Assembly Technology for High-Performance PCBAs

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Servers and other network equipment contain high-performance printed circuit board assemblies (PCBAs). Some PCBAs, for example, PCBAs that mount CPUs, are very large and densely populated with leading-edge electronic packages and components. These PCBAs therefore require a more efficient and precise assembly technology to manufacture than ordinary PCBAs. The behavior of these packages and components during assembly must be thoroughly understood in advance so suitable measures can be taken to protect them from damage. This paper describes an assembly technology for this type of large-scale PCBAs that are processed by reflow soldering. It also describes a technology for attaching thermal interface materials that thermally couple devices to their heatsinks.

1. Introduction

To ensure stable high-performance operation in servers and other network equipment, the large-scale printed circuit boards (PCBs) of their PCB assemblies (PCBAs) must use leading-edge, high-performance components[1] and be assembled using the latest methods.

Fujitsu manufactures high-performance, high-reliability PCBAs by combining new assembly technologies with the latest components and improved techniques for evaluation and guaranteeing reliability.

This paper outlines Fujitsu's development of new assembly technologies for mounting components onto PCBs and for attaching thermal interface materials (TIMs) that thermally couple devices to their heatsinks.

2. PCB assembly technology

This section outlines a methodology for producing large-scale PCBAs using leading-edge components and methods for guaranteeing their reliability.

2.1 Technical trends

The PCBAs of servers and other network equipment contain high-performance components and modules.[2] For example, the system board (SB) of the PRIMEPOWER HPC2500 UNIX server, which is the central PCBA of the unit, can mount up to eight of the latest CPUs and related chipsets, a large memory, power units, and several other large components (**Figure 1**). To achieve this, the board has been enlarged to the maximum allowed size for PCBAs. Also, it has sufficient layers to construct a wide data bus for high-speed data transfer.[3]

2.2 Technical problems with PCB assembly

The following describes the processes and problems associated with mounting components onto a large-scale PCB using reflow soldering, the technology needed for ball grid array (BGA) packaging, and the installation of a large memory.

1) Reflow soldering

The components of PCBs are typically mount-

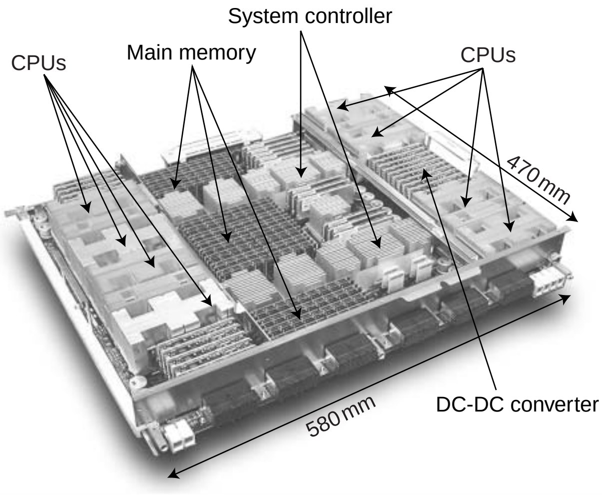


Figure 1
System board of UNIX server PRIMEPOWER HPC2500.

ed using reflow soldering. This process prints a paste-based solder onto PCB pads. Once the components have been placed on the board, the board is placed in a reflow furnace. When the solder melts, the parts become soldered to the PCB. Because the entire PCB is heated, all of the parts are soldered at the same time. However, this also means that the furnace must be controlled so the temperature limit of the components is not exceeded

During reflow soldering of a large, multi-layered PCB, the biggest problem is how to heat the PCB to a temperature that will melt the solder but not damage its heat-sensitive components. Another problem is that the PCB's large surface area and the presence of large components make it difficult to evenly heat the entire assembly. Therefore, the furnace temperature must be carefully determined and accurately controlled and steps must be taken to heat the board as evenly as possible. This is especially important regarding the ever-growing use of lead-free tin-silver-copper (Sn-Ag-Cu) solders because their melting temperature is 35°C higher than that of conventional tin-lead (Sn-Pb) eutectic solder.[4)] This can become a major problem, making it necessary to use a highly accurate reflow control technology.

