Low Cost High Reliability Assembly of POP with Novel Epoxy Flux on Solder Paste

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Abstract
A novel epoxy flux was developed with good compatibility with no-clean solder pastes, which imparts high reliability for BGA assembly at a low cost. This compatibility with solder pastes is achieved by a well-engineered miscibility between epoxy and no-clean solder paste flux systems, and is further assured with the introduction of a venting channel. The compatibility enables a single bonding step for BGAs or CSPs, which exhibit high thermal warpage, to form a high-reliability assembly. Requirements in drop test, thermal cycling test (TCT), and SIR were all met. The high viscosity stability at ambient temperature is another critical element in building a robust and user-friendly epoxy flux system. The material was found to able to be deposited with dipping, dispensing, and jetting. Its 75°C Tg facilitated good reworkability and minimizes the adverse impact of unfilled underfill material on TCT of BGA assemblies.

Introduction

For portable devices, the vulnerability for drop failure of area array packages such as BGA, CSP, or PoP has called for reinforcement of those packages when being assembled onto a PCB. While underfilling is regarded as one of the solutions, the increased cost of an additional curing step, plus the reduced temperature cycling reliability, prompts a preference toward the epoxy flux approach which eliminates the curing step. Epoxy flux serves as a flux when soldering array packages onto a PCB at reflow, and cures after reflow, thus providing the needed reinforcement without the need of the additional curing step. With pad cratering being the primary failure mode of many portable devices [1], epoxy flux comes out as the top solution for low-cost high-reliability SMT assembly solutions among all the polymer reinforcement options, as illustrated in Table 1.

Novel Epoxy Flux

1. Challenges

Epoxy flux works well without the need of solder paste at assembly. However, when the area array packages warp upon heating, solder paste is indispensable in order to prevent opens. Use of solder paste caused a challenge when applying epoxy flux at the same time, mainly due to oozing of the solder paste at reflow when immersed in the liquid epoxy flux, as shown in Fig. 1. Here the epoxy flux was not specifically formulated for compatibility with the solder paste. The glass slide was used to mimic the body of the BGA. As a result, upon heating on a 250°C hot plate, the wet flux of the solder paste dissolved in the liquid epoxy flux, with solder powder being carried everywhere by the wet flux. The widely dispersed solder powder still remained highly scattered at the end of solder coalescence. In this study, a newly developed epoxy flux A, which is compatible with solder paste, was evaluated for assembly and reliability. Results of the assembly process with epoxy flux on top of solder paste, drop test, temperature cycling, and SIR are presented and discussed in the following sessions.

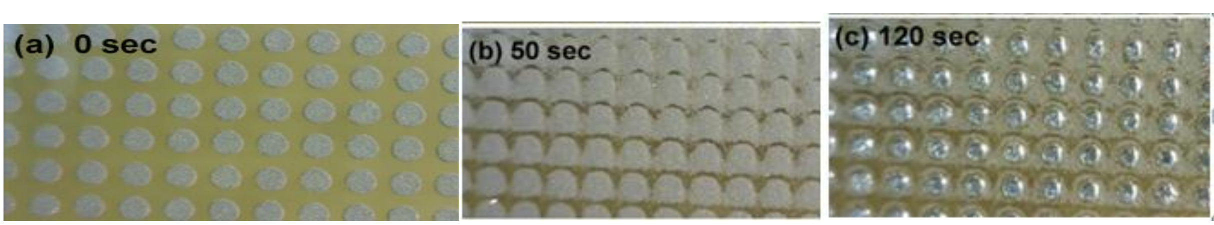


Figure 1 Reflow progress of printed solder paste immersed in epoxy flux and covered with a glass slide on a 250°C hot plate.

2. Preventing Powder Diffusion

First of all, the epoxy flux needs to have all of the solder powder confined to where it was printed. Since all solder pastes contain liquid or creamy fluxes, the miscibility between the epoxy system and the solder paste fluxes should be designed to be limited. This way, the slow diffusion of solder paste flux into the epoxy will not cause the powder to flush into the epoxy environment upon heating. Fig. 2 shows a printed wet solder paste with half of the paste dots covered with epoxy flux A (right side) without the paste oozing out. The well-defined wet solder paste dots soaked in epoxy flux A indicates that the miscibility between solder paste and epoxy flux is limited. Fig. 3(a) shows a picture of the solder paste covered with the epoxy flux after being reflowed on hot plate. No solder ball can be discerned. Fig. 3(b) shows the solder paste with another epoxy flux without designed-in compatibility. Significant interference with the solder paste coalescence is reflected by poor wetting and many solder balls.

