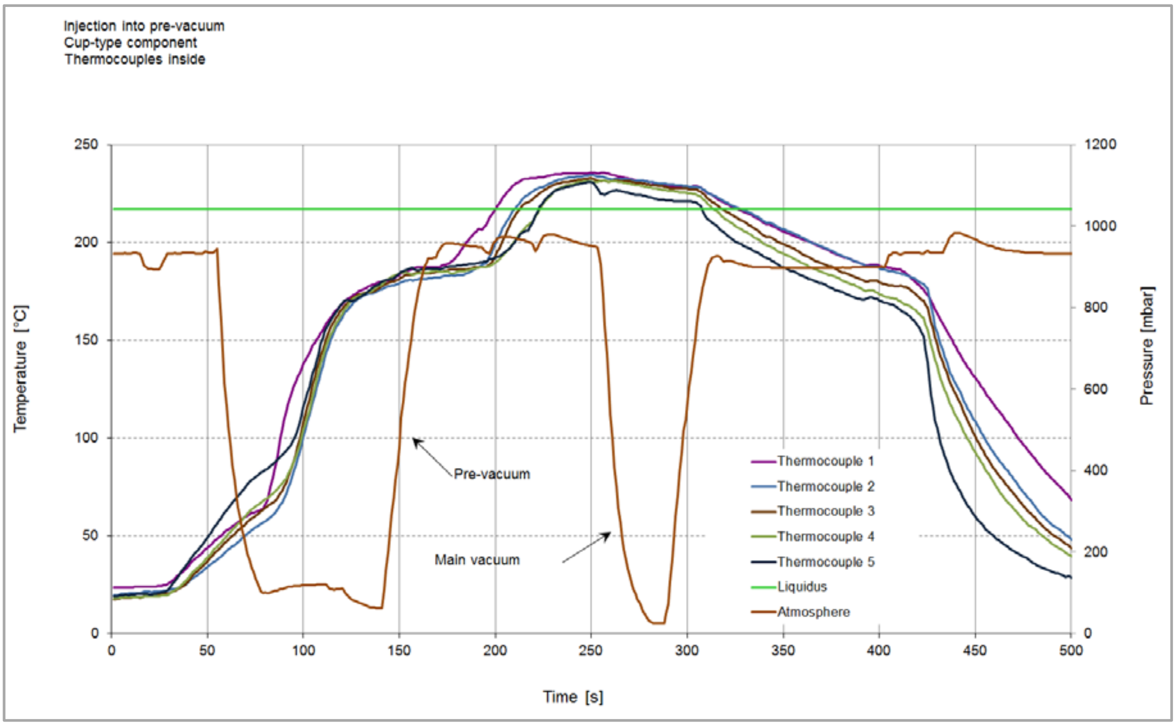


Figure 3: Measured Temperature Profiles at Various Locations on the Component During Vapor Phase Soldering with Pre Vacuum and Main Vacuum

Summary

By using vapor phase soldering in combination with in-situ vacuum, geometry-related deviations in the temperature profiles can also be eliminated in addition to reducing void content and void count. As revealed by temperature profile measurements on a MID housing, it was possible to level out the heat gradients at all measurement points to a significant extent with the help of pre-vacuum, and the small temperature difference at peak temperatures which is associated with vapor phase soldering was retained as well. Furthermore, pre-vacuum can be used to assure quicker and more uniform heat-up of components with large thermal masses. In summary it can be concluded that vacuum during vapor phase soldering provides an additional, highly flexible influencing parameter for the evaluation of an ideal soldering profile and, beyond this, prevents the drag-out of Galden® in the case of cup-shaped components.

About Rehm Thermal Systems

Rehm was founded in 1990 based on the idea of building small, inexpensive reflow soldering systems with a sealed process chamber. With “Simply.More.Ideas” in the field of thermal system solutions for the electronics industry, Rehm is now a technology and innovations leader for modern, efficient electronic PCB manufacturing. As a globally active manufacturer of soldering and drying systems, we’re represented in all relevant growth markets and, as a partner to our customers, we implement manufacturing systems which are setting standards.

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