

**Technology Mission
to Assess the Status of
Lead-free Soldering in
Japan**

19-23 February 2001

Christopher Hunt

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ABSTRACT

NPL formed a key part of a mission to Japan to assess lead-free soldering technology organised by DTI International Technology Promoters, and promoted by the SMART Group. The mission found a number of key issues. The initial driver for lead-free was the proposed EU WEEE directive in 1998, but today important drivers are company's own environmental targets and competition between these companies. Interestingly the solder alloy choice of the future will be a SnAgCu alloy, with SnZnBi forming an interesting transitional solution to material and component heat durability issues. In Japan soldering equipment is being modified to minimise the temperature range at the soldering temperature. The necessary equipment investment, the wider use of nitrogen, and the necessary technology know-how may put a large strain on SMEs not in an OEM supply chain.

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1 OBJECTIVE

To establish the status of lead-free soldering in Japan. This included looking at the drivers, technology issues, supply issues, cascading of technology through the supply chain, and determining future implementation plans.

2 EXECUTIVE SUMMARY

A technology mission supported and organised by DTI International Technology Promoters, and promoted by the SMART Group, visited Japan for a week to assess the status of lead-free soldering. The mission team comprised a total of six experts from the UK, and covered a wide range of disciplines. A very compressed programme arranged jointly by the British Embassy and JEITA (Japan Electronics and Information Technology Industries Association) allowed the team to visit a wide range of facilities. The team gained access to managers and directors at a senior level in leading Japanese companies.

Important information was established in a number of areas.

- The driver that catalysed the Japanese into moving forward with lead-free soldering was the publishing of the 2nd draft of the proposed WEEE directive. There was some preliminary work following the earlier proposed legislation in the early nineties in the USA, but it was the WEEE that really kick started it.
- The Japanese will be using SnAgCu for most applications in the future. Significant development of SnZnBi has taken place, and this alloy will be used where there are component temperature issues. The SnAgBi alloy family no longer appears popular, although Sony is still using an alloy from this family.
- Some novel attachment methods are being developed as a replacement for lead-rich high temperature solders.
- Reflow ovens are being designed to improve airflow and minimise the temperature range in ovens.
- Nitrogen is being used to widen the process window to allow flexibility in switching between alloys and hence avoid reoptimising oven settings. Nitrogen is also required with the SnZn alloys.
- There has been significant work on the fillet lifting phenomenon to minimise the effect. Solutions involve new pad and resist rules.
- A future PCB finish of hot air levelled SnAgCu, was discussed.
- The Japanese Government has funded two big research projects that were managed by trade organisations, and there are currently two further proposals being considered.
- OEMs have invested a great deal in research and developing lead-free technology. This reflects the structuring of Japanese companies, which tend to cover a wide range of disciplines. Japanese SMEs not in an OEMs supply chain will be disadvantaged by not receiving lead-free technology.

This report covers the information presented to the mission team during the visit and is not an exhaustive analysis of the current Japanese lead-free situation.

3 JAPANESE LEAD-FREE PERSPECTIVE

3.1 DRIVERS & MARKET FACTORS

3.1.1 Legislation

There is no imposed legislation within Japan directing industry to implement lead-free technology. There will be legislation at the land-fill point in a proposed "Recycled Materials Utilization Promotion Law" that will be enforced in 2003. This has been passed through cabinet and the legislation focuses on reuse and recycling of products including automobiles. Discussion of manufacturer's responsibility is in progress and is being set up by an industrial panel. Hence the initial drivers were external to Japan.

The main driver to lead-free appears to be the proposed European legislation Waste of Electronic and Electrical Equipment (WEEE). The published second draft from 1998 was the starting point for a number of Japanese companies in developing lead-free technology. From that point these companies put in place development programmes to build the technology for lead-free soldering. Road map targets are given in Appendix 2.

However, today other factors are also important and internal competition between companies is a significant factor. The companies visited are including environmental targets in their mission statements. Typically they have created senior environmental management positions and have set targets which impact on personnel's pay and progression. This is now a big driver internally within Japan. Hence the legislation that catalysed the move to lead-free technology has now become of secondary importance, especially since the WEEE implementation date has been put back to 2008.

The mission was informed of a committee in Geneva that is considering the impact of WEEE on world trade and the Japanese have been making representations to this committee.

3.1.2 Definition of Lead-free

There was a mixture of how strictly the term lead-free is applied. Clearly products termed lead-free in the past did not necessarily have to have lead-free termination finishes. Hence, they were not strictly lead-free. But with more components available today, there us a move to the definition that all the solderable surfaces and solder alloy must be lead-free. The internal component structure is not considered. What Pb% will be considered lead-free has not been agreed, but it is widely accepted that purity levels, typically 0.1%, in current standards will become the norm.

3.1.3 Marketing of Lead-free

No Japanese company currently intends to market products as lead-free. The Panasonic mini-disk player is the only example where the product has been clearly labelled as lead-free, but the literature does not emphasise this, but simply supplies this as information. The green leaf symbol has not been widely applied. In an area of Tokyo where there is street to street electronics consumer shops, the shop assistants were largely unaware of the lead-free issue. Since no Japanese company is entirely lead-free at present it is probably the case that they don't wish to overplay lead-free as an issue.

However, within a week of the missions return, Panasonic screened an advert on National TV that extolled the virtues of their product in an environmental context and mentioned the

elimination of lead from the solder. This could be a major step in using the green credentials of the company to sell a product.

It is also clear from a selection of press releases, see Appendix 6, that the Japanese companies have been press releasing their progress with lead-free. So while not overtly publicising to the customer in the high street, they have been feeding the industry with their progress, and in doing so ratcheting up the level of awareness and competition.

3.1.4 Implementation Examples of Lead-free

A number of companies manufacturing in the consumer market already have a range of products that are lead-free, see Appendix 1. They all expect to be fully lead-free by 2004 and most of them will be lead-free by mid 2002. Manufacture of more complex and difficult to assemble boards, which have reliability issues, will also be lead-free within this time-scale.

3.1.5 Dissemination of Lead-free Knowledge

Apart from general articles and conference proceedings, dissemination is carried out in a selected way. Information and knowledge are cascaded down through the supply chain. So SMEs not linked in with OEM will therefore struggle to implement lead-free. The large OEMs visited by the mission had dedicated training facilities for their staff and those from their sub-contractors.

For overseas subsidiaries advice is provided, but local factors do play a significant factor in lead-free implementation. Hence, the uptake of lead-free expertise in these circumstances will be selective

3.1.6 Cost of Lead-free Implementation

The cost of lead-free will largely be met internally and will not be passed onto customers. Currently consumer products are being sold that are lead-free and there is no cost penalty.

3.1.7 Electronics OEM Structure

Most of the Japanese companies visited show a high degree of vertical integration. Hence there is a tendency to see manufacture of component parts as well as producing the assembly. Denso revealed a raft of products and production skills. This included manufacturing the production equipment, some of the components (they have their own silicon fab), as well as the completed assemblies. We did not see it on our visit, but Matsushita (Panasonic) also have a wide range of manufacturing skills. Currently outsourcing and sub-contracting appears to be a rarity. The size of these companies and their wide skill base allow them to undertake extensive research in the lead-free area. These company profiles are unlike a large number of companies in Europe and the US, where a high degree of outsourcing for sub-contract assembly has taken place.

3.1.8 Lead-free Product Examples

All the companies supplying to the consumer market have a portfolio of lead-free products (audio, camera, video, computers). In addition some of the companies are supplying telecom and Internet switches and back-planes that are lead-free. Wide ranges of products are now being manufactured with lead-free, which does include double-sided assembly.

3.1.9 Labelling

There has been no agreement on any labelling scheme, although it is generally recognised that one would be desirable. One significant issue will be the definition of lead-free. The

current definition of lead-free in the ISO standard for the solder joint of a maximum of 0.1% impurity level is likely to be adopted. There are no proposed definitions for assemblies.

3.2 MATERIALS

3.2.1 Components

3.2.1.1 *Process Temperature Qualification*

The Japanese OEMs appear to have accepted, compared to those in Europe and the USA, that they have to do more to modify the process, rather than expect the material and component suppliers to provide parts qualified to higher temperatures. This explains, the Japanese choice of alloys which incorporate Zn and Bi. The component suppliers have not universally decided to qualify parts to higher temperatures, with no immediate acceptance of the 260 °C qualification temperature as appears to be the case in the US. Mostly parts are currently qualified to 240 or 245°C.

The Japanese are using parts above the suppliers' specification, which means they are effectively requalifying parts themselves. In addition, they are working in specific cases with suppliers on parts such as electrolytic capacitors.

With temperature sensitive parts, such as those with low Curie point magnetic materials they are using the SnBi eutectic alloys.

3.2.1.2 *Component Termination Materials*

This did not appear to be a particular issue. It appears there is already a fair degree of use of SnBi as a lead-free replacement. There did not appear to be much interest in PdNi, primarily due to cost. There is interest in the other lead-free finishes being considered by the rest of the world, but the Japanese did not appear to be in any different position. They are evaluating pure tin in some cases, and evaluating conductive adhesives as a surface finish.

3.2.2 Printed Circuit Boards

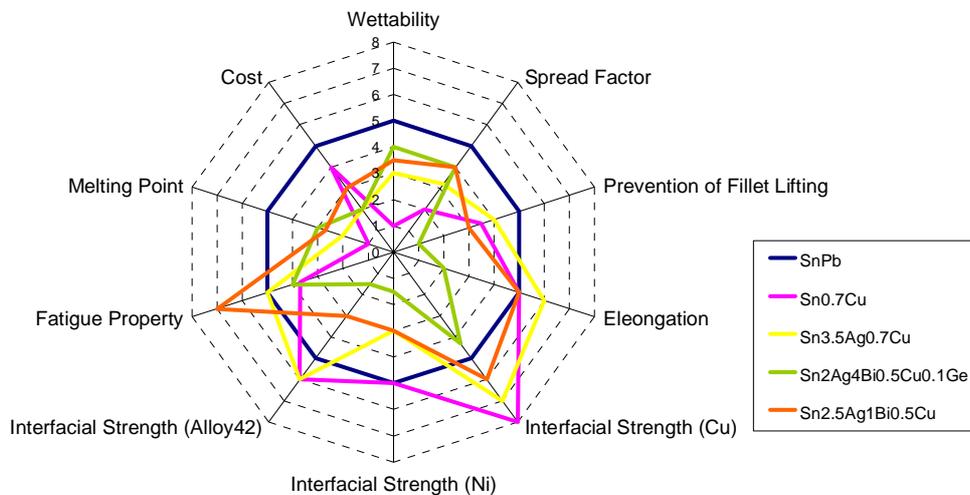
PCB materials were not really mentioned during the mission. Denso, an automotive supplier, is using FR5 in high temperature applications. Quite often the preferred PCB finish is pre-fluxed copper. A finish of the future that was mentioned more than once was HAL SnAgCu.

3.2.3 Soldering Alloys

The Japanese electronics companies appear to have evolved to a position where there are two main alloys of choice, which are selected on the basis of the intended market. The main choices of alloy for the future will be the SnAgCu alloy, and the lower melting point Sn8Zn3Bi alloy (often more simply referred to as SnZn). In the consumer market where reliability is less of an issue and the required lead-free components are not available, companies have selected the lower melting point Sn8Zn3Bi alloy. The melting point of this alloy is ~195°C, with the Bi added to improve wetting. What was surprising was the maturity of the SnZnBi solder, being used across a wide range of products and prepared for the consumer area. Significant development has been put into this alloy, both relating to the powder and the flux systems, to improve its stability and robustness in the process. The team interestingly heard that Marconi working with this alloy. A significant exception to the major OEMs using SnZn is Sony who is using Sn2.5Ag1Bi0.5Cu. The selection of any alloy is

complicated by a number of factors and the spider graph shown below, from Sony, illustrates this.

Where higher reliability is a requirement they have opted Sn3Ag0.5Cu (SAC). This specific composition has been chosen in Japan as it avoids the Iowa patent, dealt with below. This alloy was widely accepted as more environmentally tough, but has not been so widely used as the SnZn due to the higher process temperatures and concerns about the patent issues. However, in the future as the implementation issues are solved this will become the main alloy of choice.



3.2.3.1 Bismuth:

Bismuth occurs in a number of solder alloys and termination finishes, and introduces reliability, recycling and toxicity issues.

Recycling: Some, like Senju, didn't consider the presence of Bi to be a big problem in recycling, but in Europe recycling of solder would be a big issue. Since the recycling path of solder is its use in bronze, any Bi would cause severe mechanical problems. The use of Bi is wide-spread, both in a range of alloys and termination finishes.

Reliability: There is a big issue with fillet lifting which is dealt with in section 3.4.1. Bi has been identified as causing reliability issues with Ni and Alloy42 termination finishes. Denso have shown that Bi, even at small levels, degrades the mechanical properties.

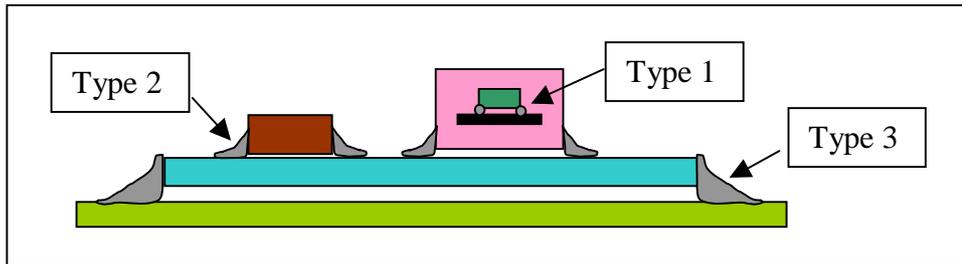
Toxicity: There is a great reluctance in the US to use Bi because of toxicity issues. Aware of these potential problems, companies like NEC are collaborating with medical research to ascertain Bi toxicity effects.

3.2.3.2 Tin Silver Bismuth Alloys

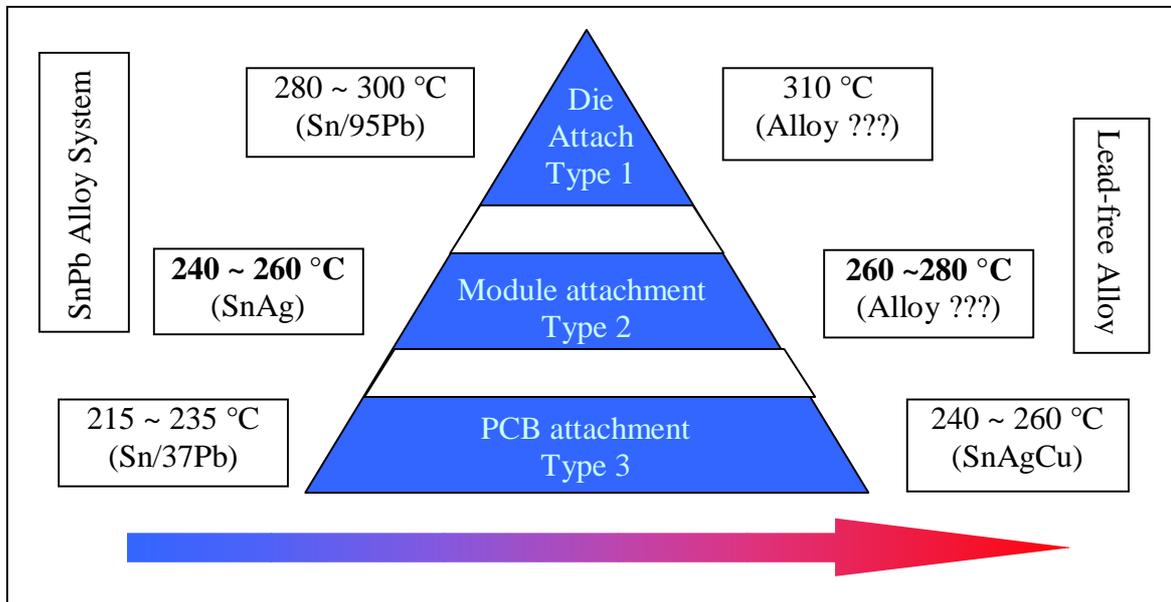
The SnAgBi (Sn3Ag2.5Bi2.5In typically used by Panasonic in the mini-disk player, and Sony's Sn2.5Ag1Bi0.5Cu) alloy family were early solutions to finding a usable alloy with a low enough melting temperature. This in part was due to the patent issue with the SAC alloys and problems in achieving a useable SnZn solder paste. Today these alloys have largely been dropped for the more reliable SAC alloy and the lower melting SnZn alloy.

3.2.4 High Temperature Attachment

Currently components are assembled using a hierarchical soldering system. This allows sub-assemblies to be manufactured using a high melting point solder alloy that will not reflow during subsequent soldering operations. Three melting point solder alloys are shown in the Figure below, with the alloys in decreasing melting point from Type 1 to Type 3 respectively.



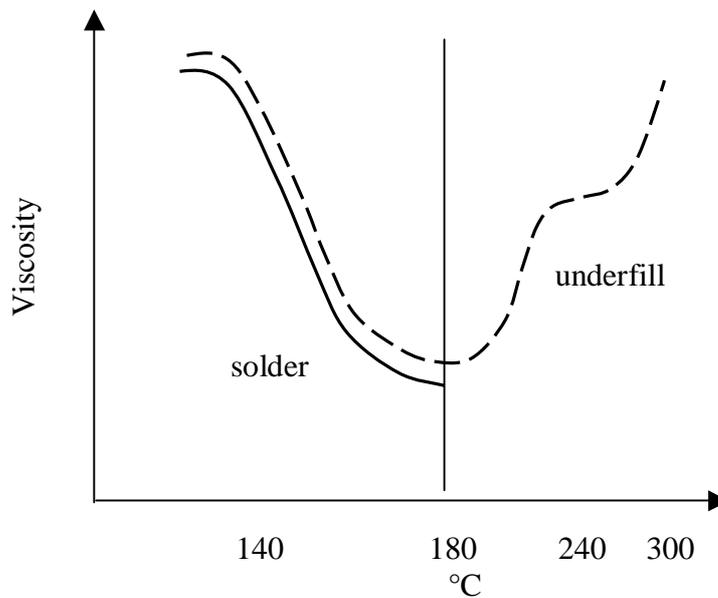
With existing SnPb eutectic solder as Type 3, the intermediate solder Type 2 is Sn3Ag, and the high melting point solder Type 1 is Pb5Sn. This is shown schematically below on the left of the Figure.



