QUALIFICATION OF A LEAD-FREE CARD ASSEMBLY & TEST PROCESS FOR A SERVER COMPLEXITY PCBA

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ABSTRACT

Since 1999, many OEM firms and their contract manufacturing partners have been converting their product portfolios to comply with EU RoHS regulations. Significant investment has been made within the electronics industry for the development of new lead-free materials and assembly processes suitable for consumer electronics applications. As a result, the majority of the industry's material, process, and reliability studies to date have focused on low-to-medium complexity products with only moderate field reliability requirements.

Many firms competing in storage array and server markets continue to take advantage of the "lead in solder" exemption permitted by the EU RoHS directive for these product segments. This exemption allows for the continued use of Pb bearing solder alloys in the manufacture of server and storage array products. In addition, the RoHS directive also states that reviews will be conducted at least every four years to assess the continued technical justification for such exemptions. Consistent with this global drive for ever more aggressive environmental stewardship, IBM is therefore actively exploring lead free alternatives for servers and storage array products.

This paper outlines the process used to qualify a lead-free entry level server complexity PCBA card. It highlights both the successes and technical challenges that remain to produce high reliability, high complexity, lead-free PCBAs (printed circuit board assemblies). It describes the end-to-end lead-free process qualification approach used including a summary of materials compatibility, primary attachment and rework assembly processes, in-circuit and functional test performance, time zero quality assessments, thermal fatigue reliability performance, and mechanical fragility issues.

This work serves as a foundation for further material, process and reliability studies that may ultimately enable a range of server products to confidently convert to lead-free card assembly. With the numerous technical and supply chain challenges that remain, continued industry development is required to ensure high quality and high reliability performance for complex PCBAs.

Keywords: server complexity PCBAs, Pb-free, reliability, server exemption, Pb-free assembly qualification.

INTRODUCTION

With the promulgation of the European Union's July 2006 RoHS directive many OEM firms competing within consumer electronic market segments have now made the switch from conventional SnPb compatible assembly materials and associated processes to new RoHS compliant, lead-free constructions.

Impacts of this regulatory driving force to change can be observed both from a technical and a supply chain point of view. Technically, material changes to PCB laminates and surface finishes, component constructions, solder pastes, fluxes, wave bar, hand repair and cleaning chemistries have been made. Associated assembly process changes to SMT, wave, hot gas rework, solder fountain rework, hand repair, and test have also been implemented. As a result, consumer electronics are now being built with entirely new material sets and assembly processes; of which the long term reliability and field performance of these new systems are basically unknown.

From a supply chain perspective, these technical changes have forged new preferred supplier relationships. Early adopters have influenced the entire electronics supply chain by selecting new materials, process equipment, and contract manufacturing partners deemed appropriate for new lead-free consumer electronic applications. First mover advantage has been gained by suppliers who have shown a differentiated service or product offering based on low-to-medium product complexity and reliability requirements.

The main challenge for OEM firms competing within high reliability market segments (e.g. server and storage product applications) is that they generally use the same supply chain to produce high complexity products. Material and process solutions deemed appropriate for consumer electronic applications may not necessarily be appropriate for high reliability applications. Subsequently, firms in this high reliability segment continue to use the lead in solder exemption, but are now preparing technical feasibility and supply chain readiness assessments in anticipation of a 2008 – 2010 EU RoHS exemption review.

INTENT & OBJECTIVES

The intent of this case study was to serve as a data reference to help better understand what card assembly and test successes have been achieved to date and what technical / supply chain challenges remain before higher complexity PCBAs can transition to lead-free assembly processes.

There were six key objectives to the study. They include:

- Build an entry-level server complexity PCBA within a manufacturing NPI (new product introduction) environment.
- Utilize an electrically functional product design for study of materials, assembly process, in circuit and functional test, mechanical hardware application, and environmental stress testing.
- Implementation of an end-to-end lead-free electronic card assembly and test (ECAT) assembly process including SMT, wave, hot-gas rework, solder fountain rework, hand iron repair, mechanical assembly, in-circuit test, and functional test.
- Assess new lead free materials and assembly process for use with entry-level server complexity production.
- Ensure time zero quality and assess reliability performance using current test standards.
- Evaluate thermal reliability, combination thermal-mechanical reliability, mechanical fragility, and general workmanship of a complex PCBA.

APPROACH

To date, much of the lead-free material, process, and reliability data that has been generated across the industry has been based upon test vehicle (TV) study [1]. This type of work has proven to be valuable in understanding baseline material and process performance. However, there are several drawbacks to this approach, when trying to bridge new knowledge to actual product manufacturing volumes. Drawbacks include: studies are generally under engineering control; evaluation does not stress actual manufacturing and NPI operations, test vehicles are designed for specific risk sites and variables of interest only, mechanical hardware has generally not been a focus of study, and most TVs monitor continuity of interconnects only; not stressing actual electrical function of components and the card within the system.

