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Tackling Head-In-Pillow Defects with Vapor Phase Technology

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Abstract

In the electronics manufacturing industry, head-in-pillow (HIP) defects are one of the most common issues that affect circuit boards containing BGA/LGA (Ball Grid Array/Land Grid Array) packages. These defects can result in costly repairs and greatly reduce a component's lifespan. HIP defects are compromised solder joints that are often attributed to undesired environmental factors during the reflow process. These factors include reflow in an oxygen-filled environment, exposure to temperatures surpassing a component's thermal limit, and uneven thermal distribution across the PCB (Printed Circuit Board). The exploration of innovative reflow processes has led to the renewed adoption of Vapor Phase Soldering within the electronics manufacturing industry. Vapor Phase Soldering introduces an oxygen-free environment and a unique heating process that could address the cause of HIP defects. Collecting images and data from a reflowed BGA/LGA hybrid connector in a convection oven and then using vapor phase technology for a rework, we look to investigate if the Vapor Phase Reflow process addresses this defect. When analyzing the data we found a noticeable improvement in solder quality as well as increased coplanarity after the Vapor Phase rework. These findings offer preliminary support for the benefits that are offered when reflowing PCBAs (Printed Circuit Board Assembly's) using the Vapor Phase Soldering method.

Key words: Vapor Phase, Head-In-Pillow, Coplanarity

Introduction

BGA/LGA hybrid connectors function much like the human body's nervous system. They allow the brain, known as a microprocessor, to interface with all other components on the PCBA. The sensitive digital cortex has a low tolerance for faults and a PCBA without its brain is little more than some copper and silicon.

One common fault that threatens a system's integrity is the head-in-pillow (HIP) defect. These defects have become increasingly common with the adoption of lead-free alloys in BGA-style components. Although the development of HIP defects can result in immediate intermittent failure of a PCBA, the more common outcome is a failure in the field due to moderate or thermal stress. The defects tend to form during the reflow process and a few factors that often contribute to their formation include: exceeding a component's thermal limitations, the unequal distribution of heat during reflow, and exposing a component to an oxygenated environment. This

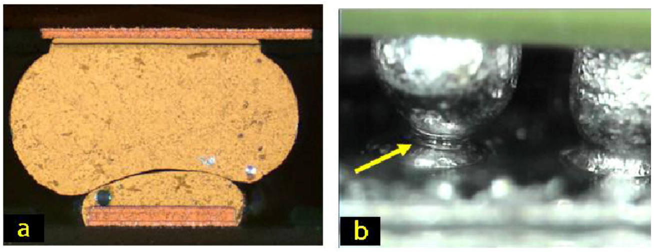

Fig. 1. Example of a Head-In-Pillow defect where image a) is the optical micrograph of a solder joint. This defect is likely caused by an oxide layer forming between the pad and lead. Image b) is the side view of the HIP defect effecting a BGA solder ball [4].

non-ideal environment, and the subsequent development of HIP defects, has plagued the industry for many years.

Before the late 1980s the preferred reflow method was Vapor Phase Soldering due to its enhanced heat transfer capabilities [6]. However, because of speculation over its negative environmental impact, Vapor Phase technologies were abandoned in mainstream electronics manufacturing. Modern innovations in the Vapor Phase Reflow process have resulted in the adoption of PFPEs (perfluoropolyethers) which have a reduced environmental impact. This has caused a resurgence in the use of Vapor Phase reflow in many industries, especially those with low tolerance for electrical failures.

The changes in the reflow process between convection and vapor phase put into question which process would be more favorable regarding HIP defects. Research conducted by Leicht and Thumm indicated the reflow environment observed when using Vapor Phase Soldering reduced the conditions that cause HIP defects [3]. To investigate the impact of changing the reflow environment, a comparison was made between convection and vapor phase processes. The discrepancy between the two processes supports the conclusion that using Vapor Phase technology reduces head-in-pillow defects, addressing its key causes and making it an effective countermeasure.

What is a Head-In-Pillow Defect?

As illustrated in Figure 1, head-in-pillow defects are mechanically weakened solder joints. These defects are most commonly found on BGA/LGA style packages. They often retain electrical integrity which allows them to pass functional tests, yet they still result in in-field failures [8, 5, 1]. As previously mentioned, these failures are due to mechanical or thermal stresses that are exerted on the defective component. Due to the nature of BGA packages these defects can be costly.

How does a Head-In-Pillow Defect Occur?

There is a multitude of factors that can result in head-in-pillow defects. One of the primary causes is the occurrence of a common solder defect known as ”poor wetting” [8, 5]. This issue is often the result of oxidation during the soldering process. Oxidation is the chemical reaction between oxygen molecules and exposed metal that results in the formation of oxide layers. These layers cause imperfections in the solder joints which lead to the aforementioned defects. Traditionally, flux is used to break down these oxide layers, albeit without complete effectiveness.

Another factor that can cause a HIP defect is warpage. Warpage is the deformation of either the components or the PCB [7, 5]. Different materials will expand at different rates when exposed to high temperatures. This is further exaggerated if the heat is disproportionately distributed across the surface of the material. As PCBs and components are soldered they undergo a heating cycle which uses different temperature zones to gradually heat the PCBA. This can lead to uneven thermal distribution, as one end of the PCBA is heated before the other, subsequently leading to PCB warpage.

The different temperature zones require a higher peak temperature as the PCB must be held above the solder paste's melting point for up to 30 seconds. This is often achieved by increasing the maximum applied temperature up to 35 degrees Celsius, as per the solder paste manufacturer's specifications. The use of this overhead is to ensure that thicker PCBs and high mass components reach and exceed the solder paste's melting point [3]. Applying peak temperatures of this magnitude disrupts the functionality of BGA/LGA style packages due to the component's internal material composition. These higher temperatures often exceed the limitations of the component which cause it to unevenly expand and subsequently warp. As the PCB and/or component warp, the solder balls disengage from the pads. This leads to defective solder joints as either oxides form in between the pad and ball, or the pad and ball cool at different rates and fail to form a proper solder joint as seen in Figure 2. Both of these effects lead to the creation of HIP defects.

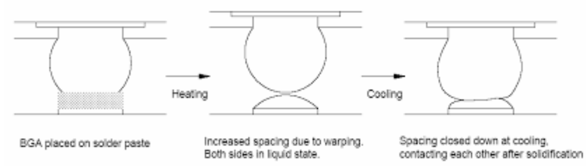

Fig. 2. Diagram representing one cause of HIP defects. As the solder melts, the land pad and BGA ball disengage. After the solder starts cooling they make contact again, yet do not form a bond [2].

What is Vapor Phase?

