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Creating Solder Joint Reliability with SnCu Based Solders
Some Practical Experiences

Our thanks to Kester for allowing us to reprint the following article.

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Abstract

Tin-silver-copper has received much publicity in recent years as the lead-free solder of choice. SAC305 was endorsed by the IPC Solder Value Product Council in the United States as the preferred option for SMT assembly; most assemblers have transitioned to this alloy for their solder paste requirements. The SAC305 alloy due to its 3.0% content of silver is expensive when compared to traditional 63/37 for this reason many wave assemblers are opting for less costly options such as tin-copper based solders for their wave, selective and dip tinning operations.

In recent years tin-copper based solders with a variety of elemental additives have emerged which improve the overall properties and performance of tin-copper solders. Tin-copper solder without the incremental additions of certain elements is rarely used but the addition of nickel or nickel and bismuth as found for example in K100 and K100LD respectively do offer improvements in wetting, joint cosmetics and in some cases solder joint reliability.

These alternative SnCu based solders are not normally used in reflow soldering but are gaining use globally in wave and selective soldering operations. This paper will describe how to achieve solder joint reliability using SnCu based solder with nickel and other additives such as bismuth.

Comparing SAC and Tin-Copper Based Solders

At this time there is no doubt more technical information exists for SAC solder. The number of users for SnCu based solders has steadily increased in recent years and about 30% of assemblers are now using various alternatives of SnCu solder in wave or selective systems. SAC solders still account for about 60% and 10% use other lead-free solders such as tin-silver and tin-bismuth. However the rate of conversion to tin-copper has increased in 2006 and into 2007. What are the main differences between SAC and SnCu based solders? Is it as reliable as SAC in wave soldering applications? These are common questions often asked by engineers.

One of the main attraction and difference is cost. Below is Figure 1 indicating the relative cost of SAC to SnCu. The cost of material will impact the initial cost of loading but also the operating costs of wave and selective systems. The approximate elemental concentrations of K100LD and K100 are detailed; it must be noted that very few use tin-copper solder without some additives.

Alloy	Elemental Composition	Relative Cost (approx)
Sn63	Sn63Pb37	1x
K100LD	Sn99.3Cu0.7 + Ni + Bi	1.5x
K100	Sn99.4Cu0.6 + Ni	1.5x
SAC305	Sn96.5Ag3.0Cu0.5	3x

Figure 1. Solder Comparison

The other difference is solder joint cosmetics. SAC solders tend to demonstrate various levels of solder shrinkage effects. Solder hot tears as documented in IPC-STD-610D are not considered a defect if the tear bottom can be seen during inspection or that the tear does not contact the board barrel or termination of the component. Examining the bottom of the tear is next to impossible to do since the tear is not always straight down and the other concern is the long term impact of thermal cycling on the hot tear. The photographs shown below Figure 2 and 3 indicate typical hot tears seen with SAC solder in wave soldering.

Figure 2. SAC hot tear

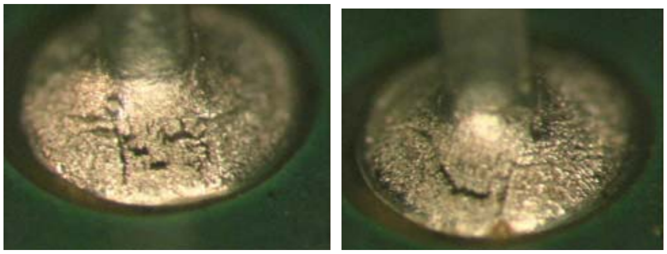

Figure 3. After 500 thermal cycles, iNemi Wave Project

Figure 3 shows solder joints using SAC305 after 500 thermal cycles; the fracturing seems to have aggravated but at this time it is not known if this will have an impact on long term joint reliability. These pictures are part of the iNemi Lead-free Wave Solder Project which is still ongoing. SnCu based solders with certain minute additives will show much lower levels of shrinkage. The shrinkage effect also happens when hand-soldering with SAC; SnCu based solders with additives does not do this.

