Reflow Soldering Guidelines for Lead-Free Packages

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Application Note 353

Introduction

The recent directives and legislations by nations around the world have mandated elimination of lead usage in some sectors of the electronics industry by 2006. Altera® has taken an industry leadership position and has adopted lead-free technologies to provide solutions that align with the 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-Free Qualification Report [2]. See the Altera web site for more information on Altera's lead-free product offerings and solutions [1].

Reflow Soldering Process Considerations

Comparison to conventional 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 Application Note 81 [4] and most of the guidelines and recommendations listed are applicable for lead-free soldering [4]. However there are some important differences that 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 discussed below.

Printed Circuit Board Considerations

The important printed circuit board (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. The end-user should determine the PCB surface finish based upon wetting, storage, planarity and cost issues. In addition, it must be ensured that board materials can withstand reflow temperatures without warpage or other damage. For most cases, FR-4 board material remains 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 should be non-hazardous, mechanically reliable, thermal fatigue resistant, good wetting, relatively low melting temperature and must be compatible with a variety of lead-bearing and lead-free surface coatings[5].

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

Solder Paste Handling

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

Screen Printing

The printing process for lead-free pastes is identical to the process used for eutectic solder pastes. It is important to follow 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 should be considered 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. This can be rectified by modifying to stencil aperture designs to increase the paste coverage on the pads.

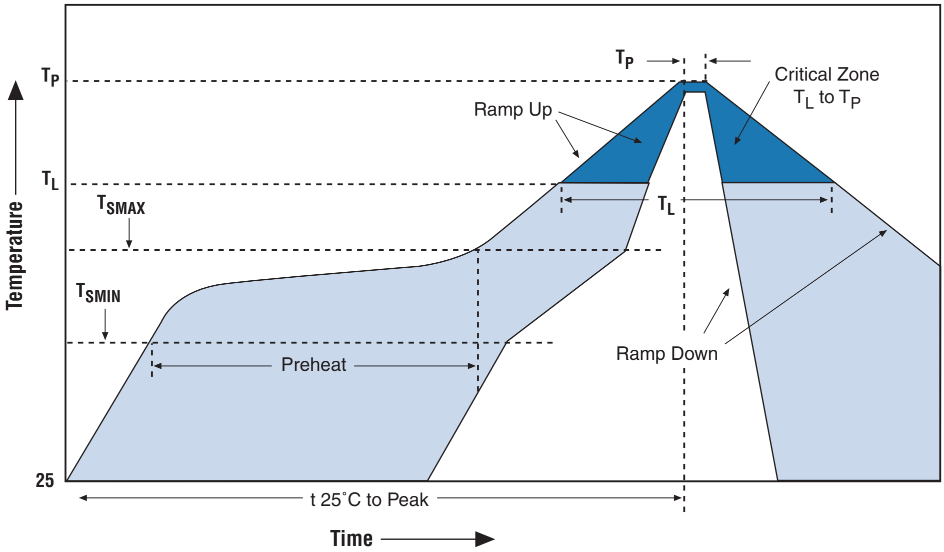
Reflow Process Considerations

The characterization and optimization of the reflow process is the most important factor to be considered for lead-free soldering. The reflow process window for conventional soldering is relatively wide. The melting point of the eutectic solder is 183^{o}C. The lower temperature limit for reflow is usually 200^{o}C. The upper limit is around 235^{o}C, which is the maximum temperature that most components can be exposed to. These high and low temperature limits provide a process window of over 35^{o}C. The lead-free alloy used for BGA solder balls has a melting point of 217^{o}C. This alloy requires a minimum reflow temperature of 235^{o}C to ensure good wetting. The maximum reflow temperature is in the 245^{o}C-260^{o}C, depending on the package size (see Table 2). This narrows the process window for lead-free soldering to 10-20^{o}C.

The increase in peak reflow temperature in combination with narrow process window makes the development of an optimal reflow profile a critical factor for ensuring 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. The reflow profiling should 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 minimum reflow temperatures and that smaller components do not exceed maximum temperature limits[7]. Since the components are subjected to higher reflow temperatures it is important to select the appropriate moisture sensitivity level (MSL) for the components and the component handling and storage recommendations must be strictly adhered to [3].

