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HIGH THERMAL MASS, VERY HIGH LEAD COUNT SMT CONNECTOR REWORK PROCESS: PROCESS AND PROBLEM RESOLUTION

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ABSTRACT

Very large high thermal mass surface mount connectors are difficult to rework. This paper will examine the difficulties of reworking a very high thermal mass, high density, 5040 lead count surface mount connector. As we approached this problem it was clear that the rework equipment available did not have the power required to perform this rework in an acceptable process window. A multi-functional team was assembled to develop, execute and qualify the connector rework process. This paper will describe the special equipment selected expressly for this process: Localized vapor phase reflow tool, site redress process, selective site solder paste printing process and the quality control processes.

To assure success multiple paths were developed in parallel. The local vapor phase process came out clearly superior to alternative processes, and was established and qualified within a few months. The process was verified through mechanical measurements, cross-sections, high-resolution X-Ray and stress testing and results met all requirements.

Key words: Very Large SMT Connector, Rework, high lead count

INTRODUCTION

Recent trends in the electronics industry continue to support the increase in performance and density of printed circuit board assembly designs, leading to further miniaturization. These trends include deep sub-micron CMOS I/O circuits and scalable processors meeting multi-gigahertz performance requirements. The industry group iNEMI[1] has similarly forecast increased frequencies and decreased footprint in future products, which will place substantial challenges on fine line technologies needed for assembly of electronic systems. As off-chip bandwidth requirements grow to meet the needs of high-end servers, and density of circuits becomes paramount to scalable architectures, the need to continue single-ended mode signals while achieving high frequency limits the interconnect solution to a custom design.[2]

We report in this work the development of a rework method that utilizes local vapor phase technology to attach a large 14 x 120 receptacle connector. This large connector supports 6 Gb/s single-ended mode signaling at a contact density of approximately 28 contacts per cm^2, and plugs a single processor node into one of eight mid-plane header connectors. Its approximate external dimensions are 28 cm length x 5 cm in width x 4 cm in. height. It supports 5,040 I/O and is surface mounted to a 4-5 mm thick printed circuit board. Figure 1 shows a picture of the connector at the edge of printed circuit board.

The connectors are made from individual wafers that are interference fit into stainless steel organizers. The individual wafers possess signal contacts on one face and ground contacts on the opposing face with the individual grounds are commoned within wafers. There are two ground connections for every signal connection. For the receptacle wafers, both signal and ground spring beam contacts are contained within insert molded apertures, while the header wafers possess signal and ground contact blades captured within molded plastic. This basic layout and design information will become important as we understand the defects which require rework.

The industry trends highlighted above present numerous challenges and limit the number of process choices we have in support of rework development. The original attach process for this connector utilizes vapor phase reflow, which is not widely used in the industry today. In fact, iNEMI[3] has highlighted that despite discussions around the return to vapor phase technology, at this time it is only being considered for niche applications.

