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Underfill Agent for BGA/CSP Mounting

Introduction

With the rapid evolution of such mobile information equipment as cellular telephones, PHSs, laptop PCs, and VTRs with built-in cameras, the market is demanding that electric and electronic equipment be made smaller, lighter, and faster, even as more features are in demand. As part of this trend, ICs (LSIs) need to be made smaller. At the same time, ball grid arrays (BGAs) and chip size/scale packages (CSPs) are becoming increasingly popular to make the packages smaller, to similar sizes of bare chips, and to improve their properties. This miniaturization is being achieved by protecting the bare chips, and by making use of package functions, such as stress relaxation, dimension matching, and standardization (generalization).

On a circuit board, a BGA or a CSP is connected to electrodes by means of solder balls. Stresses such as heat cycling, shock, or bending can cause the connection of the BGA or CSP to be broken. To prevent this, a sealant (an underfill agent) is applied to the clearance space between the BGA or CSP and the circuit board; this helps to relax the stress and to hold BGA or CSP in place.

This issue briefly discusses BGAs and CSPs and the need for the underfill agent. It also introduces underfill agents that Three Bond has developed for mounting BGAs and CSPs to meet a variety of customers' requirements.

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1. What is BGA/CSP? [1),2)]

With the rapid evolution of such mobile information equipment as cellular phones, PHSs, laptop PCs, and VTRs with built-in cameras, the market is demanding that electric and electronic equipment be made smaller, lighter, and faster, even as more features are in demand. As part of this trend, ICs (LSIs) need to be made smaller. To achieve this goal, we must downsize, integrate, and densely mount electronic components. In the field of IC (LSI) packaging, there is a limit on the maximum number of pins with the conventional QFP (Quad Flatpack Package), as it uses a linear pin array and the substrate area therefore becomes several to a few tens as large as the inner chip area. Thus, it becomes increasingly difficult for the QFP technology to meet the packaging requirements.

In turn, the BGA/CSP technology has attracted attention in the area of chip mounting (see Three Bond Technical News, No. 50 Flat Package Mounting Adhesives).

- What is BGA?

  BGA stands for "Ball Grid Array"; it is an IC package in which solder balls are arrayed on grids; it is smaller than the conventional QFP.

- What is CSP?

  CSP stands for "Chip Size (Scale) Package"; it is a narrow-pitch BGA, sometimes referred to as "FPBGA (Fine Pitch BGA)." CSP is the general name given to packages that are as large as or slightly larger than the chip itself.

In BGA/CSP packages, the area occupied by packaging becomes smaller than in the case of QFP, and solder balls are melted for connection. As a result, their height tolerance is large, and the problem of lead deformation often seen in QFP is not occurred. Furthermore, when the solder balls melt, a self-alignment effect due to surface tension occurs, and mismatch during mounting can be self-corrected by as much as up to 0.6 mm in the case of a 1.5-mm pitch (Fig. 1-3). On the other hand, in packages such as QFP that use to solder leads for interconnection, the area in which there is surface tension is small, and the self-alignment effect does not occur. Thus, if the chip has been moved from the predetermined position and left on the circuit board, it is soldered in the incorrect position, leading to lower mounting yields due to the formation of a solder bridge (Fig. 1-4).

Recently, a bonding method known as "flip-chip mounting (bare-chip mounting)," in which bare IC chips are mounted with no package (mold), has been developed, and it is expected to make packages even more compact in size. Despite that new technology, BGA/CSP have quickly become popular, as they are much easier to use for chip mounting under normal conditions (no need for a clean room).

As mentioned above, the application range of BGA/CSP is expected to expand drastically into the massive consumer market for cellular phones, PHSs, personal computers, and other digital devices, due to its advantages of having a small packaging area and high mounting yield.