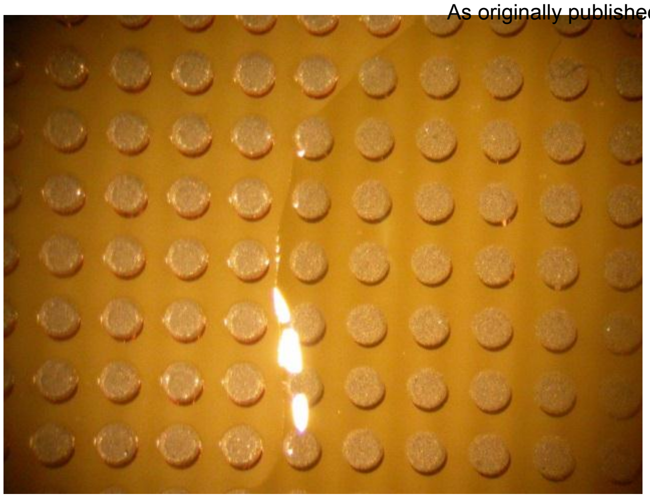


Figure 2 Demonstration with half of the paste dots covered with epoxy flux A (right side) without the paste oozing out.

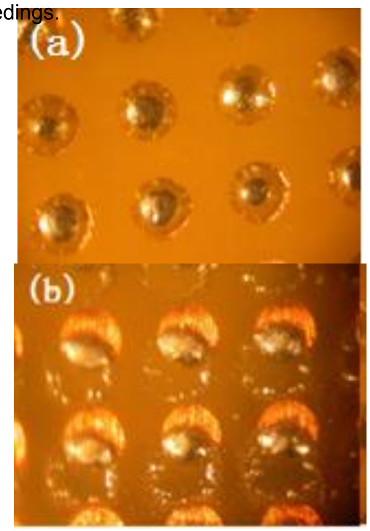


Figure 3 Photo of the solder paste covered with epoxy flux A (a) and an epoxy flux without designed-in compatibility (b) after being reflowed on hot plate.

Fig. 4 shows the reflow progress of a printed solder paste immersed in epoxy flux A under a glass slide on a hot plate. In this case, all the solder powder remained as printed dots and eventually all coalesced into integral solder bumps.

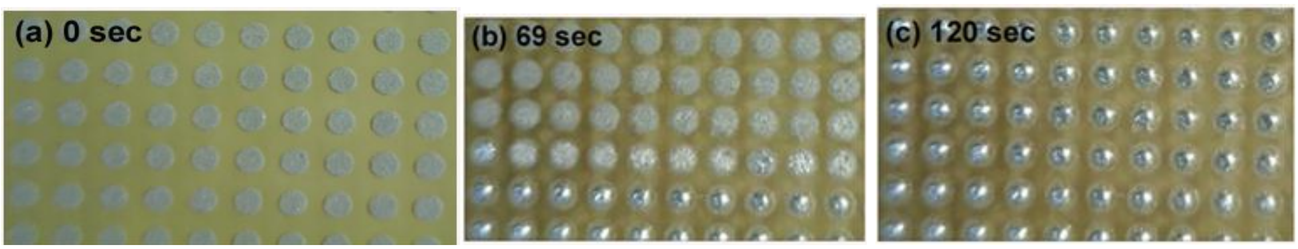


Figure 4 Reflow progress of printed solder paste immersed in epoxy flux A and covered with a glass slide on a 250°C hot plate.

3. Allowing Escape of Volatiles

Since all solder pastes contain a significant amount of volatiles, allowing the escape of volatiles without causing bubbling within the epoxy system during reflow is critical. To achieve this, the epoxy system should be able to absorb the volatiles, then allow the volatiles to permeate through the liquid phase and eventually vent out. In Fig. 4, complete coalescence of the solder paste indicates the flux and volatiles has been driven away from solder paste location, and lack of bubbles indicates that the volatiles have been absorbed or permeated through the epoxy system.

BGA Assembly with Epoxy Flux A

1. Component and Test Board

The BGA component used was a 7mm x 7mm BGA (A-CTBGA84), with a SAC305 bump, 84 I/O, 0.5mm pitch, 0.34mm bump diameter, 0.22mm bump height, ball matrix 12 x 12, and arranged in 3 rows, as shown in Fig. 5. The test board used was from Practical Components, PCB011.