The approach used in this case study expands upon conventional test vehicle studies. Alternatively, a product vehicle (PV) was used for evaluation. Benefits of this approach include: a fully electrical functional design, full mechanical hardware assembly, complete ICT and FCT using firmware, supply chain interaction with NPI manufacturing operations, and the ability to perform accelerated life testing on an actual product design. One noted drawback of the PV approach is the higher hardware cost which typically drives smaller sample sizes.

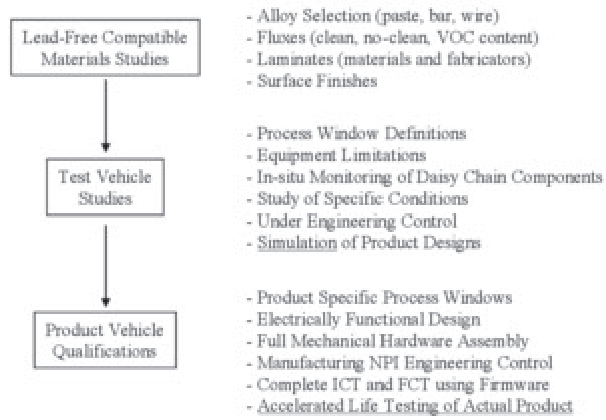

Figure 1: Lead-free product vehicle evolution.

Figure 1 above, shows the evolution and associated characteristics of lead-free material and assembly process studies using three different approaches – material studies, test vehicle studies, and product vehicle studies.

LEAD-FREE PRODUCT VEHICLE

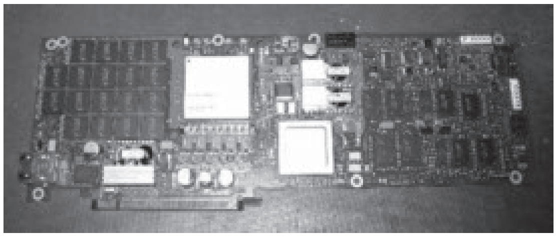

Figure 2: Entry-level server product vehicle

An Entry Level Server board is subjectively defined in the context of this study as a high density (>2K placements) PCBA requiring a relatively thin (<0.10”) PCB and a wide variety of array components and temperature sensitive devices. Design aspects of the entry level server product vehicle (PV) used in this study are shown below:

Dimension	4.4 x 12.3”
Thickness	0.062”
Surface Finish	OSP
Total Component Placements	2,348

Passives

0402, 0603, 0805, 1206 capacitors / resistors, Tantalum capacitors.

Temp Sensitive

SMT electrolytic capacitors, LEDS, oscillators, crystals.

Leaded Devices

QFP, QSOP, TSSOP, SOT, SSOP.

BGA Devices

PBGA1236, PBGA1147, PBGA117, PBGA104, PBGA96, FBGA71, TBGA48, μBGA52, CSP53.

Connectors

Power connectors, Ethernet gigabit, drone board headers, micro-fit headers, and Berg connectors.

The product vehicle integrated high density electrical component loading. In total the design incorporated 51 BGA placements with nine different BGA package technologies ranging from 1mm pitch organic flip chip BGAs, micro-BGA stacked die memory packages, and 0.5mm pitch chip scale packages. Both double-sided and mirrored BGA configurations were present on the assembly.

MATERIALS

The product vehicle incorporated a complete lead-free assembly compatible material conversion including PCB, SMT & PTH components, and assembly materials.

Printed Circuit Board

The PCB was qualified for use with elevated lead-free processing temperatures. Key elements of the qualification included evaluation of the laminate material, PCB fabricator capability, and manufacturing location. Qualification included subjecting a representative raw card TV through simulated lead-free preconditioning protocols, followed by a battery of reliability tests. [2]

BGA Type	Pitch (mm)	Body Size (mm)	Max Temp (C)	Ball Alloy
FCBGA	1.0	42	245	SAC305
FCBGA	1.0	35	245	SAC305
PBGA	1.0	14x10	260	SAC405
LFBGA	0.8	14x15	260	SAC305
LFBGA	0.8	13x5	260	SAC405
TBGA	0.75	8x7	260	SAC305
FBGA	0.8	10x16	260	SAC305
µBGA	0.65	7x5	260	SAC305
CSP	0.5	3x5	260	SAC405

Table 1: BGA technologies for qualification

BGA Components

A bill of materials scrub was conducted to ensure that all components (SMT and PTH) were compatible with elevated lead-free processing temperatures. There were nine different BGA package constructions included. Attributes of each component type is shown above in Table 1. All BGA devices employed SnAgCu ball metallurgies.

Temperature Sensitive Devices

As part of the bill of materials scrub, an evaluation of all temperature sensitive devices was conducted. Currently, many components including electrolytic capacitors, crystals / oscillators, and tantalum capacitors have significant temperature and time at temperature restrictions. Identification of these devices is critical to ensure that they are properly monitored using thermocouples during SMT reflow profiling activities; making certain that time / temperature limits are not exceeded. If limits are exceeded, the long term reliability of the device may be significantly degraded. There will likely be no externally visible or detectable damage using x-ray or acoustic microscopy that would suggest that the device has indeed been damaged.

