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Implementation and Solder Reflow Guidelines for Pb-Free Packages

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Summary

Recent legislative directives and corporate driven initiatives around the world have called for the elimination of Pb and other hazardous substances in electronics used in many sectors of the electronics industry. The Pb-free program at Xilinx was established in 1999 as a proactive effort to develop and qualify suitable material sets and processes for Pb-free applications. Xilinx has taken the leadership position by quickly forming partnerships with our customers, suppliers, and participating in industry consortiums to provide technical solutions that are aligned with industry requirements.

Xilinx has researched alternatives for Pb compounds and has selected matte Sn lead finish for lead-frame packages and SnAgCu solder balls for BGA packages. In addition, suitable material sets have been chosen and qualified for higher reflow temperatures (245°C–260°C) that are required by Pb-free soldering processes. Pb-free products from Xilinx are designated with an additional “G” in the package designator portion of the part number.

For reflow soldering applications, SnAgCu solder has been chosen by the industry as the most viable Pb-free solder to replace eutectic Sn/Pb solder. Compared with other Pb-free alloys, SnAgCu has better characteristics in terms of cost and processability as well as comparable or better reliability than eutectic Sn/Pb solder. However, SnAgCu alloy has a much higher melting temperature (217°C) than the standard eutectic Sn/Pb solder. Thus, assembly processes must be optimized accordingly to achieve the best yields and reliability.

This document contains guidelines on reflow soldering, inspection, and rework process for Pb-free packages.

Backward Compatibility

Backward compatibility, as described in this Application Note, refers only to the soldering process. Pb-free devices from Xilinx have the same form, fit and function as standard Pb-based products. No changes are required for board design when using Pb-free products from Xilinx. However, finish materials for boards might need to be adjusted. Xilinx® standard packages are not recommended for use in a Pb-free process.

Lead-frame packages (PQG, TQG, VQG, PCG, etc.) from Xilinx are backward compatible, meaning that the component can be soldered with Sn/Pb solder using Sn/Pb soldering process. Lead-frame packages from Xilinx use a matte Sn plating on the leads, which is compatible with both Pb-free soldering alloys and Sn/Pb soldering alloy.

BGA packages (CPG, FTG, FGG, BGG, etc.), however, are not recommended to be soldered with Sn/Pb solder using a Sn/Pb soldering process. The traditional Sn/Pb soldering process usually has a peak reflow temperature of 205°C–220°C. At this temperature range, the SnAgCu BGA solder balls do not properly melt and wet to the soldering surfaces. As a result, reliability and assembly yields are compromised.

Special considerations for Pb-free soldering are shown in the Reflow Soldering Considerations section.

Reflow Soldering Considerations

The reflow soldering process for Pb-free components is very similar to the conventional eutectic solder reflow process. However, there are some important differences that must be taken into consideration for Pb-free soldering as the soldering material used for Pb-free soldering is different and higher reflow temperatures are required.

The optimal profile must take into account the solder paste/flux used, the size of the board, the density of the components on the board, and the mix between large components and smaller, lighter components. Profiles should be established for all new board designs using thermocouples at multiple locations on the component. In addition, if there is a mixture of devices on the board, then the profile should be checked at various locations on the board. Ensure that the minimum reflow temperature is reached to reflow the larger components and at the same time, the temperature does not exceed the threshold temperature that might damage the smaller, heat sensitive components.

In general, a gradual, linear ramp into a spike has been shown by various sources to be the optimal reflow profile for Pb-free solders (Figure 1). This profile has been shown to yield better wetting and less thermal shock than conventional ramp-soak-spike profile for Sn/Pb system. SnAgCu alloy reaches full liquidus temperature at 235°C. When profiling, identify the possible locations of the coldest solder joints and ensure that those solder joints reach a minimum peak temperature of 235°C for at least 10 seconds. It might not be necessary to ramp to peak temperature of 260°C and above. Reflowing at high peak temperature of 260°C and above can damage the heat sensitive components and cause the board to warp. Users should reference the latest JEDEC J-STD-020 standard for the allowable peak temperature on the component body. The allowable peak temperature on the component body is dependent on the size of the component. Refer to Table 2 for peak package reflow body temperature information. In any case, a reflow profile with the lowest peak temperature possible should be used.

For sophisticated boards with a substantial mix of large and small components, it is critical to minimize the delta T across the board (less than 10°C) to minimize board warpage and thus, attain higher assembly yields. Minimizing the delta T is accomplished by using a slower rate in the warm-up and preheating stages. A heating rate of less than 1°C/sec during the preheating and soaking stages, in combination with a heating rate of not more than 3°C/sec throughout the rest of the profile is highly recommended.

It is also important to minimize the temperature gradient on the component, between top surface and bottom side, especially during the cooling down phase. In fact, cooling is a crucial part of the reflow process and must be optimized accordingly. While a slow cooling rate can result in high assembly yields, it could lead to formation of thick intermetallic layers with large grain size; thereby, reducing the solder joint strength. On the other hand, a faster cooling rate leads to smaller solder joint grain size, and results in higher solder joint fatigue resistance. However, overly aggressive cooling on stiff packages with large thermal mass can lead to cracking or package warpage because of the differential cooling effects between the top surface and bottom side of the component and between the component and the PCB materials.

