Eliminating Wave Soldering with Low Melting Point Solder Paste

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ABSTRACT

Wave soldering has been a process of record for countless consumer electronic, automotive, medical, IT infrastructure and desktop computing assembly applications for decades.

Miniaturization of components and the need for more functionality have been major drivers for the expansion of surface mount technology in nearly all electronic assemblies. As the number of through hole components used declines, selective soldering has had a tremendous level of growth, further expediting the decline in assemblies built using the wave soldering process. With the advent of lead free soldering in the past decade, SMT reflow temperatures have increased from a typical peak temperature of 210º to 220º C with tin/lead solder, to a typical peak temperature of 240ºC+-5ºC. With the common use of low melting connectors, audio and video jacks, and other temperature sensitive through hole components, some assemblies still require a wave soldering step. Wave soldering has been eliminated in a large number of applications where both lead free materials and heat sensitive components are used. The enabling technology requires a low melting point solder paste and effective adaptation of pin in paste technology. This paper will give case histories of the successful replacement of wave soldering with low temperature PIP processing. The costs of wave soldering materials, energy, substrate savings and others will be discussed based on actual case histories. Second side SMT reflow using a solder alloy with a eutectic melting point of 138ºC has gained significant technical success. This paper will discuss the cost and technological drivers behind this emerging trend.

INTRODUCTION

The wave soldering process dates back to 1958 (1). It was an answer to the low productivity of hand soldering PWB's in high volume manufacturing. It was also a source of considerable material waste from evaporation in foam fluxers to the disposal of tin/lead solder dross. Considerable hand touch up was required, but overall, the process was superior to hand soldering with cored wire.

Surface mount technology dates back to the early 1980s. The availability multilayered chip capacitors and J-leaded Quad Flat Packs (QFPs) in the mid 1980s enabled the rapid growth of surface mount technology applications. RMA (Rosin, mildly active) solder paste development also was a key factor in the commercial success of surface mount assembly processing.

Since the late 1990's, the demise of wave soldering, or Pin in Through Hole (PITH) in favor of surface mount technology (SMT) has been predicted. However, the lower cost of many through hole formatted components delayed the demise of PITH processing for decades. The industry conversion to higher temperature lead-free processing delayed the conversion even more.

For example, a dual row shrouded header rated to withstand 105ºC (a typical top side preheat temperature in a PITH process) is priced at $.84 in an online catalogue. The same component rated to withstand 130ºC costs $1.23. Similarly, audio-visual input/output jacks (RCA connectors) are typically rated to withstand no more than 200ºC. These components can not withstand a SAC alloy reflow so they must be assembled using PITH.

In 2007, a major consumer electronics OEM firm requested a RoHS compliant solder paste that could be reflowed at 190º C or lower. Upon further exchanges in data, it was realized that this OEM wanted to eliminate wave soldering without changing the components used. At the time, the OEM was using a SAC based SMT process for the front and back of their boards, followed by a PITH process for the lower temperature resistant through hole components.

The OEM wanted to eliminate the wave soldering process by using a low temperature solder paste to assemble the SMT and through hole components during the second reflow. A lower temperature paste would be needed to allow the through hole components to survive. It became clear that the low temperature paste would require excellent pin in paste process capabilities, or preforms might be required to get good hole fill.

Process Cost Reduction

Before the discussion on the alloy and solder paste evaluation, the main driver behind this case history was manufacturing cost reduction. In the competitive consumer electronics market, low price drives market penetration. Market penetration lowers cost. Eliminating the wave solder step offers several cost savings.

First, cost is reduced by increased throughput or reduced cycle time. Fewer fixed assets are producing more finished goods when the wave soldering step is eliminated. If a wave soldering machine is running at a relatively fast 1.5 meters (59 inches) per minute and the conveyor is 6.5 meters (256 inches) a minimum of 4 minutes and 20 seconds of conveyor time is eliminated from the process.

In addition to conveyor time, any time and labor used to palletize the 2 sided assembly is eliminated, as well as the time to de-palletize and the maintenance of the pallets.

Other significant costs that are eliminated are the cost of bar solder, the cost of wave soldering flux and the energy cost to preheat the boards after fluxing and the energy required to keep the bar solder molten.

