本文考察无铅合金对焊接设备、程序和有关经营成本特别是对手焊工具的要求，并提供实施无铅工艺的建议。本文表明，现有焊接设备应升级或更换，以满足有关百万件产品的缺陷率标准。无铅合金更难控制，对设备的侵蚀更大，而且设备运行成本更高。预期合金成本更高、过程温度更高、过程窗口更小、助焊剂侵蚀更大、残留形成增加、焊锡锅和焊头的劣化加快、焊槽的铜污染增加，以及氮气使用量增加。

Considerations for Implementing Lead-Free Soldering

Mark Cannon

Smaller process windows equal greater stress. How to manage the changeover.

The smaller process windows of lead-free alloys increase demands on soldering equipment, procedures and associated operational costs. Indications suggest that existing soldering equipment is being either upgraded or replaced to meet standards for defects-per-million levels.

What specific problems areas are associated with LF implementation? LF will be more difficult to control, more aggressive on equipment and more expensive to run. Expect higher alloy costs, higher process temperatures, smaller process windows, more aggressive fluxes, rising dross formation, faster deterioration of solder pots and tips, increased copper contamination of the solder bath and increased use of nitrogen.

In a reflow oven, smaller components get hotter than larger components. Each joint must get hot enough to form an intermetallic compound. Under LF conditions, the PCB stays the same. However, if the oven stays the same then the smaller process windows can cause problems typical of a large ΔT; some parts are too hot, some are not hot enough.

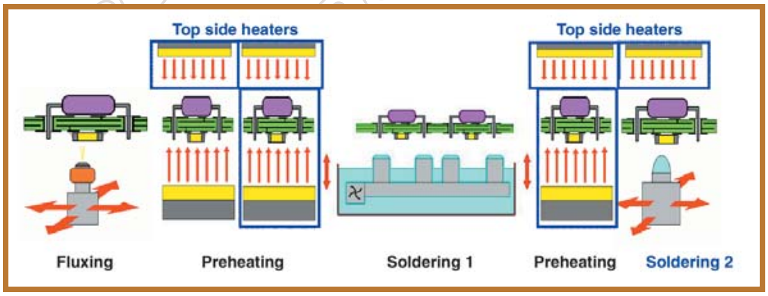

FIGURE 1: New soldering ovens combine simultaneous and sequential solder modules for throughput and flexibility.

Reflow concerns for LF include:

- Maximum allowable component temperatures and heating gradients: 1 to 4°C/sec.; cooling gradient: 3 to 5°C+/sec.
- Flux specifications; soak conditions; wetting behaviour of component and pad.
- Laminate temperatures (T_g).

Ideally, LF reflow will occur at the lowest process temperatures and with the smallest ΔT. The best-in-class ovens will have multistage flux management, flexible profiling, active cooling, and low energy and nitrogen consumption.

LF implementation will mean a reexamination of quality assurance procedures. Getting processes under control in initial stages is more difficult. And the higher process temperatures and smaller process windows will require more thorough first-article inspection. Manual optical inspection systems will require higher magnification and a flexible viewing angle from 0 to 90°.

The reflow process concerns also apply to rework: better temperature control and a smaller ΔT. Controlling the ΔT in a hot-air nozzle that requires a keep-out area of 3 mm is a challenge, especially on a densely packed board.

Serious consideration should be given to examining alternative selective reflow technologies capable of uniform heat distribution, such as medium wavelength IR. Such systems can conduct low temperature LF rework at ideal gradients, and without the use of nozzles or nitrogen.

The production soldering area requiring the closest examination is wave soldering. The higher process temperatures – and higher costs – associated with LF alloys are expected to greatly affect the cost of wave soldering.

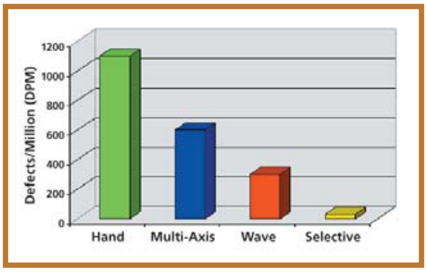

FIGURE 2: Selective soldering ovens can reduce DPM …

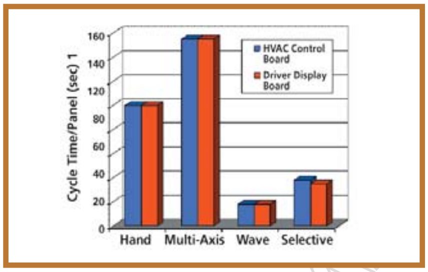

FIGURE 3: … improve cycle times …

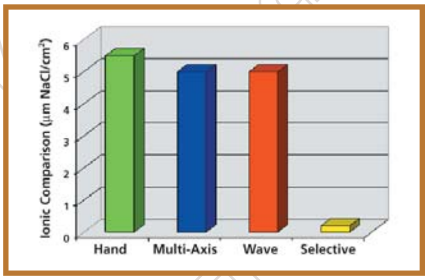

FIGURE 4: … and cut ionic contamination.