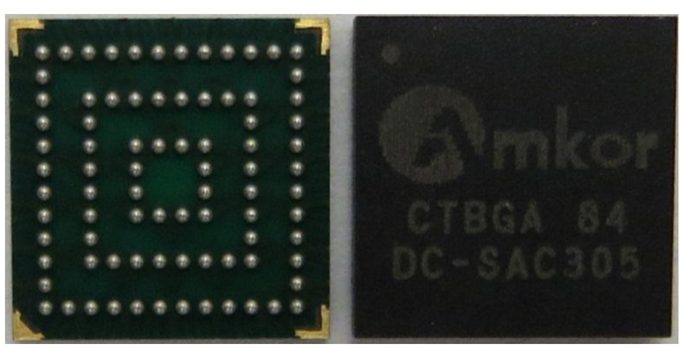
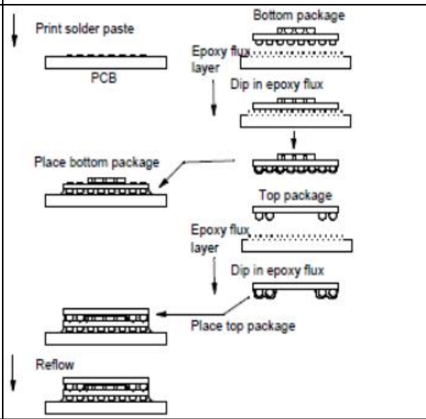
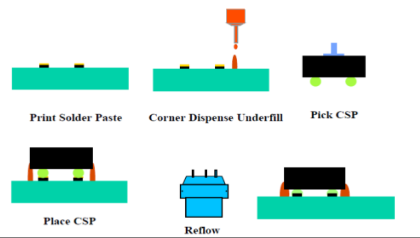
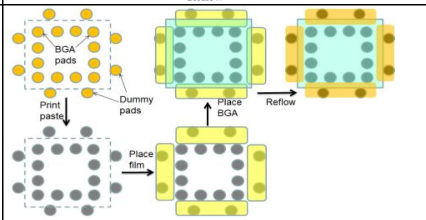
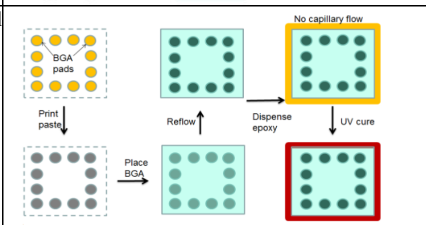
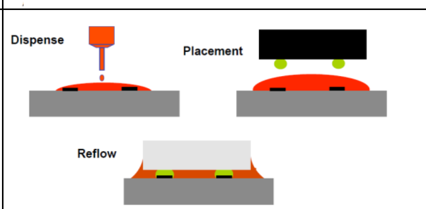
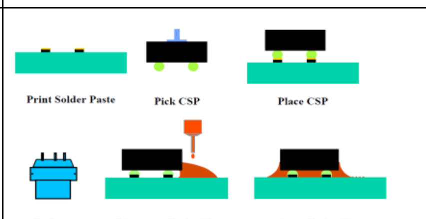


Figure 5 CTBGA84 used in demonstration of Epoxy Flux A.

As originally published in the IPC proceedings.

Table 1 Process and pros and cons of various polymer reinforcement technologies at BGA/POP assembly [2]

Polymer reinforcement method	Process	Pros	Cons
Epoxy Flux		• Only one extra dipping step needed. The simplest process among all polymer reinforcement approaches. • No solder wetting interference concern • No PCB prebaking needed, due to designed-in venting channel • Significant reinforcement. • Promising reduction in both joint & crater failures • Reworkable • Compatible with assembly of BGA & PoP, including PoP stacking • Compatible with solder paste, thus can tolerate warpage at soldering.	• Need epoxy flux bed • Larger nozzle size may be needed for pick & place at dipping step
Corner Bond		• Cure at solder paste reflow process. • Reinforce BGA to some extent. • No prebaking needed • Often reworkable	• Premature curing can result in difficulty of BGA collapse • Polymer wicking interfere with solder paste reflow • Premium dispensing equipment is needed, & significant increase in cycle time • Cannot reach top package • Less promising for preventing crater failure.
Place-N-Bond Underfilm		• No dispensing equipment needed • Melt at solder paste reflow process. • Reinforce BGA to some extent. • No prebaking needed • Often reworkable	• Need dummy pads designed in • Cannot reach top package • Less promising for preventing crater failure
Edge Bond, Liquid Epoxy		• Fast UV cure, no heat cure needed • Epoxy won't interfere with soldering • Easy inspection	• One more step dispensing needed. Cycle time is unacceptable • premium dispense equipment needed. • Less promising in preventing crater failure • Can not reach top package
No Flow Underfill		• Simple dispense • Cure during reflow • High reinforcement • Reduction in both joint & crater failures • Some reworkable	• Placement cause voids • Prebaking often needed • For large BGA, open & chip drifting or lifting due to earlier gelling at the hotter perimeter • Solder wetting hampered due to premature gelling • No filler allowed
Capillary Underfill		• Mature technology • The highest reinforcement. • Promise reduction in both joint & crater failures • Mature technology • The highest reinforcement. • Promise reduction in both joint & crater failures	• Requires post reflow underfill dispense, capillary flow & cure. Cost more time & equipment • May require prebake to avoid voiding if there is delay prior to underfilling • Solder extrusion at rework & TCT issues • Reworkability can be issue, including components around BGA which was flooded by underfill