Table 2 shows the various limitations of identified temperature sensitive devices included on the product vehicle.

Component Description	Temperature Limitation
Aluminium SMT Electrolytic Capacitors	Preheat 100-150C for 120 sec. Peak Temp 250C for 5sec. Total TAL 40 sec max.
Tantalum Capacitors	Preheat 150 – 180C for 120 sec Peak Temp: 250C for 5 sec. Total TAL 40 sec max.
SMT Crystals / Oscillators	Limited time at temperature. Peak reflow temp 260C. Max time @ peak 5 sec. Max TAL 90 sec.

Table 2: Temperature sensitive devices

As a result of identifying all temperature sensitive components on the PV the following actions were taken:

- All SMT electrolytic capacitors were hand soldered only. Currently, these components cannot withstand lead-free SMT reflow temperatures.
- The maximum board temperature target was set at 250C for all processes.

Assembly Materials

A no-clean, VOC-free lead-free assembly material set was employed. All materials were selected through a comprehensive evaluation of industry available lead-free materials by the CM. Selection criteria included process yield, product quality and reliability considerations. A summary of material types is shown below in Table 3.

Reflow Atmosphere

SMT reflow and hot-gas rework operations used an inert nitrogen atmosphere (≤100 ppm O2 controlled), while primary attach wave solder, solder fountain rework, and hand iron repair operations were conducted in air.

Material	Alloy / Chemistry Used
Solder Paste	No-clean, type III, SAC405
Bar - Primary Wave	SAC405
Bar - Solder Fountain	SnCuNi
Repair Wire	Cored wire, SAC405
Wave Flux	VOC free, No-clean
Repair Flux	No-clean liquid and tack flux
Heat Sink Attachment	Thermal grease and putty

Table 3: Lead-free assembly materials employed

Surface Insulation Resistance (SIR)

All lead-free materials were tested for surface insulation resistance compatibility, prior to product assembly. An IBM internal SIR test vehicle was used for testing. Electromigration dendritic growth was monitored at elevated temperature and humidity, under an electrical bias of 15V.

QUALIFICATION BUILD HARDWARE

Hardware assembly qualification consisted of evaluation of both primary attach and forced rework card quantities.

Table 4 shows the qualification test matrix employed for this evaluation.

Cell	Assembly Type	Environment Testing
1	Primary Attach	ATC 1 CPH for 1000 cycles
2	Forced Rework	
3	Primary Attach	ATC 1 CPH for 3000 cycles
4	Forced Rework	
5	Primary Attach	High Temperature Storage (HTS)
6	Forced Rework	
7	Primary Attach	Shock / ATC 1000 cycles
8	Primary Attach	Vibration / ATC 1000 cycles
9	Primary Attach	Shock/Vibe/ATC 1000 cycles
10	Primary Attach	Monotonic 4 Point Bend Testing
11	Forced Rework	
12	Primary Attach	t_0 Construction Analysis
13	Forced Rework	
14	SIR Test Vehicle	SIR Electromigration Testing

Table 4: Qualification environmental test matrix

All assemblies were tested as fully built sub-systems including all mechanical hardware (stiffeners, heat sinks, and blowers). All hardware was required to pass both ICT (in-circuit) and (functional) FCT prior to all test starts.

PROCESS

Primary attachment operations included printing, solder volume analysis, placement, SMT reflow, PTH wave solder, and final visual and x-ray inspections. Forced rework included BGA hot gas, PTH solder fountain, and hand repair operations.

SMT Assembly

Lead-free process windows are much smaller than those for the conventional SnPb process [3]. Therefore, improved accuracy is required during SMT reflow profiling activities. Thermocouple attachment methods are critical in ensuring minimum solder joint temperatures are met, TAL (Time Above Liquidus, 217C) intervals are properly measured, temperature sensitive device limitations are not exceeded, and PCB temperatures do not exceed qualified temperature limits.

The SMT assembly process for the product vehicle is summarized:

- 18 thermocouples (TCs) were used to monitor solder joint, component body, and PCB times at temperature. An example of TC locations is shown in Figure 3.
- SMT peak reflow temperatures generally ranged from 230C to 249C including joint and body temps.
- SMT time above liquidus values generally ranged from 49 to 100 seconds.
- PCB maximum peak temperature was 251C.

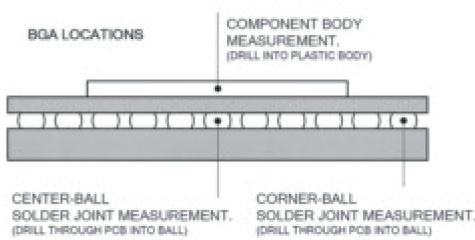

Figure 3: TC location example for BGAs.

