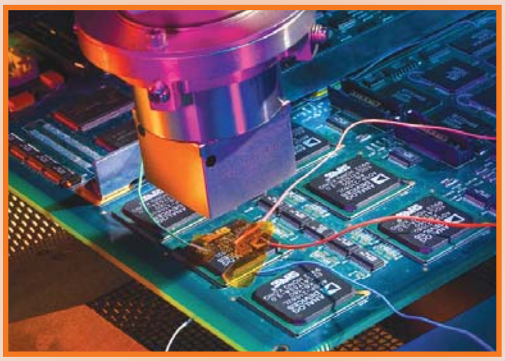
Rework with Lead-Free Solders

Paul Wood

Temperature differences between eutectic and lead-free solders mandate tighter processes, better profiles and precise rework systems.

Time, cost, quality, repeatability: These are the primary concerns of the repair and rework cycle. Too much time means excess cost, which is not acceptable. Poor quality has never been an option with electronics manufacturing. Repeatability requires process control, of course, but being able to quickly duplicate precise heating profiles—from operator to operator, facility to facility—underlies the entire repair and rework process.

Remember the days of through-hole components and tin-lead solder? Just heat the iron and go. Component profiles were not complex, operators could see all connections and the properties of solder were well understood.



Those days are long gone. Today, small, sensitive array packages, with complex profiles and hundreds of connections that can only be seen with sophisticated vision systems, fill the manufacturing landscape. Operator turnover is great; yet, operator experience with array packages is essential if time and quality goals are to be achieved.

Another variable has also been added: lead-free solders. Reflow temperatures are higher, time above the higher reflow temperatures is different, appearance of the joint has considerably changed, and the need for process control is even greater than it was for eutectic solders.

Can we hope to reach time, cost and quality goals with array packages and lead-free solder? With the right thermal profiles, better equipment and a bit of knowledge, the answer is yes.

The Basic Steps

Like leaded components with eutectic solder, the basic steps to proper ball grid array (BGA)/chip-scale package (CSP) rework using lead-free solder are the same—at least in theory:

1. Establish thermal profile.
2. Remove failed component.
3. Clean and prepare site.
4. Replace component with flux or solder paste.
5. Reflow.
6. Inspect.

So far, so good, but remember the caveats. Forget the soldering iron. Convection, not radiation, is the heating method of choice for lead-free rework. Convection allows for greater process control, and, without process control, repeatability is impossible.

The Thermal Profile

Better than conduction, convection also helps to establish a good, repeatable thermal profile, one that will not overheat the component or hold for too long above reflow.

Establishing the correct, ideal profile takes experience, patience and knowledge of lead free. And, while standard reflow consists of three zones (pre-heat, soak and reflow) plus cool down, lead free demands an extra ramp zone and more precise heating control.

A standard thermal profile using eutectic solder is shown in Table 1. The parameters of each zone are well understood and easily monitored.

Lead-Free Solder

The higher temperatures needed for lead-free (up to 235°C), coupled with the thermal sensitivity of BGAs/CSPs, demand precise temperature and the addition of a ramp stage where temperatures rise at a rate that will not harm packages.

Zone	Time Duration (seconds)	Target Temperature °C
Pre-heat	60 to 90	100 to 120
Soak	60 to 90	155 to 175
Reflow	30 to 60	200 to 210

TABLE 1: Standard reflow with eutectic solder.

Alloy System	Composition	Melting Range (C°)
Sn-Pb	60Sn-40Pb	183-188
Sn-Cu	Sn-0.7Cu	227
Sn-Ag-Bi	Sn-3.5Ag-3Bi	206-213
Sn-Ag-Cu	Sn-3.8Ag-0.7Cu	217
Sn-Ag	Sn-3.5Ag	221

TABLE 2: Eutectic and lead-free temperatures.

