Reworking BGAs/CSPs Using Lead-Free Solders

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, feeding back to time, cost and quality.

Oh for 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. You didn't have to be a rocket scientist to work the repair and rework bench.

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

Let's now add another variable: lead-free solders. Reflow temperatures are higher, time above the higher reflow temperatures are different, appearance of the joint is considerably different, 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 BGA/CSP rework using lead-free solder are the same – well, 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. Now the caveats.

Forget the soldering iron. Convection not radiation is the heating method of choice. Convection allows for greater process control, of course, and without process control repeatability is impossible.

The Thermal Profile

Better than conduction, convection also makes it easier to establish a good, repeatable thermal profile, one that won't over heat 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 Figure 1. The parameters of each zone are well understood and easily monitored.

Figure 1: Standard Reflow

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 220

Lead-Free Solder

The higher temperatures needed for lead-free (up to 235°C), coupled with the thermal sensitivity of BGA/CSP's demands precise temperature and the addition of a ramp stage where temperatures rise at a rate that will not harm packages. That’s why today’s more sophisticated rework systems employ four heating zones and one cooling zone. Without this extra step, lead-free rework is doomed. Higher temperature requirements, coupled with the thermal sensitivity of BGA/CSP, can be problematic without the ability to ramp temperatures at a rate that will not harm packages.

The addition of a controllable pre-heater allows for efficient, controlled pre-heating and avoids the thermal damage risked when working with expensive, but sensitive, packages unsuitable for heating above 240°C with quick reflow times.

Tightening Lead-Free Temperatures

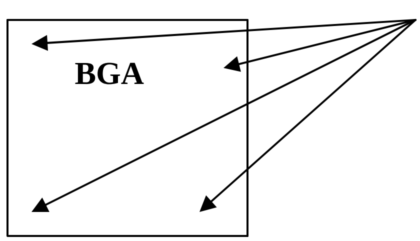
The temperatures used in lead-free are being tightened by both the suppliers and solder manufacturers. The maximum solder temperature has a peak of 235°C and a low of 2I7°C.

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 - 233°C solder temperature. In addition, the time above reflow has gone from 60 - 90 seconds (for eutectic solder) to 15 - 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.

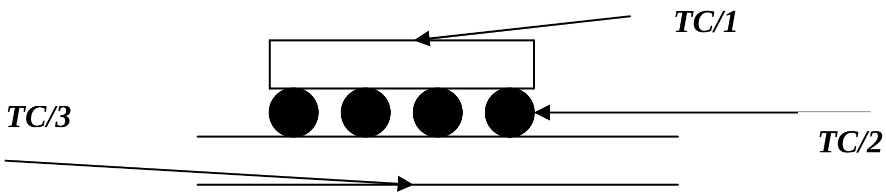
New Delta Considerations

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.



Delta Measurements across the surface of the components used to be 10°C 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 tc/1, tc/2, tc/3, all have to be within 10°C (from the lid to the ball and under the surface of the bottom of the PCB as shown below).



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

Figure 2: Lead Free Temperatures

Alloy System	Composition	Melting Range
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

Solder Paste Composition and Temperature

The wetting process and temperature profiles must be controlled to make sure joints are not brittle. With lead-free, there must be better regulation of heating and faster ramp up and down, 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, high enough 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 compared to lead-free solder profiles is shown in Figure 3. The differences are substantial. The key to success is system control and the ability to ramp up faster and cool down quicker.

Figure 3: Reflow Temperatures /times For Tin Lead Compared to Lead-Free

Zone	**Tin Lead**		**Lead Free**	
	Temp	Time	Temp	Time
Pre-Heat	100C-120C.	60-90s	130C-140C.	100s
Soak	160C-170C.	90s	140C-170C.	90s
Ramp	NONE		170C-225C.	100s
Reflow	Max 220C.	60s	225C-235C.	15-30s
Cool	60C.	30-60s	60C.	30-60s

Now compare the rework plot for eutectic solder versus that for lead-free. The primary temperature differences between the two processes are easy to see.