The key is to optimize cooling with minimal temperature differential between the top surface of the package and the solder joint area. The temperature differential between the top surface of the component and the solder balls should be maintained at less than 7°C during the critical region of the cooling phase of the reflow process. This critical region is the phase in which the balls are not completely solidified to the board yet, usually between the 200°C–217°C range. The best solution might be to divide the cooling section into multiple zones, with each zone operating at different temperatures to efficiently cool the parts.

Table 1 and Figure 1 provide guidelines for profiling Pb-free solder reflow.

Table 1: **Pb-Free Reflow Soldering Guidelines**

Profile Feature	Convection, IR/Convection
Ramp-up rate	3°C/second max
Preheat Temperature 150°–200°C	60–120 seconds
Temperature maintained above 217°C	60–150 seconds (60–90 seconds typical)
Time within 5°C of actual peak temperature	30 seconds max
Peak Temperature (lead/ball)	235°C min., 245°C typical (depends on solder paste, board size, components mixture)
Peak Temperature (body)	245°C–260°C, package body size dependent (reference Table 2)
Ramp-down Rate	6°C/second max
Time 25°C to Peak Temperature	3.5 minutes min, 5.0 minutes typical, 8 minutes max

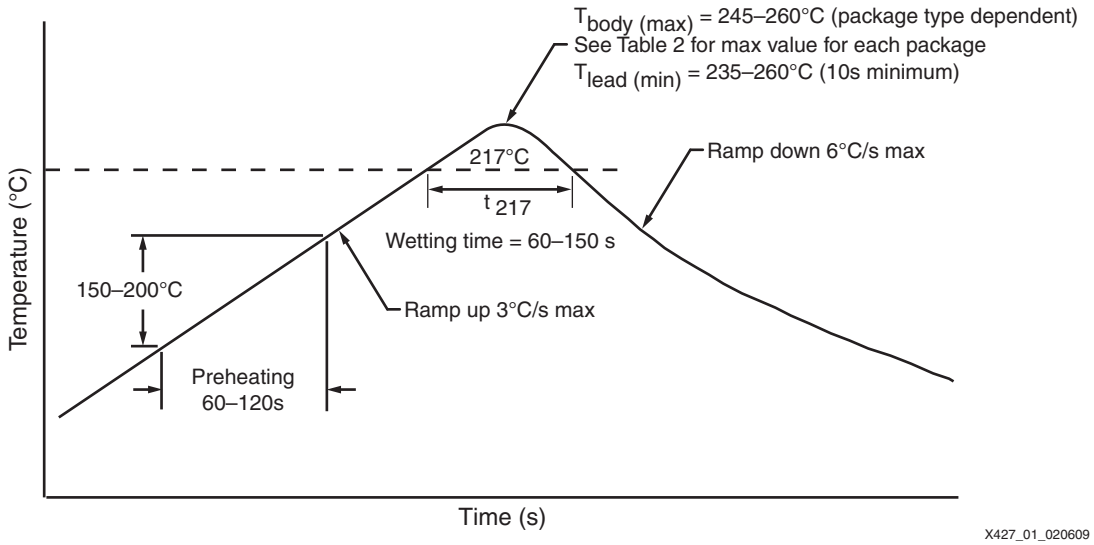

Figure 1: **Typical Conditions for Pb-Free Reflow Soldering**

Table 2: **Peak Package Reflow Body Temperature for Xilinx Pb-Free Packages (Based on J-STD-020 Standard)**

Package		Peak Package Reflow Body Temperature	JEDEC Moisture Sensitivity Level (MSL)
Lead Frame			
PLCC	PCG20 PCG44 PCG68 PCG84	245°C	3
Plastic DIP	PDG8	250°C	1
PQFP	PQG100 PQG160 PQG208 PQG240	245°C	3

Table 2: **Peak Package Reflow Body Temperature for Xilinx Pb-Free Packages (Based on J-STD-020 Standard) *(Cont'd)***

Package		Peak Package Reflow Body Temperature	JEDEC Moisture Sensitivity Level (MSL)
PQFP (Heatsink)	HQG208 HQG240 HQG304	245°C	3
TQFP	TQG100 TQG128 TQG144	260°C	3
VQFP	VQG44 VQG64 VQG100	260°C	3
VO/SO	VOG8 VOG20 VOG48 SOG20	260°C	3
BGA/FlipChip			
BGA (Cavity Up)	FTG64 FTG256 FGG256 FGG320	260°C	3
	BGG225, BGG256 BGG575 FGG324 FGG400 FGG456 FGG484 FGG556 FGG676 FGG900	250°C	3
	BGG728 FGG1156	245°C	3
BGA (Cavity Down)	BGG352 BGG432 BGG560 FGG680	260°C	3
	FGG860	245°C	3
Chip Scale	CPG56 CPG132 CSG48 CSG144 CSG280 CSG484 FSG48	260°C	3