2) BGAs

The CPUs and chipsets used in these types of PCBs use BGA packaging to allow a high component density. Also, the large-scale semiconductor dies for achieving high-end functionality require BGA packages that measure more than 2200 mm^2 and have over 2000 solder balls. The ball pitch has decreased to less than 1 mm, making it necessary for the balls to be set within ±50 µm on the board. Also, a high yield is essential because BGA solder joints cannot be repaired or visually inspected. It is therefore essential to have an assembly technology that considers the variability of ball height and the behavior of BGAs when they are heated for soldering. Also, the lead-free solders that are increasingly being used in BGA packaging have a melting temperature closer to the temperature limit of BGA packages, making it difficult to apply these solders and repair joints made of them.

3) High-capacity memories

High-capacity memories are constructed using dual inline memory modules (DIMMs). Surface-mounted DIMM connectors can be mounted at a high-density spacing of 8 mm, enabling a large memory as well as high-density wiring on PCBAs. The terminals of these connectors are arranged in two rows of 124 mm with a 1 mm pitch.

Due to the typically high cost of printed wiring boards (PWBs) used for high-performance PCBs, it is often necessary to repair the faults that occur on them. This often requires the ability to replace large BGAs as well as repair and replace densely mounted DIMM connectors.

2.3 Fujitsu's work for ensuring reliable BGA mounting

As mentioned above, it is very important to ensure the mounting quality of BGAs on PCBs. Therefore, Fujitsu is working hard to guarantee the long-term reliability of its PCBAs and establish a high product quality.

1) Work towards high product quality

Because BGA solder joints cannot be visually inspected, the footprint size is optimized, and quality is ensured using boundary scanning from the design stage. Also, the process conditions such as the amount and type of solder used and the reflow temperature are closely controlled to ensure product quality. Furthermore, because BGA packages have a large number of very small balls across a large area, board warping can seriously degrade the quality of soldering. Increases in the size of BGA packages, the use of different materials, and different installation bases can increase warp in the BGA package, PCBA, and BGA soldering points during reflow heating. It is therefore important to assess, check, and refine the process ahead of time to prevent solder shorts and open circuits.

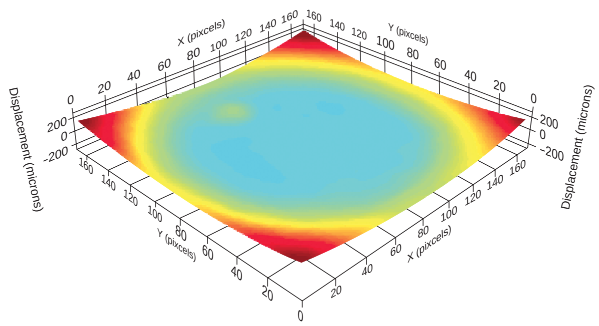
One possible method for evaluating warp during reflow heating is to perform fringe interference testing on an object with the same heat profile. The maximum allowable warp for the target probability of solder shorts and open circuits is calculated from the size of the soldered area, amount of solder (solder applied during reflow + solder balls), solder's surface tension, and total weight of components. Then, the accuracy of the calculation is evaluated by conducting tests. If the warping exceeds the allowed limit, steps are taken together with the BGA parts vendor to use alternative packaging materials that reduce the amount of package warping during reflow soldering. **Figure 2** shows the results of an example test. In this example, the BGA package warped 300 µm on the corners, which caused solder shorts. After the vendor refined the packaging materials, the warping was dramatically reduced to just 40 µm, resulting in zero errors of the BGA during manufacturing.

Recently, more component vendors have introduced the same procedures as Fujitsu for evaluating the warping of BGA packages during reflow. Fujitsu crosschecks data from parts vendors with its own data, making it important to standardize the evaluation methodology.

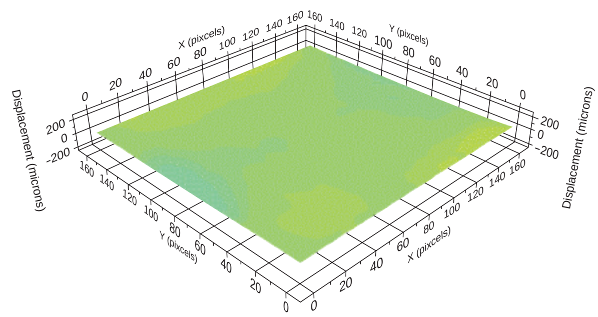
Also, Fujitsu is working closely with PCB makers to reexamine the design of PCB boards, their materials, number of layers, and balance in the density of conductor patterns.