Zone	------- Tin Lead -------		------- Lead Free -------	
	Temp (C°)	Time (sec.)	Temp (C°)	Time (sec.)
Pre-heat	100 to 120	60 to 90	130 to 140	100
Soak	160 to 170	90	140 to 170	90
Ramp	NONE		170 to 225	100
Reflow	Max 220	60	225 to 235	15 to 30
Cool	60	30-60	60	30 to 60

TABLE 3: Reflow temperatures/times for tin lead compared to lead free.

Ideally, today's rework systems will employ four heating zones and one cooling zone. Without this extra step, lead-free rework is challenging. Higher temperature requirements, coupled with the thermal sensitivity of BGAs/CSPs, can be problematic without the ability to ramp temperatures at a rate that will not harm packages.

The addition of a controllable preheater allows for efficient preheating. It also avoids the thermal damage risked when working with expensive, but sensitive, packages unsuitable for heating component top temperatures above 240°C with quick reflow times.

Tightening Lead-Free Temperatures

The temperatures used in lead free are being tightened by both the suppliers and solder manufacturers. The maximum solder temperature has a peak of 235°C and a low of 2I7°C.

But, component suppliers' maximum temperature at the component lid is 265°C, with the most common temperatures ranging from 240° to 250°C. These temperatures are very close to the 225°C to 233°C solder temperature. In addition, the time above reflow has gone from 60 to 90 seconds for eutectic solder to 15 to 30 seconds for lead free. To meet this demand, rework systems must be capable of ramping up very fast and then down again to achieve this small peak temperature.

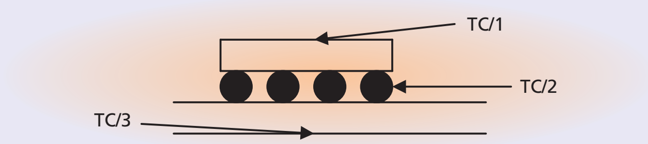


FIGURE 1: From the lid to the ball and under the surface of the bottom of the PCB, the temperatures at the thermocouples shown here all have to be within 10°C.

Lead-Free Rework Process Development at NEMI

Charlie Reynolds and Jerry Gleason

When lead is eliminated from electronic assemblies, the higher melting temperatures of lead-free alloys pose several challenges for rework processes. For example, the Sn3.9Ag0.6Cu alloy recommended by National Electronics Manufacturing Initiative, Inc. (NEMI, Herndon, VA) and several other industry organizations has a melting temperature of 217 to 219°C, which is approximately 35°C higher than the current industry-standard tin-lead process. NEMI organized the Lead-Free Assembly and Rework Project in May 2002 to focus on development of practical, reliable assembly and rework processes for components with a wide range of sizes and I/O counts. Project work is centered on assembling, reworking and testing boards that are 0.093 in. and 0.135 in. thick and intended for use in high-end computer and telecommunications products.

The NEMI project is concerned with two thermal challenges for lead-free rework: (1) damage to replacement components, especially in regards to moisture sensitivity levels (MSL); and (2) reliability degradation of component solder joints adjacent to reworked sites due to temperature exposure, which may change requirements for component clearance areas.

If a replacement part contains moisture, rapid heating to melt the solder can cause cracking, delamination or interfacial adhesion failure in the part. For this reason temperature, humidity and air exposure time specifications/requirements exist for components. The present J-STD-020B specification recommends that lead-free MSL be rated at a maximum of 245°C for large components (≥2.5 mm thick or ≥350 mm^3) and a maximum of 250°C for smaller components. (The corresponding ratings for tin-lead components are 225°C and 240°C, respectively.) However, the Lead-Free Assembly and Rework Project has measured hot gas rework component temperatures in the range of 260°C for large ball grid array (BGA) components on 0.135 in. boards.

These early results demonstrate that a cooperative industry effort is needed to (1) increase the temperature ratings of large and small lead-free components to 260°C; (2) implement a special bake-out of components to be used for rework just prior to use; and/or (3) develop improved rework tools and processes to minimize the temperatures to which components are subjected, especially during rework.