To meet the LF process demands, wave-soldering equipment should incorporate:

- A spray fluxer system designed for VOC-free fluxes and materials suitable for a low pH value.
- An improved preheat section using both short and medium IR and convection, and providing for sufficient length and flexible configuration.
- A nozzle design that permits sufficient backflow of LF solders, while maintaining dross avoidance.
- A solder pot that does not corrode rapidly when exposed to high-tin-content alloys.
- A nitrogen blanket and/or tunnel option.

Using nitrogen in a wave process can essentially reduce the dross formation by 90%. Five to 10 kg of dross formation per wave machine, per day and per shift translates into a significant solder consumption cost. If a tin-lead bar alloy costs approximately $4.25/kg, the cost of a LF tin-silver-copper bar alloy is much higher, perhaps more than $15/kg. A cost analysis of nitrogen vs. solder must be made for a LF wave process.

LF mass-production wave soldering will become more expensive. The tremendous operational costs associated with increased maintenance and bath analysis, higher dross formation, triple the cost to fill the pot, shorter bath life due to copper accumulation, enormous nitrogen costs, and higher DPM and scrap rates might cause production manufacturers to examine the possibility of switching to a selective soldering process.

In-Line Selective Soldering

How does one solder PTH components on the board? The choices are: hand soldering, wave soldering with soldermask carriers, or selective soldering. Selective soldering is post-reflow soldering on double-sided surface-mount boards of PTH components (such as connectors, power components or RF shieldings).

In-line selective soldering systems keep the PCB on a horizontal transport through the soldering process. An x-y-z servo driven, multi-directional, wettable nozzle solder pot design makes this type of machine a viable alternative to mass wave soldering. Dual pot sequential, multiwave simultaneous or combined high-speed machines can handle up to six PCBs, offering flexibility and maximum throughput (**Figure 1**).

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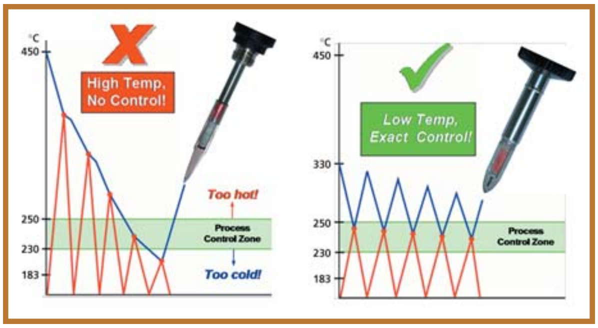

FIGURE 5: Rapid recovery and repeatable LF joint quality requires a properly designed iron.

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Better thermal performance will be required for lead-free, heavy mass and multilayer applications. One solution is a selective soldering system that uses top side, multi-jet convection preheating modules running parallel to the bottom-side selective solder pots. Such systems maintain constant PCB and solder joint temperatures throughout the process.

Selective soldering advantages include:

- Consistent LF solder joint quality and significant reduction of DPM (**Figure 2**).
- No re-melting of topside SMD components (as with wave soldering).
- PCB does not move during soldering.
- Faster cycle times compared to hand and multi-axis soldering (**Figure 3**).
- Reduced ionic contamination and flux consumption (**Figure 4**).
- Heavy mass multilayer soldering without excessive thermal stress.
- Less risk and cost than operator-dependent hand soldering.
- Significant reduction of materials and consumables costs.

Where LF quality and operational costs are the key factors, the industry should re-examine its mass production processes. The LF process demands a reliable process under more difficult conditions. An ROI analysis reveals that the cost savings associated with a selective process vs. conventional wave could occur in as few as four months.

Finally, the toughest area to control LF quality will be in hand soldering and touch-up. Although the trend is to move away from hand soldering, quality hand soldering or touch-up, when required, must be achievable.

Lead-free's demands on soldering stations are significant. Soldering irons are already running at set temperatures up to 380°C. With the 40°C increase in the LF process temperature, typical soldering stations will be working at their limit.

The problem lies in the design of the iron with respect to true temperature control of the soldering tip. Most temperature-controlled irons control the temperature of the heating element and not that of the tip, which is losing heat during hand soldering. During point-to-point soldering, the lack of heat recovery at the tip results in each solder joint being cooler than the one before (**Figure 5**). Also, high-temperature heating cartridge soldering tips are very expensive and have a short life.

Specially engineered 130 to 290W soldering irons, with internally heated tips that use a K-type thermal couple to actually measure heat loss at the front portion of the LF tip, can deliver the heat recovery required for LF hand soldering at working temperatures typically between 320°C and 360°C. ■

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