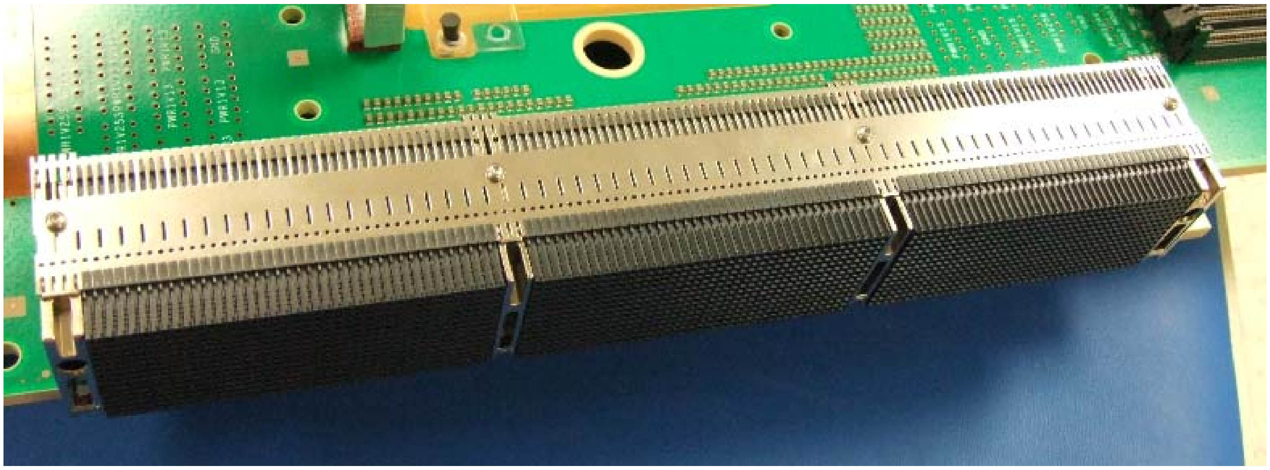

Figure 1: Receptacle connector showing wafer seating face and edge for plugging

In our case, vapor phase technology is well suited and its merits are well documented.[4 5] By boiling a liquid, energy is transferred through heat of condensation to the printed circuit board and its components. This method offers efficient heat transfer and is ideally suited for high mass component applications and reflow of solder that is independent of geometry and package density. With the advent of Pb-free solder paste and the need for higher temperatures to achieve melting points of new alloys, vapor phase reflow is being touted as an attractive alternative due to its control of maximum temperature limited by the liquid's boiling point.[6]

While vapor phase is ideally suited for initial attachment of this connector, a local vapor phase tool design offers an alternative for rework that "localizes" the process and limits the thermal exposure to the board. This simplifies the manufacturing process by minimizing the removal of additional components surrounding the connector region.

During qualification of connector rework we evaluated several methods to assess the quality and reliability of this interconnect solution. As noted, this application required increased bandwidth for leading edge performance and scalability. This limited us to new surface mount technology as opposed to through-hole soldered or press-fit connector attachment which affect both density and signal integrity characteristics. While this supports the objectives of our product electrically, the plugging of processor nodes into the mid-plane can create mechanical stresses on the solder joints even in the presence of additional guide and support features intended to protect the connector and solder joints during system actuation. During qualification of the rework process, we characterized solder joint integrity, intermetallic thickness and mechanical tolerance compliance to ensure that reworked connectors were capable of surviving these plugging stresses.

The number of leads, 5040, on the connector is extremely large compared to most surface mount connectors common in the industry. The large number of leads requires an excellent surface mount process yield. Table 1 has yield projections using a Poisson Distribution for 1, 2, 5, 10 and 25 ppm defects per lead assuming one connector per board.[7]

Table 1: Board yield projection based on 5040 leads and defects per lead

Average ppm defective/lead	% Yield with 0 Defects	% Boards with 1 Defect	% Boards with 2 or more defects
1	99.5	0.5	0.0
2	99.0	1.0	0.0
5	97.5	2.5	0.0
10	95.1	4.8	0.1
25	88.2	11.1	2.3

Twenty five ppm defects per lead is a good yield for surface mount leaded devices. In this case, the large connector yield is better. From this yield projection it can be seen even in relatively low defect rates per lead that there will be enough natural fallout to where a rework process will be required.

REWORK PROCESS

As was stated above this rework process uses vapor phase reflow technology.[8] It is important to note that this rework process applies a localized area of hot vapor to achieve selective reflow of components on the printed circuit board assembly, PCBA. The vapor phase reflow technology used to rework the large surface mount 14x120 daughter-card connector system is an off the shelf vapor phase rework machine which was adapted with special nozzles for this job.[9 10] Internally the machine is identified as a Local Vapor Phase, LVP, machine. The machine is shown in Figure 2.