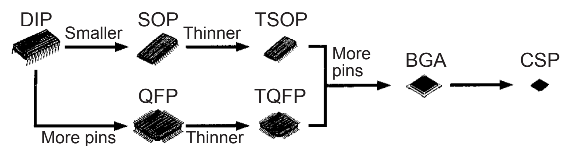


Figure 1-1. Packaging trends

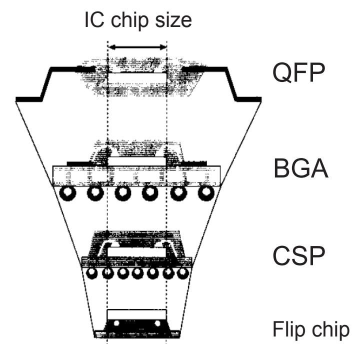


Figure 1-2. Comparison of IC packages

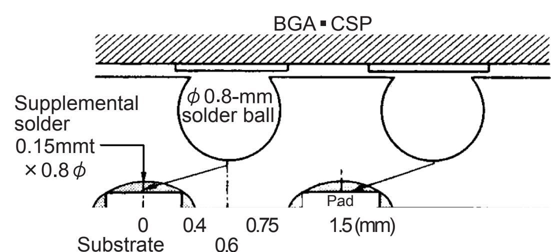


Figure 1-3. Self-alignment effect (1.5-mm pitch)

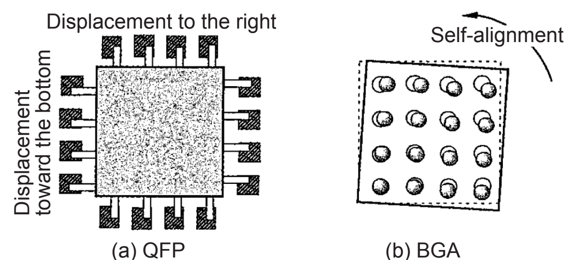


Figure 1-4. Self-alignment function

2. BGA/CSP post-mounting problems[3)]

As mentioned above, BGA/CSP greatly contribute to the downsizing and performance improvement of various electric/electronic devices. However, they involve problems with post-mounting connection reliability; the following two points are the keys to ensuring connection reliability.

1) Thermal expansion coefficient (linear expansion coefficient)

Packages must reduce stress, and this is closely related with the thermal expansion coefficient of each material. The structural question is how to handle the gap between the thermal expansion coefficient of the silicon chip (approx. 2.6 ppm/°C) and that of glass epoxy, which is used as the common circuit board (12-16 ppm/°C). Unless the stress due to this gap in the thermal expansion coefficient between the chip and circuit board is successfully released through a BGA/CSP structural contrivance, the connection reliability will be compromised.

For example, as shown in Fig. 2-1, in which an alumina package is bonded to a glass-epoxy circuit board, the bonding produces high stress due to the large difference in the thermal expansion coefficient, and the solder balls have cracks and may cause connection failure as a result. In pin-insertion-type packages, the pins work to reduce such stress, while in lead-type packages the leads reduce the stress. In surface-mount-type packages such as BGAs and CSPs, however, the bonding distance is so short that the bonding is more likely to break due to stress.

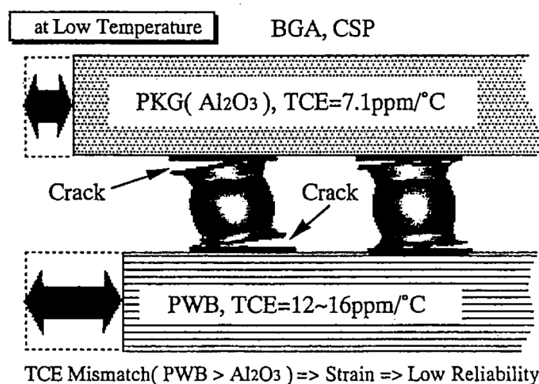


Figure 2-1. Schematic description of the package (PKG)-circuit board (PWB) bonding breakage due to a difference in the thermal expansion coefficient

2) Solder-ball bonding strength

BGA/CSP are mounted on a circuit board using solder balls. The solder bonding is so thin, at ϕ 0.2-0.5 mm, and so weak that BGA/CSP may fall off the board when external stress is applied due to shock and bending. In such a case, the cracks in the solder bonding may reduce the connection reliability.

