AN 353: Reflow Soldering Guidelines for Lead-Free Packages

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Introduction

This application note describes the differences between conventional soldering and lead-free soldering and provides guidelines and recommendations for reflow soldering of Altera's lead-free packages.

The recent directives and legislations by nations around the world have mandated elimination of hazardous substances in the electronics industry. While elimination of many of these substances do not have significant impact on reflow soldering of the electronic component, there is one notable exception, lead. The elimination of lead from solders requires special consideration in soldering of the lead-free components on to printed circuit boards. This application note outlines the differences and recommends solutions to develop reflow process for lead-free devices.

Altera has taken an industry leadership position and has adopted lead-free technologies to provide solutions that align with industry requirements. In semiconductors, lead is mainly used in packaging as a part of the eutectic solder used as the surface finish for leaded packages and as the solder balls for ball-grid array (BGA) packages. Altera has proactively researched alternatives for lead compounds and has selected matte Sn lead finish for leaded packages and Sn-3-4%Ag-0.5%Cu solder balls for BGA packages. In addition, the thermal robustness of the packages has been improved by selecting appropriate materials and processes to allow for the higher reflow temperature compatibility required for assembling boards using Pb-free solder pastes. The details of the reliability qualification of lead-free packages are available in Altera's *Lead (Pb) Free Qualification Report*.

For more information about Altera's lead-free product offerings and solutions, refer to www.altera.com.

Reflow Soldering Process Considerations

This section outlines the differences between conventional reflow soldering and lead-free soldering.

The reflow soldering process for lead-free components is very similar to conventional eutectic solder reflow process. Often the same equipment set and process steps used for eutectic soldering can be used for lead free soldering.

Altera's reflow soldering guidelines for standard surface mount components are available in *AN 81: Reflow Soldering Guidelines for Surface-Mount Devices*. Most of the guidelines and recommendations listed are applicable for lead-free soldering.

However, some important differences must be taken into account for lead-free soldering, as the material set used for lead-free soldering is different and higher reflow temperatures are required. The important factors that must be considered for lead-free soldering are described in the following sections.

PCB Considerations

The important PCB consideration is the surface finish. Several PCB lead-free surface finishes, such as Organic Solderability Preservatives (OSP) and metallic surface finishes (such as electrolytic NiAu and immersion silver), are available in the industry. You need to determine the PCB surface finish based upon wetting, storage, planarity, and cost issues. In addition, you must ensure that board materials can withstand reflow temperatures without warpage or other damage. For most cases, FR-4 board material is acceptable, but high-density and high-complexity applications may require board materials, such as high Tg FR-4.

Solder Alloy and Flux Considerations

A wide range of lead-free solder paste alloys are available in the industry. The lead-free alloys typically have higher soldering temperatures than eutectic solder. The SnAgCu family of solder alloys is most commonly used for SMT manufacturing. The lead-free solder alloy selected needs to be nonhazardous, mechanically reliable, thermal fatigue resistant, have good wetting and relatively low melting temperature, and must be compatible with a variety of lead-bearing and lead-free surface coatings *(1)*.

The important considerations in selecting flux chemistries suitable for lead-free processing are flux activation temperature, activity level, compatibility with chosen lead-free alloy and reliability properties, such as SIR and electromigration.

Print Process Considerations

The lead-free paste requires special handling and development of the printing process must take into consideration the specific aspects of the lead-free paste, as outlined in this section.

Solder Paste Handling

Depending on the selection of the solder paste, the shelf-life and the storage conditions of the lead-free pastes may be different from the eutectic solder pastes. To avoid issues related to paste handling, the paste handling recommendations provided by paste manufacturers needs to be strictly followed.

Screen Printing

The printing process for lead-free pastes is identical to the process used for eutectic solder pastes. You must follow the guidelines recommended by the paste manufacturers to accommodate paste-specific requirements. In general, the lead-free paste characteristics yield similar performance in terms of stencil life, aperture release, print definition, and repeatability.