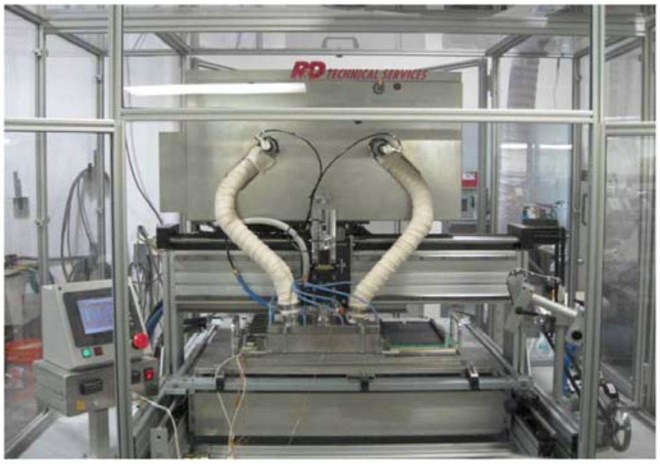

Figure 2: Local vapor phase machine for large surface mount connector rework

There are several steps to the large surface mount connector rework process:

Step 1: Before the PCBA can go through any solder reflow rework process; the PCBA needs to go through a bake operation. The bake operation removes any moisture that might have been absorbed by the PCBA since going through the initial attach process. It is important to remove this moisture to avoid out-gassing induced damage to the printed circuit board laminate material or moisture sensitive components.

Step 2: After the bake process the next steps in PCBA preparation are taping of areas that need thermal or physical protection, removal of temperature sensitive components, and removal of components that interfere with the rework operation itself. See figure 3.

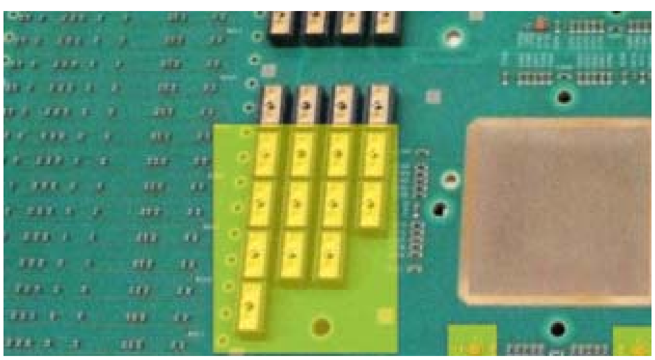

Figure 3: Yellow highlighted components will be removed prior to rework

Step 3: The large surface mount connector is removed using an internally designed nozzle connector removal system which engages the connector and attaches to the LVP machine through hoses and mechanical connections. During the removal process, the connector and PCBA are pre-heated with multiple sources of hot air and a heating strip, followed by full vapor phase reflow. At maximum reflow temperature the LVP lifts the large surface mount connector from the PCBA within the connector removal system nozzle. Then the PCBA, apparatus and connector are cooled. The connector is disposed of and the PCBA is transferred to the site dress area. See figure 4.

Step 4: At site dress, the large surface mount connector site on the PCBA is inspected for de-wet pads, excessively high solder bumps, PCB delamination and lifted SMT Pads. Touch-up is done on all de-wet pads with solder, flux and a solder iron. SMT pads that have excessive solder height or icicles are flattened using a solder iron and flux. Then the SMT pads are cleaned with isopropyl alcohol, IPA, and a lint free cloth. The PCBA is transferred to a hot gas rework machine with a controlled z-height vacuum nozzle[11] used for site redress. See figure 5.