PTH Wave Assembly

Wave solder processing was conducted in air with localized nitrogen inerting. Time between SMT reflow and PTH wave solder was limited to 24 hours to promote 100% hole-fill.

The PTH wave solder process is summarized below:

- In total 13 connector placements using 7 different connector technologies were soldered to the PV.
- 10 thermocouples were used for profiling.
- Preheat temperatures ranged from 100 to 110C.
- Solder pot temperature was set at 265C.
- Nominal contact time was 5 seconds.

Mechanical Assembly

Increased mechanical fragility of lead-free solders has been reported throughout the industry as being a significant long term reliability concern [4,5]. To help learn more about increased fragility issues, all mechanical hardware was added to the product vehicle including backside stiffener, heat sinks, blower assembly, and final tail stock as shown in Figure 4. Inclusion of mechanical hardware and associated manual process exposure was an important element identified within qualification testing.

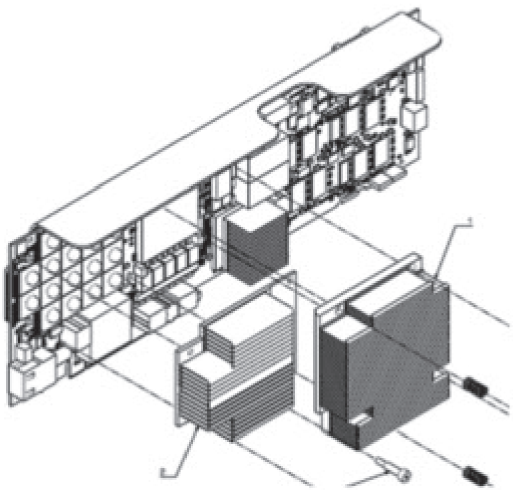

Figure 4: Mechanical assembly of product vehicle

SMT Hot Gas Rework

Assessment of the lead-free hot gas rework process was conducted using five different BGA technologies. Component types are shown below in Table 5. All BGA components were qualified to a 2X rework process.

BGA Type	I/O	Pitch	Body Size	MSL	Ball Alloy
FCPBGA	1236	1mm	42mm	3	SAC305
FCPBGA	1147	1mm	35mm	3	SAC305
PBGA	117	1mm	14x10mm	3	SAC405
BGA	104	0.8mm	14x15mm	3	SAC305
CSP	53	0.5mm	5x3mm	1	SAC405

Table 5: BGA types assessed during hot gas rework

Extremely long pre-heat times (to reach 150C) were observed. A range of 10 to 27 minutes depending on the BGA component type was recorded; Figure 5.

The BGA hot gas rework process is summarized below:
- Atmosphere was inert nitrogen locally during reflow.
- Min joint temperatures ranged from 230 to 234C.
- Max body temperatures ranged from 235 to 250C.
- TAL times ranged from 63 to 86 seconds.

PTH Solder Fountain Rework

Copper dissolution has been reported [6,7] as a quality and potential reliability issue during SAC alloy based solder fountain rework operations. Figure 6 shows the result of a SAC alloy solder fountain rework on the product vehicle; no copper remains at the knee, annular ring, or barrel.

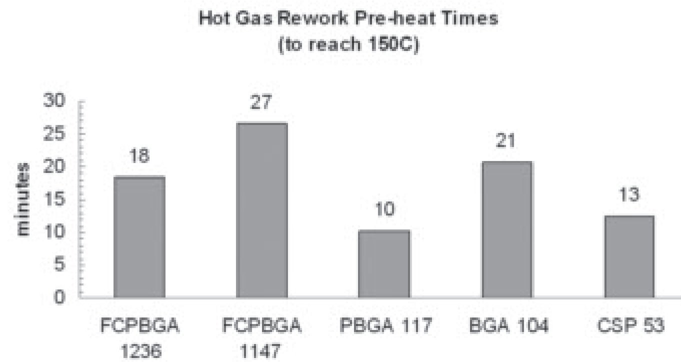

Figure 5: Long pre-heat times for lead-free BGA rework

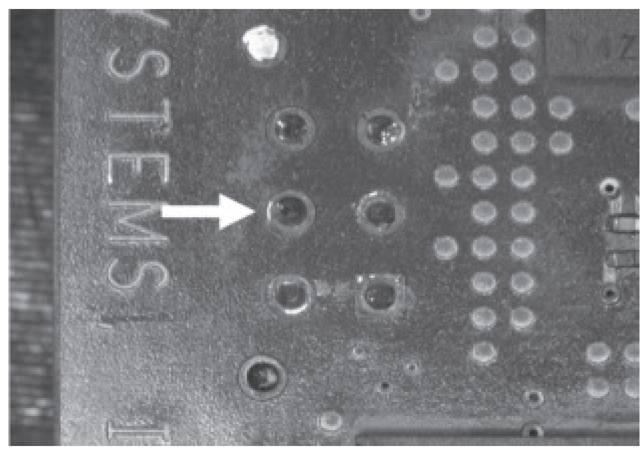

Figure 6: Cu dissolution of PTH barrels using SAC alloy

To help minimize the copper dissolution effect, an alternate alloy process was developed using a SnCuNi alloy along with a new patent pending flow-well nozzle and new pre-heat procedures. Figure 7 shows a cross section of the result of using the new alternative alloy solder fountain process. Copper plating measurements at the knee were nominally 1.4mils; satisfying 0.5mil minimum copper thickness requirements. The new process was determined to yield significant improvements in Cu dissolution rates allowing for a wider process window and a 2X connector rework process.