The Vapor Phase Reflow process was developed at Western Electric in 1974 by Dr. Robert C. Pfahl [3]. Being widely used in the early eighties, Vapor Phase Reflow was the process of choice because of its exceptional thermal transfer characteristic. Despite this, in 1987, the technology was cast aside over environmental concerns, leading to the adoption of the Montreal Protocol. This policy banned the emission of CFCs (chlorofluorocarbons) which, at the time, were the favored chemical used for the Vapor Phase process. Vapor Phase reflow was then replaced in mainstream manufacturing by both IR (Infrared) and convection ovens. The process became limited to the production of more difficult assemblies, such as PCBAs with higher mass components or PCBAs with a mix of high and low mass components. Today Vapor Phase Reflow has addressed the ban on CFCs and instead uses non-toxic PFPEs

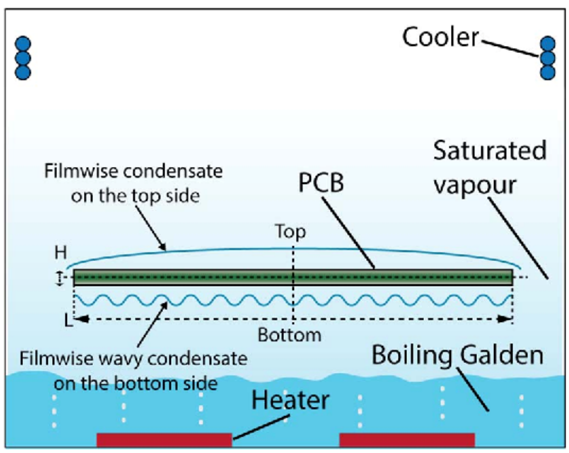

Fig. 3. Diagram representing the process of Vapor Phase Reflow. Vapor condenses to form a film around the PCBA which protects it from oxidation. This film continues to be replaced as more vapor condenses. This process heats the board as the hot vapor undergoes conduction with the PCBA [9].

(perfluoropolyethers) [3]. The process is primarily found in industries with a low tolerance for defects, such as aerospace or defense.

The Vapor Phase Reflow process, illustrated in Figure 3, works by using an inert chemical as a heat conducting medium. The PCBA is placed in a chamber above the inert chemical, commonly Galden® PFPE in liquid form. The Galden® PFPE is then heated in order to form a layer of vapor that displaces the oxygen due to its higher density. The PCBA gets lowered into the vapor layer allowing the vapor to encapsulate it. As the vapor makes contact with the PCBA it forms a film of condensation. This film acts as a layer of protection against oxidation while simultaneously conducting its thermal energy [10, 3]. The vapor continuously condenses, constantly renewing the protective film and further conducting heat. As the film encompasses the PCBA it homogeneously transfers heat. The transfer of thermal energy to the PCBA is also more efficient which allows manufacturers to employ a lower overhead temperature during reflow. Vapor phase has a max peak temperature that is dependent on the type of chemical used. This controlled peak temperature, coupled with an improved thermal transfer process, allows it to target the solder's specified reflow temperature to within a couple degrees [3]. Overall, this low temperature process reduces the risk of thermally sensitive components warping during reflow, especially BGA/LGA style packages.

Vapor Phase and HIP Defects

The major benefit of Vapor Phase Reflow is its ideal soldering environment in comparison to that of the Convection Reflow process. Because this ideal environment is oxygen-free, it eliminates any chance of oxidation while also allowing for homogeneous heating of the PCBA. In traditional convection ovens the PCBA is gradually heated as it passes through different temperature zones which causes different parts of the board to experience unequal levels of heat. When using Vapor Phase Reflow the Galden® PFPE film distributes heat evenly which reduces the chance of warpage. Additionally, the process has a limited peak temperature due to the type of Galden® PFPE being used. This low temperature solution is only viable as the heat transfer process is much more efficient and accurate with Vapor Phase Reflow. Overall, this process addresses the primary environmental factors that cause HIP defects.

Experimental Methodology

To demonstrate the capabilities of Vapor Phase Reflow one can look to a real world application of the process. A client requested services in regards to an issue they encountered during PCBA manufacturing. Post-production, 5-10% of the batch of boards had a HIP defect and the client wanted to rework the PCBAs. Vapor Phase Reflow was used to repair the defects and a comparison, before and after the rework, reveals the differences between the processes. It is important to note that the solder on the PCBA was RoHS compliant and lead free.

Convection Reflow Process

Starting with the Convection Reflow process, a PCBA containing a BGA/LGA connector was reflowed and, subsequently, developed HIP defects. Once it arrived in the facility it underwent functionality testing which resulted in intermittent failures of the component. Images of the connector's solder joints were taken in addition to a delta height measurement. The delta height measurement is the difference between the height of either side of the component relative to the plane of the PCBA substrate (see Figure 5). This measurement can be used as an indication of coplanarity and assist in the analysis of HIP defects. Data was recorded for each side of the connector and can be found in Table 1.

Table 1. Coplanarity Comparison

	Convection (μm)	Vapor Phase (μm)
Side A	113.0	1.0
Side B	143.0	2.0
Side C	199.0	9.0
Side D	134.0	46.0
Average	147.3	14.5

Delta height measurements of each side of a BGA/LGA Hybrid Connector were recorded. Data taken was for both Convection Reflow and Vapor Phase Reflow. The average of the delta heights was then calculated.

Vapor Phase Reflow Process

The defective BGA/LGA connector was then reworked using the Vapor Phase Reflow process. Both images and delta height measurements of the reworked connector were taken and recorded. Figure 4 compares the difference in solder ball quality between the results from the Convection Reflow process and the Vapor Phase Reflow process.

Data Analysis

When analyzing the data, the change in delta height was an indication of improvements in the solder ball quality and,

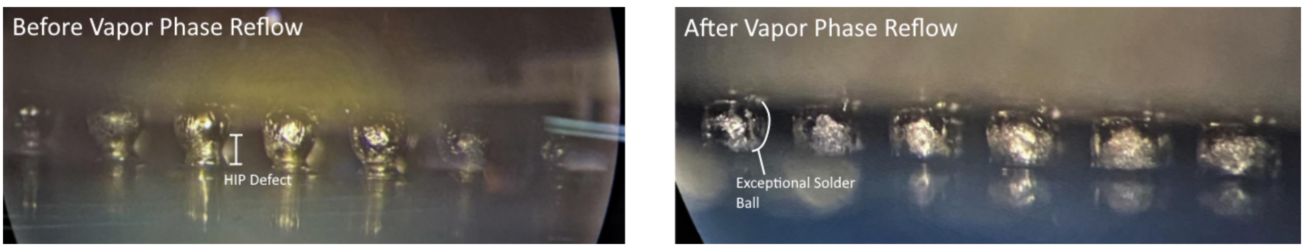

Fig. 4. Two images of solder joints of a BGA/LGA hybrid connector. The left image is after the convection oven reflow with HIP defects. The right image is after the Vapor Phase rework. Inspection of the solder balls revealed elongated solder joints and HIP defects. After the rework, the solder joint formed an exceptional solder ball.

