Lead-Free Solder Wafer Bumping

By Fred Dimock and Kristen Mattson
BTU International

Over the past 30 years we have learned that lead has negative affects on the health of humans and seen strong legislation remove it from gasoline and paints. More recently, governments in Europe and Asia have set deadlines to remove lead from consumer electronic devices that use printed circuit boards. Currently, the ban is not being applied to high reliability applications such as military or medical devices, but we all know that will come someday soon. Likewise many believe that lead free solder is coming to wafer bump reflow and are beginning to make the transition.

The transition to lead free solder will affect the entire wafer bumping process from beginning to end. Changing the bump material affects the reflow temperature, under bump interface chemistry (unstable intermetallic compounds), process atmosphere, plating procedures, cleaning methods, fluxes, etc. Add to this the requirement to shrink geometries as components get smaller and closer together, one realizes that the move is not trivial.

The transition to lead-free is much further along for the board assembly process. At first, the thought of lead-free processing caused apprehension among many surface mount engineers because they were forced to move into unknown territory. But, groups such as NEMI and the Massachusetts Lead-Free Solder Consortium have brought together resources from different parts of the industry to identify the best materials and methods for implementing these new materials. Much of the lead free focus for surface mount has been on the Tin-Silver-Copper system, aka, SAC, an abbreviation of Sn-Ag-Cu. Both NEMI and IPC officially named slightly different variations of SAC as the new standard for lead-free solder with about 4.0 % silver and 0.5% copper. The new materials require a peak temperature of 240 - 250°C for reflow instead of the current 210 - 215 °C for eutectic tin lead solder.

Early adaptors have demonstrated that these SAC compositions are viable for surface mount applications by showing they can economically and reliably produce good product. There have been challenges of new fluxes and understanding the affect of nitrogen on cosmetics, but there is no reason to believe that the lead free solder compositions will be different for wafer bump reflow. Therefore we have the luxury of tapping into the knowledge base that has been developed for surface mount and eliminate some of our apprehension.

REFLOW PROCESS CAPABILITY REQUIREMENTS

Oven control and the consistency of the solder material becomes more critical with lead free solder. Rea and Handwerker have described the alloy melting and solidification criteria used by NEMI. In their report they discuss the affects of compositional changes on the melting range (solidus vs. liquidus) of SAC and show that slight shifts in composition can affect the liquidus of the solder by up to 13°C. This large difference highlights the need for solder manufacturers to ensure that the compositions remain consistent from lot to lot and places more emphasis on oven repeatability and stability.

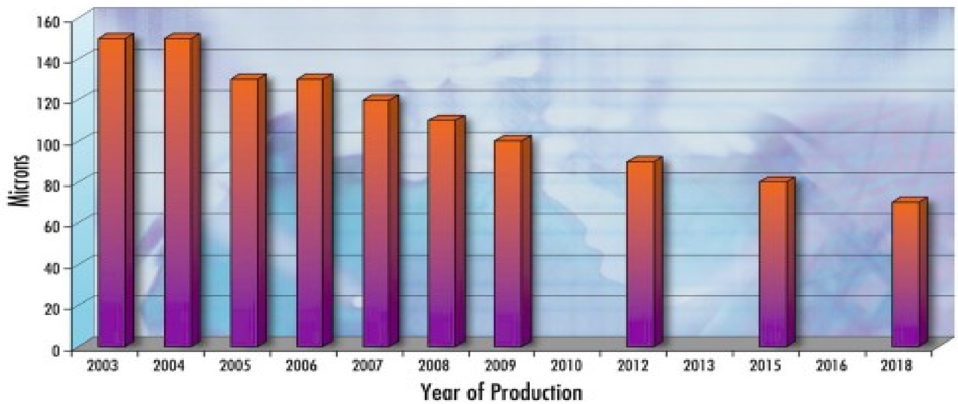

Table 1. Decreasing micron size forecast from 2003 to 2018

Tightening your process control on the reflow process can compensate for these expected slight variations in solder material composition. This can be achieved through a perfectly centered peak temperature with minimum variation run to run. If your process window is +/- 10°C around your peak temperature, and you expect a 13°C variation in liquidus temperature, your effective process window becomes only 7°C. Total thermal variation of 3°C or less across a 12" wafer at peak temperature will be required for a lead-free process.

LEAD-FREE OVEN ATTRIBUTES

This oven stability and repeatability requirement necessitates control systems that can maintain consistent temperatures and react to changes in load without the dreaded overshoots and temperature oscillations. This is where sophisticated PID algorisms are needed. Most modern ovens have these in place but some may need adjustments or upgrades.

Another temperature control factor is convection rate. Higher plenum pressure (convection rate) produce increased and more uniform process temperatures. Although, higher convection rates by themselves help uniformity and peak temperature, convection, without control, can make for an unstable process. The best way to establish complete control is to regulate the static pressure of the gas through closed loop convection feedback.

Closed loop convection provides the ultimate temperature control. It ensures that constant heating and cooling transfer rates are maintained and are repeatable. Closed loop convection, in brief, is a forced convection process that employs static pressure to maximize thermal uniformity and repeatability. No matter what pressure you use, controlling the convection rate guarantees better temperature repeatability, stability and uniformity.