One important factor that you need to be consider in designing stencils is that lead-free pastes have higher surface tension and do not wet or spread on the surface of pads as easily as eutectic solder pastes. This can lead to exposed pad finish material after reflow soldering. You can rectify this by modifying the stencil aperture designs to increase the paste coverage on the pads.

Reflow Process Considerations

For lead-free soldering, the characterization and optimization of the reflow process is the most important factor you need to consider. The reflow process window for conventional soldering is relatively wide.

The melting point of the eutectic solder is 183°C. The lower temperature limit for reflow is usually 200°C. The upper limit is approximately 235°C, which is the maximum temperature to which most components can be exposed. These high- and low-temperature limits provide a process window of over 35°C.

The lead-free alloy used for BGA solder balls has a melting point of 217°C. This alloy requires a minimum reflow temperature of 235°C to ensure good wetting. The maximum reflow temperature is in the 245°C to 260°C range, depending on the package size (Table 2 on page 5). This narrows the process window for lead-free soldering to 10°C to 20°C.

The increase in peak reflow temperature in combination with the narrow process window makes the development of an optimal reflow profile a critical factor for ensuring a successful lead-free assembly process. The major factors contributing to the development of an optimal thermal profile are the size and weight of the assembly, the density of the components, the mix of large and small components, and the paste chemistry being used.

Reflow profiling needs to be performed by attaching calibrated thermocouples embedded in the spheres of the larger BGA parts as well as other critical locations on the boards to ensure that all components are heated to temperatures above the minimum reflow temperatures and that smaller components do not exceed the maximum temperature limits *(2)*. Because the components are subjected to higher reflow temperatures, you must select the appropriate moisture sensitivity level (MSL) for the components and the component handling. Storage recommendations must be strictly followed.

For more information, refer to the *Challenges in Manufacturing Reliable Lead Free Components*.

To ensure that all packages can be successfully and reliably assembled, the reflow profiles studied and recommended by Altera are based on the JEDEC/IPC standard J-STD-020 revision D.1 *(3)*.

Figure 1 shows the range of temperature profiles compliant to the JEDEC standard J-STD-020 revision D.1 *(3)*.

Figure 1. IR/Convection Reflow Profile (IPC/JEDEC J-STD-020D.1)