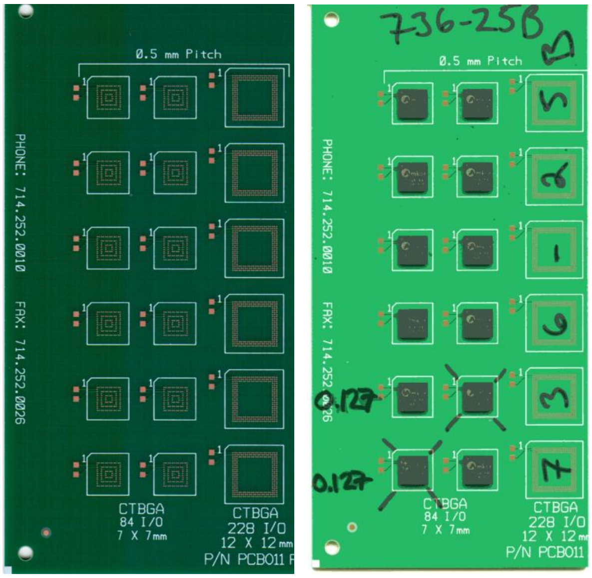


Figure 6 Test board used in demonstration of Epoxy Flux A before and after BGA assembly.

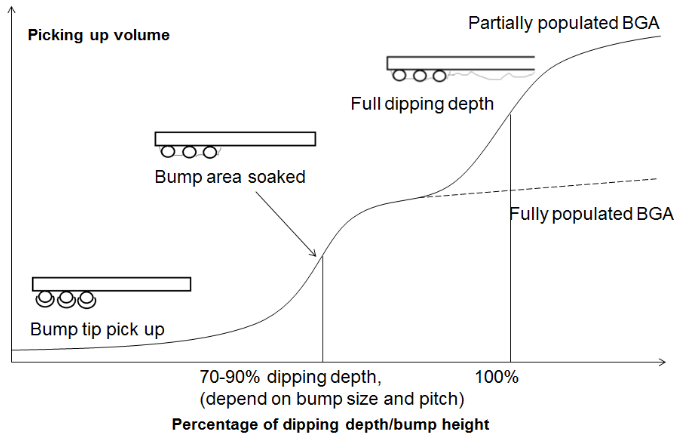


Figure 7 Relation between the flux pick-up volume, the ratio of dipping depth/bump height, and the bump pattern of the BGA.

2. Flux Dipping
Assembly of the BGA with epoxy flux A can be conducted by using either a dipping or jetting process. For dipping processes, the flux quantity pick-up is affected by the flux film thickness and the patterning of BGA bumps. Fig. 7 shows the relation between the flux pick-up volume, the ratio of dipping depth/bump height, and the bump pattern of the BGA. In general, a dipping depth with 70-90% of bump height would provide an optimal volume pick-up. Beyond that, the flux quantity pick-up may be too excessive and may cause chip floating or skewing.

The production pick and place machine used had the rotary dipping pan for the epoxy flux.

3. Reflow Profile
The production reflow oven used the thermal profile as shown in Figure 8.

The yields were checked for continuity. When the circuit resistant was less than 1 ohm, the chip installation was considered as a good installation. Epoxy flux dipping depth was 0.18mm.

4. Wetting
Both BGAs assembled with epoxy flux A (top) and conventional flux (bottom) showed full wetting on the OSP pads, as shown in Fig. 9. No difference in the extent of wetting can be discerned.

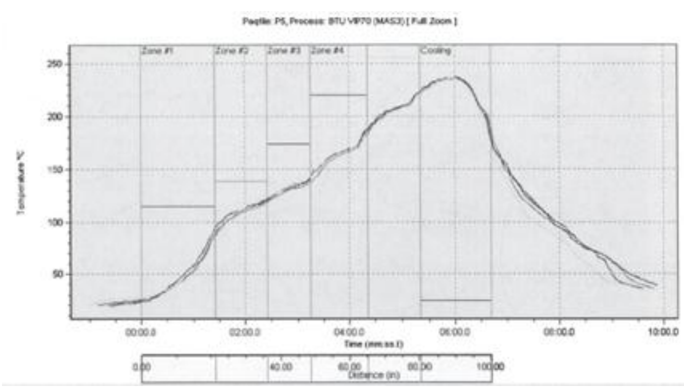


Figure 8 Reflow profile used in this study

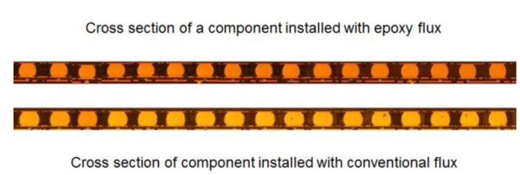


Figure 9 Cross-section of the BGA assembled, with Epoxy Flux A on the top and conventional flux at the bottom.

