

Lead Free Solder Reflow for Semiconductor Power Devices

The solders used in the Electronic Industry are rapidly converting from Tin/Lead (Sn/Pb) solders to Lead-Free (Pb-Free) solders to meet new environmental and Green requirements. Many of these requirements are controlled by laws and regulations, which vary by country and application. There has been a parallel shift for years from through-hole to surface mount assembly, which can often compound the Pb Free soldering issues. This paper will address the optimization of Pb Free soldering conditions, with a focus on differences between Sn/Pb and Pb Free soldering. This allows assemblers to build on their extensive experience with Sn/Pb solders.

I. Melting Point of Pb-Free Solders

Pb Free solders are usually Tin/Silver (Sn/Ag) solder, or variations on Sn/Ag solders. The primary difference affecting the soldering process is that the Sn/Ag solder has a higher melting point than the Sn/Pb solder. The melting point of the Sn/Ag eutectic (96.5Sn/3.5Ag) is 37°C higher than the Sn/Pb eutectic (63Sn/37Pb). The nominal eutectic melting points are 220°C for Sn/Ag solder and 183°C for Sn/Pb solder.

The off eutectic Pb-Free solders have even higher melting points. The 95Sn/5Ag solder melts at 240°C, and there are Sn/Ag/Cu and other alloys that span the melting point range from 220 to 240°C. Even when Sn/Ag eutectics solders are used, dissolved plating materials like Ag, Sn and Au can often increase the melting point to 240°C. Furthermore, the melted solder can exist in multiple phases, one of which does not melt until 240°C, which reduces the flow and wettability of the Sn/Ag solders below 240°C. As a result of these issues, it is generally wise to assume the worst case melting point of all the Sn/Ag Pb-Free solders as 240°C. This can make the effective melting point of the Pb-Free solders 47°C higher than the Sn/Pb solders.

II. Reflow Temperatures of Pb-Free Solders

The higher melting points of the typical Pb-Free (Sn/Ag) solders requires reflow to occur above 240°C. The recommended soldering or reflow profile must assure a minimum time above 240°C that takes into account equipment temperature tolerances, and with varying product and component size and mass. Power semiconductor components can include larger and more massive components as well as the standard smaller components. This makes it more difficult to optimize the reflow process for all components on the PCB.

The PCB industry has extensive experience reflowing components with Sn/Pb solders, which typically have peak reflow temperature of 215-245°C with 20-60 seconds above 183°C. If we were to add 47°C to these temperatures for ideal reflow and wetting, the temperatures would be so high that they could damage components, burn and harden fluxes, and oxidize some solderable surfaces. These maximum reflow temperature limits combined with the higher Pb-Free melting points define a narrower and more critical reflow temperature range for the Pb-Free solders. The typical reflow temperature range for Pb-Free (Sn/Ag) solder is 240-250°C with 40-80 seconds over 220°C.

It should be noted that the recommended Sn/Pb reflow temperature range is less critical, and that minor deviations in temperature of equipment and components generally do not create soldering problems. In contrast, the Pb-Free solder reflow temperatures can be more sensitive to low or high temperatures, and can result in serious problems as described above. Therefore, reflow temperature limits should be set and monitored more precisely for Pb-Free soldering. The actual temperature of small or large components should be checked during reflow profile setup. It is also important to check the components maximum temperature ratings when using Pb-Free soldering, and this is especially

important with surface mount components, where the entire component generally reaches the peak reflow temperature. Although most semiconductor components today are suitable for both surface mount and Pb-Free solders, there are exceptions and the maximum soldering temperatures or suitable assembly processes should be confirmed. The solder profile can also be influenced by high component density, heavy copper foil, and other unusual conditions.

On page 3, Figure 1 show a typical solder reflow profile for a Pb-Free (Sn/Ag) solder and Figure 2 shows a typical solder reflow profile for Sn/Pb eutectic solder.

III. Pre-Heat and Heating Rate for Pb-Free Solders

The preheat cycle and maximum heating rates for Sn/Pb and Pb-Free solders are not significantly different, and are generally not dependent on the type of solder alloy.

The preheat time and temperature are determined primarily by the flux system. The flux must clean and remove oxidation for the surfaces to be soldered, which includes PCB and component leads. Solder pastes often include both flux and volatile organic filler materials. The preheating removes excess volatile materials, while the fluxes are doing their work.

The typical preheat conditions are 80 to 120 seconds between 150°C and 200°C, but since the preheat cycle is dependent on the flux system, the preheat cycle recommended by the flux or solder paste manufacturer is best. In general, the same flux systems are used for Sn/Pb and Pb-Free solders.

The maximum heating rate is typically limited to 3.0C°/second, but most reflow systems heat considerably slower because of the mass and preheat requirements.

IV. Cooling Rate

The maximum cooling rate is typically 6.0C°/second, and is limited to prevent damage to solder joints or components cause by mechanical stresses

generated by CTE, (Coefficient of Thermal Expansion), mismatches between the components and the PCB.

In general, it is advantageous to cool near the maximum rate. The maximum cooling rate keeps the solder from devitrifying (crystallizing), which improves the mechanical properties of the solder. The solder finish should be shiny after cooling; a dull finish being evidence of devitrification.

Cooling rates can be more critical with Pb-Free solder reflow, because the temperature differential between solidification and room temperature is much greater than with Sn/Pb solders. The temperature differential for Pb-Free solders is 215°C (240-25) and for Sn/Ag solder is 158°C (183-25). A gradual cooling rate allows these soft solders to “creep”, and release the mechanical stresses, (which are proportional to the product of the CTE, temperature differential and total component length). Therefore, larger components, and components with CTEs significantly different than the PCB CTE are more susceptible to CTE mismatch cooling damage.

V. Summary

The soldering of semiconductor devices to PCB has historically used Sn/Pb solders, but Pb-Free solders are increasingly being used to eliminate Pb as required by environmental regulations. Most Pb Free solders suitable for these applications are Sn/Ag alloys with higher melting points, with correspondingly higher solder reflow temperatures.

The higher reflow temperatures are limited by the maximum allowable temperatures of components and fluxes. This creates a narrow reflow temperature window for Pb-Free solder reflow. The optimization of the Pb-Free solder reflow profiles is therefore more critical than Sn/Pb solder reflow profiles. Pb Free soldering can also be more critical for power components and other larger mass components, which take longer to heat.

Most Pb-Free solders use the same flux systems as Sn/Pb solders, and therefore use similar preheat and heating rate cycles.

Pb-Free solder maximum cooling rates are ideally the same as Sn/Pb solders, but sometimes can be problematic because they cool from a higher temperature. Large components and components with extreme CTE are the most susceptible.

Pb-Free solders are more environmentally friendly, and are suitable for soldering most semiconductor components with appropriate reflow profile changes and control.