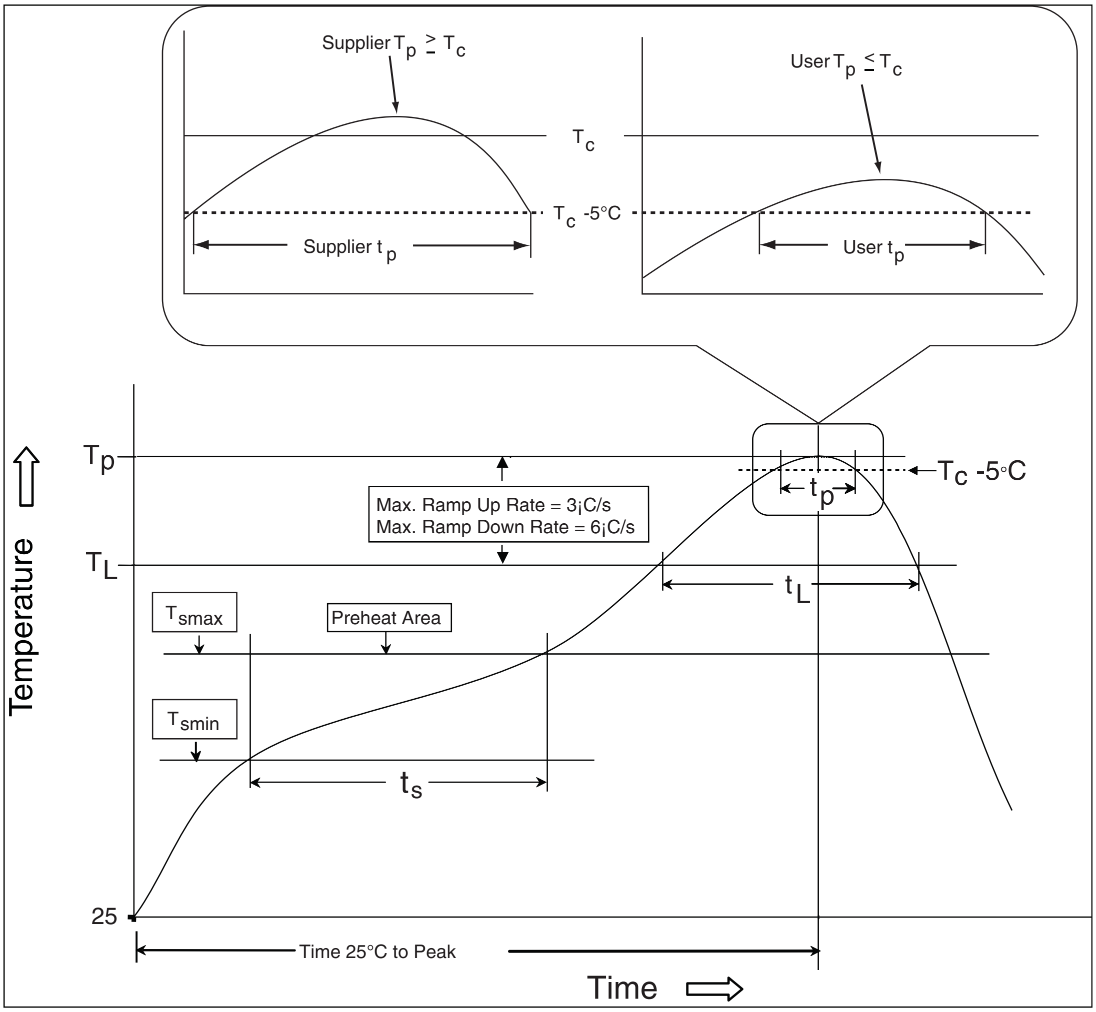

Table 1 and Table 2 list the reflow parameters and peak temperatures as recommended by JEDEC *(3)*. Industry studies have shown that the Ramp-to-Spike (RTS) process yields better results for lead-free assembly. This profile type offers better wetting and less thermal exposure than the Ramp-Soak-Spike (RSS) profile typically used in eutectic soldering.

The lead-free reflow profile recommendations are listed in Table 1.

Table 1. Lead-Free Reflow Profile Recommendation (IPC/JEDEC J-STD-020D.1) (Sheet 1 of 2) *(Note 1)*

Reflow Parameter	Lead-Free Assembly
Minimum preheat temperature (Ts_{MIN})	150°C
Maximum preheat temperature (Ts_{MAX})	200°C
Preheat time	60–180 seconds

Table 1. Lead-Free Reflow Profile Recommendation (IPC/JEDEC J-STD-020D.1) (Sheet 2 of 2) *(Note 1)*

Reflow Parameter	Lead-Free Assembly
Ts_{MAX} to T_L ramp-up rate	3°C/second maximum
Time above temperature T_L (t_L)	217°C, 60–150 seconds
Peak Temperature (T_P)	Refer to Table 2
Time 25°C to T_P	6-minute maximum
Time within 5° of Peak T_P	10-20 seconds
Ramp-down rate	4°C/second maximum

Note to Table 1:

(1) All temperatures refer to the topside of the package, measured on the package body surface.

Table 2 lists the lead-free process peak reflow temperatures (T_P).

Table 2. Lead-Free Process - Peak Reflow Temperatures (TP)

Package Thickness	Volume mm3 < 350	Volume mm3 350–2000	Volume mm3 > 2000
< 1.6 mm	260°C	260°C	260°C
1.6mm–2.55mm	260°C	250°C	245°C
> 2.5mm	250°C	245°C	245°C

You must control the peak temperatures below the recommended maximums (Table 2) and to minimize the temperature gradients across the board to reduce thermal stress on boards and components. High temperatures can put significant stress on plated through-holes and barrels, which can lead to cracking. High first-pass temperatures on double-sided assemblies increase the amount of second-side oxidation, which can cause solderability problems on the second pass.

Altera has worked extensively with leading EMS companies and has successfully demonstrated that the lead-free parts can be soldered in air atmosphere *(5)*.