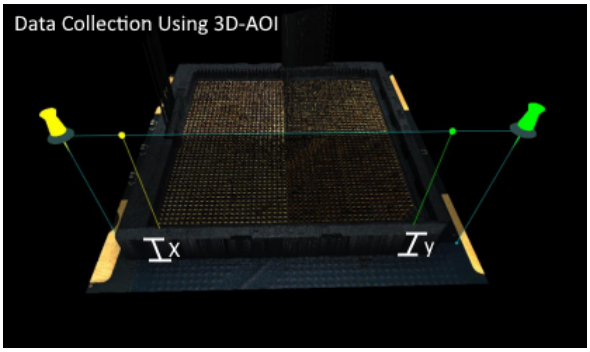

Fig. 5. Image seen in 3D-AOI during inspection. Measurements X and Y were taken relative to the plane of the PCB. Delta height is the difference between the X and Y measurements. These measurements were repeated for each side of the BGA/LGA Hybrid Connector.

therefore, the lack of presence of a HIP defect. From the results in Table 1, we can see that between the Convection and Vapor Phase Reflow processes there is a large change in the delta height for each side of the BGA/LGA connector. For example, through the Convection process, Side A measured to be 113μm whereas through the Vapor Phase process it was 1μm which resulted in a 112μm drop in the delta height measurement. Using these results, we calculated the average delta height of the components for each process. Overall, there was a difference of 132.8μm, a 90.2% decrease, in the delta height which indicates a drastic increase in coplanarity. A visual inspection of the solder balls after the rework showed that all solder bonds had greatly improved. Just as well, functionality testing revealed that the component was operating as expected.

These results can be attributed to the Vapor Phase Reflow process. The increase in coplanarity is likely a result of even heat distribution and low temperature peaks which would limit the warpage and would allow concurrent solder bonding. The increased coplanarity assists in the reduction of HIP defects as solder joints don't stretch to connect leads to the PCB. Limiting the stretching also reduces the amount of solder and pad that would be exposed to oxidation.

Along with limited exposure is the elimination of an oxygenated environment. The protection against oxidation enables an ideal reflow environment. Results indicate strong support in the claim that Vapor Phase Reflow improved the reflow environment and eliminated HIP defects.

Conclusion

Using data collected during the rework of a defective BGA/LGA hybrid connector we analyzed attributes of Vapor Phase Soldering that benefit the manufacturing of PCBAs. The oxygen-free environment, low temperature process, and even heat distribution emulate an ideal reflow environment. This environment is extremely useful in tackling head-in-pillow defects both during the manufacturing and rework of PCBAs. The ability to rework and prevent these defects ensures the longevity of electrical devices and lessens constraints placed on PCB designers. Vapor Phase Reflow is a promising solution to the dreaded HIP defect.

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Appendix A Additional Figures

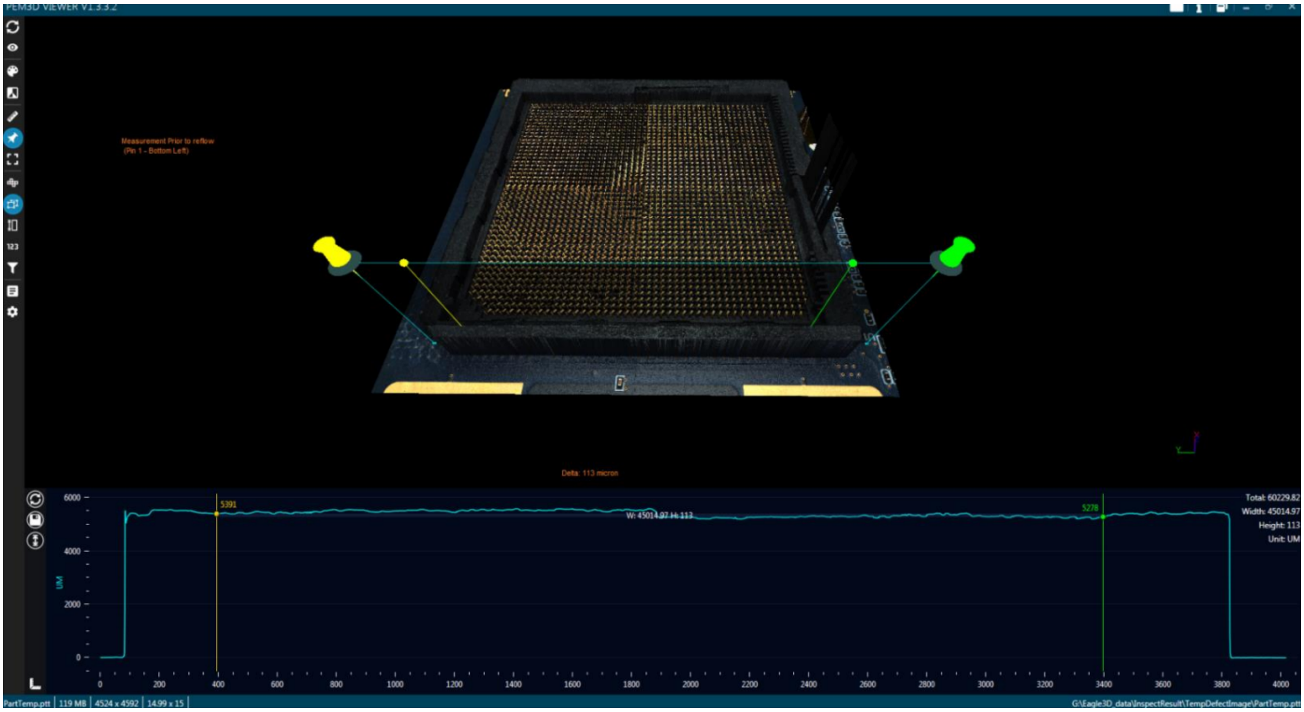

Fig. 6. 3D-AOI rendered image of side A before rework. Calculations made by pins seen in image.