Other physical and chemical characteristics comparing SAC305 to two popular SnCu based solders are shown in Figure 4. Another advantage of these alloys is the lower reactivity to metals used in soldering equipment and also lower dissolution of copper. For example the dissolution rate for SAC305 is over 2 ½ times higher than SnCuNiBi. The lower dissolution rate of copper can increase the reliability of solder joints by preserving the metallization at the bond layers. In some cases such as fountain rework operations the dissolution of copper at the elbow of a through-hole barrel has at times been complete; resulting in a weaker bond. The erosion of copper happens more vigorously at the area of more solder flow, the elbow of the through-hole barrel.

	Sn-Cu-Ni-Bi	Sn-Cu-Ni	SAC305
Melt Point	~227°C	~227°C	217-220°C
Pasty Range	0	0	3C
Appearance	Shiny	Shiny	Dull
Shrink Holes	No	No	Yes
Copper Dissolution (Sn63 = 1)	0.8	1.0	2.1
Pot Management	Easiest	Easy	Difficult
Reactivity to Equipment	Low	Low	High
Suggested Pot Temperature	255 – 265°C	255 – 265°C	250 – 260°C

Figure 4. Comparing SnCu based solders to SAC305

The other advantages of lower dissolution rates for copper are reduced solder pot maintenance, less solder analysis frequency. The solder alloy remains more elementally uniform and a more consistent solder results in better process control. Less contamination of the solder is always a plus; copper dissolution also tends to increase the melting point of the lead-free solder. The higher melting point will result in a more sluggish flow of solder resulting in lesser hole-fill.

The other difference is the wetting speed and SnCu based solders have slower wetting speeds than SAC solders. This does impact the process of solder in several ways and the optimization of contact time and immersion depth is more critical with SnCu. The optimization will be necessary to insure adequate hole-fill. If the soldering process is controlled carefully adequate hole-fill is possible with both SAC and SnCu based solders.

However wetting speeds compared using a wetting balance tester show SAC having wetting speeds higher than SnCu based solders. This means that SAC alloys have a better chance of giving acceptable hole-fill in wave and selective systems. SnCu based solders will require at times different process parameters to achieve the same results as SAC solder. Below in Figure 5 are two wave soldered solder joints accomplished with SnCu based solder and SAC305. Both have complete hole-fill although SnCu based solder does have a slower wetting speed, the results are the same.

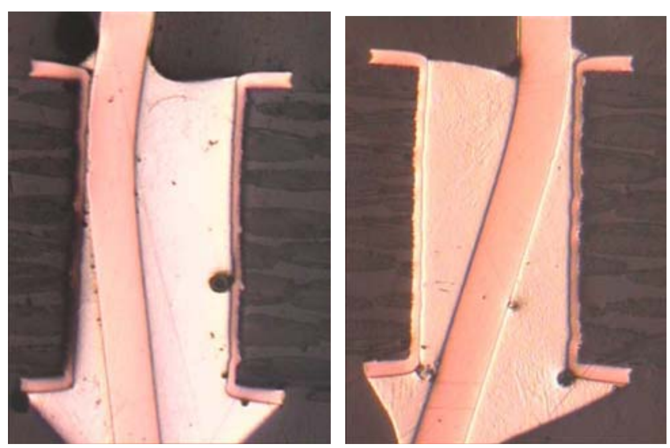

Figure 5. SnCu based solder and SAC305, on the right

To summarize several other differences between both alloys Figure 6 shows the typical solder pot temperatures used to achieve the same results as with SAC solder. The longer contact time enables SnCu based solders to wet completely the through-hole part. The immersion depth of the board was also critical here and is best to use at least ½ of the board thickness. In thicker assemblies such as 0.093 inch or more ¾ is best. The flux used in soldering will also play an important role in hole-fill, the higher the activity and stability of the activators used in the flux formulation will enable better hole-fill. Since contact time is longer with SnCu based solders a flux designed for this application will perform better.

	SnPb	SAC	SnCu based
Wetting Speed	Fast	Medium	Slow
Contact Time	Shortest	Longer	Longest
Pot Temperature	465-510 °F	500-525 °F	510-535 °F
Dross Formation	1x	1.8x	2x

Figure 6. Comparing process variables of lead-free solders to leaded

The impact of board finish and soldering will also be a factor with lead-free. Lead-free solders wet more slowly than leaded solders. Since SnCu based solders have slower wetting speeds than SAC, the choice of board finish, the number of heating cycles it sees and its storage and handling will impact its solderability. The higher the oxidation present on components and boards the mostly likely difficulties will be encountered with hole-fill and pad wetting using SnCu. The Figure7 shows the impact of soldering two finishes under similar conditions and it can be seen that copper OSP did not fair as well as the ENIG and AgImm board.