These costs are summarized in figure 1.

Wave Solder Process Cost of Ownership Model	
Flux Preheat Energy Requirement	30 KW/Hour
Solder Bath Energy Requirement	36 KW/Hour
Motors, PC Monitor etc.	5 KW/Hour
Total Energy Consumption/Hour	71 KW/Hour

Flux Used/Day (liters)	14 liters
Flux Price/liter	$4/liter

Bar Solder Consumption(Kg/day)	7 Kg
Bar Solder Cost ($/Kg)	$37/kg

Operating Hours/Day	16 Hours
Working days/month	22 Days
Energy Cost/KWH	0.15/KWHour

Cost of Energy/month	$3,749
Cost of Flux/month	$1,232
Cost of Bar Solder/month	$5,698
Total Cost/Month/Machine	$10,679

Figure 1

Other Cost Savings

If an assembler already owns a wave soldering machine and it is fully depreciated, there is no real cost or cost benefit of abandoning it. However if more lines are installed, the capital cost of the wave soldering machine is avoided.

Also, the energy consumed by each reflow oven is decreased due to the reduced peak temperature. Typically, a reflow oven with a 240ºC peak temperature setting will consume somewhere between 20 and 24 kilowatts/hour. By reducing the peak temperature to 190ºC, energy consumption has been reported to be reduced between 15 and 17 kilowatts per hour. (Figure 2)

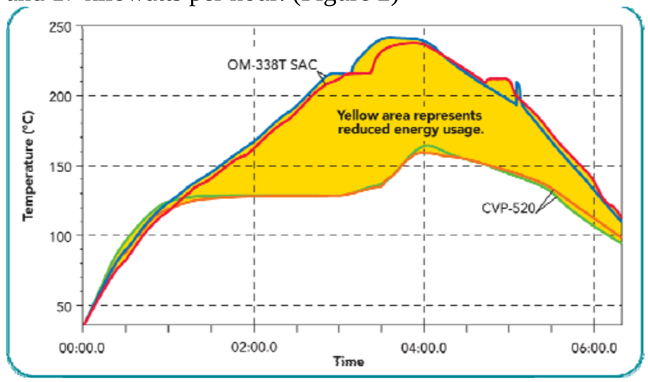

Figure 2- Energy Saved Using Lower Melting Profile

Key Success Factors

Low melting temperature was not sufficient for success in this process conversion. The solder paste had to have excellent paste in through hole performance to assemble the through hole components. Mechanical and electrical reliability experiments were required. The results of this testing are detailed later in the paper.

Paste In Through Hole Testing

Numerous stencil designs and overprint patterns are needed for paste in through hole soldering. A key is the solder paste’s ability to flow into the through hole without leaving random solder balls on the solder mask. Figures 3 and 4 show examples of pre and post reflow using the OEMs boards.

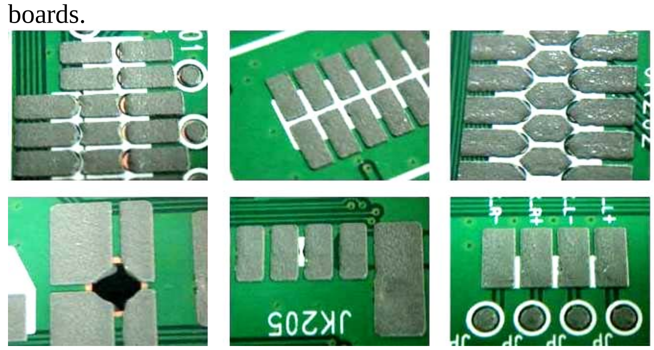

Figure 3- Pre-Reflow Paste Print Pattern Examples

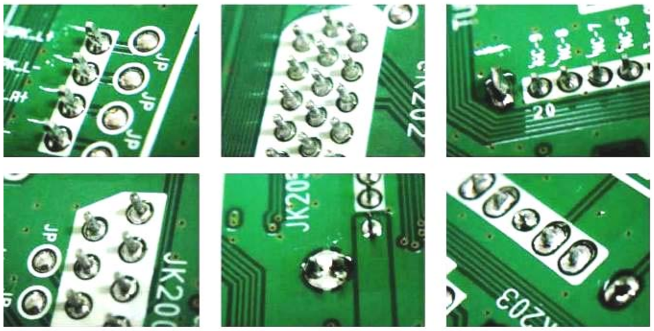

Figure 4- Post-Reflow Results

In each of these examples, the Sn/Bi/Ag alloy was drawn into the gaps between the plated through holes and the lead pins of the PITH components. There are few if any visible solder balls on the mask where the paste was printed.