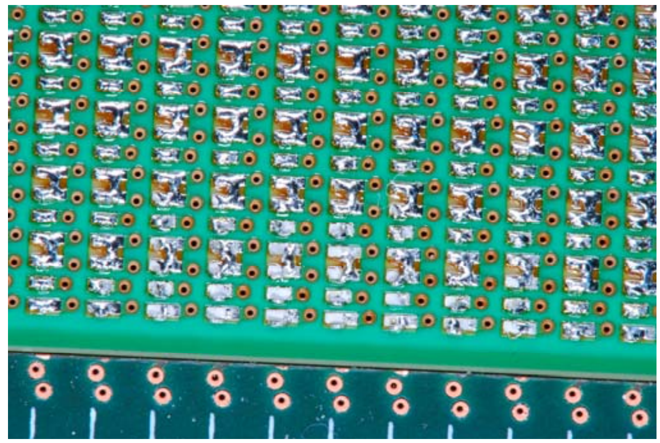

Figure 4: Mounting pads prior to site dress

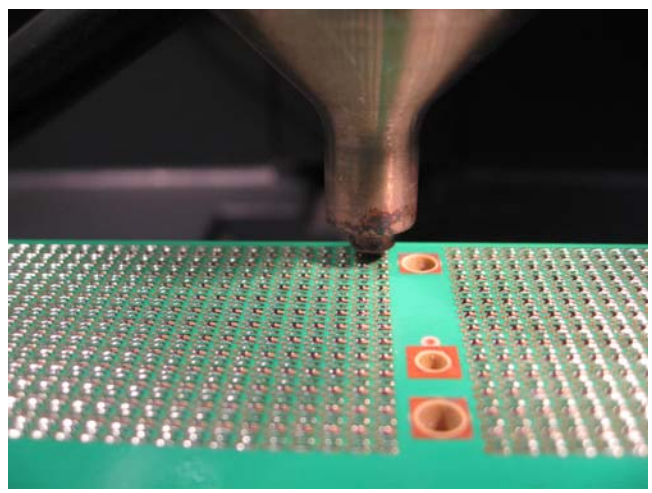

Figure 5: Site redress of the mounting pads after connector removal

Once the PCBA reaches the target pre-heat temperature the hot-gas rework tool will lower the site dress nozzle to the PCB, automatically sense the board surface, and set the vacuum for auto height adjustment. The site dress operation progresses slowly across the large connector SMT site. Once all the pads have been dressed, the SMT pads are cleaned using IPA and lint free cloth during the cool down cycle. Again, inspection is performed to examine the re-dressed SMT pads for any lifted pads, damaged pads, damaged solder mask, excess solder or solder bridges. If solder bridges are found, they are removed using a solder iron and braided copper wick.[12]

Step 5: The PCBA is transferred to a semi-automatic screen printing machine adapted to allow selective site solder paste printing. See figure 6. The stencil has cut-outs to accommodate the remaining components on the PCBA. See figure 7. Solder paste is applied to the stencil and printed onto the PCBA site in a single blade pass. Then the PCBA is removed from the solder paste screening machine and transferred to a solder paste measurement machine to verify the solder paste height and volume. After verification, the solder paste deposits are visually reconfirmed under a microscope by an operator. See figure 8.

Figure 6: Solder paste screen tool modified for connector site screening

Step 6: The PCBA is transferred back to the LVP Machine area and a new large surface mount connector is attached to the PCBA. An internal custom designed attach nozzle system is used to engage both the connector, PCBA, and the LVP system. Similar to the removal process, the connector and assembly are pre-heated with multiple sources of hot gas and a heating strip, followed by full vapor phase reflow and cool-down. Through the entire heating process the connector and the PCBA area directly under the connector are clamped under a spring load within the nozzle. This force is needed to balance between PCBA flatness and connector lead co-planarity.

Figure 7: Cut-out stencil for site solder paste screening

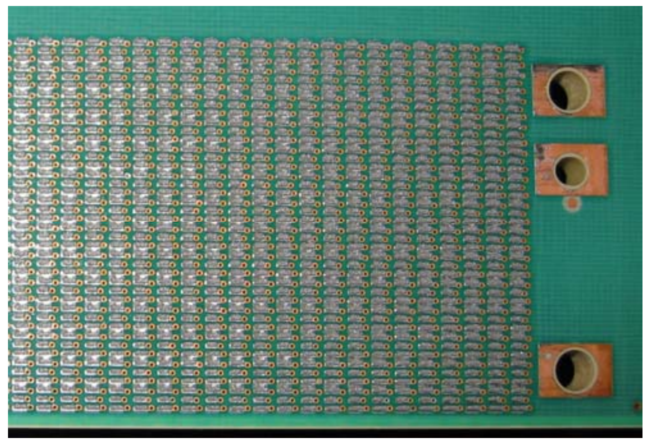

Figure 8: Connector site after solder paste screening

The PCBA and newly attached large surface mount connector system are now ready for verification by various optical inspection, mechanical measurements, X-Ray and electrical testing.

IN-LINE MECHANICAL VERIFICATION PROCESS

Due to the complexity and size of this connector the team decided on certain critical mechanical measurements and verifications as controls for the rework process. The chosen measurements for the process included connector site PCB flatness, wafer-face to guide-block true positional alignment and mechanical verification test.[13] These mechanical measurements and tests provide the ability to verify compliance with critical to function attributes of the connector for both qualification purposes as well as quality monitoring in production.