However, for high-density, two-sided assemblies, you can alleviate the problems related to a narrow process window by selecting modern reflow ovens with forced convection and more heating zones with tighter process controls on reflow parameters. Reflow ovens equipped with Nitrogen reflow atmosphere have shown to improve wettability at lower peak temperatures and reduce temperature gradients across the board and have proven beneficial for double-sided assemblies *(6)*.

Post-Reflow Inspection

Industry studies have shown that using automated x-ray inspection systems are effective for lead-free solder joints. The x-ray inspection systems may have to be optimized to take into account the contrast differences of the lead-free solder and the differences in solder fillet shape and length.

You can also use Automated Optical Inspection (AOI) and visual inspection methods for inspecting solder joints other than BGA joints. The important consideration is that lead-free solder joints are not as shiny as eutectic solder joints. Inspectors need to be trained to distinguish lead-free solder joints from eutectic solder joints. You must optimize the AOI system parameters to account for changes in the solder fillet shape and the reflection characteristics of the solder joint surface *(4)*.

Manual Soldering and Rework

Due to the higher soldering temperatures required for lead-free solders, you must set the solder tip temperature higher. The higher soldering temperature requires that the soldering iron must remain clean and coated with the solder alloy. Lead-free solders are more sensitive to the effects of a dirty soldering iron. The higher soldering temperatures can result in the soldering iron tip becoming oxidized if not cleaned and coated. You can improve the soldering performance by more active solder flux and soldering in Nitrogen atmosphere. The technicians performing the operation must be trained thoroughly in lead-free soldering operation.

BGA Rework

The rework process for lead-free BGAs is similar to that used for eutectic BGAs. The BGA rework process typically consists of the following steps:

1. Thermal profiling
2. Removal of defective component
3. Site redressing
4. Solder replenishment or flux application
5. New component placement
6. Reflow soldering
7. Post reflow inspection

The rework machine needs to be capable of handling lead-free processing temperature and needs to be preheat-system equipped with a vision system that can accurately place fine-pitch components, hot gas airflow control, and have software capable of thermal profiling and editing rework sequences.

Site redressing is a crucial process in lead-free rework. The common ways for site redressing are the soldering iron/wick method and the copper coupon redress method. The success of the redressing techniques is dependent on operator skill and training.

The components being reworked need to be baked prior to reflow if they have been exposed to moisture. The baking parameters depend on the moisture sensitivity level of the package.

Thermal profiling is very important and you must measure the temperature at the solder joints. Thermal profiles must be developed for component removal, as well as the component replacement process. Board preheating has proven to be beneficial during reflow to reduce thermal gradient related stresses on adjacent components. Also, using Nitrogen gas improves wettability and reduces manufacturing defects during rework process *(6)*.

References

1. Lau, John and Liu, Katrina, "Global Trends in Lead-free Soldering—Part I and II," Advanced Packaging, January and February 2004.
2. Baldwin, Daniel and Kazmierowicz, Philip, "Taking the pain out of lead-free reflow," www.assemblymag.com, December 2003.
3. JEDEC/Electronic Industries Alliance, Inc, "Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices," March 2008.
4. Bath, Jasbir, "A Manufacturable Lead-Free Surface Mount Process," January 2003.
5. Bath, Jasbir; Chou, Chris; Lam, Samson; Wu, Roy; and Yoon, Sam, "Lead-Free BGA Assembly," July 1, 2004.
6. Åström, Anders, "The Effect of Nitrogen Reflow Soldering in a Lead-Free Process," September 2003.

Referenced Altera Documents

This application note references the following Altera documents:

- *AN 81: Reflow Soldering Guidelines for Surface-Mount Devices*
- *Challenges in Manufacturing Reliable Lead Free Components*
- *Lead (Pb) Free Qualification Report*

Document Revision History

Table 3 shows the revision history for this application note.

Table 3. Document Revision History

Date and Version	Changes Made	Summary of Changes
February 2009 v.2.0	Technical changes to Table 1.	—
July 2004 v.1.0	Initial Release	—

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