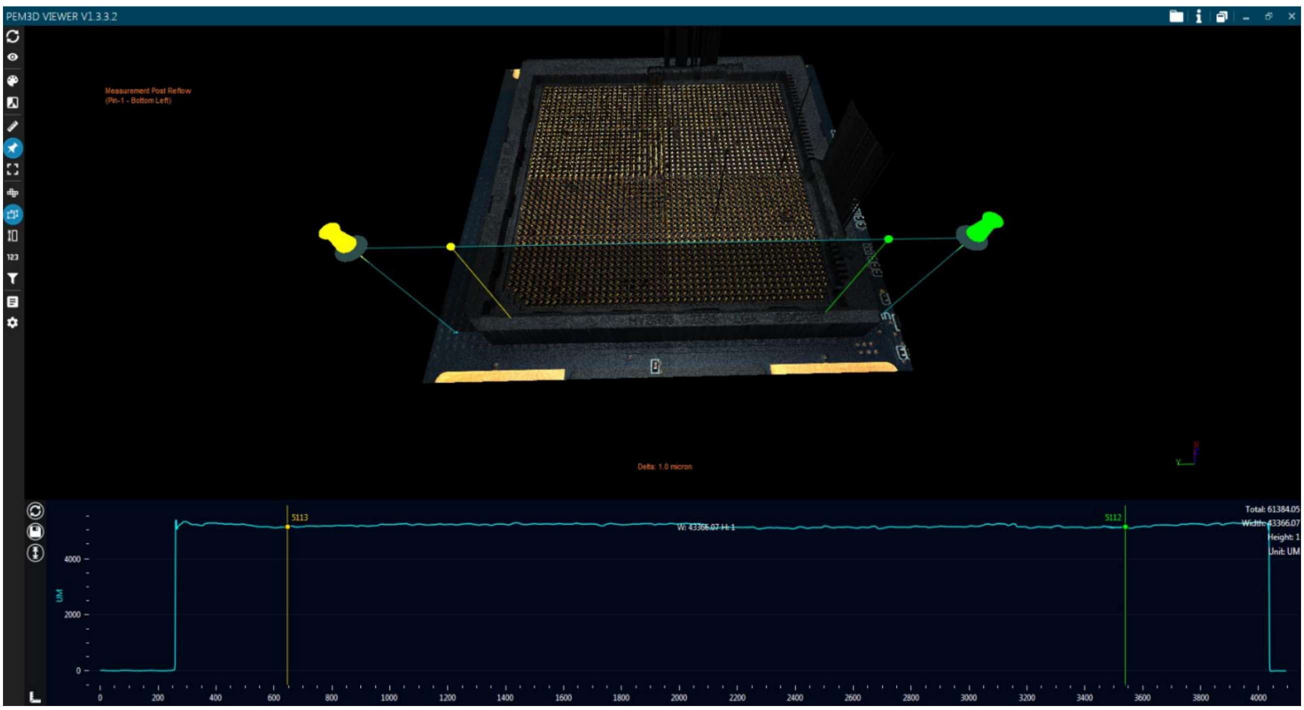

Fig. 7. 3D-AOI rendered image of side A after rework. Calculations made by pins seen in image.

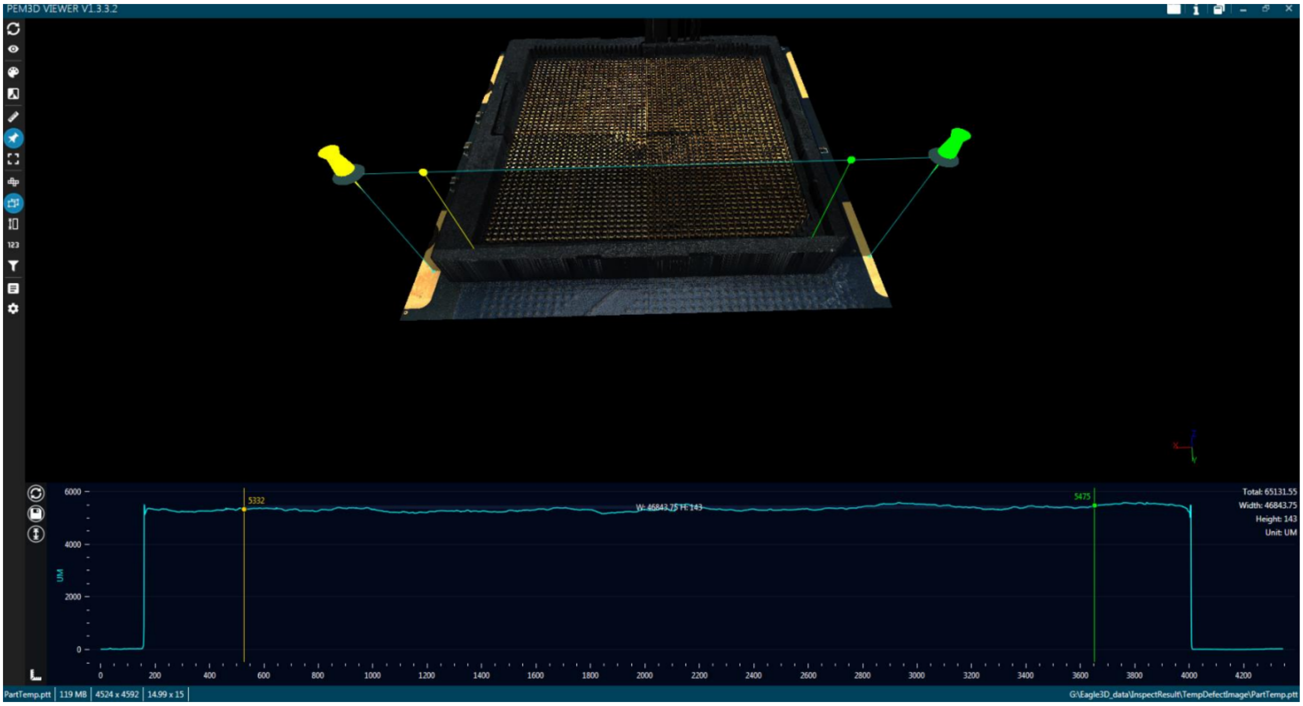

Fig. 8. 3D-AOI rendered image of side B <u>before</u> rework. Calculations made by pins seen in image.

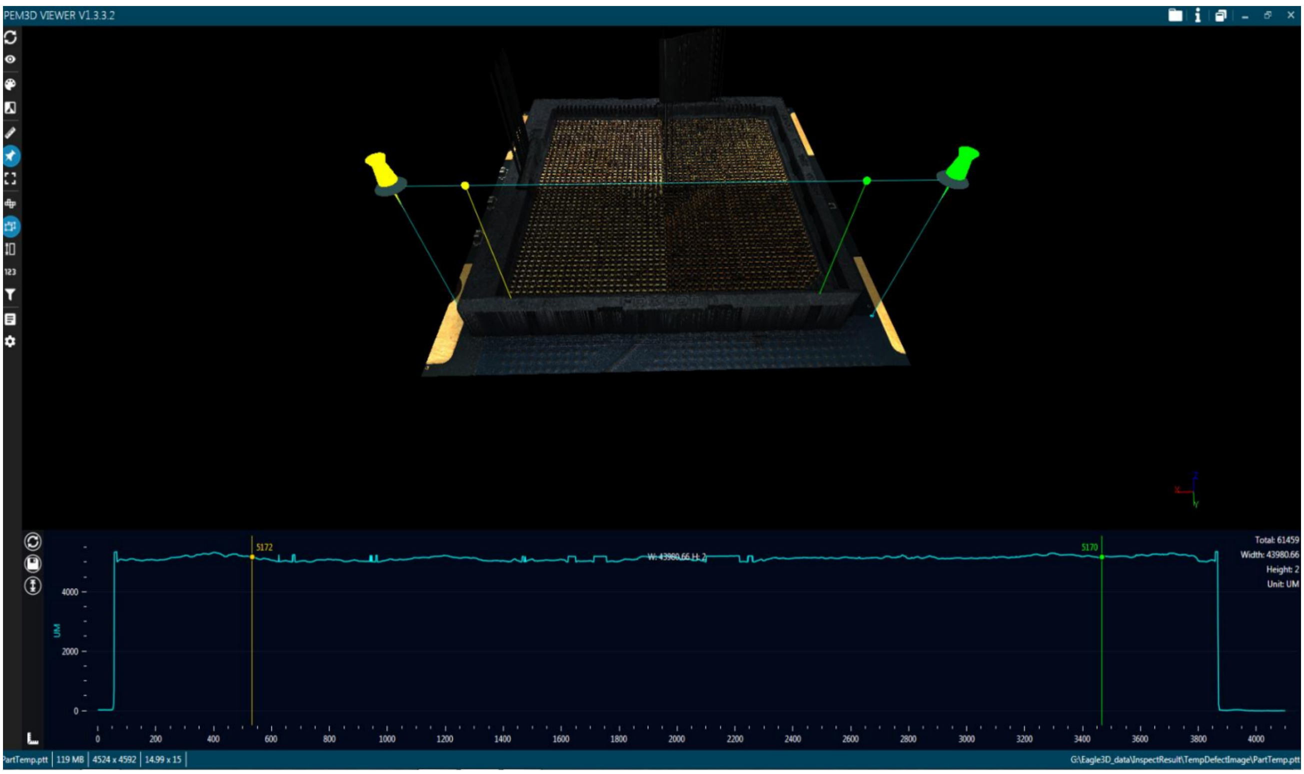

Fig. 9. 3D-AOI rendered image of side B <u>after</u> rework. Calculations made by pins seen in image.