Localized PCB flatness at the SMT site was determined to be a key contributor to reliability during stress testing of assemblies. Samples measured during initial rework were deemed acceptable, however during the course of 2X rework qualification samples were found outside of the optimum range. Therefore an in-line measurement was implemented on all 2X reworks with an automated measurement device to control site flatness prior to reattach of the connector. During the plugging process it is extremely important that the mating interface of the connector meets certain dimensional criteria. Without meeting this criterion the plugging process can result in damage to the PCB as well as damage to the mating connector.

The most critical of these measurements is verification of the wafer-face to guide block dimensions. See figure 9. The wafer-face to guide block test measures the z-dimension of the top and bottom of each wafer with respect to a plane created by the connector guide blocks, e.g. that is in front of or behind the plane created by the guide blocks. The connector guide blocks act as a hard stop during connector plugging.

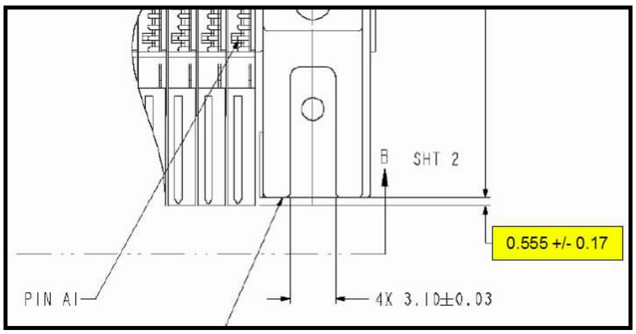

Figure 9: Wafer-to-Guide block tolerance

If the wafer is above the specification limit it will bottom out prior to guide block seating resulting in an overstressed condition of the solder joints. If the wafer is under the specified dimension it may not make good electrical contact with the mating wafer resulting in an electrical opens or intermittent connections.

Cross-Section

As part of the process development and qualification effort, reworked cards were cross-sectioned at various process stages to ensure product integrity. The IBM East Fishkill Materials Lab established a cross-section protocol to ensure consistent, comparable, valid results were achieved. Sample preparation and cross-sectioning were performed with an aluminum stiffener bolted to the backside of the connector site to avoid procedure-induced artifacts through unintentional mechanical damage caused by handling. A quantifiable figure of merit protocol was created to enable comparison and tracking of the solder joint quality from varying rework processes. Boards were sectioned at connector removal, site redress, connector re-attach, and after exposure to various stress conditions. Cross-sectioning included evaluation of solder joint integrity, lead alignment, solder balls, contaminates, pad-lift and solder intermetallic integrity. See figure 10. As part of the site redress qualification, solder thickness was also measured to ensure proper solder coating thickness. This was necessary to avoid de-wet issues associated with oxidation of thin solder or exposed copper/tin intermetallics.