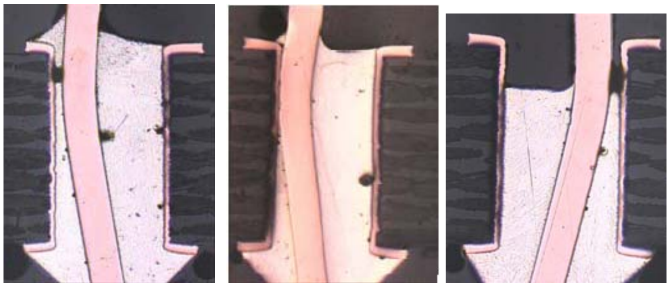

Figure 7. ENIG and AgImm compared to OSP on the right

Assemblers Practical Experience with SnCu Based Solders

At the assembler level once a product is required to be soldered with lead-free solders all the processes must be assessed as to insure the same level of quality as with Sn63Pb37. The reflow, wave soldering and hand assembly processes must all be optimized carefully to insure good joint formation as per the appropriate class of electronics with new solder alloys and new fluxes. Solder joint reliability must be assessed during the initial process validation. The validation of the wave solder process may include the following items:

- Alloy selection
- Flux selection
- Board and component finish selection and control
- Flux volume application
- Board and flux preheat requirements
- Solder temperature
- Use of chip wave or single wave
- Contact time at solder
- Immersion depth

After wave soldering assemblers must verify the quality of the solder joints and these can be through-hole or bottom-side SMD's. Each will have its own criteria of quality acceptance. Some basic tests which are normally performed are detailed below.

- Visual inspection
- X-ray analysis for voids
- Cross-sectional tests for bond verification
- Outside laboratory tests, IPC Class Inspection

A successful build of 170,000 boards with SnCu based (Kester K100) was recently completed at a contract assembler.

The board soldered with lead-free is described below.

- Board Type: 0.062 inch thick ENIG, ground plane on connector
- Board OEM: Printer board for FutureLogic Inc., a leading world wide manufacturer of thermal printers
- Components: Pure tin, matte tin, lead-free type SMD and through-hole parts

The wave solder was lead-free capable and after loading with K100 lead-free solder it was analyzed to verify the elemental concentrations but also for the presence of iron or lead. The analysis revealed it was acceptable. Regular solder analysis is recommended with lead-free wave soldering at least every 5000 board builds. A summary of the wave solder process is detailed below.

- Spray fluxing was used
- 5 sections of bottom-side convection heaters about 15 inches in width
- Quartz heater, before wave solder, width about 6 inches

- Chip wave, laminar wave
- Titanium solder pot and fingers
- No top preheaters
- 2 cooling blowers after wave solder pot
- 6° inclination used at the conveyor, adjustable
- No nitrogen blanketing was used

To achieve good hole-fill and low defects the wave process needed to be carefully optimized. Lead-free solders wetting speeds are slower so traditional speeds used with Sn63Pb37 are not always suitable. Contact time and width are critical with lead-free alloys. The board impingement thickness is also important and this was revisited. Flux application was optimized to insure the spray applied flux uniformly and throughout the through-hole. An air-knife after the sprayer was not used but this can be useful if flux application is restricted in thicker boards or tighter hole-tolead ratios. With lead-free wave soldering flux application was found important. In this case alcohol based flux was used however VOC-free fluxes with higher surface tensions may benefit with the use on an air-knife.

The parameters used in this build and which continued with the production of 170,000 boards are defined below.

Wave Solder Process Parameters:

- Conveyor Speed: 61 centimeters per minute.
- Solder temperature 265°C, only laminar wave used.
- Preheater settings WS-450PC-LF specific: 135, 140, 150, 155, 160
- Top-side preheat board: 129-131°C.
- Solder contact width: 2 inches or 5.1 centimeters.
- Contact Time: 5 seconds
- Board thickness wave impingement: ½ to ¾

The hand-assembly of some connectors was accomplished after SMD and through-hole soldering using K100 water washable flux wire. The flux percentage is a critical element in wire solder selection and in this case the flux percentage was 3% by weight. Lower flux percentages make soldering with lead-free more difficult due to their slower wetting behaviors. Although tin-copper was used the wetting speed and solder joint quality were to IPC-610D Class 3 and 100% hole-fill was obtained throughout.