Figure 4A: Eutectic Solder Reflow Rework Plot

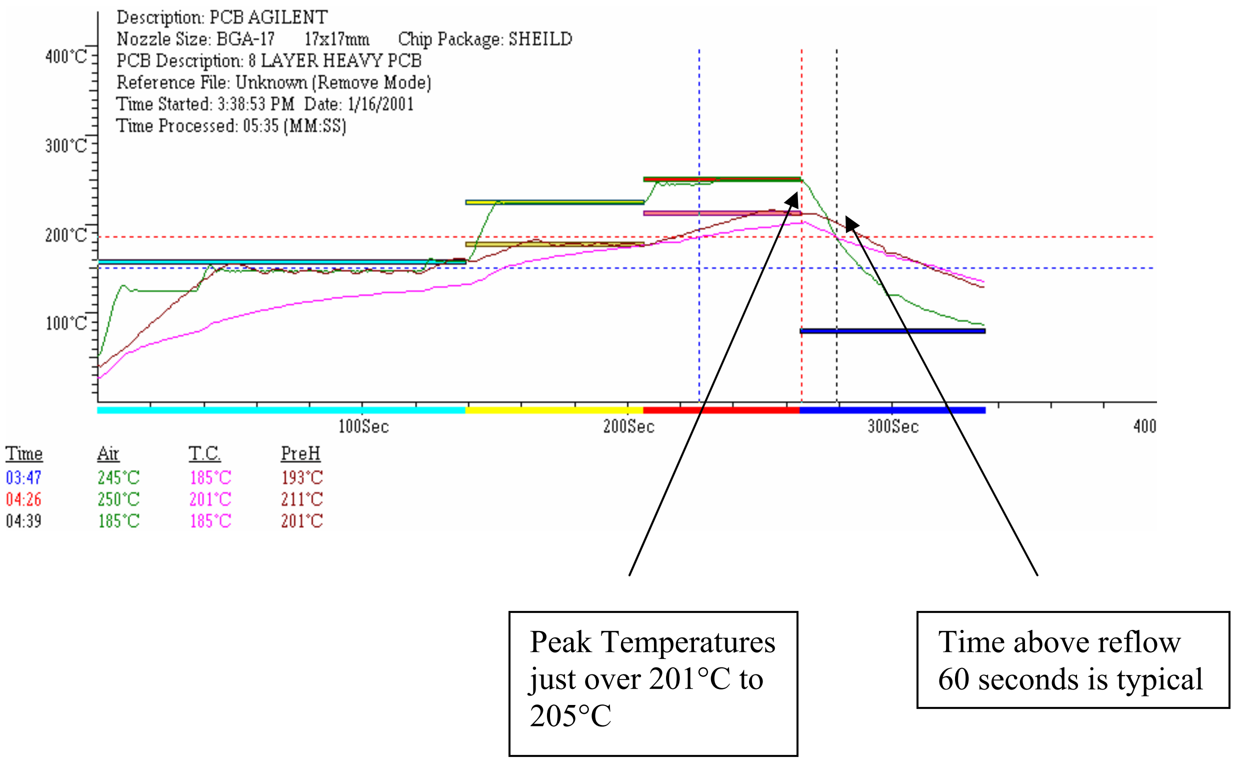
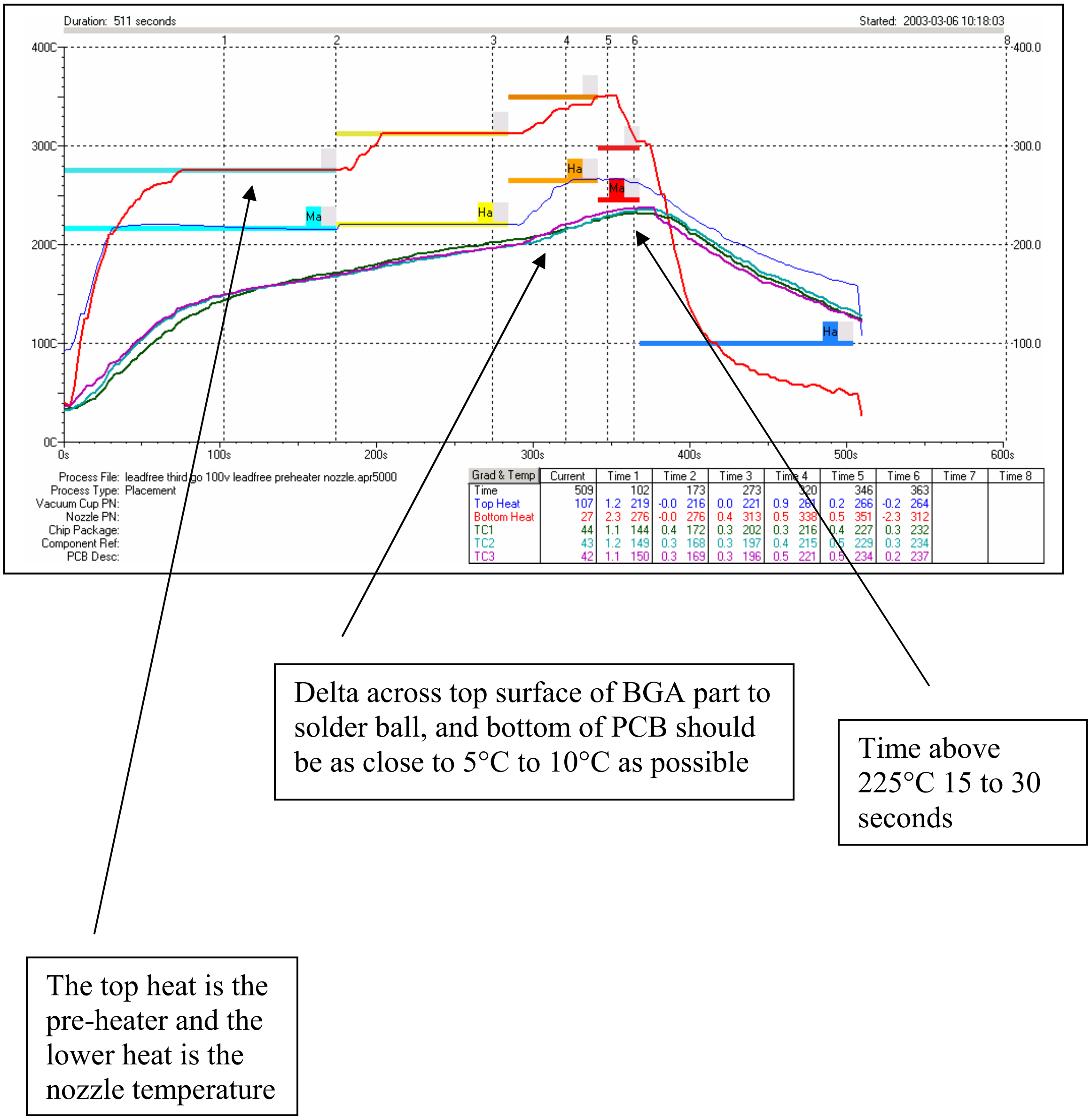