5. Filling

Fig. 10 shows a close up of the cross-sectioned BGA assemblies installed with epoxy flux A. The left picture shows a fillet of epoxy flux, the center picture shows a space fully filled by epoxy flux, while the right picture shows a vacancy between bumps. The vacancy is a designed-in venting channel through the sub-bump height dipping process. This venting channel

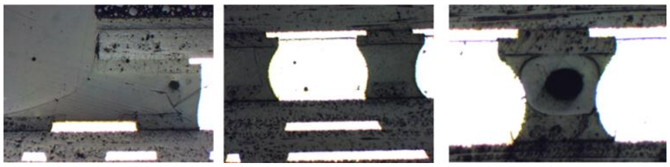


Figure 10 Cross-sections of BGA joints assembled with epoxy flux A.

serves as pressure-relief cushion to prevent chip lifting or swimming caused by excessive outgassing at reflow. This outgassing source could be caused by flux in the solder paste, moisture in the PCB or components, or products of fluxing reaction.

Fig. 11 shows the bottom view of a BGA that was pried off of a BGA assembled with epoxy flux A. Epoxy flux clearly filled the gap between nearby bumps. On the other hand, between the rows, significant venting channels can be observed.

Fig. 12 shows the top view of a PCB after the BGA was pried off of a BGA assembled with epoxy flux A. All of the Cu pads are missing from the PCB surface. Those missing Cu pads were all found attached to the solder bumps on the BGA, as shown in Fig. 11, thus, providing direct evidence of strong solder bonding caused by the joint effort of epoxy flux A and the solder paste.

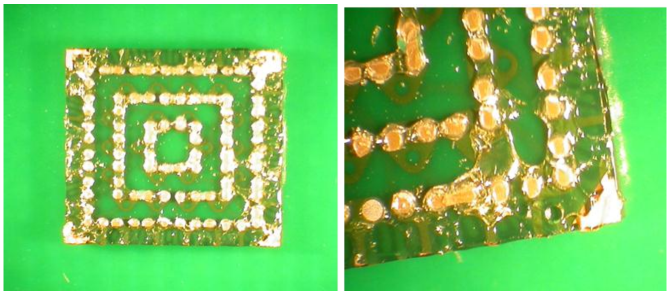


Figure 11 Bottom view of a BGA assembled with epoxy flux A after being pried off.

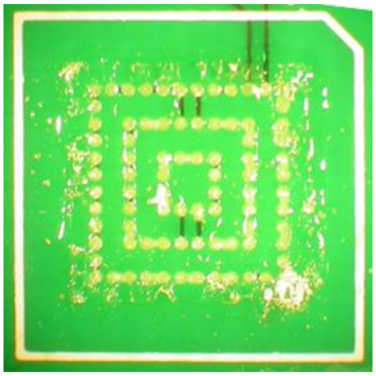


Figure 12 Top view of the PCB after the BGA assembled with epoxy flux A was pried off.

6. Shear Strength

The BGA shear strength was measured for BGAs assembled with epoxy flux A and a conventional flux with the use of a die shear tester. Ten BGAs were tested for each, with results shown in Fig. 13. The shear strength of a BGA assembled with epoxy flux A is considerably higher than that of a conventional flux. The standard deviations of both systems are comparable.

Reliability

Three reliability properties were evaluated for BGAs assembled with epoxy flux A: drop test, thermal cycling test, and surface insulation resistance, with results presented below.

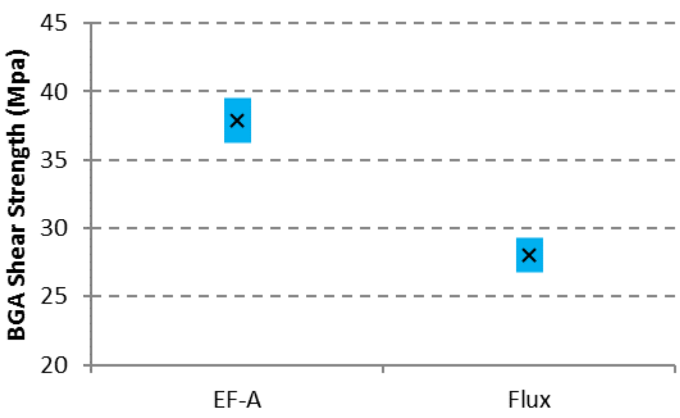


Figure 13 Shear strength of a BGA assembled with epoxy flux A and a conventional flux