3. Underfill agent for BGA/CSP mounting

To solve the above problems and improve connection reliability, a sealing resin called "underfill agent" is used to fill the gap between the package and the circuit board. As such, as the underfill agent for BGA/CSP mounting, one-part heat-curing epoxy resin is normally employed. It is coated around the BGA/CSP (1-3 edges) after mounting and penetrated into the gap between the package and the circuit board by capillary forces for the process of heat curing (Fig. 3-1). The coating shape and underfill agent amount vary depending on the package size, pitch, and gap. To avoid bubbles, it is important to release air from the package. (If underfill agent is applied to all four sides of a package, the underfill agent will be cured with the bubbles remaining between BGA/CSP and the circuit board.)

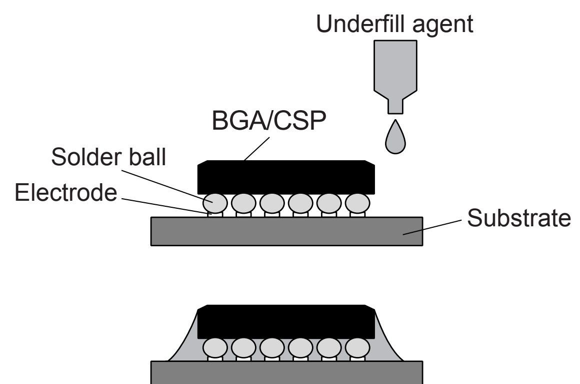


Figure 3-1. Using underfill agent

3-1. Effects of using underfill agent

Through the use of underfill agent, connection reliability can be increased by improving the following:

(1) Resistance to thermal stress caused by heat cycles

(2) Resistance to physical stress caused by mechanical shock and bending

This is due to the fact that the underfill agent reduces external stress. The stress is dissipated throughout the package, and the concentration of stress on the roots of solder balls is avoided.

3-2. Requirements of underfill agent

Underfill agent is required to:

(1) Spread sufficiently to the gap between the package and the circuit board and cure there

(2) Maintain connection reliability against thermal/physical stresses

(3) Provide excellent electrical characteristics (e.g., insulation)

(4) Cure at low temperatures in a short time (to prevent damage to the other electronic components and shorten the line tact time)

(5) Repairable (to be discussed later)

4. Underfill agent with repairability

4-1. Problems with underfill agent

The use of underfill agent significantly improves connection reliability, but causes a new problem. Specifically, when a defect is found in a BGA/CSP itself or in the connection with the circuit board after mounting using underfill agent, it will be difficult to replace (repair) it with another BGA/CSP (or circuit board). Without the underfill agent, the BGA/CSP can easily be removed by melting the solder balls. In bonding using thermocure resin underfill agent, however, it is very difficult to remove the BGA/CSP. Therefore even when a defect is found in one of the BGAs or CSPs on a circuit board, the entire module including the problem BGA/CSP must be replaced and disposed of. This increases the manufacturing cost.

4-2. What is repairability?

Repairability is defined as follows. When a defect is found in a BGA/CSP itself or in the connection with the circuit board after the underfill agent has cured, repairability allows you to:

(1) Easily remove the defective BGA/CSP from the circuit board

(2) Use the other normal BGA/CSP or the circuit board again

4-3. Underfill agent with repairability

Repairability is not always compatible with bonding reliability. It is therefore necessary to decide which will be given priority. For example, if only repairability is more important, a thermoplastic resin may be used as the underfill agent for easy repair, while if only bonding reliability is more important, a thermocure epoxy resin may be used as the underfill agent. However, ThreeBond 2274/2274B are underfill agents (Table 1) that are suitable for BGA/CSP and feature both repairability and bonding reliability. They can cure at low temperatures (ThreeBond 2274 cures at 70°C or higher; ThreeBond 2274B cures at 80°C or higher; they belong to a category of being curable at the lowest temperature of any one-part heat-curing epoxy compounded resin), and are designed to be repairable even if a defect is found.