On the right of the Figure are hierarchal solders based on a lead-free solder for Type 3. The temperatures in the boxes are the typical processing temperatures for those alloys. As shown in the diagram there currently is no suitable alloy replacements for type 1 and 2 alloys. The mission saw three techniques being developed.

Resin systems, loaded with Ag, are being developed as a replacement for type 1 solders. The issue, as with all conductive adhesives, is to make the resin robust and the thermal and electrical conduction adequate. This has not been solved for the complete range of components, but for non-power devices there are applications for these materials.

Under investigation as a replacement for the type 2 solder is the combination of the SAC alloy with an underfill resin flux system. The properties of this combined material are that the viscosity increases with temperature in the 200 to 300°C range. After the solder becomes molten the flux contributes a useful tackiness that retains components on boards during subsequent soldering operations. Typical viscosity behaviour with temperature is shown below. Currently this is only being explored with smaller components.



A third attachment method being developed builds on wire bonding for die-attach. In an extension of this, spot welding is being developed for small discretes by TDK.

3.2.5 Rework and Repair

It is likely that most repairs will be carried out using the SAC alloy. This alloy is very tolerant when repairing a wide range of alloys. The repair may result in alloys that no longer have the nominal composition, but the Japanese work indicates that this will not be a problem. The mobile phone market has made a clear request that no Bi be involved with hand repair.

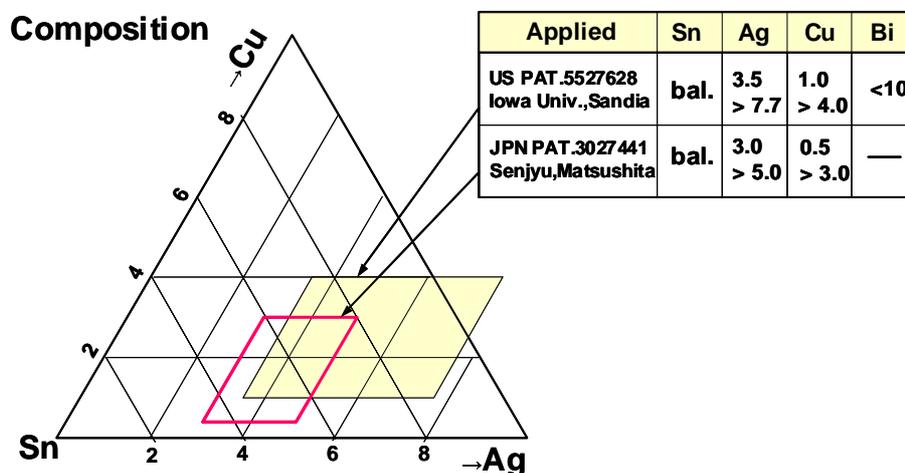
In addition, it is not possible to manufacture a cored solder wire Bi, as it is too brittle.

3.2.6 Patent Issues

The SAC alloy is probably the lead-free replacement alloy for SnPb in the long term. There is however some argument on what is the exact composition of the eutectic, and on what the composition should be for a solder. The apparent eutectic composition changes with cooling rate. Since soldered electronics cool at rates much faster than equilibrium cooling, a Ag and Cu-rich alloy is required to achieve the eutectic structure.

Two patents cover what are considered to be the SAC alloy. A patent from Iowa University, USA, has a patent in the range Sn 3.5 to 7.7 Ag, 1.0 to 4.0 Cu, plus 0 to 10 Bi, and Si, Sb,

Zn, Mg, Ca, RE to 1%. This was filed 20.07.93 and is applicable in the US only. Iowa have licensed Johnson Manufacturing of Princeton, Iowa and Multicore Solders. In Japan Senju Metals and Matsushita hold a second patent with a composition of Sn, 3 to 5 Ag, 0.5 to 3 Cu, 0 to 5 Sb. This was filed 08.07.91 and is applicable in Japan only. . This is showed schematically below. (Figure courtesy of Denso).



The Senju patent theoretically takes precedence, but there are complicating factors and the result of any legal action is not clear. The two patent holders have been negotiating and it is likely that a sharing agreement will be formalised.

It is likely that this patent issue has influenced the Japanese companies to select the lower Ag alloy from Senju, whereas in Europe and the USA the choice has been for higher Ag and Cu, typically Sn3.5Ag0.7Cu.

The Japanese have data verifying the reliability of their alloy composition. Moreover it is highly probable that the difference between the alloys is not significant and the two alloys can be used interchangeably.

3.3 MACHINE ISSUES

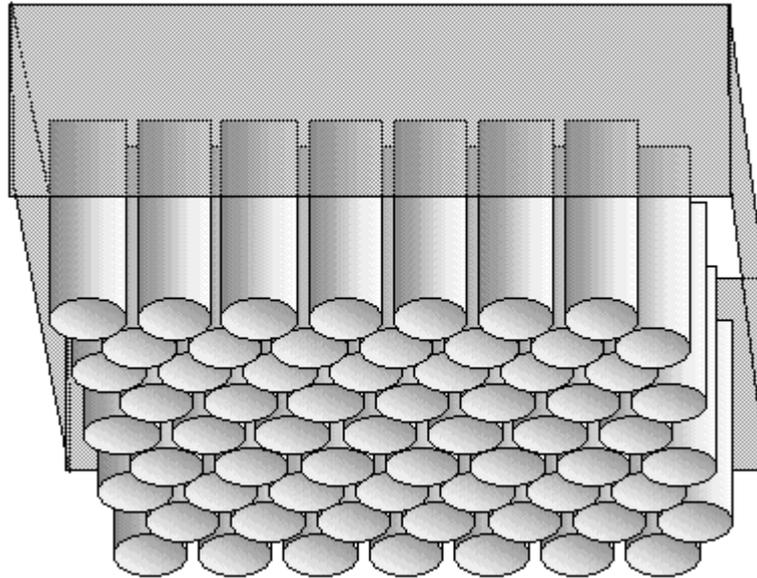
3.3.1 Reflow

Capital expenditure for new reflow ovens is a big issue. Old convection ovens cannot achieve the required low temperature spread during profiling. To meet these new requirements the oven designs are being modified by introducing more zones, achieving more laminar flow within the zone, and higher energy consumption. Heat transfer airflow rates are being increased while at the same time endeavouring to attain laminar flow. Panasonic and others have attempted to achieve the laminar flow by introducing the air through an array of apertures. Panasonic's solution is a regular array of distributed nozzles, shown schematically below. This design has been introduced on the latest oven designs to reduce the temperature range during profiling. It was interesting that the new oven designs were reportedly delivering the reductions in delta T, and are being benchmarked on this basis. Examples

A result of these design changes is that ovens tend to become bigger. However, this is at odds with another aim of reducing the line size and overall energy budget within a factory. To meet this there have been improvements in the design of other parts such as the belt and its

drive mechanism, and improvements to the power management of the system, specifically when there are no PCBs in the oven.

Size will become an issue with replacement ovens and fitting them into existing lines, which tend to be compact.



Schematic of nozzle layout within oven zone

3.3.2 Wave Soldering

It is well known that there are issues of erosion in wave soldering machines. Koki suggested that a suitable material that is resistant to this erosion is 316L stainless steel.

The robotic soldering seen at Denso could offer significant benefits in that it allows the profile to be set for each part of the process. This could have significant advantages for the more stringent requirements of lead-free soldering.

3.3.3 Use of Nitrogen

The use of nitrogen to increase process window and improve wetting was fairly wide-spread, although Sony never use N_2 . The widening of the process window is a significant driver for the use of N_2 , and some examples were given, particularly for SnZn. Using N_2 can widen the process window sufficiently that SnZn and SnPb can be processed with the same profile. For solder paste suppliers their paste must be compatible with many profiles, and the use of N_2 allows more flexibility. Similarly for the user, if N_2 is used then there is the advantage of not having to tune the profile for SnZn. The mission was shown data that SnZn oxidises more than SnPb, particularly above 150°C . As the O_2 is decreased the strength of the SnZn alloy goes up by 50%. Manufacturers of consumer equipment prefer not use N_2 , but manufacturers of high value PCBs do require N_2 and normally use $<100\text{ppm } O_2$.

Another benefit of using nitrogen was the reduction in the amount of voiding, particularly with BGAs. The use of N_2 also affects melting behaviour and hence can be employed to

compensate for poor wetting. The degree of this effect is dependent on the alloy, and for most alloys the wetting was not affected by O₂ pressure below 10000ppm, except for SnZn where an improvement was noted. With SnZn N₂ also reduces solder balling.

3.3.4 Clean or No Clean

Most of the current assembly uses no-clean products. The Japanese have traditionally used high solids fluxes without cleaning in their volume products. Hence, there is no particular emphasis on cleaning currently, and nothing new appears to be intended with lead-free.

3.3.5 Visual Inspection

Inspection issues with lead-free are well recognised, as is the requirement for retraining. It was noted that the lack of glossiness with joints is not popular with inspectors.

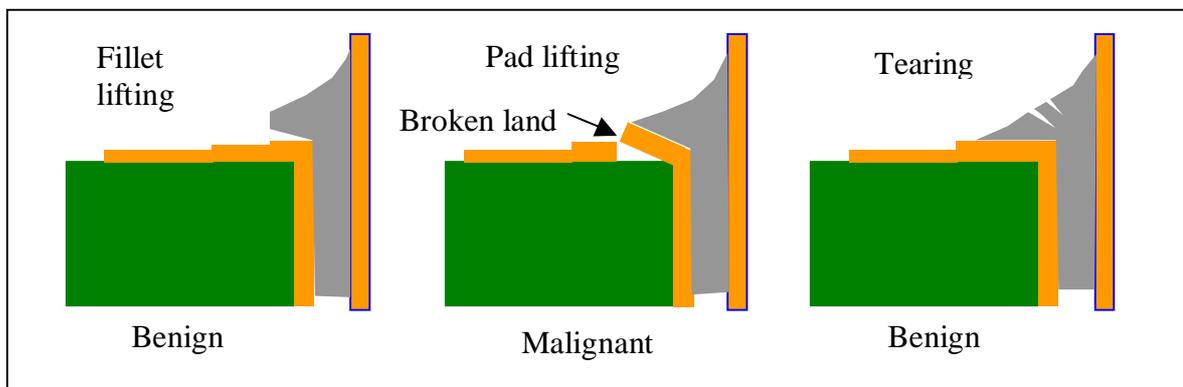
Automatic inspection was not raised as an issue in any of the visits. Denso were reported to be using 100% Automatic Optical Inspection (AOI), but this was on a line assembling with SnPb. There is a change in surface appearance, but retuning the recognition algorithms can accommodate these changes. NPL is currently carrying out a benchmarking exercise with AOI manufacturers using lead-free assemblies.

X-ray images were presented at various locations and again there were no particular issues raised. However, no demanding samples were analysed, such as would be the case of viewing through large multilayer boards.

3.4 RESEARCH AND RELIABILITY

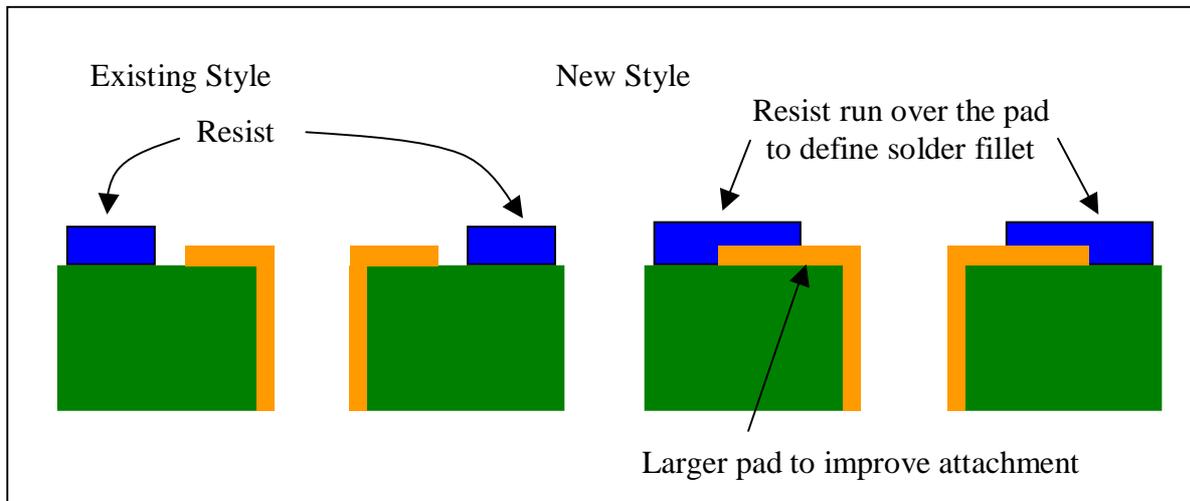
3.4.1 Reliability

The Japanese have done a lot of work in understanding the fillet-lifting phenomenon. It is very likely that the OEMs have developed methodologies to contain fillet-lifting. Sony has reported there are two classes of defect, “benign” and “malignant”. Peeling of the fillet does not cause a reliability issue. Peeling of the pad from the substrate that destroys connectivity is a definite failure. To solve this problem they are changing pad design, to allow peeling, and so minimise the effect on pad connectivity. The Japanese have defined three types of defect as described by Sony:



These three failure modes depend on the cohesive and adhesive properties of the solder and pads. Only the pad-lifting occurrence is a critical problem at test. Fillet lifting and tearing are probably not a reliability issue. They are all now exploring a design which entails running the

resist over the pad to restrict the solder coverage of the pad, as shown below. The change in resist pattern is illustrated below:



This new design limits the pull off power of the pad. Sony discussed the influence of large pads as a method of influencing thermal demand, and hence fillet lifting. It is clear that the higher temperatures with lead-free processing will cause more expansion, but then the system freezes at higher temperatures and locks the system in place. These factors coupled with the fact that lead-free is more creep resistant all compound the problem of fillet lifting by increasing the stress in the fillet. It was not possible to establish a definitive Japanese position, but it is likely that the OEMs have developed models that allow them to predict and understand fillet lifting.

A number of assembly and reliability trials have been undertaken and the mission received presentations from Sony, NEC, Panasonic and Denso. Thermal cycling work was presented which, looked at reliability of lead-free finishes with SnPb solder, and with completely lead-free systems. A range of results was presented that typifies that seen in the literature, with the choice of the assembly and component key to the ranking of solder alloys. The results show that with SnPb the introduction of Bi with an Alloy 42 leadframe reduces fatigue life significantly. With copper leadframes the addition of Bi to the termination surface finish has a beneficial effect. Work was reported with QFPs where three different leg formats were trialed. The work showed that legs at 45° had the poorest reliability, with a more vertical leg format yielding better reliability. Interestingly a SnAg finish resulted in better reliability than the standard Sn10Pb finish with SnPb solder. Using SnAg solder and a SnAg finish there was again a significant susceptibility to Alloy 42 leadframes, whereas with copper leadframes reliability was optimal. Adding Bi did result in fillet lifting with through-hole components. The addition of Bi to SnAg alloys increased the strength of the joint (up to four times at 10%) and reduced elongation (by a factor of 10, for a similar 10% addition of Bi).

Issues with flux residues have been encountered, as reported by Denso. With new formulations, that are rosin-free, the residue cracks under stress. Activators still left in the flux cause SIR issues. Reducing the activator then causes solderability issues. Hence Denso have been working with the flux supplier to introduce a deactivator into the flux that removes any activator after soldering, thereby improving SIR.

To improve the microstructure soldering machines have been modified by increasing the cooling, even to the point of using chilled N₂. Achieving a finer microstructure may well be beneficial, as grain growth will be slower with lead-free solders than SnPb, and hence more advantage will be gained by an initial smaller grain size.

Voiding in solder joints was not raised as a particular issue. Although there was some occurrence of voiding it was minimal and no different between lead-free and SnPb.

It will be difficult for SMEs to emulate the expertise in the issues discussed above, unless they are in OEM supply chain.

3.4.2 Research

The Japanese have sponsored some big research programmes through their New Energy and Industrial Technology Development Organization (NEDO). These have been managed by trade organisations, for example Japan Electronic Industry Development Association (JEIDA) and Japan Welding Engineering Society (JWES). These finished in spring 2000. There are currently proposals for follow-on projects, one on the "Standardisation of test methods for lead-free solders for the reduction environmental impact" directed by JWES, and a complementary project directed by JEITA. The NEDO work has not been formally published, but Osaka University pointed out there was a similar Japanese report, all be it in Japanese.

The mission was briefed on developments that have been discussed above. Osaka University did not present research data but rather discussed issues arising in the discussion.

3.4.3 Standardisation

Professor Takemoto of Osaka University sees the standardisation process as very important in reducing the range of alloys within Japan. Takemoto is the chairman of an influential committee within JWES that makes recommendations on Japanese alloy classification. They are going to make a recommendation to ISO 9453 for two new alloys, Sn₃~4Ag 0.5~1Cu and Sn₃~4Ag₂~3Bi.

Takemoto has severe reservations on the SnZn system, as interdiffusion with Cu and intermetallic formation will compromise alloy performance. There are also recycling issues that will hinder recovery. Takemoto also has some strong concerns with electromigration under environmental stress. However, companies using the SnZn alloy have assured him that there are no problems. But this is not one of the alloys to be recommended to ISO.

4 MISSION BACKGROUND

The mission detailed below was sponsored by The SMART Group. The SMART Group is a technology transfer organisation that started some fourteen years ago, and has now grown to encompass much of Europe. It can proudly point to having most of the world's major electronics manufacturers among its corporate members, which now number in excess of 500. NPL was one of the founding members of the SMART Group and has continued to be active throughout its existence.

4.1 INTRODUCTION AND RATIONALE FOR MISSION

The electronics assembly industry, part of the fastest growing sector in UK, is arguably facing its biggest challenge ever with the move to lead-free soldering. Driven by legislative and anticipated consumer pressure, the industry is going to have to change from using the ubiquitous tin/lead solder that's been in place since the industry's inception.

No drop-in replacement system has been identified and the strongest contenders require significantly higher soldering temperatures. This impacts the choice of board material; its finish, the composition and termination finish of components, as well as on the process itself and the equipment used.