There were three different PTH connector types evaluated during solder fountain rework trials. All component types were qualified to a 2X solder fountain rework process.

The solder fountain rework process is summarized below:
- New preheat temperature setting was 160C. The focus was

placed on heating the card and the replacement component to improve hole-fill.
- Process generally included 5 to 6 solder pass cycles with 10 second duration. Addition of the new part generally took place on the second to last cycle.
- Max peak joint temperatures ranged from 232 to 237C.
- Time above liquidus ranged from 37 to 62 seconds.

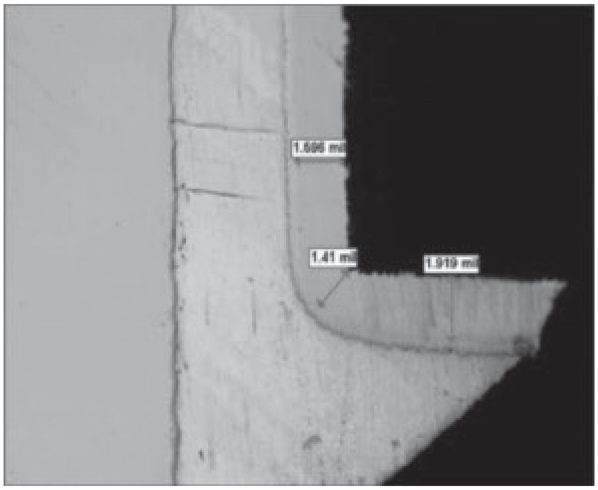

Figure 7: Alternate alloy solder fountain cross section

Hand Repair & Visual Inspection

Lead-free solder systems are known to have lower wetting properties, making the flow of solder during hand repair more sluggish. As a result, many operators are inexperienced with the art of new lead-free hand soldering. Longer contact times, use of excess flux, plastic body burns, and excessive touch up (due to grainy solder joint appearance) have been common issues observed during the process.

There were three different component types evaluated during hand repair rework trials including electrolytic capacitors, crystals, and 0402 passives. All component types were qualified for a 1X rework process.

The hand repair rework process is summarized below:
- Iron temperature was set at 800F (427C) with the use of no-clean flux cored wire.
- A limited localized use of no-clean liquid and tack flux was allowed on the product vehicle.
- Confirm liquid flux thermal activation to ensure potential paths for SIR electromigration are minimized (due to thermally un-activated flux).

In-Circuit & Functional Test

After primary attach and forced rework lots were completed, all assemblies were loaded with firmware images and tested at ICT and FCT.

Functional test (FCT) was the primary feedback tool for environment qualification tests including ATC, HTS, and Shock & Vibration testing. During test, assemblies were pulled from chambers and functionally tested every 250 cycles (hours for HTS).

QUALIFICATION TESTING

All qualification cards were required to pass both ICT and FCT tests prior to environmental test starts. Once all assemblies were confirmed functional, cards were preconditioned using thermal ship shock (TSS) conditions to simulate transportation exposures during product distribution activities.

Next, all assemblies were visually and x-ray inspected. Defects and workmanship levels were measured using IPC 610 Class 2 requirements. The test matrix for all qualification assemblies is shown in Table 4.

Test Definitions

TSS: Thermal Ship Shock. 5 cycles. -40/+65C. 1CPH per IBM ES 0871889. Visual and functional test conducted after completion of 5 cycles.

1CPH: One Cycle Per Hour.

ATC: Accelerated Thermal Cycling. 0-100C. Visual inspection and functional test conducted every 250 cycles. Following IPC 9701 thermal profile protocol.

HTS: High Temperature Storage. 125C for 1000 hours. per IBM ES 0871889. Visual inspection and functional test conducted every 250 hours.

Shock: 15G 20ms trapezoidal pulse, 20G 25ms trapezoidal pulse.

Vibe: 0.33G sweep to 200 Hz, random 1.04 grms, 15G 20ms trapezoidal pulse.

Bend: Following IPC 9702 without the use of daisy chain nets. Use of local strain gauges on component and local PCB locations to detect first fail point.

SIR: 300 hours. 50C / 80%RH per IBM ES 0871889. Minimum resistance threshold is 1.0 E7 ohms. Electrical bias 15V.