Another End Use Example

Another leading global consumer electronics manufacturer asked for help in reducing the cost of remote controller manufacturing. This customer was using epoxy to mount SMT components to an FR1 substrate followed by a glue curing cycle. Through hole components were then placed and the assembly was passed through a wave soldering machine. Additional through hole components were then inserted followed by hand soldering. The original process is depicted in figure 5.

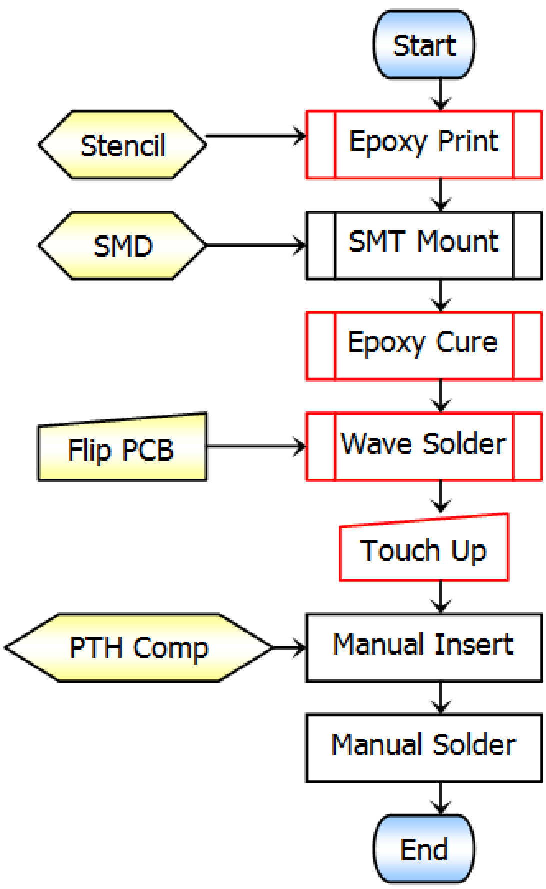

Figure 5-Case History 2 Original Assembly Process Flow

Both the FR-1 substrate and several temperature sensitive components eliminated the use of lead free solder paste to attach the SMT components to this assembly.

The use of low melting solder paste changed this paradigm. The customer was able to eliminate the epoxy glue and cure step, replacing it with traditional stencil printing and component placement. Through hole components were inserted using the same process as before, followed by a low temperature reflow profile. The profile used included a 161 second ramp to the liquidus temperature of the alloy (139ºC),

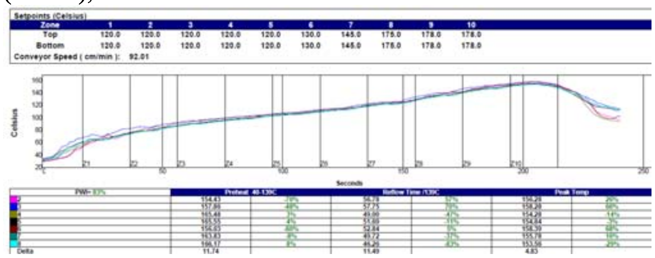

Figure 6 Low Temperature Reflow Profile

The assembly was above the alloy liquidus for 52 seconds, including a peak temperature of 156ºC. (Figure 6).

This reflow profile eliminated damage to several components and warpage to the FR-1 laminate substrate. Figure 7 shows the warpage of FR-1 after a lead free reflow profile (45 seconds over 221ºC, 240ºC peak temperature. This warpage is avoided when the low temperature alloy reflow profile was instituted into this process.