Although a number of research activities have been undertaken in UK and Europe, Japan is clearly in the vanguard on this issue having some lead-free products already on the market and in announcing challenging plans for further implementing lead-free processes.

In view of the major costs associated with such a major change of technology, UK industry could benefit hugely from the experiences gained by these early initiatives, thus providing the rationale for this mission proposal.

The desire for information on this topic has been amply demonstrated over the last 18 months. Publication of DTI's substantive report on the subject in April 1999 resulted in over 5,000 requests for copies plus numerous downloads from the NPL and ITRI web sites. It was because of this interest that an update was published in April 2000. Attendance at the two annual 'Get the Lead-Out' seminars run by SMART Group has also been far higher than that normally achieved.

4.2 OBJECTIVES OF MISSION

Areas for which answers were needed include:

- *What is the driver for the transition to lead-free soldering? Is it legislative or consumer pressure? If the latter, what evidence has been seen?*
- *Is there any differentiation between major OEMs and SMEs as to their approach to lead free soldering?*
- *Are there any moves to standardisation of alloys and are these industry or government led ?*
- *How has the supply chain reacted - compatible components, equipment and boards?*

- *Will the technology be rolled out overseas and, if so, when?*
- *What impact has there been on process yields and what types of defects have been found?*
- *What have been the main barriers to the rapid and successful transition to lead-free soldering?*
- *What have been the most challenging technological issues?*

It was to address these uncertainties, that the mission sought to undertake a range of visits in which it could pose a number of detailed questions.

4.3 TARGET ORGANISATIONS

The companies and institutes chosen needed to be involved in lead-free production and ideally include:

- METI - to gauge the government perspective on implementation and how they are facilitating this change;
- A major OEM manufacturer in the portable consumer market with a range of products, including high end products;
- An automotive electronics supplier with products exposed to high environmental stress;
- A telecoms producer, with products in the base station or Internet backplane market;
- An SME (small or medium sized enterprise) that has implemented a lead-free process, and can illustrate the hurdles and benefits of this transition;
- An institute or research consortium, which is undertaking more fundamental studies regarding the material and equipment issues with lead-free soldering technology;
- A component manufacturer that has developed the materials, encapsulation and termination finishes, and importantly how these have been selected in terms of qualification to higher temperatures and cost;
- An equipment manufacturer with product developments initiated by the need to meet the lead-free challenge.

Although the proposed mission members could suggest some companies, at least for the major OEMs, they welcomed input from the British Embassy in Japan as to the most appropriate organisations to visit.

4.4 MISSION QUESTIONS

A number of detailed questions were proposed before the mission and forwarded to the Japanese companies.

- *What is the new materials selection process?*
- *What alloys, components, substrates are being chosen?*
- *How is lead-free being defined?*
- *What process issues have they had to overcome?*
- *What design, rework, test & inspection procedures been developed?*
- *What reliability data are being acquired?*

- *Do they see an increase in the use of conductive adhesives?*
- *What are the marketing issues for lead-free?*
- *Have they introduced a labelling scheme?*
- *Are OEMs cascading down technology to their suppliers?*
- *How are Japanese companies rolling out their technology around the world?*

4.5 TEAM MEMBERS

Bob Willis - Technical Director, SMART Group and Team Leader. Bob has his own training and consultancy business that specialises in helping companies implementing Surface Mount Technology.

Dr Malcolm Warwick - International Director, Solder Materials Product Development for Loctite-Multicore Solders Ltd.

Rob Horsley - Manufacturing Engineer at Celestica UK's, Manufacturing Technology Group and leading their lead-free implementation programme. Celestica is UK's largest EMS company providing a broad range of services including design, prototyping, assembly and testing.

Dr Chris Hunt - Head of Electronics Interconnection Research at the National Physical Laboratory.

Nick Jolly – Technical Consultant to DTI's CII Directorate responsible for producing DTI's two well received reports on lead-free soldering as well as chairing the Electronics Manufacturing Industry Forum which comprises the major clubs and trade associations in the field.

Philip Fulker – Managing Director of Invicta. Invicta manufacture reflow and wave soldering machines, and are agents for a number of analytical instruments.

Phillip White – International Trade Promoter for Japan. As well as his own extensive experience in missions and the Japanese, he has also a significant knowledge in electronics manufacture.

5 JOURNAL

5.1 ITINERARY

Monday 19 February

British Embassy: Presentation by the team to Japanese industry representatives.
Meeting with JEITA (Japan Electronics and Information Technology Industries Association), including industry representatives for overview of lead-free soldering in Japan.

Tuesday 20 February

Sony (OEM, printed circuit board manufacturer)
METI (previously MITI)
Senju Metals (materials supplier)

Wednesday 21 February

Matsushita FA (Panasonics, equipment manufacturer)
Ko-ki Corporation (materials supplier)

Thursday 22 February

TDK (component manufacturer)
NEC (telecoms manufacturer)

Friday 23 February

Denso (automotive supplier)
Osaka University

6 MONDAY

6.1 BRITISH EMBASSY

Our first meeting was with Brian Ferrar at the Embassy. We heard that JEITA had helped significantly with the audience for the day and the subsequent visits. The team were very pleased with the arranged itinerary as they were not pre-eminent companies, but also a good cross section, meeting our objectives as set out in our mission proposal. It was pointed out that the Sony visit will be in English, possibly NEC as well, but the others would be in Japanese. We were told that the companies visited would have put in a lot of effort so we were to be profuse in thanks. The agenda at the embassy comprised the team making presentations, followed by a lunch with the audience, and then a meeting with JEITA and its selected members from the morning meeting.

Team Presentations: We all made our presentations, and had a number of questions at the end. There was a lunch, during which we had further questions. I spoke during lunch with Hirotaka Ueda of Amkor and enquired about surface finishes and the historical use of SnBi. He explained that they used SnBi as it was easy to plate and they did not consider that there were any reliability issues with Bi at this concentration within the joint.

Following lunch, and in the same room, there was a meeting with JEITA (17 people). The meeting was led Mr Yamamoto, of the Sony Corp. They had prepared answers to the questions we had sent earlier in the proposal.

Question:

What is the driver for the transition to lead-free soldering? Is it legislative or consumer pressure? If the latter, what evidence has been seen?

Answer:

They are removing parts from their products that are causing the most environmental load. They are not only working in lead-free but other materials as well.

Supp Question.

Is this an environmental supply issue?

Answer:

This is very chemistry dependent.

More from Matsushita

Pb is not environmentally friendly, so they are doing a risk management. They are also considering WEEE.

Supp Question:

What is the government role in going to lead-free. Is it promoting or supporting.

Answer:

Government has not regulated in this area, and has no direct involvement, and has no plans to regulate. Within industry, big and small companies are keen to move forward on their own and have incorporated environmental policies in their mission statements. But they look to Government for support in training and financial help with research in moving to lead-free technology.

Question:

Are there any moves on the standardisation of alloys and are these industry or government led ?

Answer:

Yamamoto: standardisation of alloys is handled by the Japanese welding Inst. The Prof from Osaka is in charge of this matter. We have some insight from Senju. The alloy is handled by the industries in the Welding Institute. Within the Welding Institute there is one committee, but this has not met yet, so the timescale has not been set. Activities based on work from Osaka University will form the basis for progressing their work.

Question:

Is there any differentiation between major OEMs and SMEs as to their approach to lead-free soldering?

Answer:

Matsushita answered; there is a difference, with development being done by the big companies, which then transfer to smaller companies in the form of a disclosure, under some confidentiality agreement. Thus the information flows down the supply chain.

Supp Question (BW)

How is the cascading of technology achieved, is it public or private, through conferences for example ?

Answer:

We provide materials and knowledge to our sub-contractors, and it is not in the public domain. We do not give away manuals.

Supp Question(MW):

Do material suppliers have a role in passing on information ?

Answer:

Yes they do.

Question:

Do you supply information to your sub contractors overseas ?

Answer:

They have arrangements in other countries, but they are independent of Japan, and in this case they only supply advice. In the case of Toshiba, effort is just focussed at present within Japan. Having said that, a lot of production has been shifted overseas, so they can achieve lead-free domestically, but for large scale they need to introduce lead-free

overseas. Sony have 3 types of sub-contractors (probably SMEs): 1, Sony has a financial interest; 2, Sony has no interest in the company, but the Sony work forms the majority of work for this company; 3, This is similar to 2, but Sony work is a minority. For 1 and 2 Sony will second engineers to the company. For type 3 they don't send engineers, but if they request help then engineers will be sent.

Question:

How has the supply-chain reacted to the issue of availability of compatible components, equipment and boards?

Answer:

Shibata for Murata: For ceramic components, they are trying to achieve lead-free for the component terminations, but are not considering lead-free inside the component body. With semi-conductors there are two things: termination and plating, and the die-attach solder. For the termination, the evaluation and preference and significantly determined by the user. For die-attach they have not come up with an alternative. Regarding the packaging, they need high heat durability, and must come up with new plastics. They have no implementation targets yet. They have not yet decided to qualify parts to 260°C.

Supp Question:

Will palladium be the selected surface finish?

Answer:

This question should be addressed to TI. Our direction in the future has not been decided, but we will consider other options in the future including pure tin.

Supp Question:

Do the products that are lead-free have lead-free terminations?

Answer:

Murata: for discrettes, yes.

Texas: they have lead-free terminations, PdNi.

But in general they will be able to have components with lead-free terminations by the end of 2001 or 2002.

PCB Finishes

There was no expert there to discuss PCBs. So they proposed skipping this. But a comment was requested (BW) on what the preferred finish will be?

Using prefluxed copper, ie bare copper with a rosin coating, they don't think they need to do anything different to their present position. They pointed out a difference between Japan and Europe, in that they did not go down the HASL (Hot Air Soldered Level) route, but preferred bare Cu, but also have recently seen interest in the Ag plating process.

Question:

What process issues have they had to overcome, and what defects have been defined, what is the major bottleneck, what is the most difficult problem to overcome?

Answer:

NEC answered, and discussed the SnAgCu (SAC) & SnZn alloys. With SAC and small PCBs, eg mobile phones, there is no problem, but they had a major problem with large

boards and thermal durability of parts. Hence the necessity to reduce processing temperatures with the new alloys. This has been met by new reflow systems, and has meant new capital equipment and hence cost. One of the biggest problems has been with fillet lifting and flow soldering. They have been carrying out studies for 2 years on fillet lifting, and have not solved the problem. Basically for fillet lifting the lead-free solder has too much strength, and the solder doesn't extend, or has little elasticity, so causing peeling from the PCB. With the alternative alloy, SnZn, there is a problem with oxidation. A consequence is they have had to pay close attention to production processes, which will be difficult for SMEs. N₂ for SnZn solder is regarded as essential.

Supp Question:

Change equipment to what? Issue with intrusive reflow soldering? Fillet lifting with SAC?

Answer:

Delta T, choose better oven, capable with high thermal mass, secure big space for preheat zone (longer ovens).

Supp Questiontions:

Which solder do you prefer?

NEC: The SAC alloy is preferred.

Toshiba: Similar to NEC. Again the SAC should be the mainstay, but SnZn is also being considered. There is a necessity to have high thermal durability, which the new reflow systems assist by delivering low delta T. Because of the component durability they have no choice but to use SnZn (Sn8Zn3Bi). They are trying very hard to handle SnZn, and there has been a big improvement in SnZn paste recently. But they are concerned with compatibility between Zn and other alloys: Pb, Au and Cu. They only consider using SnZn where there are no high reliability issues, such as for consumer products where the use environment is below 100°C. Their current reflow soldering ovens are 100% convection. In the past the number of zones was small and the length small, but these have been upgraded.

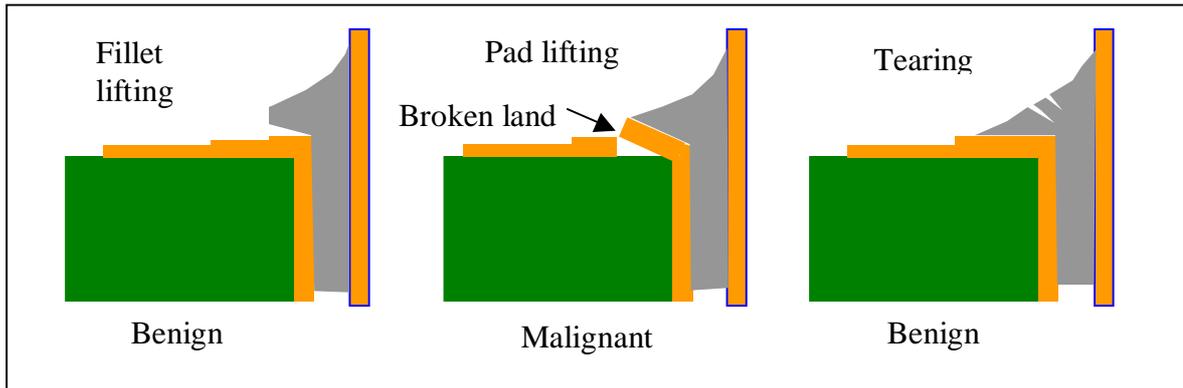
Matsushita: Issues with reflow, melting temp increases, consistency of heat across the board, durability of components. In wave, there are wetting problems, along with fillet lifting. They are using SnAgBi in the MD player. The Bi alloy will include Pb at less than 0.1% Pb. Personally they remain very interested in Bi, and are pursuing it, and have been exchanging information with Carol Handwerker at NIST. Currently the potential of Bi is not well understood for the future.

Supp Question:

Fillet lifting, is it a problem ?

Answer:

Sony: there are two classes, benign and malignant. Peeling of the fillet from the pad does not cause a reliability issue. But peeling of the pad from the substrate destroys the connectivity. To solve this problem they are changing pad design, to allow peeling of the fillet, which does not affect the pad connectivity. Sony have defined three types of defect:



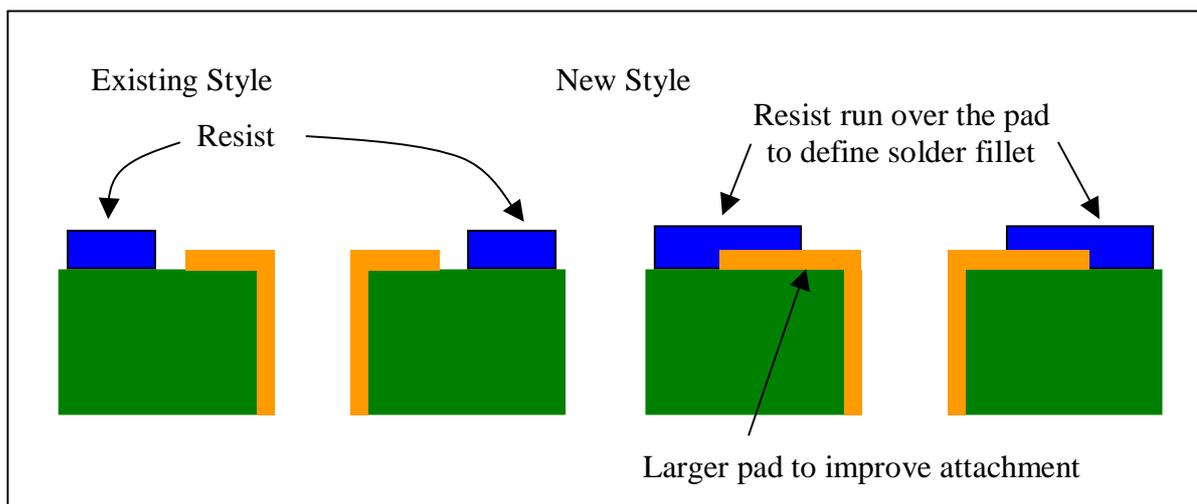
Only the pad-lifting occurrence is a critical problem at test. Fillet lifting and tearing are probably not reliability issues.

Matsushita: Same as Sony. They have an impurity problem, so peeling takes place from the land. So they have to control the impurity. The impurity is Bi, or Cu coming from the plating, and the maximum impurity level is confidential.

Toshiba: Same as above. But with big components, like transformers, there is a problem with a cavity forming causing reliability issues.

NEC: Gave examples of benign and malignant. Where the land is broken and with high temperature exposure, there is an issue with the lack of elongation of the solder. No issues with the PCB.

They are all now are exploring a design which entails running the resist over the pad to restrict the solder coverage of the pad, as shown below. This design limits the pull off power of the pad.



Sony discussed the influence of large pads as a method of influencing thermal demand, and hence fillet lifting. They also described that the higher temperatures with lead-free process cause more expansion, but then the system freezes again at higher temperatures and locks the system in place. The fact that lead-free is more creep resistant, compounds the problem of fillet lifting.

Supp Question:

Any new defects with SM and lead-free?

Answer:

No difference compared with SnPb. They have seen the component attachment break, which was attributed to a plating problem. Plating material at that time included Zn. In the case of SnZn they have observed big voids, and to some extent with the SAC alloy as well. (*Obviously not an optimised flux*)

7 TUESDAY

7.1 SONY

Attending for Sony:

Katsumi Yamamoto: Chief Technical Standardisation Officer

Yoshiki Matsuoka: General Manager: Corporate Environmental Affairs

Yoshikuni Taniguchi: General Manager, Packaging Product Engineering Dept

Tomoya Kiga: Manager: Packaging Product Engineering Dept

Hidemi Toita: Manager: Environmental Strategy Planning Office Corporate Environmental Affairs

Tadyoshi Taniai: Assistant Manager Environmental Affairs

The meeting was introduced by Matsuoka, who explained that he had many environmental responsibilities, which included lead-free. We were given two documents, which Sony has published world-wide. Their approach is fully global, not just Japan, and across their product range. They have included environmental management as part of their business management. Sony has 4 environmental management zones: Japan, Europe, USA, and Asia, with regional committees in each zone. In 1999, they created a new zone in China, which will have a big impact. The defined zones each have an integrated business and environmental management structure, and make decisions that reflect the constraints and opportunities for each zone. Within each regional zone they do not consider the specific interest of any country. This structure was illustrated in the handout.