The challenge of minimizing reliability problems for components surrounding the rework site is related to nearby component spacing and the amount of heat that escapes laterally from the hot gas rework nozzle. Nearby temperatures typically exceed 217°C when reworking large BGAs on thick boards. The goal is to develop a rework process (and new tools, if necessary) to keep the solder joints of components surrounding the rework site well below 217°C. The project team is monitoring these temperatures so that component keep-out clearance recommendations can be reported to standards organizations such as IPC and JEDEC.

The NEMI team plans to complete development of a lead-free assembly and rework process and perform a technology qualification build this fall, which will be followed by reliability tests.

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New Delta Considerations

Another factor to consider when moving to lead free is the delta across the surface of the component. Usually, a delta of 10°C is considered acceptable, but lead free requires 5°C.

The new delta is critical for thermal strength, but it is difficult to achieve as it is measured from top to bottom. From thermocouple 1, thermocouple 2, and thermocouple 3 as shown in Figure 1, all have to be within 10°C—from the lid to the ball and under the surface of the bottom of the printed circuit board (PCB).

Different lead-free compositions exist, and these will be fine-tuned as time and processes mature. The most common are listed in Table 2.

Solder Paste Composition and Temperature

The wetting process and temperature profiles must be controlled to make sure joints are not brittle. With lead free, heating must be better regulated and ramp up and down must be faster, particularly in the under-board heater. As a result, hot plates are a thing of the past when lead free is involved.

In general, temperatures must be high enough to melt and form intermetallic and to activate flux and optimize wetting, yet low enough to avoid PCB and/or component damage.

Obviously, thermal profiles for lead free are different from those of eutectic solder. Tolerances are tight, making rework difficult without some type of repeatability and process control.

An example of the standard profiles used for eutectic solders as compared to lead-free solder profiles is shown in Table 3. The differences are substantial. The key to success is system control and the ability to ramp up faster and cool down quicker.

Now, compare the rework plot for eutectic solder (Figure 2) versus that for lead free (Figure 3). The primary temperature differences between the two processes are easy to see.

Inspection Differences

Lead-free solder joints look grainy when compared to traditional eutectic soldering (Figure 4) and are often erroneously rejected by inexperienced operators for quality rea-

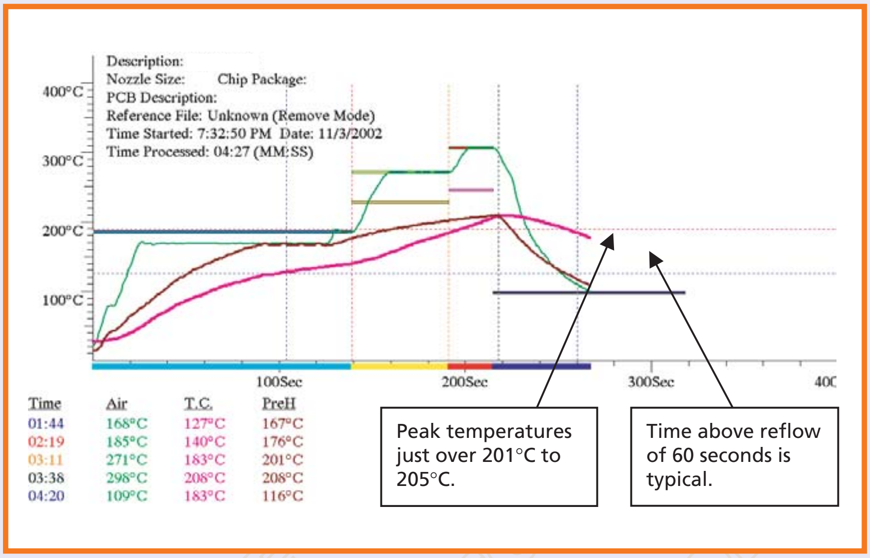

FIGURE 2: Eutectic solder reflow rework plot.