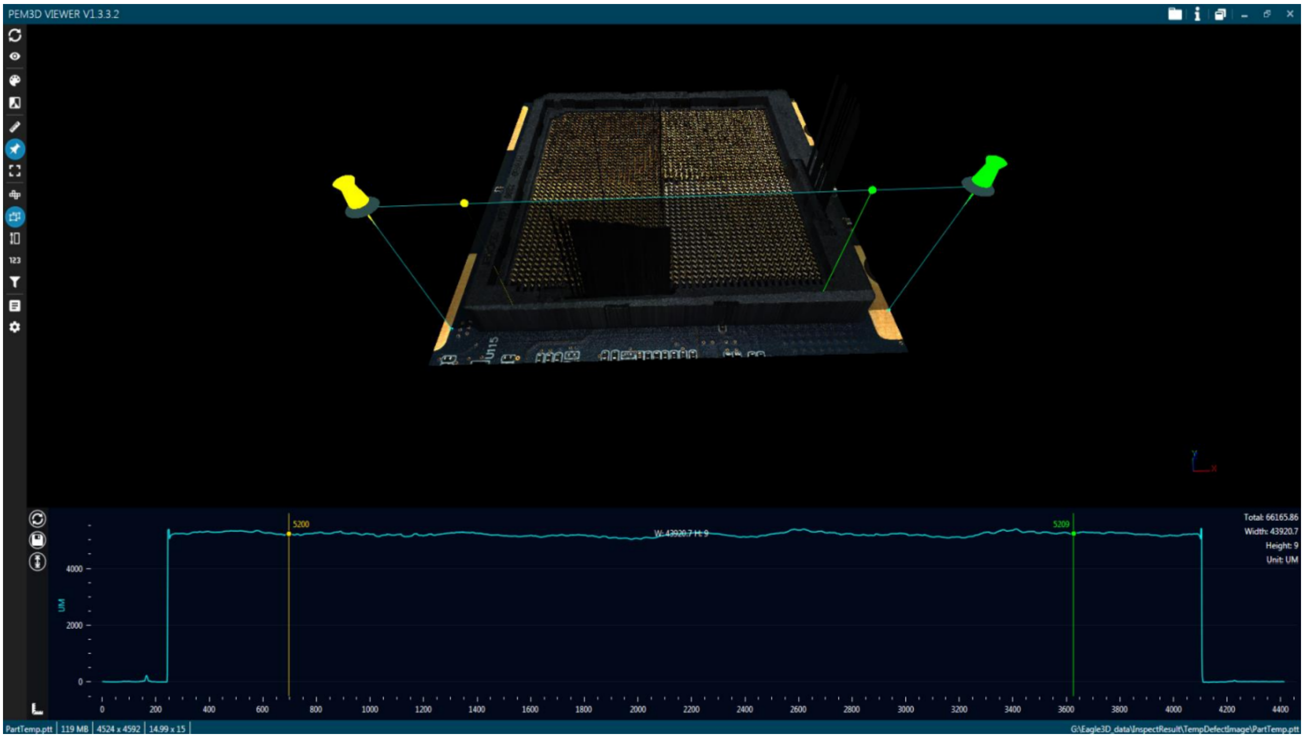

Fig. 10. 3D-AOI rendered image of side C before rework. Calculations made by pins seen in image.

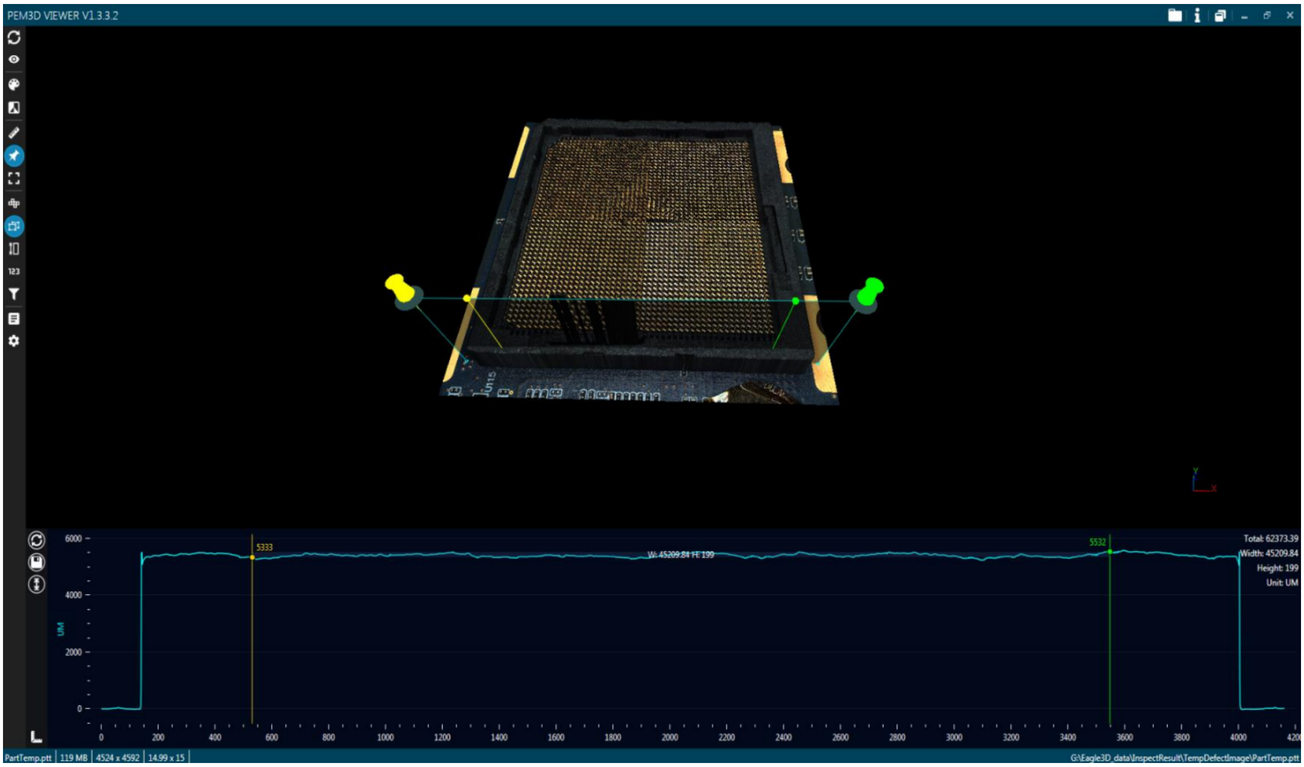

Fig. 11. 3D-AOI rendered image of side C after rework. Calculations made by pins seen in image.