Matsuoka then discussed Sony's concept of linking business and environmental management. Underneath the corporate business centre there are 7 companies, but this is a very fluid structure. Each company has its own responsibility, particularly for profit and loss. Within each company they have an environmental director and office, which have responsibility for individual products. The business director must also achieve his targets. So there is matrix management. The corporate centre has in place mechanisms for measuring performance. Each network company has a president, and he is evaluated. For this evaluation, which is open internally, the score is in terms of business performance, and the effort made. In terms of management and training resource, 10% is given to the environment. Environment issues are not additional but are fully integrated, and the President always spends at least 10% of their resource on the environment. The decision to change to lead-free has been made. He drew our attention to a future vision of Sony in 10 years time, and an intermediate position in 2005. The introduction of lead-free has been set up within this document. This completed Matsuoka introduction.

Taniguchi then discussed environmental production issues, soldering techniques, process issues, reflow ovens, stencil design, implementation issues, solder alloys

7.1.1 Environmental production issues:

They dealt with specific policy on manufacturing. Sony has a target to reduce the number of resources that are consumed in manufacture, and reduce the energy consumption during life cycle, and disposal. Their lead-free activities are part of this. There are no legal requirements with lead-free that Sony needs to meet. Development of lead-free is set in a context of competition amongst Japanese companies. They are now are at a point of commercialisation

with many alloys. They developed an alloy 1997 ($\text{Sn}_2\text{Ag}_4\text{Bi}_{0.5}\text{Cu}_{0.1}\text{Ge}$), but have been using a new alloy from 99 ($\text{Sn}_{2.5}\text{Ag}_1\text{Bi}_{0.5}\text{Cu}$).

7.1.2 Soldering techniques:

With flow soldering there has been the development of flux and an understanding of fillet lifting issues. For reflow, the development of solder paste has been the issue. For hand soldering, there has been development of flux cored solder wire. There are some issues with touch up. Generally there are reliability concerns.

7.1.3 Process issues:

In Europe there are lead-free camcorders, and for this Sony needed to improve convection reflow equipment, and achieve a 10°C delta T, with a maximum process temperature of 240°C . With this performance there are no concerns about thermal durability. They have performed joint strength measurements for each component, which show some advantages for lead-free and some disadvantages. It remains a possibility that Sony cannot approve certain lead-free alloys. However, even if the lead-free alloy is weaker, they will probably still use them. The strength measurements are made on as-produced and thermally cycled assemblies. These measurements are augmented with electrical assessment.

7.1.4 Reflow ovens:

Sony doesn't use straight IR, but use convection, and has found it is important to have a good consistency of hot air. This has resulted in the ovens becoming bigger and bigger. But in replacing ovens they must consider space availability. So they would like to use smaller ovens but with more zones. They don't have a universal solution, but there is a definite trend to smaller ovens with less energy consumption. By having smaller machines the whole plant can be reduced, and hence reduce overall CO_2 emissions.

7.1.5 Stencil design:

Sony is using offset aperture design to avoid bridging problems with the wet paste. They don't do this for cosmetic reasons, but for the quality soldering. They have had issues with SnPb soldering, but with a change of stencil they can achieve good soldering with lead-free.

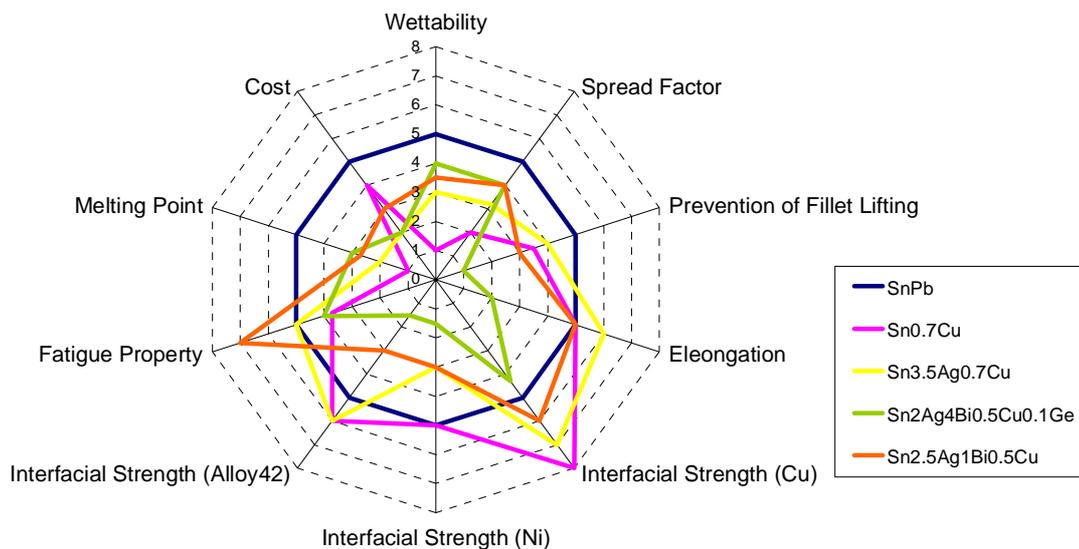
7.1.6 Implementation issues:

They still expect problems in eliminating lead from all assemblies, and because they are purchasing components from other suppliers this will remain an issue. Other products that are lead-free include TVs, which are produced in Malaysia, and small audio products, manufactured in Japan. Within Sony there is semi-conductor manufacturer, who is moving to lead-free. They are using NiPd lead-frames for examples. Currently in Europe they have not implemented as much lead-free, but are catching up fast.

7.1.7 Solder alloys:

They have looked at the alloys, and presented some melting data for the SAC alloy. They prefer to use 0.5%Cu. In flow soldering the concentration of Cu increases. Hence with a starting composition of 0.7%, they observe Cu concentration increasing quickly to 0.9%. Above this level they observe crystallisation. So they start from a lower Cu concentration. When topping up the bath they add a low Cu alloy. Small changes in Cu do not change mechanical properties. They don't see much change between 3 and 3.5% Ag. MW questioned that with the low Ag, were Sn dendrites occurring. They agreed, but with fast cooling, they don't observe crystallisation problems with low Ag. Their solder spread results for lead-free are all similar, but not as good as SnPb. The addition of Bi lowers the surface tension. All the

measurements were with nitrogen, in atmosphere the Bi oxidises and there is no advantage of adding Bi. In Sony they have used Bi. They showed the effect of Bi on wetting for a range of Ag alloys, and showed a useful graph, plotting out the useful range of Ag and Bi. Surface tension data, and the effect of Bi were presented. The wetting process is dominated by the Sn, with Bi acting like a surfactant. Strength was then discussed. With the addition of increasing Bi the strength becomes weaker. This is particularly important with Alloy 42, whereas with copper leadframes the peel strength is only weakly affected by increasing Bi concentration. The strength of joints with a Ni finish is low. With Ni and Alloy42 they see problems after thermal cycling. They don't see degradation of the solder, but problems occurring at the interface of the solder fillet and termination finish. Sony has plotted on a spider graph selected alloys including: SnPb, SAC, SnCu, Sn2Ag4Bi0.5Cu0.1Ge and their Sn2.5Ag1Bi0.5Cu. This graph is based on components with a SnPb finish. The graph was normalised to SnPb, which scored 5. We asked if they foresaw issues with selecting two alloys. They are now discussing this, and have decided to use SAC alloy for repair. After repair, the Ag will be somewhere in the range of 2.5 and 3%, and Bi between 0 and 1%. They already know there are no problems in this range.



Supplementary Question:

Are there any modifications to wave soldering machines?

Answer:

Senju Metals can better answer this. Improvements have been made to preheat and cooling.

Supplementary Question

What is their experience in organising the process and minimising delta T with boards with large thermal mass, and does this have any implications for the solder paste?

Answer:

Surprisingly, they commented that increasing thermal mass improves temperature uniformity. (Although not clear where the increased thermal mass should be)

Supplementary Question:

Do you use N₂ ?

Answer:

Sony don't use N₂ for anything.

Supplementary Question:

Is the cooling rate important during reflow ?

Answer:

Yes. (Background, microstructural changes occur more slowly in lead-free alloys than SnPb, so obtaining a finer grain structure at solidification will be more advantageous)

Supplementary Question:

Do they have any alternatives to PbSn as a die-attach solder ?

Answer:

They have not developed a solution to this yet.

Supplementary Question:

Will Sony use lead-free in their advertising ?

Answer:

No

Supplementary Question:

To what temperature are parts being qualified within Sony ?

Answer:

Suppliers are still qualifying parts only to 220 or 225°C, but Sony perceive there is a large safety margin. They don't base their production on the supplier's specifications but on the real performance. On this issue they have had specific collaborations with suppliers, and have developed a new electrolytic capacitor that can withstand higher temperatures.

Supplementary Question:

Have they have changed any of their standards ?

Answer

The standard for solder spread has been changed. They have historically required full coverage, but with non-fusible pads it is now acceptable to have some non-wetting areas. In Japan they are now applying these new rules, but there is some reluctance on the production line. So they are changing stencil design to avoid this problem.

Supplementary Question:

Are they planning to use conductive adhesives ?

Answer:

They are not currently using CAs but are continuing to explore their use at the research stage. They don't have any plans at this stage to implement CAs.

7.2 MINISTRY OF ECONOMY, TRADE & INDUSTRY (METI)

Their team was led by:

Kazushige Nobutani: Deputy Director Commerce & Information Policy Bureau

Nobutani gave an overview of METI role in the lead-free area. Japan has a wide range of consumer goods through to semi-conductor parts, and environmental issues do impact on all of these. In Japan they are going to introduce a recycling legislation, and also plan to introduce a ban in lead as with WEEE. Currently the only plans they have are to control the amount of lead at the landfill stage. This will be achieved in two ways: First, Sony, NEC, etc will do this voluntarily; second, the approach will be similar to WEEE. Much lead is used in consumer electronics, ceramics and glasses and Japanese companies are lobbying against bans, which also includes lobbying with the EU. At this time they are explaining to the EU what is the extent of their lead usage, and because Japan is a major supplier to the EC this lobbying has been effective. Japanese companies have also done well at presenting information to MEPs in Europe. Another role of METI has been to sponsor cooperative research from 1998, and many Japanese companies have been involved.

The main list of questions supplied by the mission were not addressed, rather we had a question and answer session.

Question

Is Japan thinking of opposing bans on lead from a world trade perspective ?

Answer:

There is a committee in Geneva, where Japan has expressed its concern. Excessive legislation may hinder trade. Many aspects of WEEE are not clear, so there is some anxiety in Japan as to what will happen. There are also other Pacific countries that have expressed concern.

Question:

Concerning the usage of lead, most major companies have implement lead-free, has METI been doing anything to help SMEs in implementing lead-free?

Answer:

At this point in time they are not doing anything. The major companies have worked to help their sub contractors, so METI currently does perceive the requirement for government intervention.

Comment from NJ. The UK government has not adopted a position but has produced explanatory literature. UK industry was unhappy with 2004, but hasn't complained about 2008. The commercial threat from Japan is more important than the legislation. SMEs say they will worry about 2008 in 2007. The directives will go through at the end of the year. Some member states say they would like an earlier date than 2008. There is some debate on amalgamation the WEEE and ROHS directives. Some member states go further than the current directives. They would like to see both joined back as an environment directive. Then, since ROHS is not a single-market directive, they can set their own more stringent laws. The European Parliament (EP) should make a statement in late Spring. The EP needs to set up a committee to decide what the ban on lead will actually say. But the creation of this committee will be dependent on the EP passing the directive. Nobutani made a comment that the influence of Japanese will be heard by the committee.

Question:

What is the amount of lead in the refuse, and how was this was set?

Answer:

In Japan the law on disposal of waste, is “owned” by the Environment Ministry, which has stipulated the limits, and is enacted by local government. There are 3 types of landfill site. The most stringent site will charge a levy for disposing lead. But at what level, and how is this defined? This is difficult, the law says if it contains lead it should be contained in the first category, but it is difficult to say what that level is. In Japanese law it is not normal to go to into the details. There is a general acceptance that all electronics falls within category 1. Will this apply to the new lead-free products? Yes, as there will be residues of lead from the high temperature solders. In the future these new lead-free products will still be disposed as category 1 and will not be allowed to dispose of as category 2 or 3. The companies will not ask for the lower categories while there are still residues of lead.

Question:

Do you have details of a NEDO programme?

Answer:

NEDO started in 1998. At that time there was a good reason for the NEDO project since there was a number of alloys. A second programme is to develop the process since it is clear that there are many options, as evidenced by the major companies, and it can also help the SMEs.

Question:

Have they any intention to regulate the use of logos for lead-free ?

Answer:

It is difficult to come up with a good definition of lead-free, and they don't think there will be such a definition. Because of this uncertainty it is a big problem. But consumers would like a logo, so they should accept such a move and the government would like to work with them.

Question:

Is there much awareness of lead-free in Japan ?

Answer:

They don't think there is much public awareness.

Question:

Why do you think the major Japanese OEMs have moved to lead-free ?

Answer:

The pressure has been two fold, one has been the European legislation, and the other commercial advantage.

7.3 SENJU METALS

Toshihiko Taguchi: Executive Director Material and Systems:

Seiichiro Hasegawa: Director, International Business Department

Eietsu Hasegawa: Director Soldering Material Sales Department

Toshio Mizowaki: Manager R&D Technical Centre:

Hiediki Ozawa: International Buisness Department

Rikiya Katoh: Researcher; R&D Laboratory

There was a brief introduction by Hideki Ozawa, which was then followed by a question and answer session based on the mission questions.

Question:

What is the benchmark to select a lead-free alternative?

Answer:

Katoh: temperature is the most important.

Question:

Which elements and alloy systems have been considered as lead-free alternatives ?

Answer:

Katoh: they divide into 4 families. One is based on Ag/Cu, which give high reliability. Secondly those containing Bi, which lowers the melting points. Did not deal with the rest as they are more appropriate to component finishes and PCBs.

Question:

What is the definition of lead-free ?

Answer:

We did not get a numeric answer but rather a more philosophical answer based on environmental conservation. They have an aim to remove polluting materials from their production, while being positive about recycling and reuse.

Question:

Which procedures have been updated for design, rework and inspection ?

Answer:

Surface gloss is an issue. With SnPb there was a shiny finish, but with lead-free it is not as shiny. So there has been some retraining in inspection.

Question:

Are they using one alloy for wave, reflow, rework and repair ?

Answer:

There is not a specific problem with lead-free. 80% of requests from customers are for SAC. With the mobile phone market there is a clear request that no Bi be involved. With hand repair, it is not possible to manufacture a cored solder wire Bi, so they use SAC.

Question:

What reliability data are available ?

Answer:

Selected published physical properties data include thermal cycling data along with solder joint strength. They do not work with competitors, but with customers. Senju does publish the data, but the customer retains some influence on publication. There is a programme organised by NEDO to form a database of material properties, but this has not yet started.

Question:

Has the usage of conductive adhesives increased ?

Answer:

No.

Question:

What kind of problems arise in the lead-free market ?

Answer:

Costs, availability and recycling. But recycling is less clear. If Bi is included it is not considered a big problem, just an issue of classification, although some education will be required.

Question:

Is indication (label) of lead-free solder to be introduced ?

Answer:

They showed such a label for their own solder. There has been an attempt within Japan to agree a labelling scheme but this has not succeeded yet. Different companies have their own systems. Customers having different limits further complicate the issue.

Question:

Do big players introduce lead-free techniques down the supply chain ?

Answer:

Senju say they are doing this in a partial way. Sony and Matsushita occasionally invite suppliers where they pass on information. Most of Senju's lead-free products go to big companies and CEMs, very little goes to SMEs.

Question:

How will Japanese companies expand lead-free overseas ?

Answer:

At this time higher volumes of Japanese products are produced overseas. Only small high valued products are produced in Japan. What happens overseas is dependent on local suppliers and markets.

Question:

Is Senju working on high melting point solder ?

Answer:

They have no replacement.

Senju went on to discuss equipment. Particular points were: The reduction of delta T, advantages of low oxygen concentrations in soldering, the required range of temperature profiles that a solder paste must meet, the requirement for increased cooling ability, increase ability of flux collection recovery.

Question:

Do they see the increase use of N₂ ?

Answer:

Since wettability is poorer Senju use N₂ to compensate. Their paste must be compatible with many profiles, and the use of N₂ allows more flexibility. Consumer manufacturers prefer not use N₂, but manufacturers of high value PCBs do require N₂. They normally use <100ppm O₂.

Question:

What Pb impurity do they allow ?

Answer

The standard calls for 0.1%, but they are achieving 0.05%. Japanese customers are very demanding.

Questions

Do they see interest in SnBi, bearing in mind problems in handling it?

Answer:

They see some limited use with step soldering.

Questions:

Have they considered using high Ag and Cu alloys to see if they produce superior visual and reliability properties ?

Answer:

They have never tested alloys above 4%Ag and 1%Cu. Joints are rough because they don't solidify with a eutectic structure, so if you increase the concentration you produce a eutectic at the surface. They understood this, so the conclusion is they choose a more economical alloy.

Senju are also an equipment manufacturer.

7.3.1 Reflow ovens:

They discussed profiling with 10 zone ovens, and large expensive boards and presented the required profiles. They showed the effect of preheat, with no effect on solderability at 150°C and different preheat times. At 175°C, with 60 and 120 sec preheat there is no problem, but for 180sec solderability is lost. If they then use N₂ and increase preheat temp to 200°C, solderability is maintained up to 180sec preheat. Senju are seeing reflow ovens increase in oven size with lead-free, and also an increase in the number of zones. They are now using 70kW machine, which is high powered.

They have developed a new heater unit with high efficiency. They have a labyrinth type structure, which can be lowered and improves N₂ usage. They have high efficiency of flux collection, and a new carrier system. They are using both IR and hot air. Each zone has it separately controlled fan. For flux recovery the cooling air is passed through a condenser where the flux is liquefied and collected. At present they do not have any profiling software in the oven, and are not collaborating with a third party. They typically achieve <100ppm O₂ with 480l/min of N₂. It takes 35 mins to purge the machine. They have found with longer preheats and higher O₂ more voiding occurs.

7.3.2 Wave soldering:

They thought they would need rapid cooling to reduce fillet lifting. They have observed a correlation between cooling rate and fillet lifting. They use chilled N₂ in an increased tunnel, to enhance cooling. Senju have observed erosion in the wave soldering machines, with SnPb they were using 304 stainless steel, but are now using an alternative material with lead-free. They are seeing an increase in pin-in-hole reflow (called multi-point reflow in Japan).

8 WEDNESDAY

8.1 PANASONIC

Yoshihiko Misawa: General Manager, Engineering Development

Kenichiro Suetsugu: Assistant Councillor environmental production centre.