4-4. Repair techniques

Some examples of repair techniques are shown below. In them, the cured underfill agent can be removed by heating and softening it. ThreeBond 2274/2274B harden at room temperature to work as an underfill agent, but soften when heated for removal.

1) Removing a defective BGA/CSP

The defective CSP/BGA can be peeled off using tweezers or the like by hot-blowing the CSP/BGA from its top with a local heater such as a heat gun (approx. 270-280°C), to soften the underfill agent (softens in 5-10 seconds).

- Be careful not to apply heat for an prolonged period, or the underfill agent will harden due to crosslinking and CSP/BGA will be difficult to remove.
- Pinpoint the heat so as not to affect the other components.
- Be careful to avoid damaging the other components.

2) Coarse grinding

Grind off the underfill agent remaining on the circuit board using two soldering irons (use a round-top iron and a blade-top iron). (Soften the underfill agent using the round-top iron, and scrape it off using the blade iron. The iron temperature should be approximately 350°C.)

- Be careful to avoid damage to the circuit pattern on the board. (Do not attempt to finish this work in one session; rather, it should be performed over several sessions.)

3) Finish grinding

Using the blade iron, completely scrape off the remaining underfill agent.

- Be careful to avoid damaging the circuit pattern on the board. (Do not attempt to finish this work in one session; rather, it should be performed over several sessions.)

4) Removing solder residual

Remove the solder residual on the circuit board using a solder cleaner wire or the like.

5) Finish cleaning

Finish the repair by cleaning the repair face using alcohol or the like.

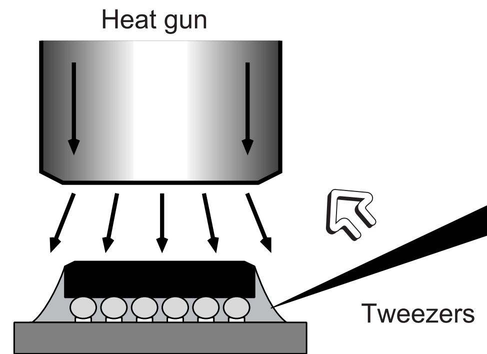
6) Mounting new BGA/CSP

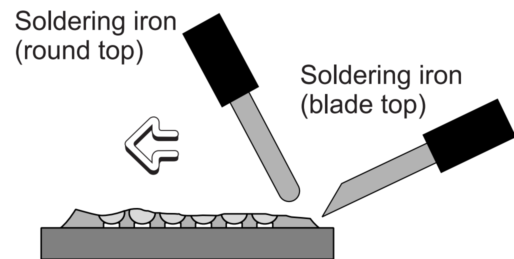
After the finish cleaning has been performed, check the pattern on the circuit board for any problems. If no problem is found, apply solder flux and mount a new CSP/BGA.

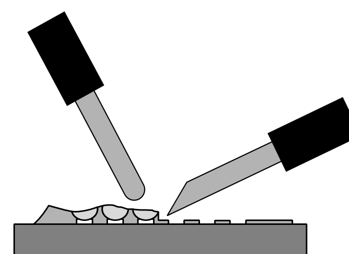
After mounting, apply the underfill agent and cure it.

<IMPORTANT>

Do not apply excessive heat to ThreeBond 2274/2274B. If ThreeBond 2274/2274B are heated for a longer time or at a higher temperature than specified in the standard conditions, they become harder due to crosslinking and become difficult to soften or repair.