Some of the basic criteria followed to obtain excellent lead-free hand-soldering are mentioned below.

- Lead-free compatible tips were used
- Correct tip geometry to achieve adequate thermal transfer
- Flux percent greater than 2%
- Soldering tip temperature 750ºF
- Marginally longer contact time
- No additional external flux was used

Hand-soldering was used particularly to solder a connector which was lead-free finished and RoHS compliant but not lead-free process capable. To avoid plastic damage this part was hand-assembled and soldered.

An Electrovert AquaStorm 200 with DI water only, no chemical additives were used to clean-off all flux residues after soldering this included paste, liquid flux and wire flux residues. The water temperature used was 140°F. Cleanliness was measured using an ionic contamination tester and found to pass. In some cases residues tend to be more difficult to remove but in this case they removed well since the fluxes were lead-free process developed.

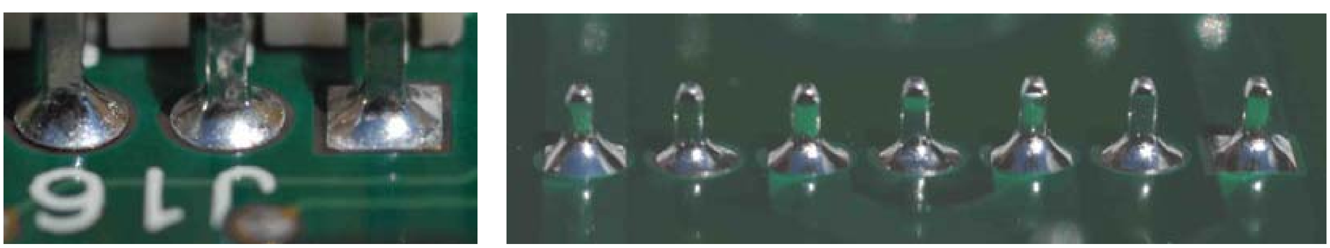

Figure 8. Typical parts wave soldered with SnCu based solder, board top and bottom

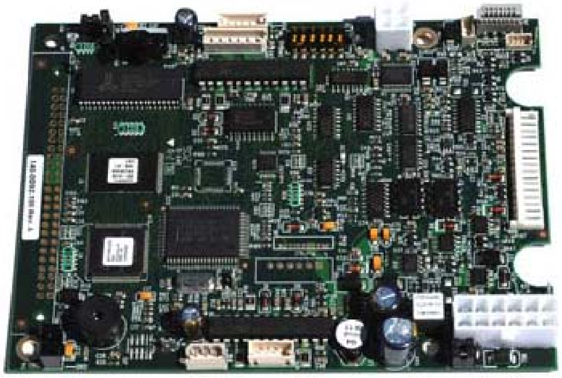

Figure 9. ENIG board with lead-free parts soldered

The assembly, Figure 9 used SAC305 solder paste for its top-side parts. All components were lead-free which is important in wave soldering to avoid lead contamination. This was verified after several hundred assemblies and the lead percentage was found to be within the RoHS limits of 0.1%. Lead once elevated is not easy to dilute down since virgin solder normally will have a small amount of lead in the range of 0.05% or less.

Figure 8 shows the typical solder joints achieved with SnCu based solder using the previously indicated process parameters. The solder joints were free of shrinkage effects and were bright in finish. All solder joints met the IPC-STD-610D criteria for Class 3. Since the process was optimized carefully during the validation process, very few defects were encountered during the build of 170,000 assemblies.

Thicker boards in the range of 0.093 inches and higher can be challenging with lead-free and another assembler successfully soldered a thicker board using SnCu based solder. The key to soldering thicker boards are the proper selection of flux, the setting up of the preheat temperature, contact time at the solder and board immersion depth. In some cases thicker boards will solder with better hole-fill with fluxes of higher activity or higher solids content.