Naoichi Chikahsia: Managing equipment build of reflow ovens.

Masanori Ohga: Manager of electrical controller manufacturer

Masato Hirano: Staff engineer of material process development.

Shozo Ueno: Marketing section and planning department.

8.1.1 Introduction to Panasert

Misawa introduced Panasert. Sales of ¥100bn yen, they will be the equipment leader in the world. They manufacture a full range of surface mount equipment, including 3D PCB fabrication.

8.1.2 Panasert's position in Japan

Ueno described their factory location and something of the prefecture (local state). They are located on an industrial estate with Fujitsu and Pioneer. They have ¥84bn sales, with 1066 personnel. Matsushita is a leading manufacturer of robots, and within the electronics industry they are the largest supplier of robotic machines. Manufacturing is carried out on this site, as well as design and development.

8.1.3 Panasonic's perspective on lead-free

Suetsugu discussed Matsushita work on lead-free. Their motive is to minimise the environmental impact. The other driver is the European legislation. By 2003 all products will be lead-free. METI and NEDO have organised two projects, one through JEIDA on reliability and manufacturability (electronic companies), and a second project through JWES on the basic characteristics of solders (materials companies). They see their national project as different to other countries, as the aim of the project was to achieve commercialisation as an output. They have associated specific tasks with particular divisions. So one will be involved in wave soldering for example. Suetsugu is the chairman of the WG on lead-free. They have two committees, one on the development of the technology, and the second on implementation. A senior manager chairs both committees. Their technology development is cascaded to staff through their training schools. For example there is a planned session in Singapore in the spring and one in Europe later on. They presented a complex flow diagram of how lead-free alloys are assessed within a process. This evaluation has been done using real products. Since 1988, they have been carrying out evaluation on over 6000 components. To date 1.8m units of mini-disk have been manufactured in Taiwan. They gave an example of the first lead-free double-sided board, which was a disk driver. They have produced 1m PCBs for video recorder using SnCu in wave soldering. With their TVs they have used SAC, manufactured in Malaysia from August, and from November last year in the UK, this is also a double sided board. The UK operation uses local materials and equipment. They discussed an impurity sensor used to measure lead, copper etc, for wave soldering, based on TGA.

They mentioned that soldering goes back to 3000BC and that Matsushita are now helping to address this problem and implement lead-free.

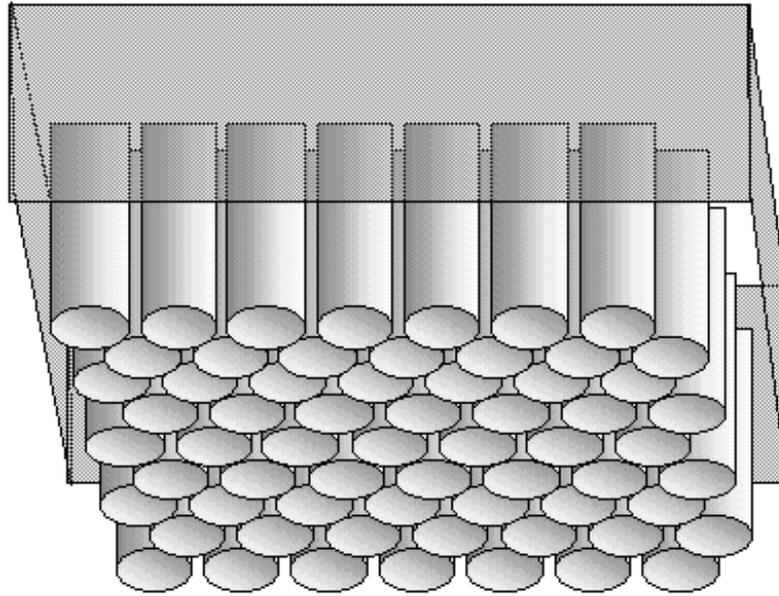
8.1.4 Lead-free reflow processes

They use Sn3Ag0.5Cu and Sn8Zn3Bi (also Sn3Ag2.5Bi2.5In), and discussed the profile and the use of N₂. Firstly they looked at the delta T, particularly with SAC where delta T is 10°C. The wetting potential of SnZn is poor compared to SnPb, with the SAC and SABI alloys intermediate. The SABI was used in the MD player. With the SAC alloy they can use the same preheat as for SnPb. With SnZn the challenge is to achieve wettability, and avoid oxidation. In order to contain the oxidation they need to reduce the preheat conditions to ~130-150°C and 60 seconds. In reflow they have to consider temperature, and require more than 5secs above 205°C. they commented on the use of N₂ in industry. With N₂ there is the advantage of not having to tune the profile for SnZn. Showed data that SnZn oxidises more than SnPb, particularly above 150°C. As the O₂ is decreased the strength goes up by 50%. Wettability of the lead-free alloys are not affected by O₂ pressure, except for SnZn where they see an improvement in going down to 10000ppm O₂, but no further improvement with decreasing O₂. Issue with solder balls with SnZn, which is beneficially influenced by N₂. The SAC alloy does not have a problem with balls. With SnZn there are a number of beneficial effects of N₂. In conclusion, they prefer to use SABI, but where high reliability is required they use SAC. While SnZn remains attractive due to lower temperature.

8.1.5 Panasert reflow machine

Chikahisa discussed reflow machines designed for lead-free. The latest Pentium K series can only withstand 215°C and Al electrolytic caps can withstand 240°C. They have found that 10°C above the melting point achieves acceptable wetting. So with some components they must use lower melting point alloys. This also puts stringent demands on the reflow equipment in terms of delta T. In their earlier machines with SnPb they were achieving up to 50°C delta T on some big boards, but with their newer machine, RSF4, they can reduce this delta T to 11°C. With the new RSF6 can get another 2°C gain in delta T. Panasert claim the delta T on their machines is as good and sometimes better than their competitors, but this has been done with lower power and have retained higher free area for the PCB.

Chikahisa discussed the nozzle layout in the reflow oven. The nozzle design in the reflow oven, is an array of 14mm diameter tubes in each zone, and a zone shown schematically below. Showed two competitors, which was a plate with holes. Their criticism is that the required laminar air flow cannot be achieved. There was similar criticism for another system with long horizontal tubes with slots. They claim for their design to achieve more laminar flow, the other designs generate more turbulence. The slot design doesn't cause much turbulence but there is not good transfer. So with the RSF6 on the FA Controller board achieved 6.5°C delta T, whereas on a conventional oven delta T is 40°C. With a car navigation board, which has a difficult connector, the respective delta Ts are 10 and 62°C. With a portable phone board, delta T is 3 and 8°C. they discussed energy reduction. Previous energy consumption for reflow was 47% of total and this has been reduced to 32% of a reduced total. A total reduction to 72% of earlier value. These savings have been achieved by controlling the airflow, reducing this after start up. A further reduction is to lower the temperature when no PCB is in the oven. Further attention to details such as the size of the chain and circulating route can additionally reduce power.



Schematic of nozzle layout within oven zone

8.1.6 Case history on developing a controller.

Ohga described the development of a process for building this controller board. They selected Sn3.5Ag3Bi6In alloy (*melting point 205C*). This controller board is one of 8 in a placement machine. The topside of the board was SM, and the bottom side wave soldered. For wave soldering they used Sn0.7CuNi. The assembly comprised a 305x230, 1.6mm, 8 layer FR4 board with a copper with preflux finish, and 360 components. The SABI alloy has a 15°C pasty range, so there was a challenge to prevent components falling off as the alloy cools. They have carried out continuous printing trials, but printing was bad for SABI at 0.5mm pitch. Particle size was quite big and caused clogging, and this was compounded by the resin, which was tough and contributed to clogging. They reduced the resin content and increased flux, and used smaller solder particles. In the oven fast cooling has been added due to the pasty range of the alloy. The reliability of the assemblies was assessed between -45 to 85°C with a 30 min cycle with 500 and 1000 cycles, equivalent to 10 years. They also used a high temperature soak test at 85°C for 1000 hours. Joint strength and vibration testing followed. They presented lots of data, too much to absorb. They have increased pad size to improve solder fillet and reliability. Discussed wave soldering and the modifications to the nozzle design for the chip wave.

There was then a very short factory tour. There was no formal question and answer session.

8.2 KOKI

Kiketsu Hasegawa: President

Kan Takita; Vice President

Manabu Itoh: General Manager Soldering Materials, Overseas Dept

Yasuhiko Kajitani: General Manager, Soldering Equipment Sales Dept

Shuichi Sato: Manager

Atsushi Kondo: Soldering Materials, Overseas Dept

8.2.1 Koki overview:

Koki started with materials, and initially imported equipment from Frys. There are 130 people in the company (this is just materials, another 50 in the equipment position), so Koki is definitely an SME. Their main products are: no-clean flux and paste, cleaners, spray fluxer, wave soldering, reflow, and curing machines. They described the management, location, and structure. Koki will start producing solder paste mid 2001 in Denmark. From the total turnover, 61% comes from materials the balance from soldering machines. Of the materials 55% paste, 32% flux, and other bits including adhesive, with 70% of turnover from Asia.

Data from JEIDA say that most companies in Japan are adopting lead-free in 2001/2002. They showed an EIAJ roadmap, with conversion by most companies by 2003. Japan is moving to lead-free to have environmentally friendly manufacture, and have value added components. They again mentioned that the driving force was initially WEEE, but now internal Japanese competition is the main factor. Their preferred alloy Sn3Ag0.5Cu, for reflow, wave & wire. Koki consider that SnZn is a material of the future.

Koki have concerns over patents and have licence agreements with AIM and Senju/Panasonic. The above SAC alloy is outside the Iowa patent. They are now pushing the Sn3Ag0.5Cu alloy. Their tests show that this new paste is performing as well as or better than conventional no-clean SnPb, except for wettability. Their wave solder flux is quite a high solids resin flux. Wetting with lead-frees, dependent on pre-heat. They now have a superior flux, which can be used with SnPb. In their wave machine they have increased the wave width from 10 to 20mm, with sufficient dip time to 4-5 sec. Additionally there is some gain if the distance between the waves is increased. They are still using 250°C, so there is an issue with low superheat. They are considering using N₂, but are striving not to use N₂. ICT is an issue with the wave solder residues, but they have developed new techniques that work around this problem. They are developing low solids VOC-free flux, lead-free flux, and the SnZnBi paste.

There was a question and answer session.

Question

Have they seen an issue with erosion in soldering ducting in wave soldering, and if so what material solutions have they arrived at ?

Answer

Koki use of stainless steel in ducting. They have moved to 316L, 3-4 years ago and don't have any problems.

Question

What is their experience of dressing rates ?

Answer

Use a shallow angle (3.5°) and lower the height of the nozzle and hence minimise the amount of dross, by reducing the exposure of the wave.

Supplementary question

What experience of dross recovery with lead-free?

Answer

They have not had any real issues, and reclaim 70%.

Question

Are there any cleaning issues with lead-free ?

Answer

No, all their products are no-clean, and there is no requirement for cleaning.

Question

What are the defects in the stencil/reflow process? (solder balling, bridging, voids, etc)

Answer

They don't have data to discuss defects. But they acknowledge that solder balling does occur. They use 70-80% aperture opening, so getting less paste, and hence less balling.

Supplementary Question

Doesn't that then raise issues with spreading?

Answer

Yes we agree, so then it is a matter of the customer requirements. Sometimes there is a Cu halo. But with consumer electronics that this may not be an issue.

Question

Does the cooling unit improve fillet lifting situation, and how?

Answer

With standard equipment improved cooling does not affect fillet lifting. Unless rapid cooling is applied immediately after wave there is no effect, and this is not possible with current equipment. They are trying to modify the equipment to influence the phenomenon towards benign fillet lifting.

Koki then asked a question:

To what degree is lead-free used in the UK?

Answer

Warwick answered, the larger OEM customer base in the UK and Europe is thinking of introducing lead-free on some specific products. Most people have carried out process evaluations. A small number of customers are building on one or two lines on simple boards with no publicity. Some of the Japanese manufacturers in Europe are at the same stage of development. We expect during this year to see some lead-free products, probably in the telecoms sector, as a start of moving products to lead-free over the next 3 years. Multicore-Loctite started some work with some customers over 10 years ago. We now have a strong conviction that those who say they will be lead-free in the next year will actually do so.

Question

What is the composition of lead-free alloys in Europe, and are the choices in Japan different, and furthermore will the Japanese choice of alloys be accepted in Europe?

Answer

Warwick answered. In Europe the selection process is different to that in Japan. In Europe there is more concern to select the eutectic composition. The result is that trials and reliability data are based on the eutectic composition. However, from a technical point of view we do not believe the composition is critical. The worldwide situation has been complicated by the US and Japanese patents. I hope this will be resolved in the near future. It is worth noting that the industry has lived with 3 SnPb alloys, so perhaps having a choice of alloys is not a big issue.

Question

The Japanese don't like use Sb, but why is Sn5Sb used in the UK ?

Answer

Warwick answered. With the Castin alloy there are only small gains from 0.5% Sb. It is likely that the major companies will not use Castin because of Japanese reluctance. There are few alternatives to Sb in selecting alloys with higher melting points, but there are technical issues with this choice.

Question:

Cost of Ag in Europe? (the different compositions in Europe and Japan of the respective SAC alloys)

Answer

Warwick answered. From a purely technical consideration high Ag is better (>4%), gives a more stable microstructure, and a shiny joint. The commercial point, is that that the Ag market will have more demand which may drive up the price. So it is sensible to use a low Ag level.

Question

Why has Japan used the 3% Ag alloy?

Answer

The cost of the alloy. In terms of joint strength we don't need to use the eutectic composition.

Question

Why has Europe not used Bi, since it is used extensively in Japan?

Answer

In the US and Europe it is acknowledged that a low Bi content may improve reliability. But there are many concerns that Bi will cause reliability problems when Pb is also present. The product mix is different with Japan, and this influences their decision. When Pb is eliminated there will be 2 issues? Does Bi improve the reflow step, and does it improve reliability in difficult service environments?

Supplementary Question:

Sony are using 1% Bi alloy to improve wettability with no impact on reliability. So why the reluctance for Bi ?

Answer

No decision in Europe until Pb is eliminated. There is also some concern in terms of recycling. There will be a similar concern in Japan, but they have not thought that far ahead, and they only have to consider a certain % for recycling.

9 THURSDAY

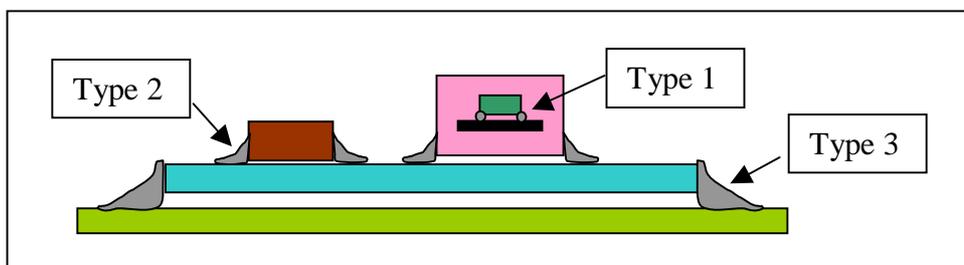
9.1 TDK

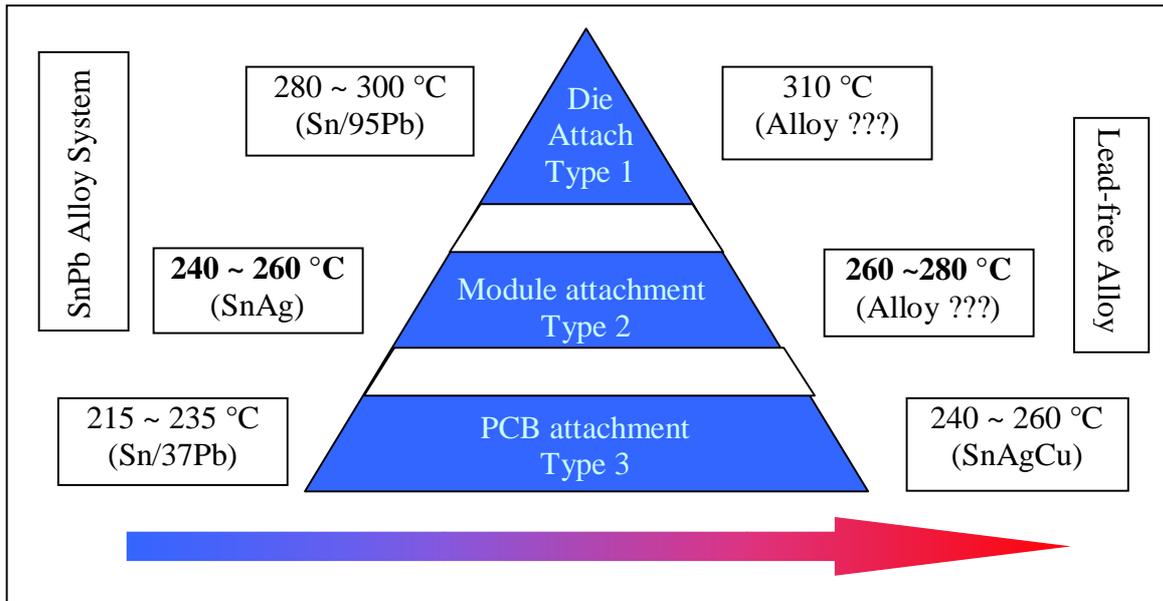
Shunjiro Saito, Executive Vice President, Technology, Safety & Environment
Chuuichi Koizumi, General Manager, Safety & Environment Office
Kiichi Nakamura, Manager, Electronic Component Business Group
Hiroyuki Watanabe, Assistant Manager, Reliability Assurance
Hisayuki Abe, Assistant Manager, Products Development Dept
Yukio Kishi, Manager, Quality Assurance Department, Quality System Engineer
Mr Kogure, Manager, Public Relations
Miss Kobayashi, Editor, Internal TDK Magazine.

The meeting was opened by Koizumi. Nakamura heads up the lead-free work in TDK. We were then showed a video on TDK. Their basic expertise is with magnetic media, and has resulted in them being leaders in recording media. They manufacture small magnetic parts, such as for hard disk read/write heads. They use a range of magnetic media, from ferrite to neodymium based materials, which allow them to manufacture miniature devices. They manufacture a number of discrete components, capacitors and inductors, necessary for slim light weight consumer products. They have a turnover of ¥440bn, with manufacturing capability around the world. They also have collaborative research activities around the world, including Cranfield Institute in the UK.