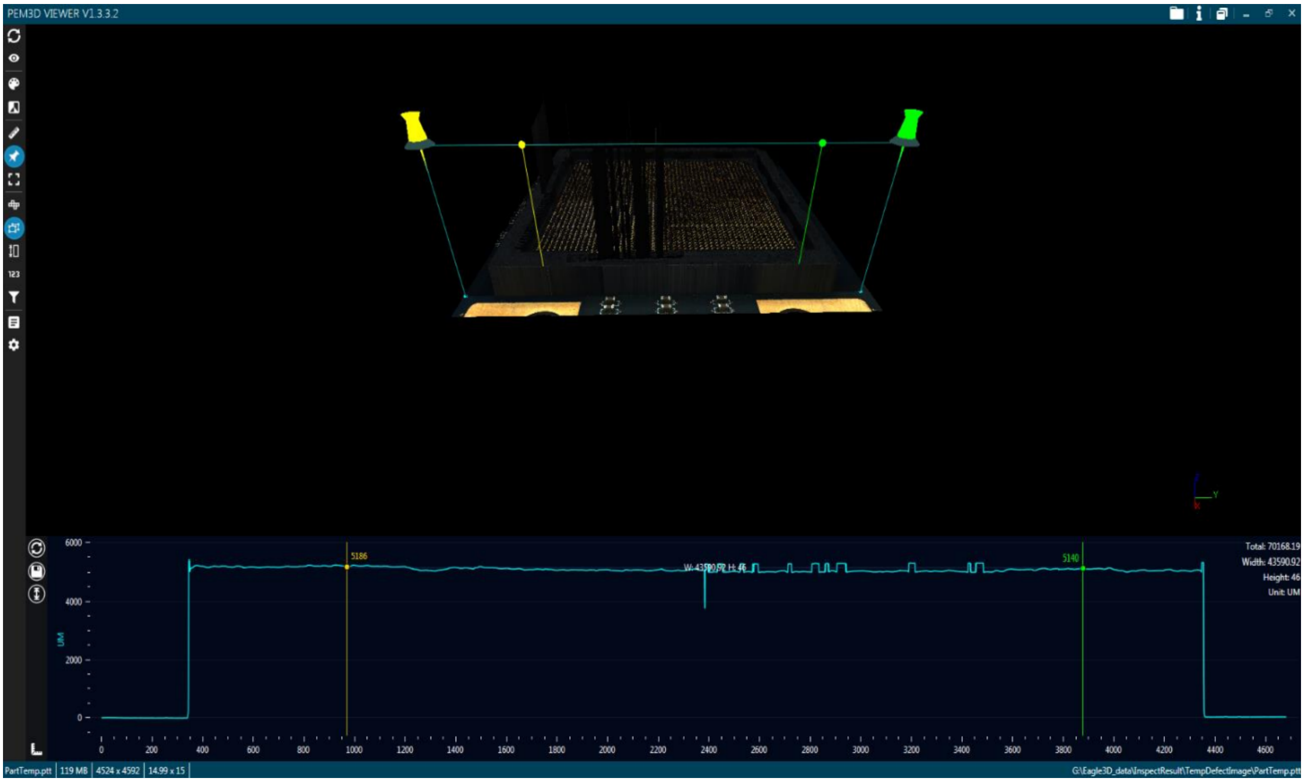

Fig. 12. 3D-AOI rendered image of side D before rework. Calculations made by pins seen in image.

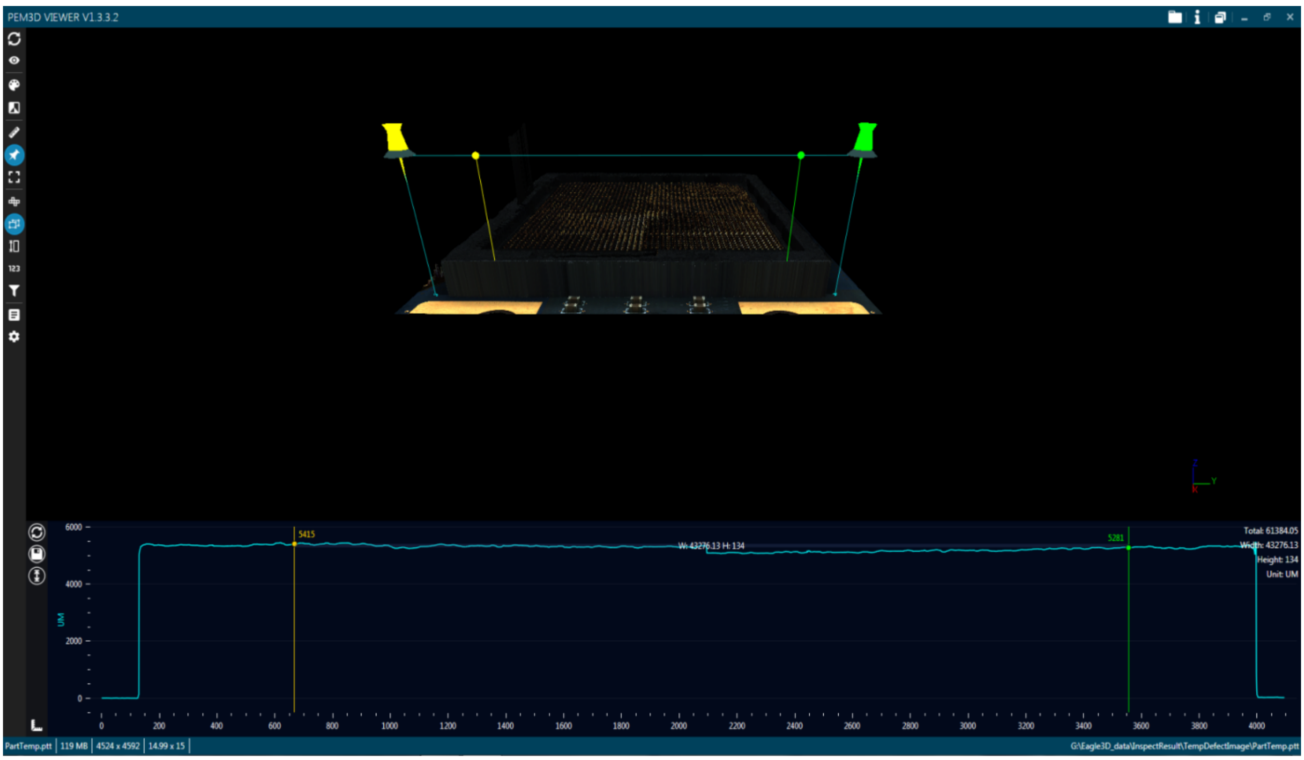

Fig. 13. 3D-AOI rendered image of side D after rework. Calculations made by pins seen in image.