Another large contractor assembled a thicker board successfully with K100LD. This alloy is SnCu based with an addition of nickel and bismuth. The board for wave soldering is described as follows:

- Board thickness 0.093 inches
- Finish Sn100CL, lead-free HASL
- Mixed technology top and bottom SMD's
- SAC305 solder paste used on top-side
- K100LD soldering of bottom-side SMD's
- All components conformed lead-free finished
- Class of fluxes used were ORH1

The Figure 10 shows the assembly top-side which was wave soldered with K100LD. Also shown are typical through-hole parts showing complete hole-fill even if the board is 0.093 inch thick. No bridging or flagging resulted in this process.

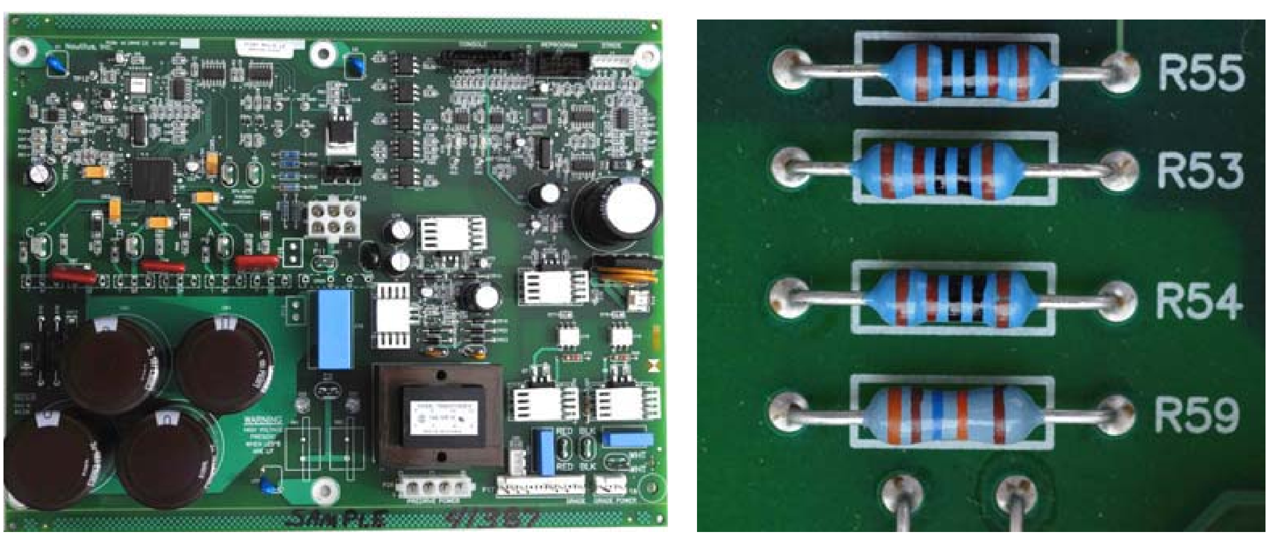

Figure 10. Sn100CL HASL 0.093 inch thick board soldered using K100LD.

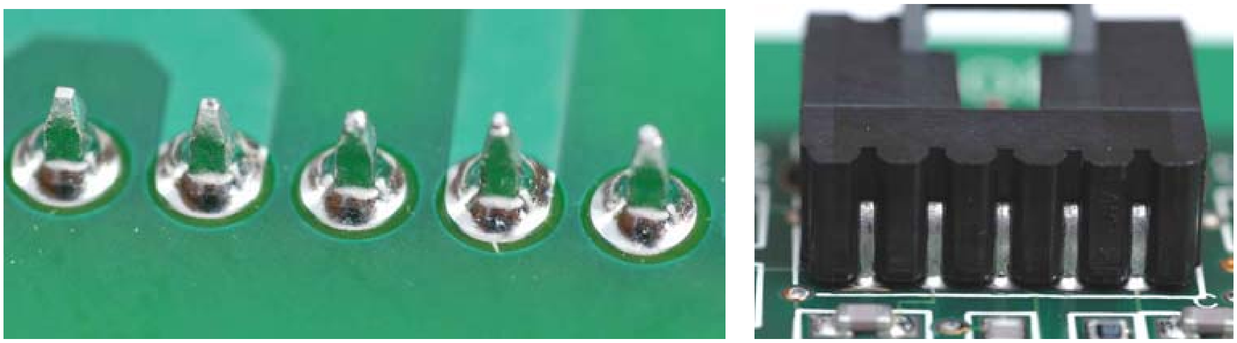

Figure 11. Component joints top and bottom, showing bright fillets and good hole-fill

The process used for this assembly was using a foam fluxer and top and bottom convection heaters. The process can be summarized as detailed below.