Koizumi then went through their environmental report, reporting their aims, their environmental milestones from the 1970s, and their corporate structure. Their director of safety and environment is a member of the board (Saito), and is also responsible for directing the lead-free programme. Their aim is to be lead-free by December 2001. This programme started in July 1999.

Nakamura then discussed the detail of lead-free at TDK. He discussed the issues of supplying components. TDK's first step was to remove Pb from the termination, secondly to improve the process robustness, and finally remove Pb from the component structure. They have many ceramic components containing Pb. They have issues at three levels, solder joints within the module, the mounting of the part on the module, and the attachment of the module on the PCB itself. (Shown in the diagram)





With the above Figure he discussed the hierarchical soldering issues associated with Sn

Pb and lead-free alloys. They have not solved the issues of soldering at the two temperature ranges above the type 3 solder joint.

They then moved onto the questions posed by the mission.

Question:

How do they select lead-free materials?

Answer:

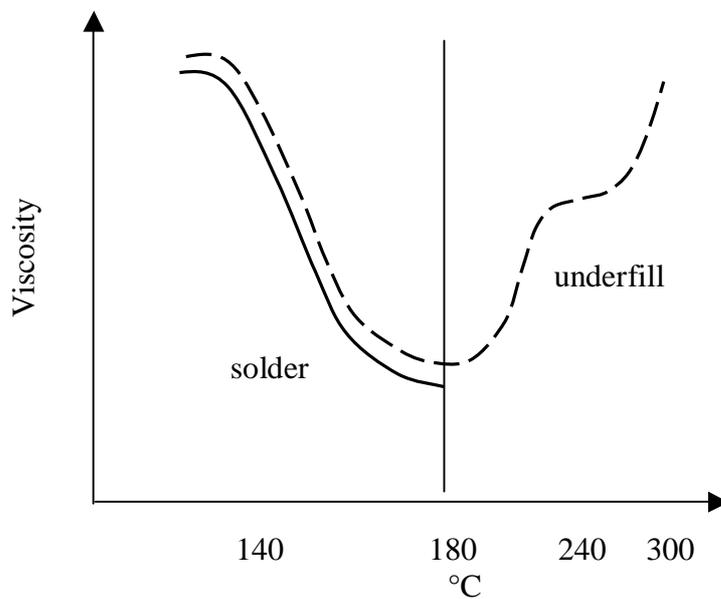
They follow material supplier recommendations. They look at the melting point and the mechanical strength / reliability data. They also prefer well known and frequently used materials. Thus, they have selected the SAC alloy, usually Sn3Ag0.5Cu, but also they use Sn3.7Ag0.7Cu. They also sometimes use alloys with traces of Bi. They use the same alloys for component terminations. They also use a SAC alloy for wave soldering, and also Sn0.7Cu0.3Ag. When they have to deal with low curie point materials they use Sn57Bi1Ag. Have also used SnZnBi. When purchasing components they require lead-free finishes, which are able to withstand 245°C. Their definition of impurities is below 1000ppm, below this there is unjustifiable cost. They have not yet defined the permitted Pb level in the solder wave.

Question:

Which is the most important process issue to overcome?

Answer:

They discussed the availability of solder pastes with higher melting temperatures. They traditionally used high Pb alloys, but they have to move away from this. They have considered SnSb, but this has also been rejected on environmental grounds. He then discussed flux issues, and developments in conjunction with Senju. They have discussed an underfill flux.



They explained by using the underfill flux with high temperature properties, that retains some adhesive properties, which allows and maintains component attachment. After soldering the underfill flux flows underneath the part to increase adhesion. This work is based on the SAC alloy.

On some parts they are using spot welding inside components within the components. On some of the discretes they are using conductive adhesives. On some components they are going to use pure tin.

Question:

What design changes have been implemented ?

Answer:

Some features such as glossiness have been changed. The design temperature of some of the components.

Question:

What reliability data have they obtained ?

Answer:

They have obtained data on a number of properties:- reliability, wettability, process toughness, fillet lift off, whiskering. These were not dealt with in detail.

Question:

Are you using conductive adhesives ?

Answer:

TDK don't use these as they are not reliable.

Question:

What problems do they anticipate in moving to a lead-free system ?

Answer:

They are many but they focus on cost. Component termination and the selection of a lead-free alloy. They are concerned about the selection of a single alloy by the industry. Issues

with machine suitability, and there will be a requirement for new equipment. During the transition there will be a duplication of parts with normal and lead-free parts.

Question:

Are there any PCB issues ?

Answer:

No.

Question:

Comment on the dissemination of lead-free information ?

Answer:

In Japan there is a good flow of information, and no technological barriers in Japan.

Question:

Is the cascading of lead-free information overseas effective ?

Answer:

They invite people from their overseas companies here for training. They also visit these companies to help them. A number of the big manufacturers have cascaded this information overseas. TDK give a high priority to meet these needs. They see the same design rules applied around the world as in Japan, although there will be local input.

Question:

Is there increased cost?

Answer:

Yes there is, but TDK will work to contain this cost and don't plan to pass the cost on. But maybe they will have to do so in limited cases.

Question:

Why address the issues of lead-free?

Answer:

They can't ignore the EU directives. There is also pressure from the semiconductor industry. They also have their own environmental mission statement.

Additional questions.

What is their preferred component finish?

Answer

Discretes use 100% Sn, but also SnCu and a trace of Bi. It is similar for ICs as well. Starting to use the SAC alloy as well.

Question:

What limits do they have for component durability ?

Answer:

Currently they are limited to 245 °C, but can achieve 260 °C if there is a requirement in the market.

Question

What % components have Pb-free terminations?

Answer

For chips more than 95%.

Question

Are they using Pd finish on lead-frames?

Answer

No, because it is too expensive.

Question

Why use Bi and how much?

Answer

2-3% Bi improves wettability.

Question

Is there an issue with large components and the flux underfill.?

Answer

They have not been tested but it may or may not be a problem, all the work has been done with small components.

Question

What is TDK's opinion on cascading of information in Japan?

Answer

This is mainly achieved through JEITA and conferences, where there are a large range of company sizes present.

Question

What countries other than Japan are requesting lead-free components?

Answer

Europe, US. particularly the telecom sector, Compaq and HP.

9.2 NEC

Eiichi Kono, Principal Researcher, Packaging Technology Centre.

Naomi Ishizuka, Senior Engineer, Packaging Technology Centre.

Kono discussed NEC lead-free targets and alloys. NEC will eliminate Pb by Dec 2002, by March 2001 March achieve 50% of 1997 levels. Each division should ship one lead-free product by March 2001. This switch will include communication equipment, which includes switch and optical equipment, through to the personal consumer market. They have made an alloy selection, both the SAC alloys and the SnZn alloy. The SAC alloy has very good mechanical properties, although poor higher processing temperature and poorer wettability. They have selected Sn3Ag0.5Cu for their communications products. They are using this as opposed to Sn3.5Ag0.75Cu due to the Iowa patent. About the SnZn paste, there have been a lot of advances. However, oxidation of Zn remains a problem, poor wetting is an issue that can be offset by N₂, and there is a scarcity of reliability data. The Zn alloy is used in a number of consumer products. They are considering Bi alloys as well; they have many demands that take into account properties as well as cost.

Then discussed the SAC alloy. They showed reflow developments reducing delta T from 26 to 10°C. Then discussed wave soldering with SAC. Said surface dendritic cracks were acceptable. See significant advantages with N₂ inerting. The fillet lifting that is known to occur with Bi alloy does occur with SAC alloy as well. This occurs when SnPb alloy plated PCBs are used, and failure occurs on the component side of the PCB. They also see fillet lifting with the land detaching. NEC currently are using a SnPb plated component finish, they

will then move SnBi for components. For PCB, they are using pre-fluxed, but will move to HAL with the SAC alloy.

Then discussed SnZnBi. After thermal cycling they see that SnZn out performs SnPb for both QFP and 2512 chip components. At 85/85 they saw corrosion, whereas at 40/90 there were no problems (they say they didn't observe loose corrosion products). He accepted this but said that it was acceptable (presumably before the intended use environment). For some ICs, like Intel Pentium they must use SnZn, since these devices are only qualified to 220°C. In NEC they do use components above their rated values. NEC is now rating components at 240 and 250°C. SnZn reflow is done with N₂.

For large computer boards they are using vapour phase soldering with the SAC alloy, and wave soldering in N₂. The liquid they use has a boiling point of 230°C. They are using vapour phase soldering for BGAs with >1000 I/O.

NEC have lead-free products in the market and have now sold 300,00 pagers over the last 3 years. With their desk phone, they have not seen any problems.

The mission questions were then addressed:-

Question:

What is a selection method of a new material?

Answer:

Toxicity: don't use Sb, investigating Bi

Joining strength, long-term reliability

Melting point, wetting characteristics

Cost and supply

Solder paste and soldering with flux

Process

Manufacturing equipment

NEC think considerations from various points of view are essential.

Question:

What alloys, components, and substrates do you select?

Answer:

Alloys: Sn-3Ag-0.5Cu, (Sn-3.5Ag-0.75Cu), Sn-8Zn-3Bi

Components: NEC started using conventional components, but they now demand high temperature resistance from their suppliers, and Pb-free finishes.

Substrates: Conventional ones (materials and surface treatment).

Sn-Ag-Cu hot air leveller for wave soldering.

Question:

How do you define lead-free?

Answer:

Solder: NEC take no account of small amounts of Pb included in refined Sn. So they use the standard suppliers definition of purity.

Question:

What are problems in a soldering process to be overcome?

Answer:

Reflow

Long-term reliability of Bi including Sn-Ag solder with alloy42 leadframes.

Solder paste with high pre-heat temperature: 180 °C.

Reflow furnace with small DT

Wave

Poor wetting, flux issues.

Nitrogen atmosphere wave soldering equipment

Fillet- and Land-lifting

Question:

Do you use conductive adhesives increasingly?

Answer:

NEC haven't considered conductive adhesives as substitutes for solders because of poor productivity.

Question:

Do you have a label for lead-free solder?

Answer:

Not yet. There is a feeling, that there should be something e.g. PCBs – but there are many types.

Question:

How do Japanese companies introduce lead-free technologies to overseas factories?

Answer:

Each company does this individually. NEC has more than 20 divisions. Each division introduces lead-free technologies to its own overseas factories and subcontract companies.

There then followed a more informal session.

Question:

What is the selection method for new solder ?

Answer:

They don't like Sb. They are still looking into the use of Bi, and are collaborating with medical research to ascertain Bi toxicity effects. The mechanical and process properties are also important.

Question:

What alloys, components, and substrates are selected?

Answer:

Already discussed the alloys. With components NEC are still moving to fully lead-free finish and higher temperature durability parts. For PCB they have developed HAL of SAC.

Question:

How do you define lead-free ?

Answer:

They only call assemblies lead-free if the solder and the termination finishes are lead-free.

Question:

What are the problems in the soldering process to be overcome ?

Answer:

NEC is aware of long-term reliability issues with Bi in the SnAg alloy and Alloy42 lead-frames. Solder paste and preheat of 180°C. They need to achieve better delta T. With wave soldering there is poor wetting and issues with the flux. Need to consider if the process requires N₂. The fillet lifting issue is not a particular problem as they have developed process rules to negate the effects.

Question:

Are leading companies cascading lead-free knowledge ?

Answer:

NEC only does this through its sub-contractors and through JEITA.

Question:

Are Japanese companies introducing lead-free overseas ?

Answer?

Yes they doing this through their overseas divisions.

NEC questioned the team on the alloy composition being used in Europe, and the current status of WEEE? The team responded with the required information.

10 FRIDAY

10.1 DENSO, Kota Plant

Attending for DENSO:

Fumio Kojima, General Manager, Production Eng. R & D Dept

Keizo Takeuchi, General Manager, Materials Eng R&D Dept

Hiroyuki Wakabayashi, Assistant General Manager, Materials Eng. R & D Dept

Mutsumi Yoshino, Manager, Soldering Technology Group, Production Eng R&D Dept

Kojima, who presented information about Denso from two brochures, opened the meeting. Touched on the products, particularly automotive, but there was also telecoms and a wide range of sensors used in automotive applications. Denso was formed in 1949.

This plant is within the Electronic Systems Group, and 4000 people work there. Yoshino is part of a production department. Denso employ 2500 people in the UK. There many customers are listed in the report.

There was then a presentation by Wakabayashi discussing environmental pressures. They have to meet the requirements of WEEE and ELV. Since ELV has already been enacted it is of more importance to Denso. Complying with WEEE and ELV will entail Denso removing 86 currently used hazardous substances for which they are currently developing alternatives. They will introduce recycling targets in 2005, with 86% recycling target in 2006 and a 95% target by 2015.

Travelling to Denso we had the opportunity to discuss with Yoshino Denso's lead-free status. They are not currently producing lead-free but have done a number of trials. Their selected alloy is the Japanese SAC (Sn3Ag0.5Cu), which has been selected for reliability reasons. There was a lengthy discussion on the products and the operating conditions. The engine compartment is rated at 105°C and the cabin at 60°C. Currently Toyota mount the Engine Control Unit (ECU) in the cabin, but have plans to move this into the engine control chamber and as close to the master cylinder as possible. Currently the highest operating system in the car is the ABS controller. The board temperature here is 120°C, and they are using FR5 with a 150°C Tg. We also discussed the weight of wiring harnesses and in the future of using an information bus. Yoshino discussed the progress being made in Europe in defining a standard.

Denso presented assembly trails they have been working on. Presented work on minimising the temperature range during profiling, which was similar to Panasonic. Denso presented work looking at reliability of lead-free finishes with SnPb solder, and with completely lead-free systems. The results show with SnPb the introduction of Bi with an Alloy 42 leadframe reduces fatigue life. With copper leadframes the addition of Bi to the termination surface finish has a beneficial effect. This work was done with QFPs with three different leg formats. The work showed that legs at 45° had the poorest reliability, with a more vertical leg format yielding better reliability. Interesting a SnAg finish resulted in better reliability than the standard Sn10Pb finish. When using SnAg solder and a SnAg finish there was again a significant susceptibility to Alloy 42 leadframes, whereas with copper leadframes reliability was optimal. When adding Bi they did see fillet lifting with through-hole components. The

addition of Bi to SnAg alloys also increased the strength (up to four times at 10%) and reduced elongation (by a factor of 10, for a similar 10% addition of Bi).

Denso have also encountered issues with flux residues. With new formulations, that are rosin free, the residue cracks under stress. Activators still left in the flux cause SIR issues. Reducing the activator then causes solderability issues. Hence Denso have been working with the flux supplier to introduce into the flux a deactivator that removes any activator after soldering.

Denso have their own IC wafer fab production facility. This facility probably produces all their required ICs. In the entrance hall were examples MCM type modules with flip chip and some wire bonding.

They then went onto answer the mission questions.

Question:

What is the driver for the transition to lead-free soldering? Is it legislative or consumer pressure? If the latter, what evidence has been seen?

Answer:

Denso has seen the pressure for change mostly coming from regulation. There is also some change coming from the attitude of producers.

Question:

What is the new materials (alloys, components, substrates) selection process?

Answer:

They prefer to use alloys not bound by patents. There has been no standardisation by the Japanese government. Denso showed a very useful ternary alloy graph to aid the discussion. They will use the Japanese SAC alloy. They are talking with suppliers on surface finish and process temperature.

Question

Will the technology be rolled out overseas and, if so, when?

Answer:

They have not yet cascaded their lead-free knowledge to overseas plants.

Question:

What process issues have they had to overcome?

Answer:

They have process issues with lead-free, and the higher temperatures. They have achieved better reflow with 7 zone ovens.

Question:

What impact has there been on process yields and what types of defects have been found?

Answer:

Denso have seen fillet lifting. With Sn6Bi see faster crack growth than with Sn2Bi on Alloy42. Thermally cycling between -30 to 105°C Denso see lots of problem with Alloy42 even using the SnPb alloy, but the effects are worse with Bi. Big problems with the circuit boards where they are seeing problems with barrel detachment. No problems with reflow. New materials are selected on strength and reliability. They see small reductions elongation as a result of introducing Bi. For these tests used an alternate method based on a torsion test of a tube of solder. The addition of Bi has a severe effect on fatigue. Denso have done a lot of interesting mechanical work. Using SAC

components with improved heat resistance, and PCBs with water soluble pre-flux, based on an OSP.

Question:

How is lead-free being defined ?

Answer:

Define lead-free as when the solder and the surface finish but not the Pb in ceramics.

Question:

What have been the process issues in developing a lead-free process ?

Answer:

Developing a solder paste with the change in temperature profile. Denso have developed a paste with Harima. They have been using a no-clean but have switched from a rosin system to an acrylic one. The past includes a deactivator to reduce residue problem. There has been a big issue with soldering iron tips, where the temperature has had to go from 320 to 400°C.

Question:

What reliability data is being acquired?

Answer:

Regarding reliability data Denso see a problem with the SAC alloy combined with Bi surface finish on components. Denso are using a condensation cycle and looking for a colour change of exposed copper foil at 85/85.

There were a number of issues that were dealt with cursorily

The cost of lead-free is an issue. Denso do not currently have, or plans for, a labelling scheme. Transfer of technology, is largely achieved the provision of an evaluation standard. Transfer of technology to overseas Denso plants is structured around a manual.

Short factory tour

We were shown one long production line for the ECU. Only the printer and placement machine were not built by Denso. Built into the line were AOI machines, which were claimed were running 100% inspection. (After the visit team members said it was a Panasonic line, and the AOI machine was a). A robotic machine carried out Wave soldering, and hence the PCBs were not on a conveyor. This allows much greater flexibility in controlling the process. Each assembly is then put onto test, a soak at high temperature followed by soak at cold temperature with full electrical test.

What was impressive about Denso was that it was so self-contained and obviously has a lot of expertise across a wide range of disciplines. This gives it great control over its products, and it is very unlikely that it shares this expertise, except in the limited areas as discussed, e.g. solder paste.

10.2 OSAKA UNIVERSITY

Professor Tadashi Takemoto: Collaborative Research Centre for Advanced Science and Technology: Environmental & Resource Engineering. Takemoto also chairs the Japanese national committee that shadows ISO TC44SC12 on solders and fluxes.