2) Work toward guaranteeing long-term soldering reliability

As mentioned earlier, BGA footprints are designed to optimize the positions of the soldering area, in addition to having a well-placed parts layout. To guarantee high reliability during use, different reliability tests are performed in simulated operating environments, for example, thermal tests (e.g., temperature cycling and high-temperature creep tests) and mechanical tests (e.g., bending and shock tests). Also, because of the increasing integration scale of BGA packages, diversification of materials, and smaller ball pitches, reliability during manufacturing and operation has become even more important, and we are currently working on the introduction of statistical analysis procedures to increase the



(a) Before improvement: warp=300 µm (225 °C)



(b) After improvement: warp=40 µm (225 °C)

Figure 2
Warping of BGA package during reflow soldering.

reliability. In previous reliability tests, BGA packages were soldered using solder balls with a diameter of 0.5 to 0.7 mm, which can absorb a large amount of stress and provide the same long-term reliability as that of a quad flat package (QFP).[2] However, there is a problem regarding the shock resistance, which requires evaluations that include mechanical shocks caused by the manufacturing process, device transportation, earthquakes, and the operating environment. Manufacturers are moving away from the conventional Sn-Pb eutectic solder and toward lead-free solders such as Sn-Ag-Cu, which are physically harder. As a result, when products that use these lead-free solders are subjected to mechanical shocks, less of the energy is absorbed by the solder and more is transmitted to the joint interfaces. It will therefore be necessary to adapt our reliability evaluations to accommodate these new solders.

Also, to improve the behavior of large connectors for memory when they are heated, it is important to optimize their placement and footprint size and improve their quality guarantee together with parts vendors. As with the BGA packages, we verified the connection reliability of these connectors in various environmental tests, and as a result we were able to guarantee the long-term overall reliability of PCBAs.

3. Assembly technologies for thermal interface materials (TIMs)

This section describes the development of assembly technologies for attaching TIMs that thermally couple devices to their heatsinks.[5]

3.1 Technology trends

The chipsets and CPUs mounted on PCBAs become hot during use, making it important to use an effective cooling method. CPUs and various other devices use specially designed high-efficiency heatsinks that transfer their heat to cooling fins (**Figure 3**). Present day CPUs dissipate over 70 W of heat, and this figure is expected to increase as the speed and integration scale of CPUs increase.[6]

Therefore, it is important to increase the efficiency of heat transfer between packages and heatsinks and between heatsinks and the air. Due to the restrictions on where parts can be placed on a PCBA, heatsinks of various sizes, shapes, and complexities and associated assembly technologies are needed.

3.2 Development of cooling assembly technology at Fujitsu

The main problem in assembly using TIMs is achieving the optimum process conditions when attaching packages with TIMs to heatsinks. TIMs come in the form of pastes, sheets, and adhesives and are individually applied to the devices to be cooled. In general, removable heatsinks are attached with heatsink compound and thermal sheets, and glue is used when permanent attachment is required (**Figure 4**).

1) Thermal coupling using heatsink compound

Heatsink compound is a high thermal con-

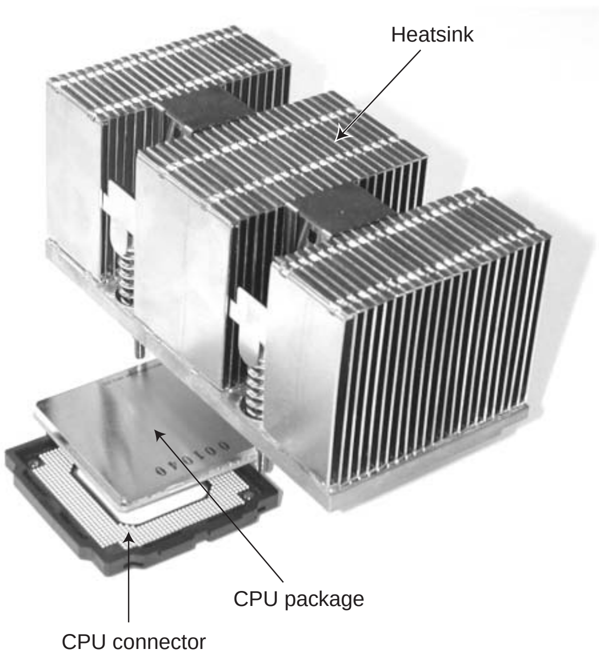


Figure 3
Heatsink and CPU package.