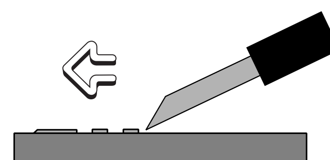


Figure 4-1. Example of repair techniques

5. Grades of the ThreeBond underfill agent for BGA/CSP mouting

Table 1 shows the grades and characteristics of the ThreeBond underfill agent for BGA/CSP mounting. All grades of the underfill agent are designed to cure at low temperatures in order to protect electric/electronic components from heat.

* As in the case of normal one-part heat-curing epoxy compuonded resin, the performance (except for repairability) of the underfill agent tends to improve when it is cured for a longer time or at a higher temperature than specified in the standard conditions (e.g., tensile-shearing adhesive strength, Figs. 5-1 to 5-3.)

Table 1. Properties and characteristics of Grades of the ThreeBond underfill agent for BGA/CSP mounting

	Unit (for reference purposes)	ThreeBond 2202	ThreeBond 2274	ThreeBond 2274B	Test method
Appearance	-	Black	Black	Black	3TS-201-01 (Visual check)
Viscosity	Pa•s (P)	13 (130)	12 (120)	4.7 (47)	3TS-210-02 (BH-type viscometer)
Specific gravity	-	1.14	1.14	1.13	3TS-213-02 (Specific-gravity cup)
Standard curing conditions	-	70°C × 50 min	70°C × 50 min	85°C × 45 min	-
Stability during storage	Months	7	6	6	In a refrigerator (5-10°C)
Hardness	-	D88	D86	D84	3TS-215-01
Tensile-shearing adhesive strength	MPa (kgf/cm^2)	10.0 (102)	11.0 (112)	16.0 (163)	2TS-301-11 (Fe/Fe: SPCC-SD)
Glass transition temperature	°C	105	65	97	3TS-501-05 (TMA, 10°C/min)
Linear expansion coefficient	$\times 10^{-5}$/°C	7.4	9.3	7.3	3TS-501-05 (Tg or lower)
Volume resistivity	Ω•m (Ω•cm)	1.3×10^{15} (1.3×10^{17})	2.5×10^{11} (2.5×10^{13})	4.5×10^{14} (4.5×10^{16})	3TS-402-01
Surface resistivity	Ω	1.5×10^{17}	8.6×10^{11}	8.4×10^{14}	3TS-401-01
Dielectric loss tangent	-	0.017	0.010	0.012	3TS-405-01 (1 MHz)
Dielectric constant		3.46	2.97	3.36	3TS-405-01 (1 MHz)
Repairability	-	No	Yes	Yes	-
Features	-	- Curable at low temperatures - Moderate viscosity - High adhesivity - High bonding reliability	- Curable at low temperatures - Moderate viscosity - High adhesivity - High bonding reliability - High repairability	- Curable at low temperatures - Low viscosity - High adhesivity - High bonding reliability - Repairability	

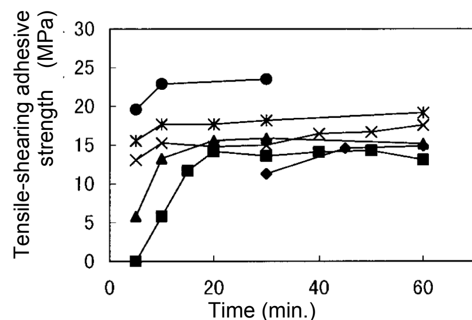


Figure 5-1. Tensile-shearing adhesive strength of ThreeBond 2202 cured at various temperatures

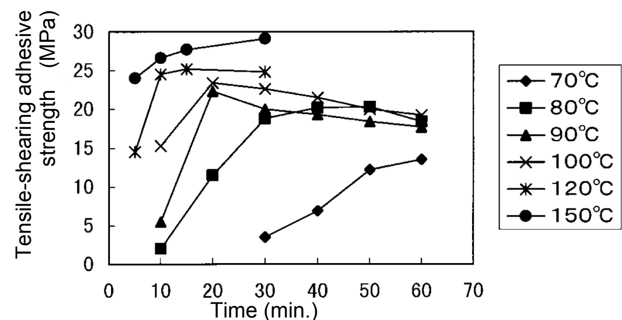


Figure 5-2. Tensile-shearing adhesive strength of ThreeBond 2274 cured at various temperatures