Professor Katsuaki Suganuma; Inst of Scientific & Industrial Research

Takemoto gave an overview of what research is going on at Osaka. He pointed out the two projects from NEDO, for which JWES and JEITA have been the project coordinators. JWES did the basic work on the alloys, and developed lead-free solders. JEITA did work on the process feasibility. Osaka involved with JWES. At a recent MATE conference 40% of the 90 papers concerned with the lead-free issue. Takemoto discussed who have recommended what alloys. Again mentioned patents between Senju and Iowa University. Although they have defined the range alloys there has been no the specific alloy composition recommendation. This will be dependent on the patent issue. The NEDO project finished in spring 2000, but there is on-going work. There is an application for a project to produce "standardisation of test methods for lead-free solders for the reduction environmental impact" 2001.3 to 2002.3. JEITA has a similar proposal for lead-free solder reliability work, and on a similar time scale. He sees the standardisation process as very important as reducing the range of alloys within Japan. They are going to make a recommendation to ISO 9453 for two new alloys, Sn₃~4Ag 0.5~1Cu and Sn₃~4Ag₂~3Bi. Takemoto has severe reservations on the SnZn system owing to interdiffusion with Cu and the intermetallics that form. There are also recycling issues that will hinder recovery. He has some concern with electromigration under environmental stress, but has been assured by companies using the SnZn alloy that there are no problems.

Suegenuma has been working SnZn and will be presenting a paper at a conference on March 9th. Suegenuma has a different opinion on Zn. Suegenuma agrees there are fluxing and corrosion issues. He will report on the project, with 60 companies, that is halfway through and runs from 2000 to 2002. Suegenuma's personal opinion is that we don't need the 3% Bi in the SnZn alloy as it introduces a solidification problem and reduces the mechanical properties (it makes it brittle). Suegenuma is exchanging information on SnZn with Marconi. This project has some internal university funding and other complex funding sources. They are considering how to modify the tests to measure lead-free properties.

Some work is being done with SnBi, processing conditions and use environments. Suegenuma stressed that SAC was the first choice and would be worked on the most. Suegenuma is also working on a project to use ICAs for die-attach, but can't be used for power devices due to poor thermal properties. They have done some modelling work on fillet lifting, and would like to expand this. But the solidification process is difficult to model, and he acknowledged that Chris Bailey at Greenwich was an expert. The three modes of pad lifting can all be solved, so none are worse than others. Takemoto believes that the best lead-free alloy is a quaternary SnAg_{2.5}In_{0.1}~0.5Bi with perhaps 0.5% Cu for grain refining. It is good for high reliability but cost is a problem. This view is biased. MITSUI have the patent (actually Takemoto), but there are no data in the public domain, but do exist confidentially. They haven't done any work in whiskering.

There was an interesting discussion on the patent issue. There is a license agreement between Multicore and Iowa. Multicore have been in discussion with Senju on a patent sharing agreement. Another licensee of the Iowa patent is making agreements. MW questions the validity of these, but if they are valid that will make things simpler. The research in the UK was outlined. Multicore is involved in a German project, INNOLOT, to validate lead-free processes and to identify superior alloys particularly for the automotive industry. There is a joint project with UK universities and industry on lead-free flip chip. Celestica are involved in HDPUG.

On the question of the definition of lead-free, Takemoto commented that this is already defined in ISO 9453: as 0.01 for SnAg and SnCu, and with SnSb, SnBi SnIn at 0.05.

Takemoto commented that if the surface finish on parts contains Pb then the assembly is not lead-free.

He offered to send an equivalent of the NEDO report, in Japanese, from last years JWES research project.

11 ACKNOWLEDGEMENTS

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12 APPENDICES

12.1 Appendix 1: Products produced using lead-free process exhibited in The Eco Productronics Show 2000

Company	Products	Board used lead free process	Alloy composition	Soldering Methods
Panasonic	Mini disc player	Main board	Sn-Ag-Bi-In	Reflow soldering
	Headphone stereo	Main board	Sn-Ag-Bi-In	Reflow soldering
	VTR	Main board	Sn-Cu	Flow soldering
	TV	Main board	Sn-Cu	Flow soldering
	Vacuum cleaner	Power Switch	Sn-Cu	Flow soldering
		Vacuum Nozzle	Sn-Cu	Flow soldering
	LCD display PC		Sn-Ag-Cu	Flow soldering
	Home-heating	Heater	Sn-Ag-Cu	Hand soldering
Automatic tip mounter	Control board	Sn-Cu	Flow soldering	
Hitachi	Refrigerator	Main board	Sn-Cu	Flow soldering
	Washing machine		Sn-Ag-Cu	Flow soldering
	Vacuum cleaner	Control board	Sn-Ag-Cu	Flow soldering
	PC	Mother board	Sn-Ag-Cu	Flow soldering
	Air conditioner		Sn-Ag-Cu	Flow soldering
Pioneer	DVD player	Power switch	Sn-Ag-Cu	Flow soldering
		Audio-circuit	Sn-Ag-Cu	Flow soldering
	Car audio		Sn-Ag-Cu	Flow soldering
	CATV converter		Sn-Ag-Cu	Flow soldering
Sharp	VTR		Sn-Ag-Cu	Reflow soldering
Casio	Calculator		Sn-Ag-Cu	Reflow soldering
	Handy terminal		Sn-Ag-Cu	Reflow soldering
	Mobile phone		Sn-Ag-Cu	Reflow soldering
NEC	POS system		Sn-Ag-Cu	Reflow/Flow soldering
	Note book PC	Main board	Sn-Zn-Bi	Reflow soldering
	Desk top PC	Main board	Sn-Zn-Bi	Reflow soldering
	Pager	Main board	Sn-Ag-Cu	Reflow soldering
Ricoh	Copy machine	Main board	Sn-Ag-Cu	Reflow/Flow soldering
Omron	Sensor		Sn-Ag-Cu	Flow soldering
Sony	VTR	Main board	Sn-Ag-Bi-In	Reflow soldering
	TV	Tuner circuit board	Sn-Ag-Bi-In	Reflow/Flow soldering
	MD	Main board	Sn-Ag-Bi-In	Reflow soldering
Mitsubishi	Refrigerator	part of board	Sn-Ag-Bi-In	Flow soldering
Sanyo	Refrigerator	part of board	Sn-Ag-Cu	Flow soldering
IBM	Hard disk	Main board	Sn-Zn-Bi	Reflow soldering

12.2 Appendix 2: Roadmap for implementation of lead-free assembly process

Company	Plan for reduction of use of lead & full scale implementation of lead free process		Remarks (Products already produced by lead-free process)
	Action	Target	
Panasonic	Complete abolition	By Mar 2003	Min-disc player, VTR, PD, Headphone stereo
Sony	Full implementation – Japan	By Mar 2001	Camera-built-in VTR, TV, minidisk player
	Start lead free process – Overseas	By Mar 2002	
Hitachi	Reduction to ½ of actual use of '97	By Mar 2000	8 mm camera, notebook PC, washing machine, calculator
	Full implementation for in-house production	By Mar 2002	
	Complete abolition in Hitachi Group *except overseas production	By Mar 2004	
Oki Electroic	Completion of evaluation	By year 2000	
	Partial use	By year 2000	
	Complete abolition	By year 2000	
NEC	Reduction to ½ of actual use of '97	By year 2003	Pager, notebook PC
	Complete abolition	By Dec 2002	
Toshiba	Complete abolition – mobile phones	By year 2000	
Mitsubishi Elec	Establishment of lead free technology	By year 2002	Refrigerator
	Reduction to ½ of present use	By year 2004	Applied for 4 home appliances (TV, washing machine, refrigerator, air conditioner)
Fujitsu	Reduction to ½ of present use	After Dec 2001	PC, LCD, server computer and etc
	Full scale application	After Dec 2002	
NTT	To introduce for environmentally safe products	By year 2001	Lead-free, cadmium free and etc
Sanyo	Produce at least 1 lead free product at each company	By Mar 2001	
	Expedite implementation for main products produced in Japan	By Apr 2002	
Sharp	Implement for products produced in Japan	By Apr 2001	
	Implement for overseas product	By Apr 2002	
Seiko Epson	Step-by-step reduction	By end of 2001	
	Complete abolition		
Automotive Ind	Reduction of ½ of present use	in 2000	Except battery
	Reduction to 1/3 of present use	in 2005	Except battery

12.3 Appendix 3– Product group and choice of surface treatment (actual use)

Product	Alloy	HAL	Plating	Other coating
PC	SnZnBi	SnZn	Niau	-
General purpose computer	SnAgCu	SnAg	-	-
Mobile phone	SnAgCu	Ag	NiAu	-
Medical electronics	SnAgCu	SnAg	-	-
Office appliance	SnAgCu	-	-	OSP
Power supply	SnAgCu	-	-	OSP
TV	SnAgCu	SnAg	-	-
Home appliance	SnAgCu	-	-	OSP
Air conditioner	SnAgCu	-	-	OSP

12.4 Appendix 4: Choice of lead-free alloy by industries

Industries	Lead free alloy proffered			
Consumer-electronics	SnAgCu	SnZnBi	SnCu	SnAgCuBi
	SnAgCuSb			
Industrial-electronics (telecoms)	SnAgCu	SnCu	SnAgCuSb	
Automotive electronics	SnAgCu	SnAg	SnAgCuSb	
Medical electronics	SnAgCu	SnAgCuSb		

12.5 Appendix 5: Additional Questions

The team also prepared additional questions that were not passed onto the Japanese as they were too numerous, but were none the less used as supplementary questions during the visits.

The following questions were prepared by NPL:

GENERAL

- Q1. How realistic is the suggestion that the industry should (could) adopt one replacement for wave-soldering (e.g. SnCu) and one replacement for reflow soldering (e.g. SnAgCu)?
- Q2. Will the choice be product or process dependent rather than universal?
- Q3. Should international standards incorporate suggestions of replacement Pb-free solders?
- Q4. How is the design function being integrated in the implementation of Pb-free soldering?
- Q5. To what extent is DfE driving or supporting the move to Pb-free soldering?
- Q6. To what extent can conducting adhesives be used to replace Pb-containing solders (e.g. special or niche applications)?
- Q7. Do you have any field data relating to the use of conducting adhesives?
- Q8. What do you consider the main barriers to the implementation of Pb-free technologies?
- Q9. To what extent are individual companies working alone, or sharing R&D activities?
- Q10. What is the focus of these R&D activities?
- Q11. What is the progress of the JEMAI and JWES sponsored R&D activities?
- Q12. What is the progress of the ISIR and RCAST sponsored R&D activities?
- Q13. Will the results of any of these activities be placed in the public domain? If so, when?
- Q14. To what extent is the supply chain being involved in planning for Pb-free soldering?
- Q15. To what extent is the supply chain being involved in R&D activities for Pb-free soldering?
- Q16. To what extent have the SMEs (rather than the OEMs) taken up Pb-free soldering?
- Q17. Are the timescales for SME implementation of Pb-free soldering different from those quoted by the OEMs? If so, what are the timescales?
- Q18. Is there any evidence that Pb-free soldering can produce better (i.e. stronger, more reliable) joints? If so, what is the source?
- Q19. Have operator retraining needs (assembly, inspection, rework, testing etc) been identified?
- Q20. What are the present views of JEIDA

INSPECTION & TESTING

The main concern here is the nature and extent of any changes necessary for testing and/or inspecting product manufactured using Pb-free soldering, and of any consequential changes to international standards and/or guidelines.

- Q21. Are any changes necessary to conventional methods of testing product?
- Q22. If so, what are the suggested changes?

- Q23. What are the most appropriate regimes for reliability testing (thermal cycling, vibration)?
- Q24. Are any changes necessary to current inspection practices?
- Q25. If so, what are the suggested changes?
- Q26. To what extent do the appearance and geometry of Pb-free soldered joints require new visual inspection guidelines?
- Q27. Have any new guidelines been generated in Japan either on a national or an in-company basis?
- Q28. What changes are required for the continued use of AOI and AXI techniques?
- Q29. Are new international standards for testing and inspection required?
- Q30. Have the shapes & appearance of Pb-free joints been characterised? Do these vary from one Pb-free solder to another?

HIGH TEMPERATURE SOLDERS (>280°C)

The main concern is with the use of 90/10 Pb/Sn solder in power circuits, BGA spheres, die-attach, hierarchical soldering, and under-bonnet automotive applications.

- Q31. What replacements are available for the 90/10 Pb/Sn solder?
- Q32. Have you trialled any potential replacements?
- Q33. Do you know of any reliability concerns with any possible replacements? For example some concerns have been expressed over the performance of Sn-25Ag-10Sb.

GENERAL ADDITIONS TO THE SOLDER ALLOYS

- Q34. Do you have you any concerns over the use of certain additives (e.g. Bi, Sb) to control the melting point of the solder?
- Q35. Are these concerns based on health, safety, environmental or availability reasons?
- Q36. To what extent have you observed fillet lifting?
- Q37. Have you ever observed fillet lifting in wave-soldered joints? If so, under what conditions?
- Q38. What is the evidence that fillet lifting results in reduced joint reliability or field performance?

REWORK & REPAIR

The main concern is the possibility of detrimental effects of “mixed” systems, especially following repair of Pb-free systems with a Pb-containing solder, or vice versa.

- Q39. Are you aware of any problems such as reduced performance, poorer reliability?
- Q40. What is the physical nature of these problems (e.g. fillet lifting, component overheating)?
- Q41. Is there a level of Pb that can be tolerated in rework operations?
- Q42. How can such problems be overcome in the field?
- Q43. To what extent does the use of Bi-containing alloys affect the life of reworked joints?
- Q44. What alterations must be made to iron tip temperature and operation?
- Q45. What are your views on the need for labelling to overcome these problems?
- Q46. What would be your preferred method of labelling?

EFFECTS OF HIGHER TEMPERATURE SOLDERING OPERATIONS

The main concern here is the temperature stability/compatibility of board and components with the higher soldering temperatures associated with the majority of Pb-free solders.

- Q47 Do you have concerns over the stability of the common board materials (e.g. FR2 and FR4)?
- Q48 Are these concerns of a chemical nature (e.g. materials degradation)?
- Q49. Are these concerns of a physical nature (e.g. planarity, twist, bend)?
- Q50. Are these concerns of an electrical nature (e.g. loss of insulation resistance)?
- Q51. Which boards are most appropriate for Pb-free soldering?
- Q52. Are there any components that are known to be sensitive to these higher temperatures?
- Q53. What was the nature of the effects on these components (cracking, functionality, charring)?
- Q54. To what extent can the use of these components be “designed out” of product?
- Q55. Should components be requalified regarding temperature stability?
- Q56. If requalification is necessary, what is an appropriate requalification temperature? 260OC?
- Q57. Have you found the need to clean boards (or change the cleaning regime) after soldering with Pb-free systems? Has charring, or more active fluxes, altered the need to clean?

COMPONENT TERMINATIONS

The main concern here is the availability and performance of Pb-free terminations, and the possible detrimental effects during processing and service life.

- Q58. What are your favoured Pb-free component termination materials? And why?
- Q59. Should there be a consensus for such termination materials (e.g. PdNi, AgPd, Sn.....)?
- Q60. Are plated or hot-dipped finishes to be preferred? And why?
- Q61. What are the particular advantages of SnBi plated finishes? Whiskers? Compatibility?
- Q62 Have you encountered any solderability issues with Pb-free component terminations?
- Q63. Have you encountered any changes in soldering yield with Pb-free component terminations?
- Q64. Have you encountered any new failure mechanisms with Pb-free component terminations?
- Q65. Have you encountered any reliability and/or performance issues with Pb-free terminations?
- Q66. Have you encountered any availability problems for components with Pb-free terminations?

BOARD FINISHES

The main concern here is the availability and performance of Pb-freeboard finishes, and the possible detrimental effects during processing and life.

- Q67. What are your favoured Pb-free board finish materials? And why?
- Q68. What are the main issues with Pb-free board finish materials? Whiskers? Reliability? Solderability? Availability? Poor bonding? Flux compatibility?
- Q69. What do you believe is the future for OSP finishes?
- Q70. Have you encountered any solderability issues with Pb-free board finishes? If so, details?
- Q71. Have you encountered any storage issues with Pb-free board finishes? If so, details?

Further General Questions:

- What materials in the process are lead-free, alloy, PCB finish, component finish, and component construction?
- Are there any studies looking at the impact of lead in land fill
- Are there any strategies to remove lead from the waste stream?
- Is there any interest in using conductive adhesives as a mass soldering replacement?

The following questions were prepared by Celestica

General

- Was there an impact on product yield by moving to a lead-free process?
- What is/are products?
- What are production volumes?
- How many assembly lines are lead-free and how many are still tin lead?
- Are all the lead-free lines using the same alloys?
- Have any new or novel processes, or equipment, had to be used in the assembly process?
- Is the product labelled with the solder alloy(s) composition used i.e. for rework/recycling purposes?
- How was the process qualified i.e. reliability testing?

Components

- What percentage of components used are lead-free?
- If tin lead and lead-free components are both used, how are they differentiated?
- Are there any material compatibility problems due to mixing tin lead and lead-free components?
- What is the preferred lead-free lead finish?
- What is the preferred solder sphere alloy for area array type packages?
- Have components been re-qualified for the higher process temperatures?
- Have any components been modified i.e. reflective coatings, shields?
- Has a lead-free alternative to high melting point (high Pb) solder been found/used?

Boards

- Has the board material changed for the lead-free process?
- What surface finishes are being used?
- If surface finish(es) have changed for lead-free processing, what were they before and after?
- Has the board design changed for lead-free processing i.e. thermal mass distribution across board?

Printing

- Has the equipment been changed or modified?
- What is the equipment being used?
- Are new squeegee types or new machines settings required?
- Has throughput been affected i.e. cycle time, increased defects?
- Have new defects or operating problems been found?
- Are any enclosed head systems in use i.e. similar to Proflow, Rheopump, Crossflow?
- Has the flux vehicle been re-developed for lead-free?
- How is waste paste disposed of?