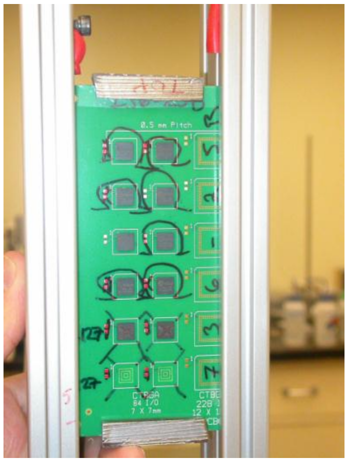


Figure 14 Test board positioned in the frame with steel weight mounted on both top and bottom ends of boards

Figure 15 Frame for drop test setup (left), with a test board already landed on the bottom of test frame (right).

1. Drop Test

Drop Test Method

Current drop testing was being done with 0.5mm A-CTBGA84 7x7 components on a corresponding board that is 70mm wide from the end containing the component locations (see Fig. 6).

Boards and components were dried @ 120°C ~3hrs prior to assembly. Components are dipped in epoxy flux 200 micron deep, and placed and then reflowed in an air atmosphere using the profile shown in Fig. 8. Dwell time of the dipping was a few seconds in order to allow equilibrium wicking of the epoxy flux A around the bumps.

Two pieces of steel 1 cm2 square weight, ~4.5cm long, with a notch cut in them that is the thickness of the board, are placed on the top and bottom, as shown in Fig. 14 and Fig. 15. They were 33g each. The attached weights serve three purposes: (1) Prevents the board ends from splaying out from repeated drops onto a hard surface; (2) provides a hard-on-hard contact surface to increase the g-force when the board hits the steel anvil, and; (3) increases the amplitude of the vibration traveling through the board upon impact.

The frame was built out of 20mm 8020 material (20-2040) to keep the boards traveling perpendicular to the floor/anvil when dropped, as shown in Fig. 15. A piece of steel ~3cm x 4cm x 5mm was bolted to the inside bottom member of the frame. Boards were dropped from a height of 5 feet. After every 50 drops, the daisy-chained components are measured for resistance compared to the original values taken before the start of the test (see Fig. 16). The fail criterion is set at 1.0 ohm, which is about 3X the resistance when compared with a well soldered CTBGA84 component, which has a resistance of ~0.3 ohms. The component is rated failed when resistance is equal to or higher than 1.0 ohm.

The Weibull analysis of drop test results of the BGA assembled with four epoxy fluxes and a conventional flux is shown in Fig. 17. The characteristic life □ and slope □ are shown in Table 2.

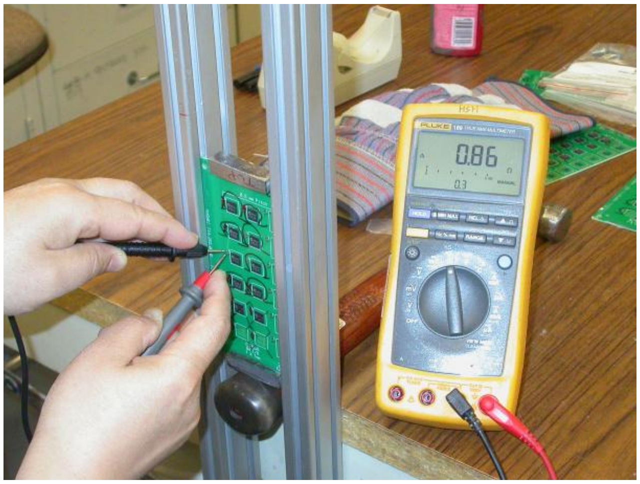


Figure 16 Component resistance measurement at every 50 drops.

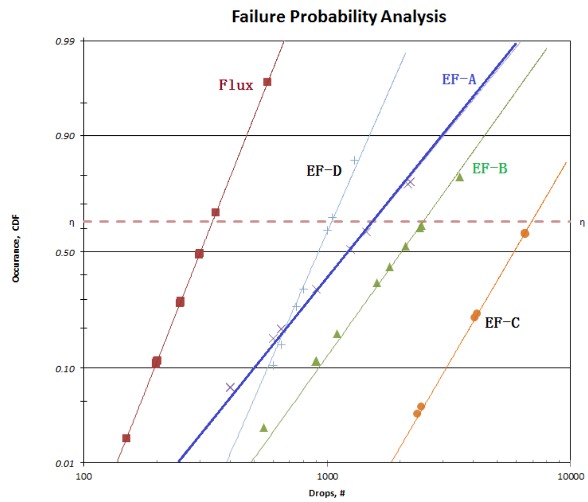


Figure 17 Weibull analysis on drop test results of assembled CTBGA84

Table 2 Weibull analysis of BGA assemblies installed with a conventional flux and a variety of epoxy fluxes

