考虑无铅焊料时，由于同封装组件本身的峰值温度限制相比，其熔化温度较高，可以推测，适用于手机或“PDA”的返再加工技术可能不足以处理大型服务器母板或网络背底板。为了满足不同主板的特定返再加工需要，要求不再依赖一种型号适合所有产品的设备。实验表明，在再加工大型“BGA”板返工时，全底面板、低容量红外线加热、固定式主板夹具固定和吊车型门式回流装置的结合可消除所面临的很多翘曲问题。

Large Format Rework for Eutectic and Lead-Free Applications

Stan Kench

How the combination of low-mass IR, stationary board fixturing and gantry reflow can eliminate warping.

Boards range from less than 1 in^2 to over 2 ft^2 in size and come populated with sensitive area-array packages and devices that also span a wide size range. When comparing lead-free solders and their relatively high melting temperatures to the peak temperature limitations of the packages themselves, it can be surmised that a rework technology that works for a cellphone or PDA board may not be sufficient for a massive server motherboard or networking backplane. Meeting specific rework needs of disparate boards requires a move away from one-size-fits-all equipment.

The heating and process control technology of most rework equipment is inadequate for efficient, repeatable rework of thermally demanding, large-format boards, particularly when lead-free solder is used. Existing technology can be used or modified to suit large BGA assemblies but is usually inefficient, slow and could cause damage to the assembly.

All rework technology follows a basic formula: preheat, device reflow, device removal, cleaning of the removal site and reattachment of a new device. Each package adds to the rework challenge by possessing a specific range of heat sensitivity and soldering process characteristics.

Area-array components do not have exposed leads that can be visually aligned to pads and soldered by hand. Rework equipment must provide the necessary optical alignment system and heating capability to reflow all leads at once. The ideal rework process attempts to closely simulate the reflow oven, yet is localized to the reworked component. Since the machine cannot enclose the board in the uniformly heated tunnel of a reflow oven, the rework station's bottom heating and control software must collaborate to supply the energy required to heat the board enough so that it will not warp or be damaged when the target component is heated to peak reflow temperature.

Even more than the component, the board itself is the dominant variable that determines rework difficulty. The highly localized heat required to reflow a single BGA can cause any board to warp, although most return to a normal planar state after cooling.

Warping is caused by the PCB material around the target component trying to expand as it is heated while being constrained by the cooler, surrounding PCB material toward the board edges. In extreme cases, the area of the board under the component can even delaminate.

Effective bottom-side heating minimizes the thermal gradient from the reworked component to the board edges, resulting in less thermal stress and a board that stays flatter throughout the process (**Figure 1**). It also reduces residual stress in the solder joints when the board cools. These issues are not unique to large boards, yet every additional increment in board size exacerbates the issues proportionally.

With large BGA boards, a specific thermal profile must be developed for the entire board and each component to be reworked, top and bottom. Most rework tools that perform well on smaller boards lack the bottom-side preheating capability required for quality rework on boards and components that either have very large mass or size or are hard to heat, such as large heatsinks or multiple ground planes. Trying to overcome the lack of suf-

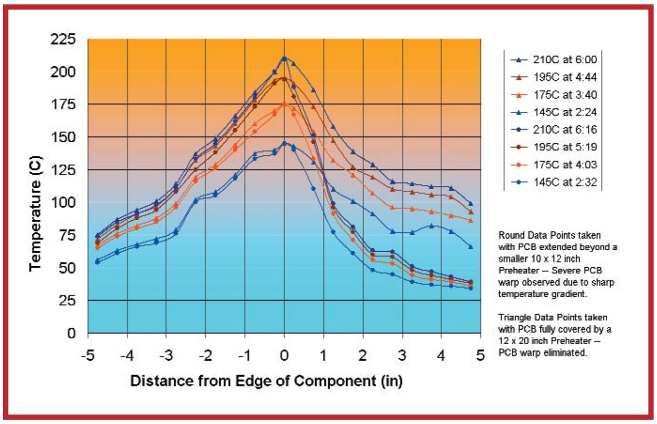

FIGURE 1: Warp-inducing thermal gradients with and without full board preheating.