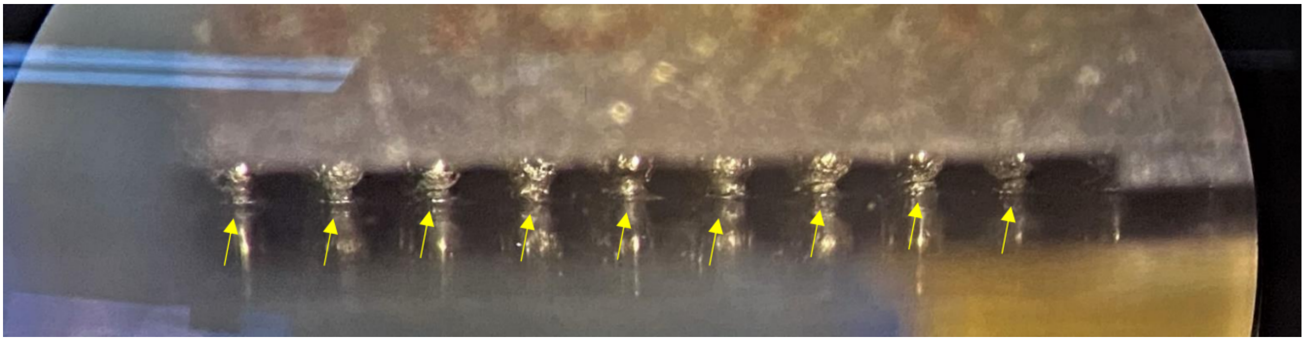

Fig. 14. Side A solder balls before rework is done by Vapor Phase Soldering.

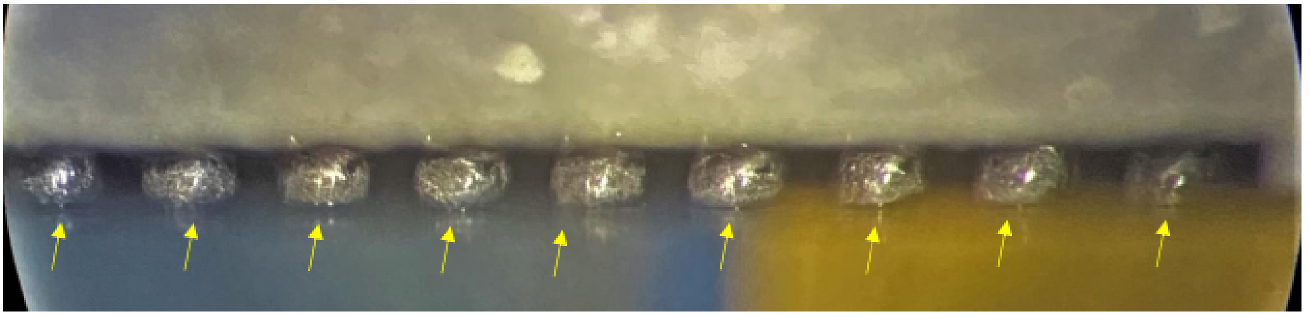

Fig. 15. Side A solder balls after rework is done by Vapor Phase Soldering.

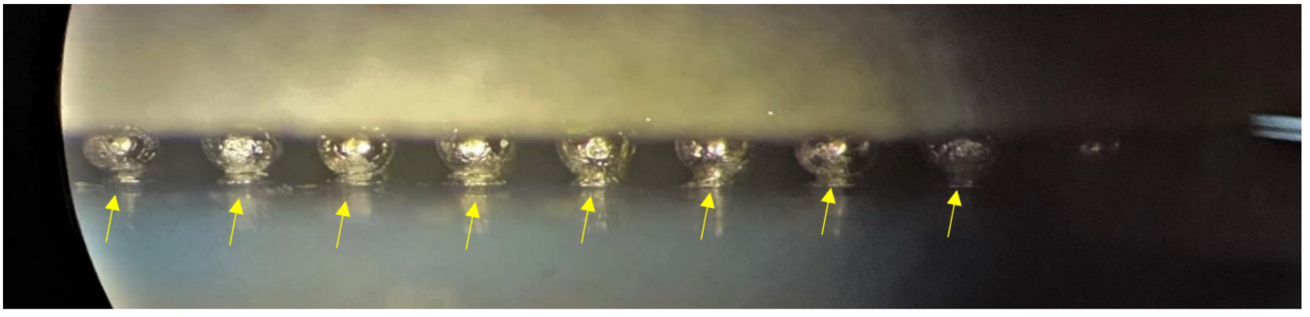

Fig. 16. Side B solder balls before rework is done by Vapor Phase Soldering.

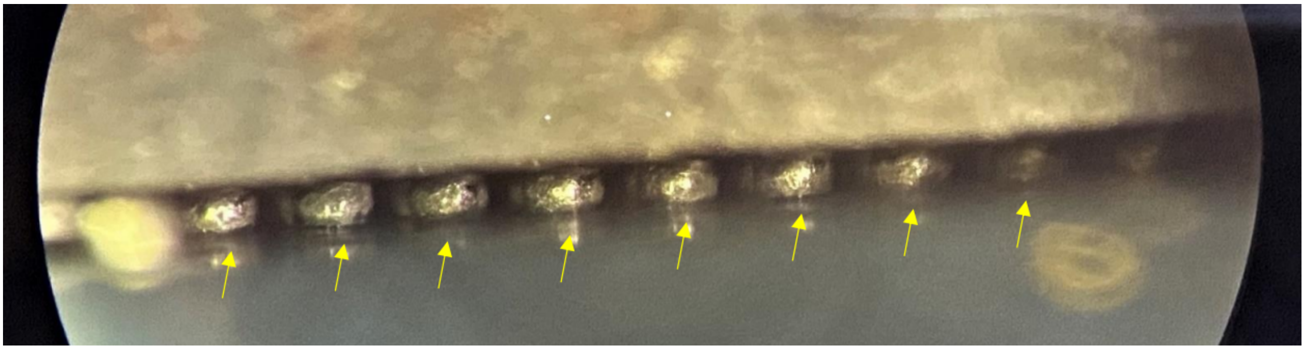

Fig. 17. Side B solder balls after rework is done by Vapor Phase Soldering.