Environmental Test Results

Qualification testing duration was seven months. Thermal reliability evaluations were conducted using cells 1-6. Combination thermal/mechanical reliability evaluations were conducted using cells 7-9. Mechanical bend, reliability evaluations, and handling assessments were conducted using cells 10-11. Workmanship quality evaluations were conducted using cells 12-13. Table 6 shows the performance summary of all ECAT environmental stress tests.

Test Cell	Test Environment	Result
1	ATC 1000 cycles; 1CPH	Pass
2		
3	ATC 3000 cycles; 1CPH	TSOP Joint Failures Observed
4		
5	HTS	Pass
6		
7	Shock/ATC 1000 cycles	Pass
8	Vibe/ATC 1000 cycles	Pass
9	Shock/Vibe/ATC 1000 cycles	Pass
10	4 Point Bend Testing	Pass
11		
12	Time Zero Construction Analysis	Pass
13		
14	SIR Electromigration	Pass

Table 6: Summary ECAT qualification performance

TSOP Observed Failures

During extended ATC testing TSOP solder joint failures were observed. An example is shown below in Figure 8.

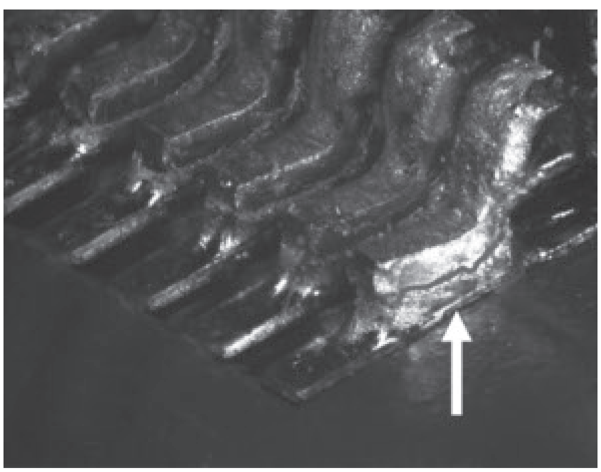

Figure 8: TSOP solder joint thermal fatigue failure

First failures were reported starting as early as 1000-1250 cycles. Root cause determination for these failures is still in progress at the time of publication. Initial investigation has revealed no anomalies in the SMT assembly process that would contribute to such failures. This unexpected failure is a good example of new failure mechanisms that may be present in functional card designs, but unanticipated in a TV design. Much of the data shown through test vehicle studies to date would indicate that this is an early failure, but with the added mechanical stress exposures during back-end mechanical assembly, failures such as the one reported here may be more prevalent; indicating increased sensitivity to card handling during the PCBA manufacturing process.

Time Zero Construction Analysis Results

Construction analysis was conducted on both primary attach and forced rework qualification hardware. Below is a summary of results.

- Visual inspection included SMT lead-free solder joint assessment, BGA collapse evaluation, and defects monitoring. Pass.
- X-ray analysis included SMT and PTH solder joint voiding and PTH barrel fill. Pass.
- Intermetallic formation for SMT and PTH solder joints was acceptable for primary attach and forced rework samples. Cu dissolution was minimized for PTH rework assembly; resultant 0.5mils minimum Cu thickness attained.
- Scanning acoustic microscopy was conducted on selected primary attach and forced rework BGAs to verify first level package survivability through all process steps. Pass.

CONCLUSIONS

With all qualification test cell analysis complete, the product vehicle was determined to be qualified for the following three elements:

- New lead-free assembly material compatibility usage.
- New lead-free primary attachment processes including SMT, wave, and hand solder.
- New lead-free rework processes including hot gas rework, solder fountain, and hand repair.

The resulting work shown in this case study demonstrates several successes. They include:

Successes

1. Confirmed capability to build lead-free entry-level server PCBA assemblies to meet currently known thermal and mechanical reliability requirements.

2. End-to-end PCBA assembly, rework, and test process qualified for use with an entry-level server complexity assembly.

3. Control of new materials and processes through new lead-free engineering specifications.

4. Current capital equipment sets within server manufacturing operations are generally capable of producing new lead-free entry-level server products. This confirmation should help to minimize capital expenditures during conversion.

5. Results of qualification environmental testing as currently defined were successful – Pass. ATC, HTS, bend testing, time zero construction analysis generally yielded good results, with the limita-

tion that lead-free field life prediction models for these accelerated life tests are not yet validated.

6. Lead-free design guidelines are appropriate. Some minor changes are required, but in general no major changes are required for card designers.

7. Material sets (as tested) are suitable for lead-free server reliability requirements. A no clean, VOC free, lead-free process has been successfully qualified. SIR and environmental test Pass.

8. New lead-free rated laminates are capable of withstanding elevated lead-free processing temperatures and can demonstrate good reliability performance provided adequate raw card qualification trials are conducted. (and the PCB design falls within the specific technology limits covered by those qualification trials and limited temperature profile ranges).