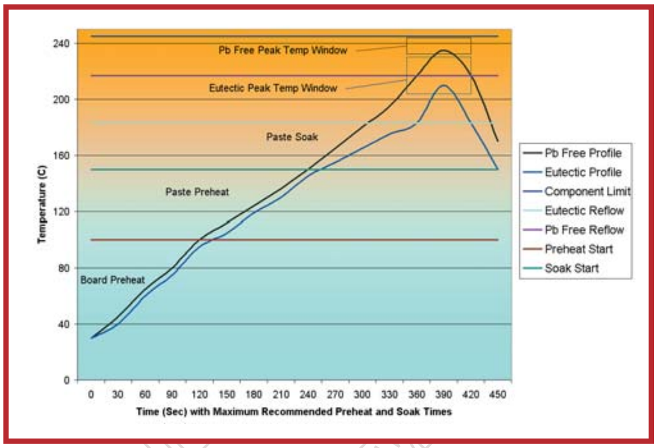

FIGURE 2: Rework profile comparison for eutectic and lead-free paste.

ficient bottom-side heating by extreme top-side heating of the target component results in solder joints that have high residual stresses. When the component is heated much more than the board (to drive energy to solder joints and melt solder), the component may expand more than the board. This causes residual stress as the component and board contract different amounts during cooling. Faster cooling, as occurs when a cold board sucks heat away from the solder joints quickly, may increase residual stress.

Effective bottom-side preheating minimizes the thermal gradient from the component being reworked all the way to the edges of the board. The results are less or no warping, less residual stress and lower component temperatures required to melt the solder.

Limiting component temperatures is critical to lead-free rework because the peak reflow temperature may reach 230° to 235°C for a component that is designed to withstand 245°C maximum. This shrinks the process window considerably from the eutectic process, in which peak soldering temperatures are 205° to 215°C for a component with the same maximum temperature rating. To exceed 217° to 220°C for 30 sec. during the lead-free soldering process without exceeding 245°C anywhere in the component (compare this to exceeding 183°C for 30 sec. in the eutectic process) requires acute process control from the rework system combined with the ability to deliver much of the total energy required via efficient bottom-side heating (**Figure 2**).

Most rework technology uses either convection or high-mass IR for under-board heating, but the heat is centralized to the area of rework and not spread evenly across the board. Common rework equipment is configured with stationary, parallel, top- and bottom-heating devices as well as a moveable table fixture for the board.

Small boards adjusted for rework are usually well heated both top- and bottom-side. However, when a large board is moved, for example, to rework a BGA on the right quadrant, the full left quadrant is projected away from the rework table, and thus away from the under-board heating mechanism. When reworking a component on the backside of the board, the front side is away from the preheater. This colder area of the board then acts like a giant heat sink and draws heat away from the rework area. If reworking several areas, moving a large board around causes nonuniform heating and cooling and can create undue stress.

When reworking large boards, the preheat temperature must be gradually tapered from the component being reworked to the extreme edges of the board. If the thermal gradient is too sharp, the board will warp. This is apparent when reworking boards with ceramic column grid arrays or components where high temperature, non-melting solder balls or columns are used. The board has to remain flat during rework since solder joints are unforgiving. In BGAs that use eutectic solder balls, the balls will take up a bit of unevenness in the board when they melt due to some stretching and contracting of the solder joint.

In response, several issues have been investigated: under-board heating methods and configurations, rethinking board fixturing, and the potential to teach rework machines simultaneous solder-joint and board preheat thermal profiling for large-mass rework.

Low-Mass IR

Experiments[1] have shown low-mass IR to be more efficient than forced convection for large-area heating because the heat transfer is surface-to-surface. With the help of new control technology, quartz IR lamps heat more quickly and are more controllable than older ceramic or high-mass radiant IR heaters that cannot change emitter temperatures quickly.

Low-mass IR panels can be designed to cover the entire under-board area. On a mid-range machine, this can be 20 x 24", providing 3000W of low-mass IR heating on the bottom-side of the rework area. This will evenly preheat an average motherboard or small server-type board up to ±100°C in a matter of 150 to 180 sec. The same job with forced air convection would require a heater with the power and airflow of a reflow oven heating zone. A machine, pumping out several CFM of 300°C air for 15 min. a cycle, would build up residual heat over time and consume much more energy than would low-mass IR lamps – and would create an uncomfortable environment for the operator. IR panels heat a maximum size board evenly, quickly and repeatedly without residual heat buildup over time. A surface an inch from the lamps is very hot, but a surface 5" from the lamps experiences almost no heat at all. Excess heat diffuses into the atmosphere. IR heat is consistent and more tolerant of ambient temperature and air current variations in the surrounding work area.