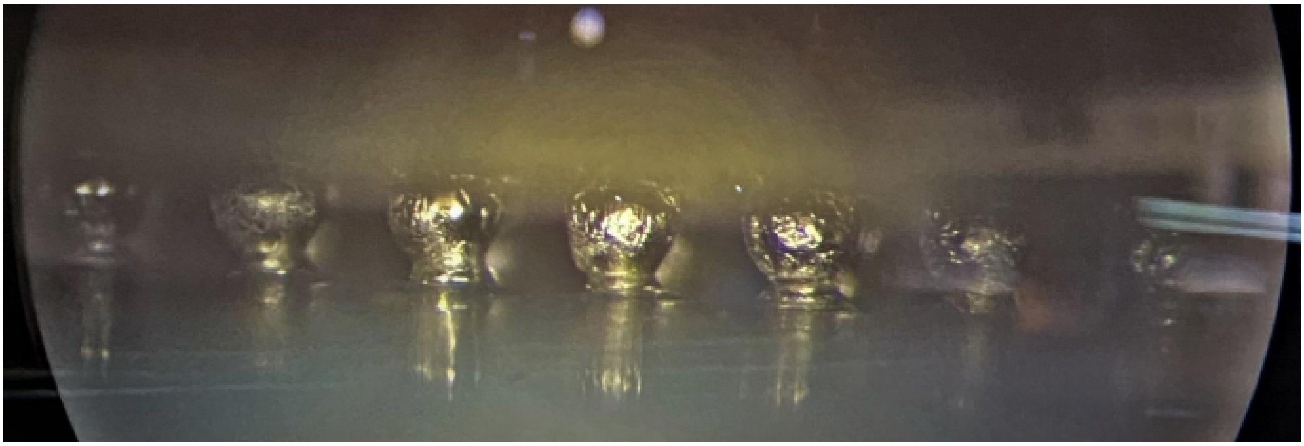

Fig. 18. Side C solder balls before rework is done by Vapor Phase Soldering.

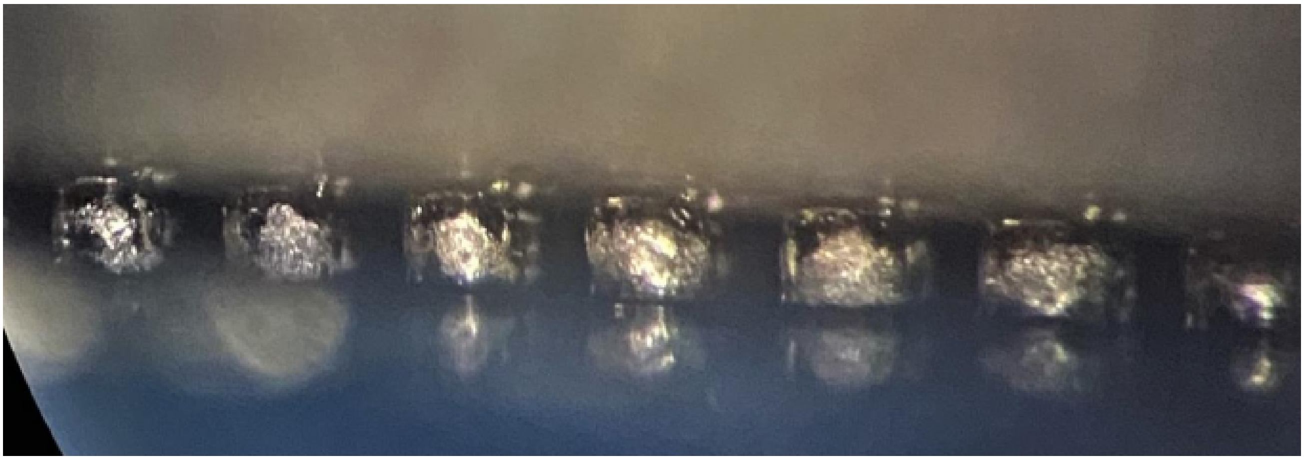

Fig. 19. Side C solder balls after rework is done by Vapor Phase Soldering.

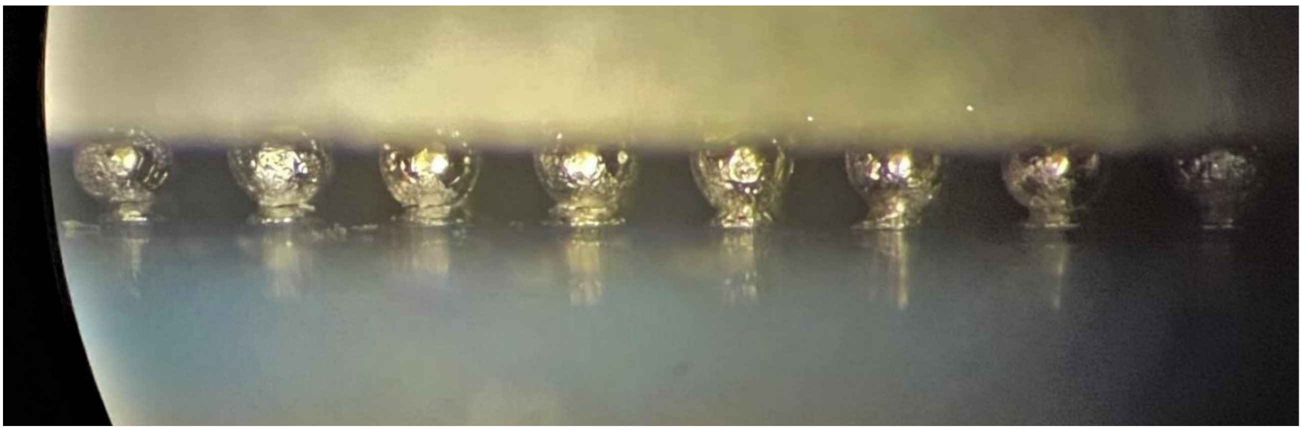

Fig. 20. Side D solder balls before rework is done by Vapor Phase Soldering.

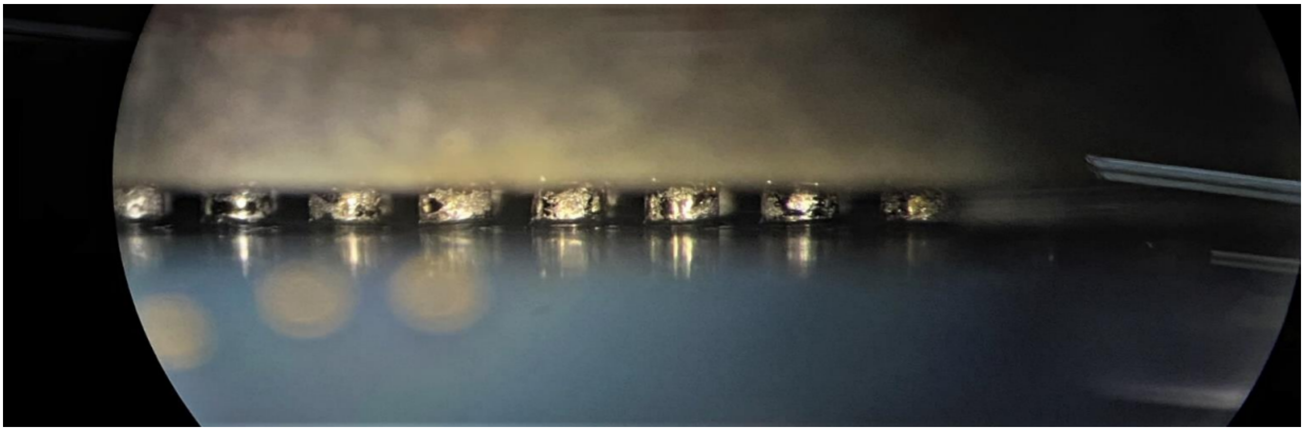

Fig. 21. Side D solder balls after rework is done by Vapor Phase Soldering.