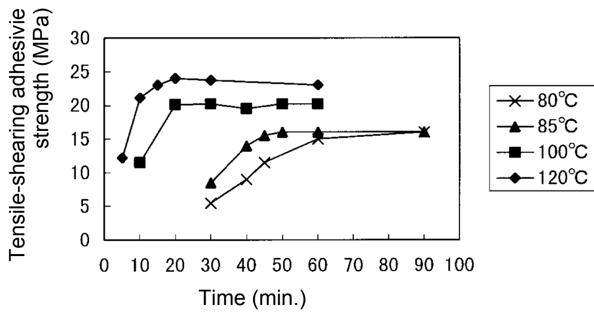


Figure 5-3. Tensile-shearing adhesive strength of ThreeBond 2274B cured at various temperatures

5-1. Characteristics of the underfill agent of each grade

● ThreeBond 2202 (standard type)

1) Curable at low temperatures

Curable at 70°C or higher, with minimum thermal damage to neighboring components.

2) Moderate viscosity

Moderate viscosity enables easy spreading (filling) into the gap between BGA/CSP and the circuit board, while limiting its reach to neighboring components.

3) High adhesivity

High adhesivity at low-temperature curing.

Adhesivity increases with curing at higher temperatures or for longer periods than specified in the standard conditions.

4) High bonding reliability

High connection reliability against thermal stresses such as heat cycles, and physical stresses such as mechanical shock and bending.

Bonding reliability increases with curing at higher temperatures or for longer periods than specified in the standard conditions.

<For application>

ThreeBond 2202 is the best choice if high adhesivity at low temperatures and high bonding reliability are required rather than repairability.

● ThreeBond 2274 (repairable)

1) Curable at low temperatures
2) Moderate viscosity
3) High adhesivity
4) High bonding reliability
5) Repairability

If a bonding defetct is found after the underfill agent has cured, BGA/CSP can be removed by heating and the cured underfill agent can be removed as well.

<For application>

ThreeBond 2274 is the best at providing high adhesivity at low temperatures and high bonding reliability, as well as repairability. Its properties before curing are nearly the same as those of ThreeBond 2202, so it provides workability as high as that provided by 2202.

● ThreeBond 2274B (repairable and low-viscosity)

1) Curable at low temperatures

Curable at 80°C or higher.

2) Low viscosity

Low viscosity and easy spread (filling), suited for large, narrow pitches and narrow-gap BGA/CSP.

3) High adhesivity

4) High bonding reliability

5) Repairability

<For application>

With low viscosity, ThreeBond 2274B is the best choice for a narrow-pitch, narrow-gap BGA/CSP. When cured for a longer period or at a higher temperature than specified in the standard conditions, it provides the highest bonding reliability (and less repairability).

* The spread (filling) and curing conditions of underfill agent vary depending on the BGA/CSP type (material, size, pitch, gap, etc.), circuit-board surface conditions, heat capacity of the neighboring components, and amount of underfill agent. Determine the optimal conditions in preliminary tests using actual components.

Conclusion

Not all of the BGAs or CSPs used in various electric/electronic products require reinforcement with the underfill agent. In some cases, bonding reliability can be ensured through an improved package structure or design.

However, the importance of reinforcement using underfill agent will increase due to the fact that bonding reliability and package strength may decline as the semiconductor chips (packages) are made more compact and circuit boards are made thinner.

Developing new products in addition to the above three grades of underfill agent, Three Bond continues to make efforts to meet diverse customer needs (including higher workability, bonding reliability, and repairability).

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