Table 2: **Peak Package Reflow Body Temperature for Xilinx Pb-Free Packages (Based on J-STD-020 Standard) *(Cont'd)***

Package		Peak Package Reflow Body Temperature	JEDEC Moisture Sensitivity Level (MSL)
Flip Chip BGA	SFG363	260°C	4
	FFG323 FFG324 FFG665 FFG668 FFG672 FFG676	250° C	4
	BFG957 FFG896 FFG1136 FFG1148 FFG1152 FFG1153 FFG1513 FFG1517 FFG1696 FFG1704 FFG1738 FFG1759 FFG1760	245°C	4
QFN	QFG32 QFG48	260°C	3

Reflow Oven

To achieve consistently high assembly yields, an upgrade to newer equipment with more zones might be necessary to have better process control (minimizing delta T). A forced convection reflow oven is recommended while IR reflow might not be suitable.

Nitrogen

Although nitrogen is not required, it is recommended to achieve better wettability and widen the process window. Nitrogen is especially beneficial when temperature differential across the board can be large. Additionally, nitrogen improves the appearance of solder joints by inhibiting the effects of oxidation.

Inspection

Pb-free solder joint looks duller and grainier than Sn/Pb solder joints. This is mainly due to surface roughness of the high tin Pb-free solder alloy. Additionally, wetting spread is generally not as great as with Sn/Pb solder joints. Training must be provided to technicians/operators to distinguish Pb-free solder joints from Sn/Pb solder joints. More detailed information can be found in the latest IPC-A-610D Standard [Ref 1].

Hand Soldering

Two important factors in hand soldering are the quality of the soldering iron and the skill of the technician. Tight temperature and time control is especially critical for Pb-free applications due to the higher temperature. Excessive soldering iron tip temperature can result in dewetting and thermal damage to boards and components. When the tip temperature is not high enough, or when flux activation is insufficient, poor wetting can occur. Using the correct solder tip temperature with adequate heat transfer is essential for creating reliable solder joints [Ref 2]. Preheating is recommended to reduce the delta T and to avoid having to use higher operating tip temperature. The tip temperature and duration depends on the size of the joint. In general, the tip temperature is higher than Sn/Pb soldering and it is in the range of 350°C–375°C for duration of up to 5 seconds. It might be necessary in some cases to use different solder sized tips for best result. Larger tips are more suitable for larger joints.

There are new soldering systems available in the market today that allow for variable power, constant tip temperature regardless of the load. Constant tip temperature is important for

Pb-free soldering since it reduces operator intervention and eliminates the risk of causing thermal damage to delicate components.

Finally, it is critical to maintain a clean tip since Pb-free is more sensitive to dirty soldering iron tips.

Pb-Free Rework

The key to successful rework is to minimize the temperature difference between the solder joint and the component body. When setting up the profile, place thermocouples at the following locations: Top of the package, bottom center of the solder joint, and corner areas of the solder joint. To achieve good wetting, a peak temperature of 230° C–235° C minimum at the solder joint is necessary. Additionally, time above liquidus (217° C) should be in the 45–90 seconds range.

To minimize the temperature differential between the solder joint and the component body, adequate bottom side heating of the board is recommended. Before engaging the top nozzle, users should apply bottomside heat until the top of the board reaches 150° C. The top nozzle should be optimized so that heat goes mainly to the solder joint areas.

In addition, it is important to ensure that the component body temperature does not exceed its allowable limit (245°C–260°C, package size dependent, see Table 2). Allowable maximum component body temperature is dependent on package size and volume. This information can be found in the latest J-STD-020 standard.

More Information

Reliability information for Pb-free products is available in the Device Reliability Report which can be found on the Xilinx web site at www.xilinx.com/products/quality/reliability.htm.

For more information about Pb-free products from Xilinx, visit the Pb-free web site at www.xilinx.com/pbfree.

References

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Revision History

The following table shows the revision history for this document.

Date	Version	Revision
12/09/02	1.0	Initial Xilinx release.
09/16/04	2.0	General revision to conform to revised Pb-free document standards.
12/09/05	2.1	Ramp-up rate data in Table 1 and Figure 1 revised. Peak reflow temps revised, added packages, and changed flip chip lead free designations from FFR and BFR to FFG and BFG in Table 2.
01/30/06	2.2	Table 2 updated to include VOG8 MSL value.
11/17/08	2.3	Table 2 updated to include CSG484,FFG323, FFG324 and FFG1738 information, and removed +0/-5°C tolerance from peak temperatures. Added [Ref 1] and [Ref 2]. Added more information to Inspection, page 5 and Hand Soldering, page 5.
02/12/09	2.4	Table 2 updated to include FTG64, FFG665, FFG1136, FFG1153, and FFG1759. Revised Table 1, page 3 and Figure 1 to latest JEDEC standards.

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