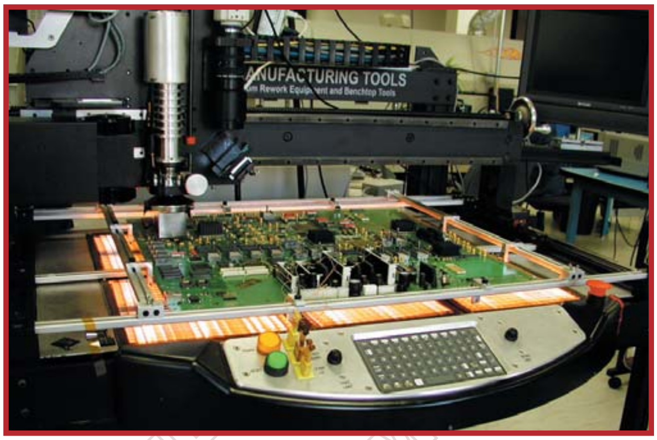

FIGURE 3: A 22 x 24" chipset test vehicle loaded into a rework system configured with a gantry-type top-heating device. The bottom-side infrared heater can be seen covering the under-board area.

An overhead gantry design moves the reflow mechanism to the component. The board itself remains stationary and heated by modular IR panels (**Figure 3**). The under-board IR heater may use multiple zones so that when boards smaller than the maximum size are reworked, uncovered zones may be switched off. The total board heater coverage provided with the gantry design minimizes thermal gradients across the board that cause the most severe warping in large boards.

For efficient thermal profiling of both solder joints and the board preheat control point, software must learn and repeat simultaneous independent heating profiles for the top and bottom heaters. Using separate component and board teaching thermocouples permits optimized profiles to be established, tested, saved and repeated for the component reflow/top heater and the board preheat/bottom heating panel simultaneously.

Thermocouples working in a closed-loop teach mode instruct the rework machine how to control power to the bottom heater and, at the same time, tell the top heater how it should activate to create the optimal solder profile for any given device or solder formula (**Figure 4**). Closed-loop thermocouples permit any variability up to 100% power to be applied to the bottom heaters.

Two main thermocouples (solder joint and board) are used to set up every recipe. Up to six additional thermocouple ports can be used as limit thermocouples for critical applications. Example: a plastic connector is near a BGA to be reworked and cannot exceed 180°C. A limit thermocouple sends teach information to the machine that overrides the application of heat to the top heater. It might slow the heating process, but will keep the plastic connector from melting. This thermally protects sur-

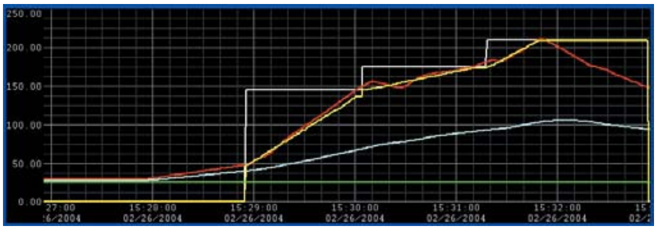

FIGURE 4: Actual auto-profiling rework recipe shows the target profile (yellow), the actual solder joint "teach" thermocouple reading (red) and board "teach" thermocouple reading 4" from the component being reworked (light blue).

rounding components, and keeps a bottom-side component opposite the top-side component being removed from reflowing. Boards often have two BGAs back-to-back, but only one needs to be removed. Limit thermocouples can be set to stop the bottom-side component from exceeding a given temperature. Again, this may slow the top heating, but it will save the other component.

Such temperature monitoring is valuable when working with lead-free solder formulas. The higher temperatures required to reflow lead-free solders reduce the process window and increase the potential for thermal damage to the board and nearby parts. An additional thermocouple can be added to limit the maximum temperature of the component package while soldering.

Experiments have proven that the combination of full bottom-panel, low-mass IR heating, stationary board fixturing and a gantry-type reflow device eliminates many warping problems when reworking large BGA boards.^{2}

Adding the capability of top- and bottom-side specific and simultaneous thermal profiling in a closed-loop teach mode proves to be a big time saver and adds an extended level of repeatability to the rework process. Repeatability requires process control, and taking it to the level of stored programmability provides quick top- and bottom-side thermal profile duplication that enhances the entire rework process. ■

References

1. Experiments conducted at PMT between May and August 2001 to measure PCB heating response to low-mass IR and hot air convection preheater panels of similar wattage both placed 1.25" from the PCB. The 14.5 x 12.5 x 0.09" populated test board reached 100°C in 3.5 min. with low-mass IR heating and in 6.5 min. with hot-air convection heating.
2. Experiments conducted at PMT between May and June 2004 to measure effects of partial board preheating. Some data and results from these experiments are described in Figure 1.

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