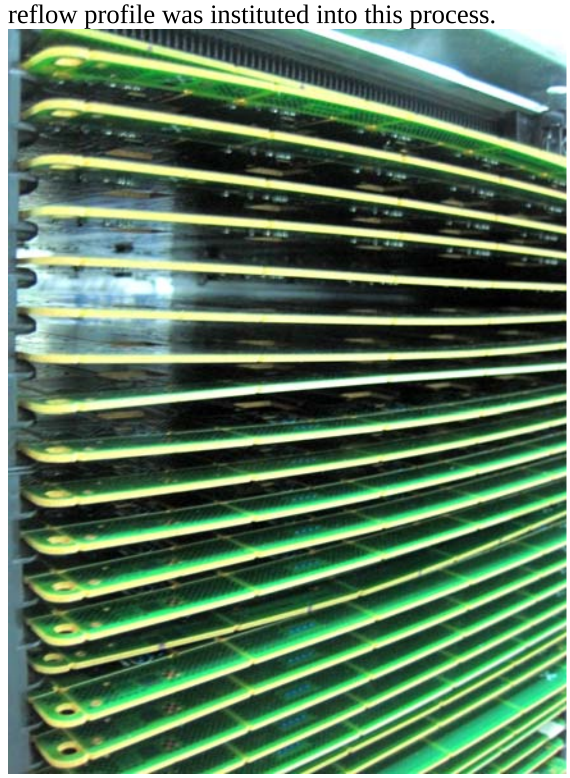

Figure 7-Warped FR-1 Boards after SAC Reflow Profile

The new process flow is depicted in figure 8. Using low temperature paste to attach the SMT and through hole

components eliminated the need for wave soldering, while using lower cost components and FR-1 laminate in a RoHS compliant process.
This has been the new process of record for this global OEM who primarily uses contract manufacturers to assemble these remote controls. See figure 8.

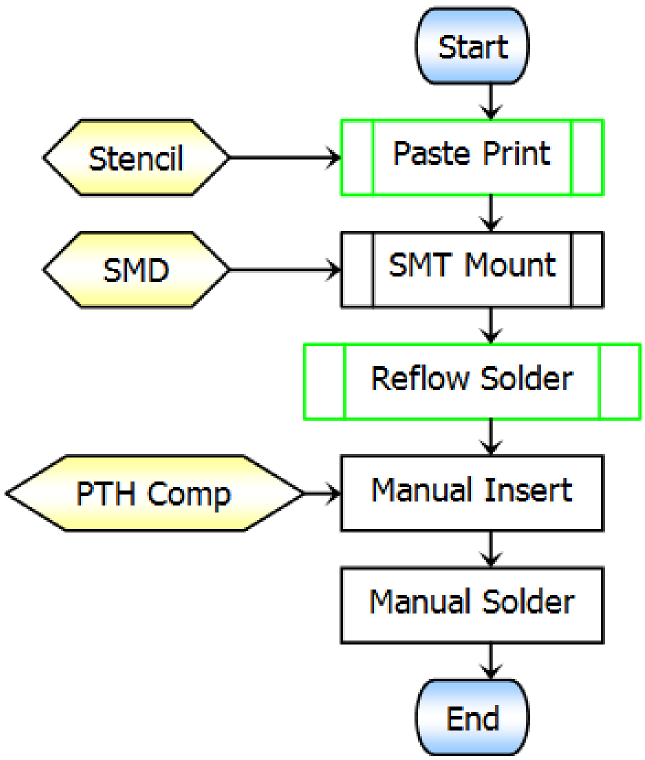

Figure 8- Lower Cost Assembly Process

Once again the cost of energy to operate the wave soldering machine, the cost of bar solder and wave soldering flux were eliminated. The glue printing and curing step was replaced by solder paste printing and reflow. Overall, Savings similar to those detailed in figure 1 were realized.

Alloy Selection
Tin bearing, Lead free alloys using indium, bismuth, cadmium have been known for many years. Indium is relatively expensive and is a poor wetting material. Cadmium is known to cause serious heath issues. Bismuth is used in materials ingested by humans (Pepto-Bismol is an example) and costs about the same as tin.
The Tin/Bismuth (Sn/Bi) binary has a eutectic point at a ratio of 52% Sn and 48% Bi. The melting point of this alloy is 138ºC. See figure 9.