Reflow

- What solder alloy is being used?
- Is existing equipment being used or is it new for lead-free?
- What new features have been included on the equipment i.e. side heating, board centre supports?
- Has through-put been affected?
- Have new defects or operating problems been found?
- What type of reflow process being used i.e. convection ,infra-red, vapour phase?
- What is flux/flux type being used?
- Is the reflow atmosphere air or nitrogen?
- Is extra cooling capacity being used?
- What has been the impact on energy consumption?
- What type of reflow profile is being used i.e. constant ramp to peak, high plateau?
- How is oven profile checked?
- How often is oven profile checked?
- Has oven maintenance increased?

Wave

- What solder alloy is being used?
- Has the equipment been modified for lead-free i.e. new materials/coatings on bath and pumps etc ?
- Has through put been affected?
- Have new defects or operating problems been found i.e. increased bridging, fillet lifting, solder balling, residues?
- Is the wave under air or nitrogen atmosphere?
- What flux/flux type is being used?
- For bottom side components has a re-formulated adhesive had to be used?

- What machine settings have been changed i.e. bath temperature, pre-heat?
- What has been the impact on energy consumption?
- Has increased dross been noticed?
- Is dross re-cycled?
- Has maintaining solder bath composition presented any problems ?
- Is bath level maintained with same alloy as the bath itself i.e. to maintain overall composition?
- Have any wear/corrosion/erosion issues been noticed?
- Has equipment maintenance increased?
- Is Pb contamination an issue i.e. from board or component lead finishes?
- If Pb contamination is a problem, how often is the solder bath replenished?

Wash

- If a cleaning wash system is used, has it been changed for lead-free processing i.e. temperatures, time, chemicals?
- Has through put through the system changed?

Inspection

- Has manual optical inspection criteria changed i.e. dull joints , poorer wetting?
- Has the defect rate increased?
- Are there any new defects?
- Have Automated Optical Inspection (AOI) programmes been revised for lead-free?
- Are there any significant machine setting differences for transmission X-ray inspection?
- Do automated x-ray laminography programmes require modification?
- Is increased voiding present and if so is it problematical for x-ray inspection techniques?

Test

- Are there changes to test procedures (ICT) already in place?
- Are harder flux residues a problem for test pin probes?
- Is through put affected in anyway?

Repair/rework

- What alloys are being used for wire and paste?
- What repair fluxes/flux types are being used?
- Is there a 'universal' lead-free repair alloy?
- Do soldering irons already used for tin lead have to be modified for lead-free?
- Have BGA rework stations had to be modified i.e. to give extra heat input?
- How are tin lead and lead-free boards distinguished?
- Are tin lead boards repaired with tin lead or lead-free solder?
- Are repair/rework procedures qualified i.e. reliability tested?

12.6 Appendix 6: Japanese Press Releases

These were compiled by:-

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Friday, February 2, 2001
Sony To End Lead Solder Use By 2005

TOKYO (Nikkei)--Sony Corp.'s (6758) environmental action targets for 2005, announced Friday, include plans to switch to 100% lead-free solders and eliminate heavy metals like cadmium and hexavalent chromium from all its product lines. The Green Management 2005 initiative also targets improvements in product energy efficiency, with the goal of reducing power consumption by 30% from the fiscal 2000 level. To lower resource consumption, the company will also target a 20% reduction in product weight. In addition, Sony's plan outlines a 30% reduction in waste generation throughout its operations as a factor of turnover, and more active utilization of natural energy sources. Progress in its efforts will be reflected in evaluations of in-house company performance and performance pay for the firms' managers. (The Nihon Keizai Shimbun Saturday morning edition)

Friday, February 9, 2001
Sony To Eliminate Lead Solder In Digital Camcorders

TOKYO (Nikkei)--Sony Corp. (6758) will from summer begin using non-lead solder in its digital camcorders, aiming to use the material in all camcorder bodies, as well as in the parts and accessories supplied by other firms, by March 2003, company sources said Friday. To enable use of the non-lead material, the company will spend several billion yen to retool the production line at its camcorder factory in Aichi Prefecture. Sony will also transfer its non-lead solder technology to other domestic and overseas manufacturers, for use in camcorder accessories such as AC adapters and batteries, the sources said. The company also plans to expand use of the non-lead solder in all its electronics products by the end of March 2006. Such a move is part of the firm's environmental protection action program, which also includes reducing carbon dioxide emissions and recycling packaging materials. (The Nihon Keizai Shimbun Saturday morning edition)

Thursday, January 18, 2001
Furukawa Elec Develops Lead-Free Soldering System

TOKYO (Nikkei)--Furukawa Electric Co. (5801) has developed a heat treatment system for use in lead-free soldering of electronic components onto circuit boards. The new system is a reflow furnace that heats a circuit board coated with solder and bonds semiconductors and electronic components to it. The company improved bonding performance by utilizing a new hot air blowing structure that heats the entire circuit board uniformly. Increases in the temperature of the components are controlled by heating the underside of the circuit board

with infrared radiation. A standard model is priced at 13 million yen, less than conventional systems. The company is targeting sales of 500 units in the next year. (The Nikkei Industrial Daily Thursday edition)

Thursday, January 4, 2001

Group Prints Data Book To Promote Eco-Friendly TV Purchases

TOKYO (Nikkei)--The Green Purchasing Network, a group that promotes environmentally conscious buying, has issued an environmental data book on televisions. The data book covers 134 models from nine manufacturers, providing information like each product's annual energy consumption and the amounts of recyclable plastics used. At least 80% of the televisions come with energy-saving features and avoid the use of flame-retardants with bromine. But most of the products fail to use lead-free solder. The data book is priced at 800 yen. The Green Purchasing Network has 2,310 members, including corporations and government bodies. It plans to publish data books on 15 products, like autos, personal computers and office supplies. (The Nikkei Industrial Daily Thursday edition)

Wednesday, December 20, 2000

Nippon Columbia To Eliminate Lead Solder From Domestic Plant

TOKYO (Nikkei)--Nippon Columbia Co. (6791) will eliminate lead solder from domestically produced audio products, starting with goods sold from April 2002. The company will receive technological assistance from its major shareholder, Hitachi Ltd. (6501), in introducing replacements for lead, including silver and copper. Nippon Columbia will eliminate lead solder from operations at its Shirakawa plant in Fukushima Prefecture. The Shirakawa plant produces AV amplifiers, DVD players and other equipment. The factory currently uses about six tons of lead solder per year. (The Nikkei Industrial Daily Wednesday edition)

Monday, November 20, 2000

Riken's Lead-Free Solder-Plated Wire Has Lower Melt Point

TOKYO (Nikkei)--Riken Electric Wire Co. (5808) has developed a lead-free, solder-plated lead wire for electronics parts that has a melting point of only 227 C, which is 5 degrees lower than competitive products made from 100% tin. Riken's new product, sold under the brand name NF Lead, is made from 97.5% tin, 2.5% copper and a trace amount of additives. Because the new wire has a lower melting point, manufacturers of electronic parts can lower the temperature setting of the furnace used for reflow soldering of components, meaning there is less risk of heat damage to the parts. Riken is investing 30 million yen at its Ichijima factory in Hyogo Prefecture to modify existing equipment and establish three lines for the mass-production of NF Lead. It expects to be producing more than 100 tons of the lead wire per month by the end of next March and around 200 tons per month by the end of March 2002. The company also plans to invest 50 million yen to introduce two new production lines for NF Lead at its wholly owned subsidiary in Taiwan. The aim is to have the subsidiary producing some 100 tons of lead wire per month by next summer, mainly for supply to Japanese-affiliated electronics parts manufacturers in the region. (The Nikkei Industrial Daily Monday edition)

Monday, November 6, 2000

IBM Japan Develops Lead-Free Hard Disk

TOKYO (Nikkei)--IBM Japan Ltd. has developed a prototype lead-free hard disk for personal computers, company officials said Monday. In the prototype, lead-free material is used for solders to mount devices on an electronic substrate, in place of a lead-tin blend. The Japanese subsidiary of International Business Machines Corp. has also replaced a halogen-based flame retarding agent with a halogen-free substance in the hard disk. Halogen is believed to generate dioxin when it is burned improperly. IBM Japan is acting ahead of a European Union ban on the use of lead and halogen in electronic equipment due to take effect in 2008. The company plans to begin selling the new hard disks after carrying out further quality and durability tests. (The Nihon Keizai Shimbun Tuesday morning edition)

Friday, October 13, 2000

NEC Notebook Computer Runs For 8 Hours On Battery

TOKYO (Nikkei)--NEC Corp. (6701) on Thursday began marketing 31 personal computers for businesses, including notebook models that it says can run for up to eight hours on a standard built-in battery. The longest-running new notebook computer is equipped with a low-power, 10.4-inch reflective TFT (thin film transistor) LCD and a low-voltage microprocessor made by Intel Corp. It uses 18% less power than earlier models. Battery volume was increased 140% by using lithium ion batteries. The notebook PCs are priced from 268,000 yen, and NEC is targeting monthly sales of 25,000 units. NEC is also targeting monthly sales of 40,000 units of its new desktop models that feature motherboards with lead-free solder. At the same time, the company also started selling firewall software to prevent illegal access to PCs connected to the Internet. The software will cost 50,000 yen for five licenses. NEC is seeking to fill out its line of products that support corporate Internet business. (The Nikkei Industrial Daily Friday edition)

Friday, October 6, 2000

Matsushita's Capacitor Can Take Lead-Free Solder

TOKYO (Nikkei)--Matsushita Electronic Components Co. has developed a coin-type electric double-layer capacitor that can withstand the high temperatures generated during the use of lead-free solder. Manufacturers of cellular phones and notebook computers want to use double-layer capacitors, but because the conventional components have low heat resistance they became unusable as manufacturers moved to the adoption of environment-friendly lead-free solder. Matsushita's new capacitor can handle temperatures about 10 degrees higher than the conventional components, facilitating the use of double-layer capacitors. Because the capacitors can be soldered to the board using a simple reflow method, manufacturers can also cut their costs and boost productivity. Matsushita anticipates a growing market for electric double-layer capacitors as a backup power source in portable information terminals. Predicting global demand for some 1 billion units in 2003, the company plans to have a system in place by the end of fiscal 2000 to produce the new component at a rate of 5 million units per month. (The Nikkei Industrial Daily Friday edition)

Wednesday, September 27, 2000

Mitsubishi Materials Unwraps Lead-Free Thermistor

TOKYO (Nikkei)--Mitsubishi Materials Corp. (5711) said Tuesday that it has developed a chip-size thermistor made without lead solder and plans to begin marketing the eco-friendly device from October. The company's move to lead-free solder in its chip-size thermistors comes in response to the widening trend among consumer electronics makers like Fujitsu Ltd. (6702) and Matsushita Electric Industrial Co. (6752) to eliminate the use of lead in their information technology and audiovisual products. It is normally difficult to mount small chip-size thermistors when they are made without lead solder, but Mitsubishi Materials said that its devices are highly mountable even when made in sizes of 1 x 1.5mm. Chip-size thermistors are used in consumer products like cellular phones and personal computers to compensate for changes in temperature. Mitsubishi Materials claims a 50% share of the domestic market and the capacity to make 80 million units per month. The company plans to increase capacity to 130 million units per month by next spring. (The Nikkei Industrial Daily Wednesday edition)

Monday, September 18, 2000

Toshiba Reports R&D Centers Environmental Outlays

TOKYO (Nikkei)--Toshiba Corp.'s (6502) R&D center says that its environmental protection spending totaled 658 million yen in fiscal 1999, while the benefits of its environmental protection efforts totaled 277 million yen. Rival NEC Corp. (6701) also publicizes such figures for its R&D operations, but this is rare within the industry. Toshiba's R&D center spent 461 million yen on developing new environmentally friendly technologies like lead-free soldering. The cost of administrative activities like environmental education was 96 million yen, and the cost of implementing measures to reduce the burden on the environment, such as installing energy saving transformers, was 31 million yen. The direct benefits -- such as reduced power and water charges and the sale of recycled materials -- of environmental protection efforts totaled 269 million yen. (The Nikkei Industrial Daily Monday edition)

Friday, August 25, 2000

M'shita Elec Ind Spends 52 Bln Yen On Environment In FY99

OSAKA (Nikkei)--Matsushita Electric Industrial Co. (6752) spent 52.6 billion yen on environmental measures in fiscal 1999, the company announced Thursday. Matsushita Electric's expenditures on its environmental efforts that year were distributed among 262 operational bases, both in Japan and abroad, of 10 group companies. The company's economic benefits from its efforts came to 8 billion yen. Fiscal 1999 was the first year that Matsushita Electric Industrial included foreign operations in its environmental accounting. Among expenses, 13.2 billion yen went to research and development and 7.3 billion yen was for capital spending to make plants more energy efficient. Among economic benefits, 2.8 billion yen came from improved energy efficiency at plants. Waste reduction led to 3.6 billion yen in savings. The company's future environmental goals include eliminating lead solder from all group products -- both domestic and foreign -- by the end of fiscal 2002. In addition, by 2010, the company aims to reduce domestic carbon dioxide emissions by 7% compared with fiscal 1999. (The Nihon Keizai Shimbun Friday morning edition)

Sunday, August 20, 2000

Matsushita Elec Industrial Group To Stop Using Lead Solder

OSAKA (Nikkei)--The Matsushita Electric Industrial Co. (6752) group will discontinue the use of lead, which harms the environment and humans, in solder used in its products by the end of fiscal 2002, group sources said. The group will instead use materials such as silver and copper to make its products more environment-friendly. The Matsushita group currently uses 300 tons of lead each year in the 800 tons of tin-lead solder in its products. It will replace the tin-lead solder with tin-silver-bismuth and tin-silver-copper combinations. It will also replace some solder with conductive adhesive. The group already uses lead-free solder in four product lines, such as MD players and VCRs. It plans to go lead-free for the solders used in 123 product lineups by the end of fiscal 2000. It is difficult to control the quality of solder made using non-lead substances because it melts only at higher temperatures. Thus, when using non-lead solders, electronic components must be made highly heat-resistant. Currently used lead soldering and other manufacturing equipment must also be replaced. The Matsushita group is developing lead-free solder through a tie-up with major solder manufacturers Senju Metal Industry Co. and Nihon Superior Co. (The Nihon Keizai Shimbun Monday morning edition)

Tuesday, July 25, 2000

Tyco Amp To Provide Solder Method To Affiliates

KAWASAKI (Nikkei)--Tyco Electronics AMP KK, the world's largest connector manufacturer, plans to provide environmental technologies to other companies in the Tyco group. As a first step, Tyco Electronics AMP will share lead-free solder-plating technology with its U.S.-based parent, and with Japanese affiliate fuse manufacturer Tyco Electronics Raychem KK and relay maker Tyco Electronics EC. It will also supply the technology to four Tyco factories in China that supply products to Japan. Tyco Electronics AMP began working to develop lead-free solder-plating technology two years ago. The company has completed testing, and plans to begin adopting the new environment-friendly solder-plating in its own products in August. (The Nikkei Industrial Daily Tuesday edition)

Monday, May 29, 2000

NEC To Produce Environmentally Friendly Tantalum Capacitors

TOKYO (Nikkei)--NEC Corp. (6701) plans to begin producing tantalum capacitors without materials that are harmful to the environment. The company intends to use tin instead of lead in the solder coating on the capacitors' terminals, and it will use new nontoxic inorganic materials as flame retardants in the plastic packaging, replacing the bromine and antimony it uses now. NEC, which in June will begin selling the revamped capacitors, plans to convert its entire lineup in 2001. (The Nikkei Industrial Daily Monday edition)

Friday, April 21, 2000

Matsushita Elec To Remove Lead Solder From AV Wiring

OSAKA (Nikkei)--Matsushita Electric Industrial Co. (6752) plans to halt the use of toxic lead solder in VCRs and other audiovisual equipment by the end of fiscal 2002, company sources told The Nihon Keizai Shimbun Friday. Lead solder damages the environment, and moves are growing worldwide to regulate its use. The company currently uses about 150 metric tons of lead to connect circuits in audiovisual equipment each year. It will stop using lead solder for domestic audio equipment and VCRs during the current fiscal year, and extend the ban to include digital camcorders, PCs and other audiovisual equipment by the end of fiscal 2001. The prohibition will take effect worldwide by the end of the following business year. Lead lowers the melting point of solder, and removing it increases the likelihood of oxidation and breakage in circuit wiring. Matsushita plans to use copper, silver or some other metal instead. It has worked with major solder makers to overcome the drawbacks of using other metals and is beginning to see the possibility of similar performance from the alternatives as offered by lead solder. (The Nihon Keizai Shimbun Saturday morning edition)

Friday, January 14, 2000

Chemical Firms Sell Halogen-Free Materials

TOKYO (Nikkei)--Major Japanese chemical companies are accelerating their efforts to supply environmentally friendly materials for electrical appliances and information equipment in response to increased demand, industry sources said. Sumitomo Bakelite Co. (4203) and Toshiba Chemical Corp. (4232) are selling halogen-free printed circuit boards to Toshiba and other manufacturers of notebook computers. Halogen can emit dioxins when burnt. Mass production of halogen-free materials for cellular phones will begin by the year's end. The two companies have changed the structure of epoxy resin to create the halogen-free materials. Asahi Chemical Industry Co. (3407) has developed noncombustible materials for electrical appliances, using phosphorus-type noncombustible agents instead of halogen-based products. The company will start selling the materials for use in the outer frames of electrical appliances and information equipment by the end of this month, targeting annual sales of 30,000 metric tons, company sources said. Showa Denko KK (4004) is selling lead-free solder for mounting electronic parts, and paint companies are promoting sales of paint that does not contain tin. (The Nihon Keizai Shimbun Saturday morning edition)

Saturday, January 1, 2000

Sony Chip Packaging Suited To Lead-Free Solders

TOKYO (Nikkei)--Sony Corp. (6758) has taken lead-free manufacturing a step further by developing resin-based chip packaging that protects semiconductor components from the higher temperatures required for lead-free solders. Environmental concerns are leading manufacturers to seek ways to replace toxic lead solders with substitutes. But the alternative materials have higher melting points than lead and must be processed at temperatures that are 10-20 C higher. The new packaging is designed to withstand temperatures of up to 260 C, or 25 degrees more than conventional packaging, protecting sensitive circuits from the heat. Sony has already begun adopting the packaging and aims to change over its worldwide semiconductor-manufacturing operations to it by the end of 2000. The company is targeting a completely lead-solder-free product line by the end of March 2002. (The Nikkei Industrial Daily Saturday edition)