Flux Material	Slope β	Characteristic Life (63.2%) η	Ratio of η (epoxy flux/flux)
Flux	2.940	302	1
EF-A	1.332	1228	4.07
EF-B	1.492	2016	6.68
EF-C	1.958	5870	19.44
EF-D	2.924	921	3.05

Drop Test Results

All epoxy fluxes show a better characteristic life than the conventional flux. The ratio of characteristic life of the epoxy flux and the conventional flux ranges from 3 to 19, as shown in Table 2. Here the epoxy flux A is 4X the characteristic life of the conventional flux. This is a very significant improvement in reliability against drop shock failure.

2. Thermal Cycling Reliability

The BGA assembly setup of test boards for the thermal cycling test (TCT) is the same as the drop test. The temperature cycling range is -55°C to 125°C, with 113 minutes per cycle. The test samples were checked every 300 cycles for continuity of the chips. An increase in resistance of the chip for more than 10% was considered a fail.

For CTBGA84s assembled with epoxy flux A, all 12 chips were good after 1700 cycles. Two chips failed after 2000 cycles. The TCT test is still ongoing. Since -55°C to 125°C is a fairly harsh test condition, the TCT performance of epoxy flux A assemblies was considered acceptable.

3. Surface Insulation Resistance (SIR)

Epoxy flux is thermoset in nature. It is designed for no-clean processes. Accordingly, the SIR value of cured epoxy flux with or without solder paste should meet no-clean requirements. Fig. 18 shows the SIR data of epoxy flux A when tested alone per J-STD-004A. Results show it passes the SIR requirement. Fig. 19 shows the SIR results for epoxy flux A on top of the solder paste. The combined material system showed an SIR value lower than the individual solder paste or the individual epoxy flux when tested alone. This could be attributed to the increased difficulty of the volatiles of the solder paste flux to escape. Regardless, the SIR of the combined material system still passes the SIR requirement as a no-clean system.

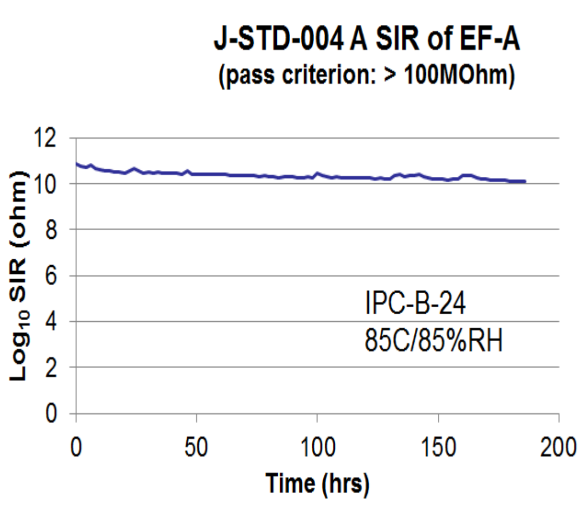


Figure 18 SIR of epoxy flux A per J-STD-004A

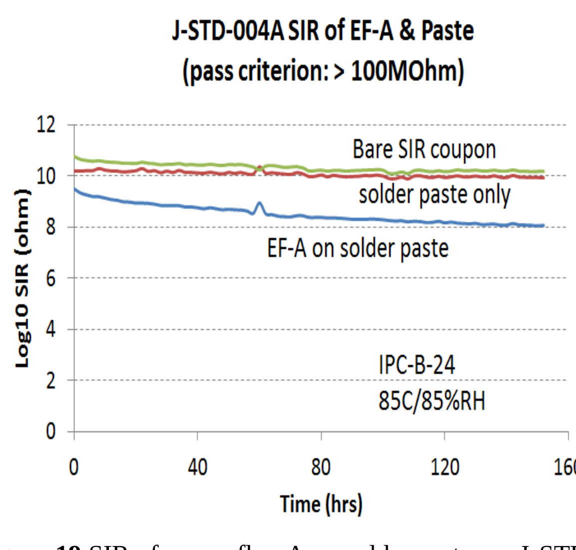


Figure 19 SIR of epoxy flux A on solder paste per J-STD-004A

Characteristics of Epoxy Flux A

The handling window of epoxy flux A was examined by checking the pot life and storage stability. Pot-life was measured by viscosity change at room temperature in days. The viscosity increase of epoxy flux A at room temperature was found to be less than 15% after 7 days, as shown in Fig. 20. This stability promises a long pot life during SMT assembly process, particularly for dispensing or jetting process. As already hinted by the high viscosity stability at room temperature, epoxy flux A exhibits a 6-month shelf life at storage temperatures < -18°C, as shown in Table 3.