The reflow profiles studied and recommended by Altera are based on JEDEC/IPC standard J-STD-020 revision C [6] to ensure that all packages can be successfully and reliably assembled. Figure 1 on page 4 shows the range of temperature profiles compliant to the JEDEC standard J-STD-020 revision C [6]. Table 1 on page 4 and Table 2 on page 5 list the reflow parameters and peak temperatures as recommended by JEDEC [6]. 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.

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



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

Table 1. Lead-Free Reflow Profile Recommendation (IPC/JEDEC J-STD-020C)

Reflow Parameter	Lead-Free Assembly
Minimum preheat temperature (Ts_{MIN})	150°C
Maximum preheat temperature (Ts_{MAX})	200°C
Preheat Time	60-180 seconds
Ts_{MAX} to T_L ramp-up rate	3°C/second maximum
Time above temperature T_L (t_L)	217°C 60-120 seconds
Peak Temperature (T_P)	See Table 2 below
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

Notes 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

It is important to control the peak temperatures below recommended maximums (see Table 2 above) 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 [10]. However, for high density, two sided assemblies the problems related to a narrow process window can be alleviated by selection of 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 [9].

Post Reflow Inspection

Industry studies have shown that automated x-ray inspection systems can be effectively used 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.

Automated Optical Inspection (AOI) and visual inspection methods can also be used 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. The inspectors should be trained to distinguish lead-free solder joints from eutectic solder joints. AOI system parameters must be optimized to account for changes in the solder fillet shape and the reflection characteristics of the solder joint surface[8].

Manual Soldering and Rework

Due to the higher soldering temperatures required for lead-free solders, the solder tip temperature has to be set 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. The soldering performance can be improved by more active solder flux and soldering in Nitrogen atmosphere. The technicians performing the operation must be properly trained 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:

- Thermal profiling
- Removal of defective component
- Site re-dressing
- Solder replenishment or flux application
- New component placement
- Reflow soldering
- Post reflow inspection

The rework machine should be capable of handling lead-free processing temperature and should be preheat system equipped with a vision system that can accurately place fine-pitch components, hot gas airflow control and 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 soldering iron/wick method and the copper coupon redress method. The success of the redressing techniques is dependent on the operator skill and training.

The components being reworked should 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 efforts to measure the temperature at the solder joints should be undertaken. Thermal profiles should 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 use of Nitrogen gas improves wettability and reduces manufacturing defects during rework process[10].

References

[1] http://www.altera.com/products/devices/leadfree/lead-free_index.html

[2] http://www.altera.com/literature/rr/rr-lead_free.pdf

[3] http://www.altera.com/literature/wp/wp_chmfgrelldfr.pdf

[4] http://www.altera.com/literature/an/an081.pdf

[5] Lau, John and Liu, Katrina, “Global Trends in Lead-free Soldering - Part I and II,” Advanced Packaging, January and February 2004.

[6] JEDEC/Electronic Industries Alliance, Inc, “Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices (IPC/JEDEC J-STD-020C),” Draft version, January 2004.

[7] Baldwin, Daniel and Kazmierowicz, Philip, “Taking the pain out of lead-free reflow,” www.assemblymag.com, December 2003.

[8] Jasbir Bath, “A manufacturable lead-free surface mount process,” http://www.solectron.com/newsroom/making_news/mtn_2003_01_circuits%20assembly.pdf, January 2003.

[9] Åström, Anders, “The effect of Nitrogen reflow soldering in a lead-free process,” http://www.smtinfocus.com/PDF/Pbfree_N2_reflow_soldering_Linde.pdf

[10] Bath, Jasbir; Chou, Chris; Lam, Samson; Wu, Roy; and Yoon, Sam, “Lead-Free BGA Assembly,” http://www.assemblymag.com/asb/cda/articleinformation/features/bnp__features__item/0,,129148,00+en-uss_01dbc.html.

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