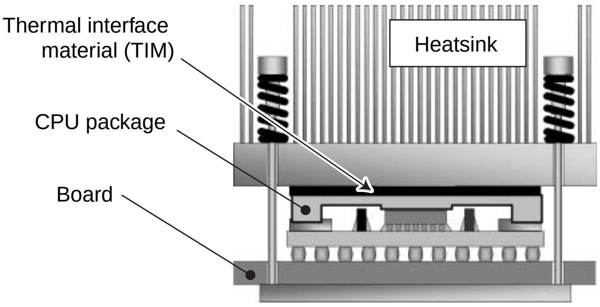


Figure 4
TIM thermally couples CPU package to heatsink.

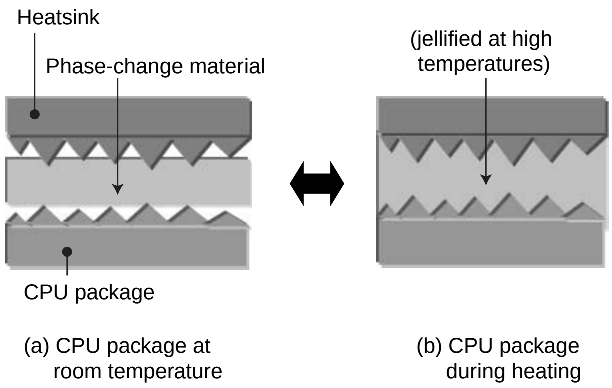


Figure 5
Thermal interface using phase-change material.

ductivity paste used to thermally couple a device to a heatsink; it must not be allowed to leak onto the PCBA. For packages that dissipate a large amount of heat, a high-quality compound [thermal conductivity: 4 W/(m·K)] that is solidified using pressure must be used. Because a paste can change its shape, its material properties during assembly must be considered to ensure reliable, long-term thermal coupling and high heat throughput for devices that dissipate a lot of heat. The optimal application amount and pressure can be determined by studying the adhesive, thermal conductive, ductile, and other basic properties of the compound. Then, the R&D and design departments can jointly determine the optimal way to assemble a product having the required structure and cooling performance. Finally, the method of applying the compound and the required quantity and pressure needed to achieve the required thermal conductivity can be determined.

2) Thermal coupling using thermal sheets

A thermal sheet is a thin sheet of TIM and is easier to handle than heatsink compound. Although thermal sheets tend to have a low thermal conductivity on their contact surface, new materials that overcome this problem are being developed for applications in high-temperature packages. The new sheets use a phase-change material that jellifies at high temperatures. This jellification increases the adhesion and thermal conductivity of the contact surface, allowing the sheets to be used with devices that dissipate a lot of heat (**Figure 5**). Also, the sheets solidify at room temperature, so they can be removed relatively easily after the device they are attached to has been powered down.

3) Thermal coupling with adhesives

The adhesives used for thermal coupling take several hours to harden, which slows down assembly. Therefore, after careful consideration, we developed an improved method in which high heat transfer tape is applied to part of the interface to keep the parts together while the adhesive hardens, after which the tape adds strength to the bond. By using this method, after heatsink attachment, the next process can be immediately performed, which improves productivity and also improves the reliability of the device/heatsink bond.

4. Conclusion

This paper described some of the problems encountered when mounting BGAs and other components onto a large-scale PCB. It also described a technology for attaching TIMs that thermally couple devices to their heatsinks.

The development of servers and network PCBAs that use the latest technology requires continuous improvements in the quality of the assembly process as well as the development of assembly technologies using new analytical methods. We will continue our efforts to provide high-quality, high-reliability servers and network equipment to our customers.

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