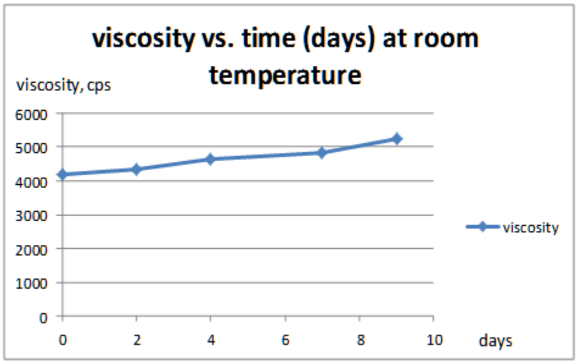


Figure 20 Viscosity stability of epoxy flux A at room temperature.

Table 3 Characteristics of epoxy flux A

Tg DSC method, cured	75°C or higher (depending on cure conditions)
Softening point (after reflow)	70°C
Typical viscosity (Brookfield, Model HB DVII-CP)	4000 - 6000 cps
Epoxy flux activation temperature	170 °C
Pot life (at room temp.)	Viscosity increase less than 15% in 7 days
Shelf life (at < -18°C)	6 month

Also shown in Table 3 are the viscosity at room temperature, glass transition temperature, softening point, and fluxing activation temperature of epoxy flux A. The relatively low Tg and softening temperature not only facilitate a good reworkability, but also minimize the adverse impact of board-level unfilled underfill toward TCT performance. The viscosity at 4-6Kcps allows not only a dipping process, but also dispensing and jetting processes.

Summary on Epoxy Flux A

A novel epoxy flux was developed with good compatibility with no-clean solder pastes. It provides high reliability for BGA assembly at a low cost. This compatibility with solder pastes is achieved by a well-engineered miscibility between the epoxy and the no-clean solder paste flux system, and is further assured with the introduction of venting channel. This compatibility enabled a single bonding step for BGAs or CSPs, which exhibit high thermal warpage when forming a high reliability assembly. Requirements in drop test, TCT, and SIR are all met by this epoxy flux A. The high viscosity stability at ambient temperature is another critical element in building a robust and user-friendly epoxy flux system. The epoxy flux A can be deposited by dipping, dispensing, or jetting. Its 75°C Tg facilitates good reworkability and minimizes the adverse impact of unfilled underfill material on TCT of BGA assemblies.

Family from Epoxy Flux A

With epoxy flux A as a platform, a series of epoxy fluxes have been developed with various emphasis in specific applications. Examples of those family members of epoxy flux A are briefly discussed below.

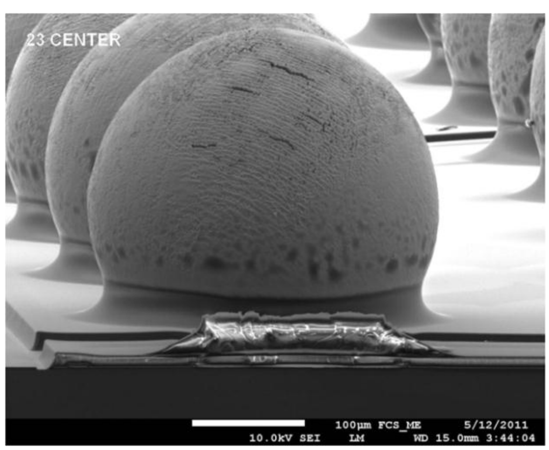


Figure 21 WLCSP ball mounting with epoxy flux E.

1. Epoxy Flux B
Epoxy Flux B enhanced the drop test reliability of epoxy flux A, as shown in Fig. 17 and Table 2. Some compromise in pot life and storage temperature requirement is recognized.

2. Epoxy Flux C
Epoxy flux C enhanced significantly the drop test performance of EF-A, as shown in Fig. 17 and Table 2. In achieving this, the wetting ability is compromised slightly.

3. Epoxy Flux E
With a raised Tg at 140°C and very good wetting, epoxy flux is designed for printing applications and is specially formulated for ball mounting for WLCSP, as demonstrated in Fig. 21. Epoxy flux E allows no-clean processes and is very compatible with underfilling materials and processes.

It should be noted that solder bumps formed by ball mounting with the use of any flux generally have a thin film of flux remaining on the top of bumps. Depending on the flux chemistry, the flux film may be significant in thickness. However, in the case of epoxy flux E, this thin film is hardly discernible, as evidenced in Fig. 21. Test results show that this thin flux film did not compromise joint formation at all at assembly of the BGA onto the PCB.

References

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2. Ning-Cheng Lee, “Package on Package”, IMAPS, short course, September 9-13, 2012, San Diego, CA.