Figure 4B: Lead-Free Solder Reflow Rework Plot



Inspection Differences

Lead-free solder joints look grainy when compared to traditional eutectic soldering and are often erroneously rejected by inexperienced operators for quality reasons. When lead-free is implemented, companies must set a new standard and train operators in proper inspection criteria. (See figure 5)

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 compliment X-ray. Although in these tough times, many companies have made vision systems the only mode of inspection in order to avoid the high cost of X-ray – typically $75K to $120K.)

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 CSP's and BGA'S – a mandatory requirement BGA/CSP inspection.

Advances in technology have resulted in visual inspection systems that can go "low" enough (below 2 mils), to "see" under BGAs. 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 true daylight illumination for color rendering and color balance without blind spots, qualities that are necessary for accurate visual inspection and evaluation.

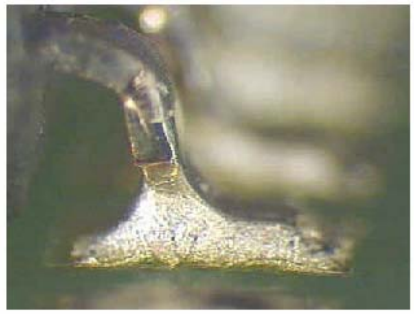
- Insert VPI-1000 Photograph -

***Caption**: Metcal's VPI-1000 Optical Inspection System floods the underside of the component with bright-white metal halide light that replicates natural daylight, enhances the color rendering and produces sharp, clear, crisp images on the system's hi-resolution flat screen color monitor.*

Note: CSPs have a stand off height of 0.007″ to 0.008″ (0.2MM), and BGA 0.0.018″ to 0.020″(.5MM). When choosing a vision inspection system, make sure the system is capable of easily getting under these components.

Figure 5: Differences in Appearance

LEAD-FREE QFP JOINT ***CONVENTIONAL JOINT***



Conclusion

Array packages and lead-free processes will continue to require post production soldering/rework. Rework isn't 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, 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.