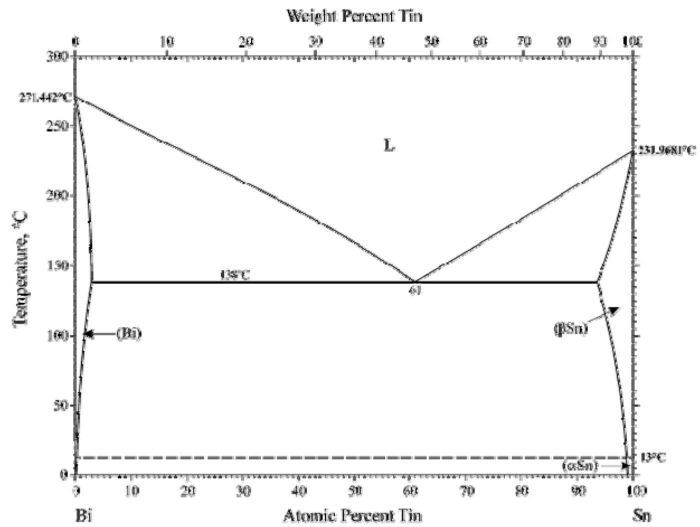

Figure 9(2)-Tin Bismuth Phase Diagram

Bismuth bearing alloys have been excluded from many applications because of the low melting phase tin/bismuth/lead (96ºC) when lead bearing component finishes were common. With today's lead-free components, this low melting phase is no longer an issue.
The addition of silver as a grain boundary refiner has been shown to increase the resistance of thermal fatigue (3, 4).

Low Temperature Alloy Reliability
Before entering high volume production of the low melting point paste, mechanical and electrical reliability studies were undertaken. Results of this testing are discussed below.

Mechanical Reliability
Using a Dage Series 4000 shear tester at room temperature (25ºC) chip and at a speed of 700µ/second, 01005 capacitors and resistors were checked for sheer force at failure.
Samples were subjected to a thermal cycle regime of -45ºC to +125ºC with 30 minute dwells at each temperature. The tin/bismuth/silver alloy was tested against
Tin lead eutectic and SAC 305, as well as silver free Sn/Bi and a commonly used 1% silver Sn/Bi/Ag alloy were used as controls.

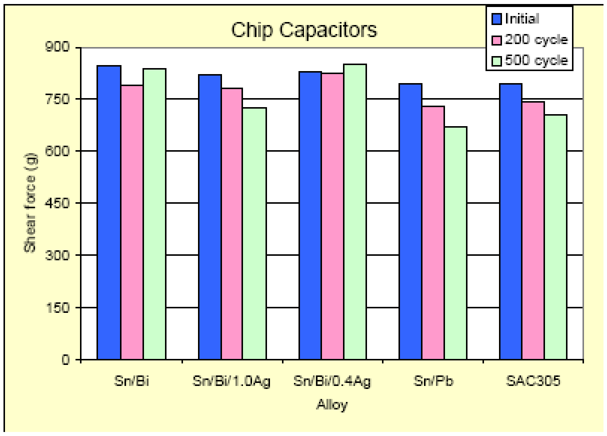

Figure 10- Shear force after thermal cycling-Capacitors

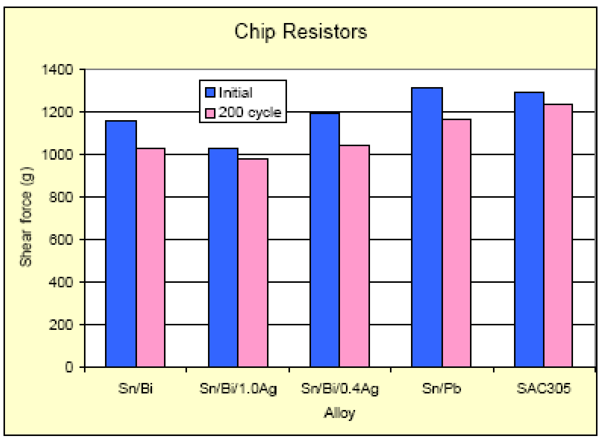

Figure 11- Chip Resistors

As can be seen in figures 10 and 11, the shear force required to remove chip components soldered with the low melting point solder paste was similar to pastes made with Sn/Pb eutectic and SAC 305 alloys. The drop in shear force after thermal cycling was also similar for each alloy tested.