Table 2. Conversion Rate

Convection Rate IWC	PEAK ˚C	DELTA ˚C
0.3	212.1	7.1
0.5	216.9	5.8
1.0	222.3	4.5
1.4	224.9	3.9

Questions about atmosphere requirements were not easy to answer for surface mount processing because it depends upon the needs in the specific market being sold to. Over the years many reflow houses had learned to process tin lead eutectic solder without nitrogen, and are highly unlikely to return because of the added cost. Much of the recent consortium work has shown that SAC solders need a low oxygen nitrogen atmosphere for cosmetic reasons, not performance. Air results in a discolored surface with wrinkles. Wafer bumping requires a smooth surface thus a stable nitrogen atmosphere with low oxygen content is important. Many ovens can provide a stable nitrogen atmosphere but to obtain this atmosphere at a reasonable cost one needs a sophisticated gas management system with gas recirculation and precision control.

Flux is an important lead-free solder issue. The higher reflow temperatures mean that fluxes need to be less susceptible to burning and must stay on the parts longer. Many of the solder suppliers have developed no-clean fluxes that work well at the higher lead free processing temperatures. From an oven perspective, the flux management system needs to be able to handle the increased temperatures and larger quantities of flux. Older or low-end ovens may have inadequate flux collection systems that can become quickly plugged and even drip flux onto expensive wafers. However, flux management technology has improved significantly in recent years.

The challenges organizations will face depend upon which side of the wafer bump reflow equation they are coming from. If they are currently using tin-lead eutectic solder with a nitrogen reflow process they understand most of the flux issues but will have to deal with equipment capability concerns. If they are currently processing high lead in hydrogen the move will require extensive learning because they will need to deal with flux and nitrogen reflow in addition to equipment issues.

EUTECTIC LEAD TO LEAD FREE

The major difference between eutectic tin-lead solder and SAC lead free solder is the reflow temperature. On the surface the difference between 210/215 and 240/250°C is small but the 30°C increase in temperature can affect many aspects of the process and equipment.

Higher process temperatures mean there is a need for higher furnace set points and/or higher convection rates. If they have a top of the line oven with an excess of power, good temperature control and the ability to work at higher temperatures, the current ovens will work. Low-end ovens that are already working at their limits will need to be replaced, while in between ovens may be able to be upgraded with simple retrofit kits (consult with the manufacturer).

Higher process temperatures also means there is a need for slower belt speeds to maintain the same ramp rates. At ramp rates of 3°C per second it takes an additional 10 seconds to heat the extra 30°C and another 10 seconds of added cooling time. Maybe 20 seconds doesn't sound like a lot of time, but with a five-minute cycle it translates to a 7% decrease in throughput. Go ahead – tell your boss that you want to slow down the line speed by 7% and see what happens!

Additionally higher process temperatures could affect other components and materials on the wafer. If the UBM is temperature sensitive or alloys with the lead free solder it may have to be changed.

HIGH LEAD TO LEAD FREE

Much of the world's supply of bumped wafers is currently produced using a dedicated high lead wafer bump reflow process in Hydrogen atmosphere. For these companies the change to lead-free will be the very dramatic. Along with changes in materials and the issues seen by the eutectic solder people, the biggest challenge will be learning to deal with flux.

In the past manufacturers of large-expensive wafers moved to high lead solder with the hydrogen-based process because there was little to no residue from the reflow operation. This clean process had distinct advantages, especially when the pitch between balls was small. They went in this direction because flux management at that time was poor and a clean environment was needed to maximize yields.

Much of the dedicated high lead wafer bump reflow is done by large OEM's with large-scale manufacturing. A front-end type batch reflow furnace is employed by a number of these manufacturers. This type of tool will not be able to make the transition to lead-free processing. The system was originally designed to control at 360°C and does not control well at the lower temperatures required for lead-free reflow (approximately 120°C less). In addition, a major problem is the use of flux fort the lead-free process. These batch systems were designed for a clean environment and cannot with stand the addition of flux residue. They are not well suited for cleaning or managing the flux contamination.

Figure 1 . High-performance wafer bump reflow line.

CONCLUSIONS

Soon, the lead free mandate will apply many of our to processes and materials. With lead-free on the near horizon for wafer bumping, we have a lot of work to do.

A process with precision temperature control is needed. When it comes to precision temperature control for lead-free processing, it is important to control all the factors that affect the transfer of thermal energy. With more items being controlled, repeatability and reliability are increased. One such item is closed loop convection. Process engineers looking to achieve the most effective and reproducible thermal transfer process, especially for high temperature lead-free processing, should be taking a serious look at this.

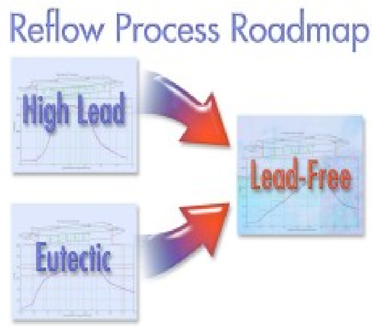

Figure 2. Reflow process roadmap

We in the wafer bump reflow environment can use this knowledge base developed to speed up our implementation but we will have our own set of unique issues.