- Wave pot temp. 260-265°C
- Conveyor speed 3.0-3.5 feet per minute
- Contact time 3-5 seconds
- Contact width 2 inches approx.
- Board to wave contact thickness ½ to ¾
- Board preheat 100 to 130 °C, flux dependant

The board had also bottom-side SMD's and these also exhibited excellent wetting without flagging, see Figure 12. Typical bridges and flagging can occur with lead-free solders if the flux is overheated during preheating or the activity of the flux is not sufficient to sustain the longer contact at the solder. Other issues encountered with thicker assemblies besides hole-fill, bridges and flagging are voids and solder mask blistering. The blistering is due to the slower conveyor speeds and longer contact times. Voids are generated for a variety of reasons but on thick boards the flow dynamics of a higher surface tension solder tend to create voids in the through-hole barrel. Tighter hole to lead ratios tend to give higher voids in thicker assemblies. A longer contact sometimes helps but not always. To summarize the main defects seen with thicker assemblies are:

- Lack of hole-fill
- Bridges and flagging
- Voids
- Mask blistering

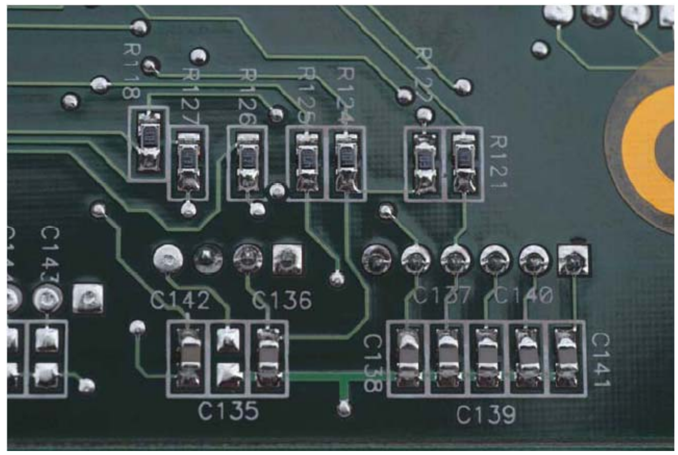

Figure 12. Bottom-side SMD's without flagging in extended contact time

In reference to dross creation all users reported less quantities generated with the use of SnCu based K100 and K100LD. The solder pot temperatures were a little higher than used with SAC305 but proper controls reduced the incidence of dross or oxides at the solder pot, Figure 13. Several ways to reduce dross is to use solder containing a dross reducer which both these alloys contain.

Figure 13. Low dross formed with SnCu based solder

However if a dross reducer is not added to the bar solder the following can help in keeping dross low. The following practices are recommended.

- Avoid constant removal of oxides, dross layers prevents further oxidation
- Keep solder pot full, avoid excessive cascading of the solder
- Keep a turbulent free wave; use slower pump speeds
- Use slightly lower solder temperature
- Keep impurities low
- Avoid high copper dissolution
- Use dross reducer, as a last resort

Conclusions in the Use of SnCu Based Solders

SnCu based solders particularly those containing certain additives can be a good choice in wave soldering applications. Solder joints can be created reliably is the whole process is optimized for the use with these solders. Although SnCu based materials have slower wetting than SAC type solders proper selection of board and component finishes including proper solderability management can enable the reliability of both through-hole and SMD parts.

Hole-fill can be an issue with thicker boards but if the process is optimized with longer contact times and slower conveyor speeds. Here the flux selection is important since longer dwells at the wave solder tend to de-activate many fluxes. A flux designed for the soldering of thicker assemblies is recommended. Water washable and higher solids fluxes do tend to give better hole-fill. No-clean fluxes need to be chosen carefully and their performance at slightly higher solder temperatures used with SnCu based solders must be assessed in reference to hole-fill potential and other defects such as voids.

SnCu based solders with additives to enhance soldering behavior can offer both bright joints free of shrinkage effects common with SAC solders and offer defect-free assemblies if the wave solder process is designed around them.

In wave soldering SnCu based solders are an alternative to more costly SAC lead-free solders.

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