BGA Devices

Assembling BGA devices that have SAC 305 spheres with low melting point paste can be accomplished, but may not be ideal for high reliability applications. Using a reflow profile with a peak temperature of 190º means the assembly will not approach the liquidus temperature of SAC 305; the spheres will not collapse and form a homogeneous alloy with the paste. A phase boundary can be observed, in cross sectioned samples, between the reflowed tin/bismuth/silver paste and the unmelted SAC 305 sphere. (Figure 12). This phase boundary did not fail after 2,500 thermal cycles normally used to test consumer goods. (0º to 100ºC with 10 minute dwell times).

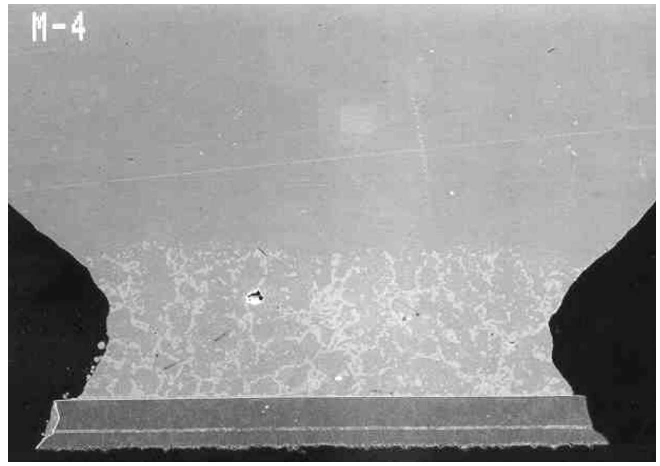

Figure 12 (Photo Courtesy of HP)

However, when a typical automotive thermal cycling test was conducted (-40º to +125ºC with 30 minute dwell times) fatigue cracks appear in cross sections in fewer than 1,000 thermal cycles. See figure 13.

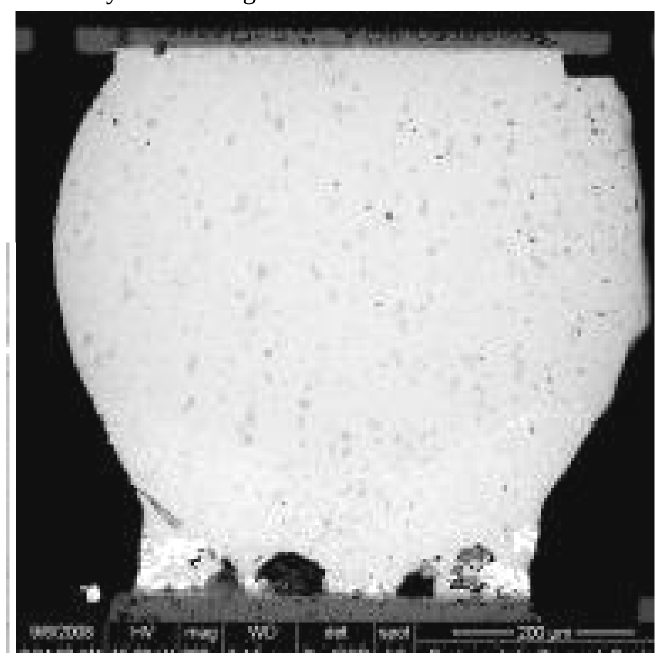

Figure 13-SAC 305 BGA after 1,000 Cycles (-40º to +125ºC)

A third thermal cycling regime has also been tested. This regime is typically used by the remote control OEM discussed above in the qualification of materials**.** This profile includes 30 minute dwell times at -20ºC and +85ºC, a typical consumer product type of thermal fatigue test. As can be seen in figure 14, there is no evidence of crack propagation at the solder/SAC305 sphere interface (3).