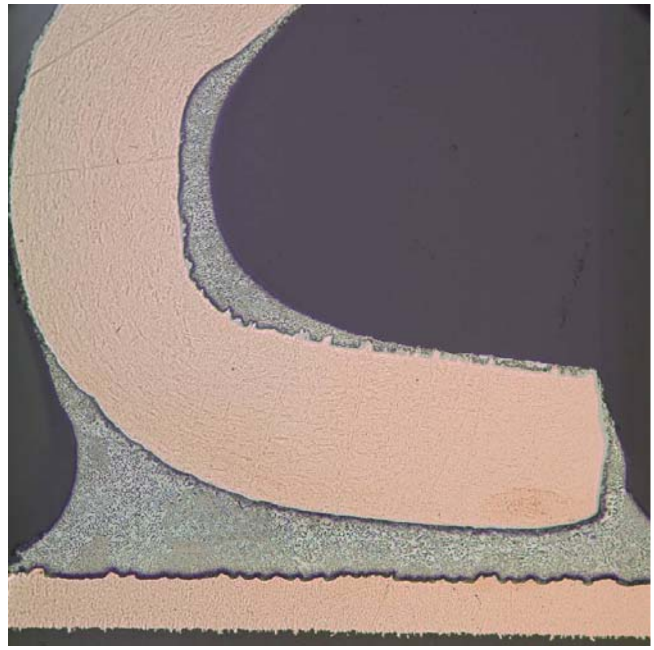

Figure 10: Cross-section of a solder joint

X-Ray Characterization

Reworked boards were inspected with 2D and 3D X-Ray protocol to ensure product quality. A 2D X-Ray auto-inspection algorithm was developed to detect solder defects and misaligned leads. The algorithm was tuned to ensure capture of significant defects, including low solder, non-wets and shorts. The program was tuned to minimize false calls which require operator interpretation. 3D X-Ray CT Scan was performed on any questionable solder joints flagged by the 2D inspection. For rework process qualification, full connectors were sampled with CT X-Ray, regardless of 2D X-Ray results.

Alternate Approach for Qualification

Due to the nature of the defects and the manner in which they fail an alternate test approach was developed. The test methodology sequence was as follows:

1. Mechanical verification at time zero
2. Multiple connector plug cycles in the system configuration
3. Mechanical verification
4. Accelerated thermal cycling

The Accelerated Thermal Cycling, ATC, followed by mechanical verification generally continued past the end of test until at least one solder joint had failed. By performing the thermal cycling and mechanical verification to detect the weak solder joints, it was possible to establish relative merit between the different rework methods.

Process selection activities began with samples from two different types of rework approaches. The first used the same basic tooling as the new build process and the second used a localized heat rework tool. Table 2 summarizes the results of this initial evaluation.

Based on this limited sample size, the two approaches appeared equivalent, so the localized vapor phase heating rework method was selected as the process to put through qualification testing. This process provided greater flexibility and less overall risks to the total assembly than the new build reflow process. The process was optimized and then samples were submitted to the reliability evaluation. The results of this testing are shown in table 3.

Table 2: A comparison of rework methods using mechanical and thermal stress methods

Process	Post Plug Cycle Result	1^{st} ATC Interval
Localized Heating- Sample 1	Pass	Pass
Localized Heating – Sample 2	Pass	Not Performed
Localized Heating – Sample 3	Pass	Not Performed
New Build Process - Sample 1	Pass	Pass
New Build Process - Sample 2	Pass	Pass

All samples passed the initial system level multi-plug preconditioning as well as accelerated thermal cycling. Testing was continued past the end of test until at least one part failed. These failures were deemed acceptable because when the acceleration factor of the test is taken into account they failed late enough in testing as to be considered end of life fails and will occur at a much a higher number of on/off cycles than systems will see in a lifetime. Therefore it was concluded that the localized rework process yielded parts exceeded all quality and reliability objectives.

Table 3: Reliability assessment

Sample	Post Plug Cycle Result	ATC Test
1	Pass	Pass
2	Pass	Pass
3	Pass	Pass
4	Pass	Pass
5	Pass	Pass
6	Pass	Pass

SUMMARY

We report a very large surface mount connector rework process which was developed in a short period of time. Different process modules were evaluated and the local vapor phase rework process proved itself to be the most stable and reliable process. As expected some defect modes were encountered during process development. Special tests were developed to find these defects through X-Ray analysis and mechanical verification testing**,** which led to further process optimization and elimination of these **defects.** A regime of plug testing and ATC testing was established to specifically stress the solder joints in such a way as to highlight the defects that were present thus enabling optimization of the process during development and selection of the best process to implement in manufacturing. Through this stress testing it was demonstrated that the process is repeatable and product produced is reliable.

ACKNOWLEDGEMENTS

We further wish to thank our co-workers who without their help this work would not have been possible. We wish to thank the IBM Fishkill Materials Analysis team for their analysis of the parts and our management who supported us in this effort.

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[9] Vapor Works Machine is made by R&D Technical Services, Burnsville, Minnesota.

[10] The rework nozzles were developed within IBM for this application.

[11] Air-Vac DRS 25. Air-Vac’s headquarters are in Seymour, CT.

[12] Soder-Wick is a registered trademark of the ITW Chemtronics Company, Kennesaw, GA.

[13] Mechanical Verification test is an IBM internally developed test.