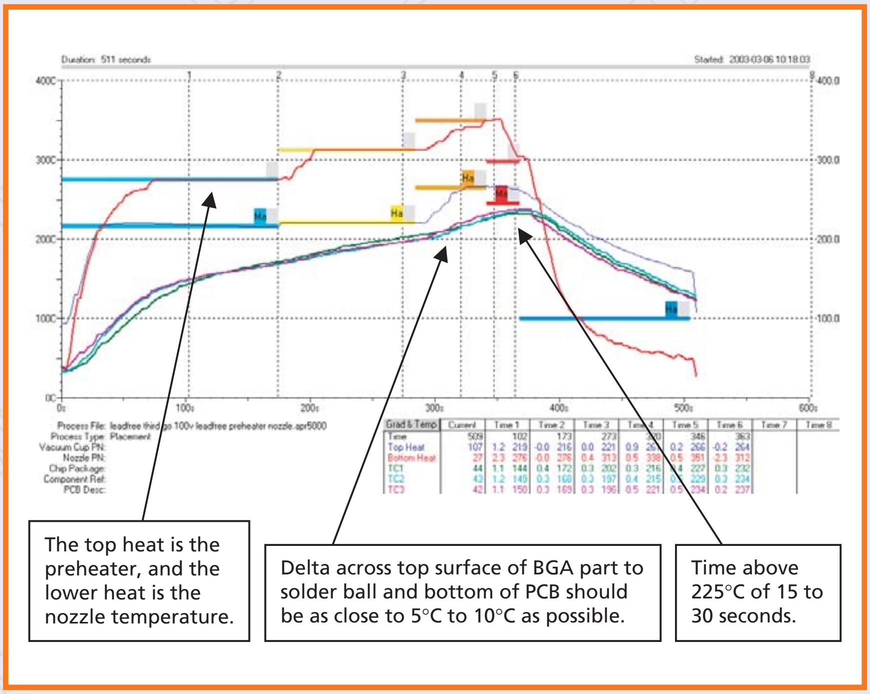

FIGURE 3: Lead-free solder reflow rework plot.

FIGURE 4: Differences in appearance between lead-free solder joints (left) and eutectic solder joints (right).

sons. When lead-free is implemented, companies must set a new standard and train operators in proper inspection criteria.

While traditional x-ray inspection works well, in part because joint appearance is not an issue, vision systems are growing in popularity. In some larger facilities, vision systems are used to complement x-ray. In these tough times, many companies have made vision systems the only mode of inspection to avoid the high cost of x-ray.

One major difference between x-ray and a newer vision system is the latter's ability to look at the joint, at both the top and bottom of the ball, and to check the formation of the intermetallic joint. In addition, some vision systems have the ability to look under CSPs and BGAs, a mandatory requirement for BGA/CSP inspection.

Advances in technology have resulted in visual inspection systems that can go low enough (0.002 in.) to see under micro surface-mount devices. Such equipment typically incorporates a metal halide light source with fiber optic light bundles that produce intense white light at 5,500°K. This lighting configuration provides daylight illumination for color rendering and color balance without blind spots, qualities that are necessary for accurate visual inspection and evaluation.

Note that CSPs have a standoff height of 0.007 in. to 0.008 in. and BGAs have a standoff height of 0.0018 in. to 0.020 in. When choosing a vision inspection system, make sure the system is capable of easily getting under these components.

Conclusion

Array packages and lead-free processes will continue to require post-production soldering/rework. Rework is not going away anytime soon. In fact, with thin profit margins, reducing scrap by reworking assemblies is more, not less, critical to survival.

And, while the basic rework steps are the same across technologies, substantial temperature differences between eutectic and lead-free solders mandate tighter processes, better temperature profiles and the use of precise rework systems with closed-loop process control.

With the narrow process windows mandated by lead free, which are linked to temperature sensitive array packages, high-quality, low-cost rework is challenging but achievable with intelligence and the right equipment. In short, the face of rework is changing, and manufacturers and vendors must keep pace. ■

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The original version of this article was presented at NEPCON Shanghai 2003.