9. Lead-free rework capability verified. Hot gas, solder fountain, and hand repair processes fully qualified. Good performance during testing.

10. Implementation of an alternate lead-free alloy solder fountain process helping to reduce Cu dissolution reliability hazards.

Although this study has shown several technical successes, it has also clearly demonstrated even more technical and supply chain issues that require resolution before high complexity lead-free server assemblies can be built reliably in large volumes world wide. The following sections outline the numerous reliability, assembly technology, manufacturing / NPI, and supply chain issues that have been identified.

Remaining Reliability Issues

1. Testing acceleration factors and field performance.

2. Mechanical fragility issues during mechanical hardware assembly, ICT / FCT test, and sub assembly construction. Need to better understand where static and dynamic mechanical loads arise within the assembly process to minimize mechanical fragility exposures.

3. New component failure mode examination. Extended ATC testing of product vehicles will likely continue to show new failure modes that test vehicle studies may not show. Added mechanical stress during back-end PCBA processing will likely play a more significant roll in overall product reliability.

4. Printed circuit board laminate material and board fabrication facility qualifications. Continued work is required to ensure laminate materials and structures produced at specific PCB fabrication locations can survive elevated processing temperatures. Both the material and fabricator's capability is essential in ensuring reliable laminate performance. These evaluations must be extended to thicker PCBs with more complex structures to support higher complexity PCBAs.

5. Temperature sensitive device monitoring and improvements. Devices including sensitive BGA devices, optics, LEDs, electrolytic caps, oscillators, etc. Currently many of these devices cannot withstand elevated lead-free SMT processing. Further work by component suppliers will be needed to ensure survivability of these components through the manufacturing process.

6. PTH connector plastic housing temperature ratings. More work is needed by connector suppliers to ensure that parts will survive extended dwell times during PTH solder fountain rework excursions. Currently, the majority of lead-free compatible connectors are only rated for primary attach wave processing and not rework.

7. Increased investment needed for qualification hardware quantities, longer development cycles, and extended test / analysis times to ensure long-term thermal and mechanical reliability of new lead-free systems.

Remaining Assembly Technology Issues

1. Migrate from test vehicle studies to product vehicle qualification studies to clearly identify the full scope of lead-free technology challenges remaining. Product vehicles integrate mechanical hardware, back-end card flexing – mechanical fragility issues during ICT, heat sink attach, sub-system build. Use of FCT as the primary feedback tool, instead of in-situ monitoring.

2. Thermal profiling accuracy improvements are needed. Smaller lead-free process windows mean increased need for improved spatial resolution of thermal measurements during process set up. Tight process control needed with increased focus on new process window profiling and profile card construction.

3. Lead-free component and PCB temperature limitations will likely restrict the use of convection reflow soldering equipment for larger server card assembly. Investigation of alternate technologies such as vapour phase soldering tools is required.

4. Continued surface finish study and implementation. Alternatives including ImmAg and lead-free HASL will be important to keep narrow process windows open for longer periods of time during processing.

5. Wave and hand repair flux development. Current formulations continue to leave high levels of residue. Continued improvements in flux chemistries are required for lead-free no clean processing of server complexity assemblies.

6. Copper dissolution and hole-fill of PTH solder joints. Alloy selection and process window optimization for wave solder / solder fountain processes on large PCBAs > 0.125" thick.

7. Lead-free compliant pin rework process development. Ensuring that Sn plated compliant pin parts will not damage internal PCB barrel structures after a 2X rework process.

8. Throughput issues for lead-free BGA hot gas rework processing. Extremely slow preheat times observed, improvements to tool sets are likely required.

9. False fails during in-circuit test. Hardened no clean lead-free flux residues have been shown to increase NDF rates (no defect found). Pin probe materials and geometries, PCB surface finishes, and clam shell designs require further development.

Remaining Manufacturing / NPI Operational Issues

1. Shop floor control. Improved segregation and control is required on manufacturing floors using multiple alloys (lead-free and tin-lead) and flux chemistry combinations (no-clean and water soluble).

2. Operator skill, workmanship, and training improvements required. Operators are still generally unfamiliar with new lead-free:

a. Hand soldering techniques using higher melting (sluggish) solders.

b. Visually inspecting final assemblies for defects as per IPC 610 requirements.

c. Segregation of SnPb and lead-free material sets on the shop floor.

3. Quality systems and SPC monitoring. Continuous improvements required here to ensure that defects and escapes are minimized within new lead-free processes. With limited lead-free experience, increased focus on statistical process control (SPC) will be required in the near-term to ensure quality levels of shipped product remain high.

4. 10 to 12 zone convection oven configurations are required for higher complexity lead-free SMT assembly. Capital equipment planning and investment will be required.

5. Dedicated lead-free wave soldering tools are required for primary attachment assembly. Swapping SnPb and lead-free solders within a single wave tool should be avoided because it will cause solder pot contamination and will result in a reduction in reliability performance of the final PTH solder joint. Capital equipment investment required.