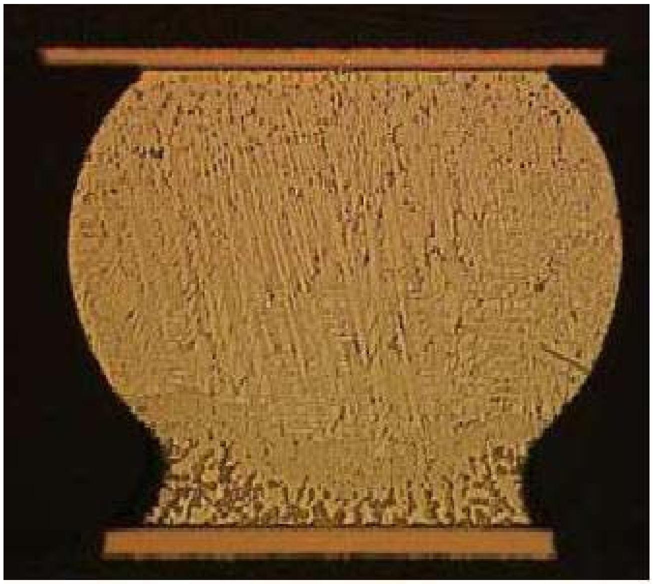

Figure 14-after 200 cycles of -20ºC to +85ºC 30 minutes Dwell

Electrical Reliability

In general, higher temperature reflow profiles will be more likely to drive off weak organic acids from solder paste flux residue. Residual ionic materials can absorb moisture and reduce surface insulation resistance (SIR), especially during damp thermal cycling test protocols. Using a very low temperature profile depicted in figure 4, LMP paste was reflowed on JIS standard coupons. (Figure 15)

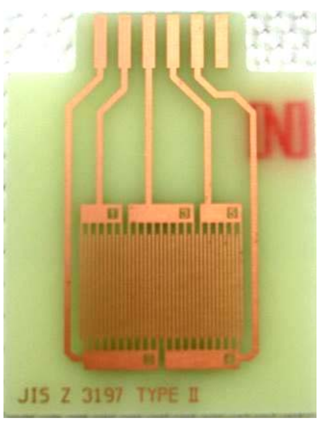

Figure 15- JIS Standard SIR Test Coupon

One of the more difficult electrical reliability tests is the JIS Z3197 SIR test. This test runs for 1,000 hours and continuously measures the SIR of copper fingers spaced 0.32mm apart and subjected to a 100V bias in a chamber set at 85ºC at 85% relative humidity.

The low melting point solder paste used to eliminate wave soldering in the two cases discussed above maintained a very high surface resistivity over the 1000 hour duration of the test, confirming the electrical reliability of the flux residue. (Figure 16)

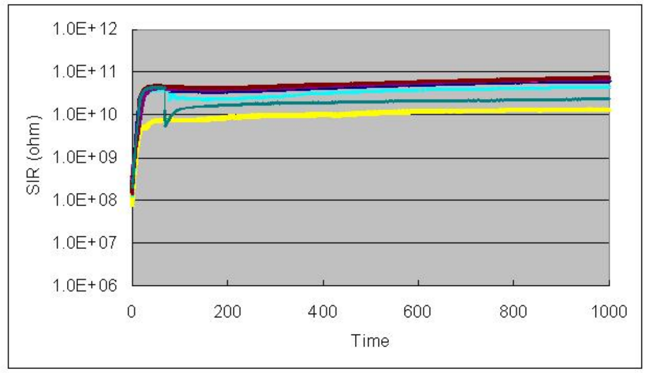

Figure 16- JIS SIR Test Results

CONCLUSIONS

Sn/Bi/Ag paste can be used to eliminate the need for a wave soldering process in a mixed technology assembly process. The lower temperature process can also reduce energy and material costs in single sided SMT applications.

Eliminating wave solder can cut production costs significantly by eliminating the cost of wave soldering flux, wave alloy and the energy of operating equipment.

Numerous global OEMs have successfully used this technique for 5 years or more. High reliability applications using SAC 305 BGA components may not be suitable applications for this technique. However for many consumer electronic applications, Sn/Bi/Ag paste used as a combined SMT and Paste in Through Hole process meets or exceeds mechanical and electrical reliability requirements.

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