6. Dedicated lead-free hot-gas rework tools are required for BGA rework assembly. Separate workstations with clearly labelled solders / fluxes / consumables are required. Capital equipment investment required.

7. Dedicated hand iron rework benches are required for manual rework assembly. Separate workstations with dedicated hand irons, consumables, and chemicals are required. Capital equipment investment required.

Remaining Supply Chain Issues

1. Divergence of global environmental product regulations significantly increases compliance requirements. Various regional regulations requiring cooperation include EU RoHS, Chinese MII Regulations, and other emerging directives from Korea, South America, and North America. [8]

2. Longer assembly process development times required for complex lead-free PCBAs conflict with shortening time to market and life cycle product demands. Therefore an increased focus on planning is required to ensure proper technical qualification work can be completed on time for product launch.

3. High levels of engagement and engineering resource requirements during qualification efforts between the OEM and contract manufacturing partner. Lead free product conversion will continue to consume significant amounts of time, money, and engineering resources.

4. Product complexity experience levels. Due to the widespread usage of the RoHS Pb-in-solder exemption for higher complexity, high reliability products, lead-free production experience within the contract manufacturing supply base and the industry remains primarily limited to simpler, non-Server PCBAs. Skill and experience levels with high complexity, high reliability products has not had the opportunity to mature. Manufacturing facility audits to assess general capability, infrastructure, and capacity are therefore recommended prior to new lead-free complex assembly NPI engagements.

5. Technology transfer. New lead-free material and process change recommendations continue to accrue across the industry. It is critical that contract manufacturer engineering and development teams transfer such advancements to operational manufacturing teams in a thorough and timely manner. Without this routine transfer, advanced lead-free product constructions will not benefit from hard won industry learning.

6. Standardization of lead-free material and assembly process requirements. Industry standards are required for determination and clear identification of all component temperature exposure limitations.

RECOMMENDATIONS

Many successes and challenges have been documented as a result of this work. The successes provide optimism that some products currently using the Server / Storage lead in solder exemption could transition to lead-free assembly. The challenges highlight that significant work remains before the majority of high reliability systems could safely use lead-free assembly processes. The industry must continue to uncover and address those concerns that can only be found by exercising the full manufacturing process on higher complexity assemblies. Additional work remains to understand the relationship between the results from traditional reliability tests to actual field reliability performance. Building on the experience started with the transition of consumer electronics and extending it with additional studies of higher complexity assemblies will continue to expand the use of lead-free assembly to new products. These on-going studies will also highlight the limits of a safe transition that may require the lead in solder exemption to continue in force for high reliability / high complexity systems until reliability of the PCBA assembly process for these products can be demonstrated.

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BIOGRAPHIES

Matt Kelly currently works for IBM as a Senior Engineer helping to convert the firm's portfolio of electronic products, focusing on high reliability Server and Storage applications, to new RoHS compliant constructions. The objective of this global role is to help ensure that new R&D technologies (including new materials & processes) are properly implemented across IBM's hardware manufacturing supply chain.

Matt holds a Bachelors of Chemical Engineering from McMaster University, is a licensed professional engineer in the province of Ontario, and has received his MBA in Strategic Management from Sir Wilfrid Laurier University.

Marie Cole is a Senior Technical Staff Member in Interconnect Technology Development in the IBM Integrated Supply Chain. She holds a B.S. in Chemical Engineering from Rensselaer Polytechnic Institute and an M.S. in Materials Science from Columbia University. For more than 10 years she led IBM's development efforts on CBGA and CCGA packaging. Recently, she drove the development and implementation of Lead Free packaging and RoHS infrastructure for IBM Microelectronics. In her current assignment, she is leading the technology development for the conversion of IBM systems to Lead Free soldering.

Jim Wilcox is a Senior Technical Staff member in the IBM Integrated Supply Chain Division. There he played a principal role in overseeing the conversion of the IBM card assembly infrastructure to RoHS compliant operations and is currently focused on establishing the technical knowledge base required to assemble reliable server class products with Pb-free soldering technologies. Jim was granted the BS and MS degrees in Metallurgical Engineering from Michigan Technological University and the Ph.D. degree in Materials Science from Cornell University. He holds 34 US patents covering a wide range of electronic packaging technologies.

Jim Bielick (not pictured) currently works in the IBM Integrated Supply Chain as a procurement and qualification engineer, focused on complex electronic card assembly hardware design, qualification, and failure analysis. Jim holds a Bachelors Degree in Metallurgical Engineering from the University of Illinois, Urbana-Champaign, IL.

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Timothy holds a Bachelors of Science from St. Cloud State University and has had an extensive career in the electronics assembly and qualification field.

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David holds an Associates of Science Degree in Electronics Engineering Technology from Rochester Community College. David also holds a Machine Tool and Die diploma from Winona Area Vocational Institute.