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ENHANCING RELIABILITY OF PB-FREE SOLDER JOINTS IN AREA ARRAY PACKAGES

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ABSTRACT

Microelectronics devices are moving toward high-density interconnects. The use of flip chips, chip scale packages (CSP's) and ball grid arrays (BGA's) has increased over the past years to meet these needs. It has been found that CSPs and BGAs have particular benefit from the use of underfills to meet assembly reliability requirements. Typically, underfill materials for these devices differ significantly in their formulation to provide different types of protection.

Underfill materials were initially developed to provide coefficient of thermal expansion (CTE) matching for flip chip devices (and now wafer level CSPs). These materials have a high degree of filler and are typically non-reworkable. Underfill systems designed for CSP devices for hand-held electronics tend to be unfilled, reworkable, and reinforce devices for shock and drop.

In this paper the authors compare the reliability of several types of underfill materials across several sizes of area array components: 0.4mm pitch wafer level chip scale packages (WLCSP) and 0.5 mm pitch chip scale packages (CSP), 0.8mm pitch and 1.0mm pitch BGA devices. The reliability of these devices (all Pb-free), are evaluated using industry standard thermal cycling and drop test methodologies. The improvement of the reliability of these devices thorough the use of underfill systems is evaluated. The physical properties of different underfills and how those physical properties affect the performance in the different types of reliability testing and across different packages are also compared.

INTRODUCTION

Underfill materials have proliferated into many electronics assemblies well beyond their use as an adhesive to extend solder joint reliability of flip-chip devices. Underfill systems are now used on a variety of devices throughout many sectors of the electronics industry. Underfill systems are typically described into one of two categories: package-level or board-level. The package-level underfills are typically designed to protect a flip chip device against CTE mismatch between the silicon die and the substrate. These materials are highly filled (low CTE), high T_g, high modulus and not reworkable. CSP underfills are typically unfilled, low modulus and low T_g.

Within advanced SMT devices, CSP packages are approaching the dimensions of a flip chip device and therefore the reliability requirements are becoming more similar. Therefore, underfill materials are needed to not only supply thermal cycling performance enhancement, but also drop/shock performance. With the wide variety of underfill materials available it is important for an assembler to choose the proper material for the reliability level needed. In this study, the performance of both package-level and CSP-level underfill materials on different sized devices are examined.

EXPERIMENTAL

For this study, test vehicles were built with different sized packages. All test boards were 1.0 mm Thick FR-4, AUS5 Solder Mask, OSP-Cu Finish, 1-6-1 buildup. Three different packages were used and each package type was on their own test vehcile,see Table 1. All packages were bumped with SAC405 solder and manufactured with a Pb-free solder paste (SAC305 alloy) with Type IV powder and reflowed in air.

Table 1. Components Tested

Type	*Pitch*	*Dimensions*	*# Bumps*
WLCSP	0.4 mm	7 mm sq	192
CSP	0.5 mm	12 mm sq	228
BGA	1.0 mm	23 mm sq	288

After assembly devices were underfilled with three different types of underfills, see Table 2. The underfill process was optimized for each material andthen used to provide a full underfill for each device tested. For each package style, a set of non-underfill packages were used as a control.

Table 2. Physical Properties of Materials Tested

Label	*CTE (ppm)*	*T_g (°C)*	*Modulus (GPa)*
A	73	18	1.8
B	63	53	3.5
C	23	94	11

Underfill A is an unfilled material designed to cure in less than two minutes at 120°C, provide protection for drop/shock testing, flows at room temperature and is reworkable.

Underfill B is an unfilled material designed to cure in five minutes at 120°C, provide protection for shock/drop testing and is reworkable.

Underfill C is a filled material (60% by weight) that cures in two hours at 150°C and is designed to provide a reliable underfill for flip chip in package devices.

After assembly devices were electricaly tested to confirm a good interconnection and then thermally cycled in a single chamber from 0°C to 100°C with 30-minute dwells at each condition and 60 minute ramp. Electrical testing of the devices were conducted every 100 cycles and a change of more than 10% was considered a failure.

RESULTS

Due to the small number (three for each condition) of PWBs tested , Wiebell plots were not generated, but the percentage of devices failed was used to compare the materials and devices.

PBGA Devices

As expected, the 1.0mm pitch PBGA package was very robust under this condition, Figure 1.

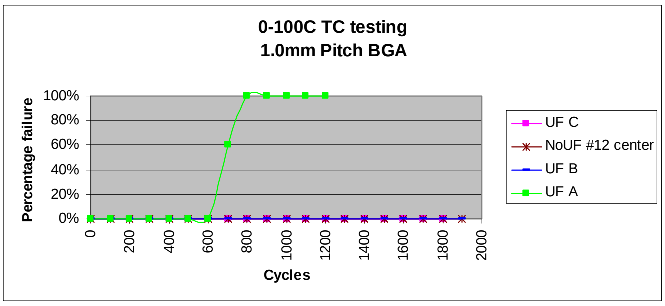

Figure 1. Thermal Cycling Results for PBGA.

The only underfill condition (including no underfill) that showed any failures was underfill A.

Cross-section analysis showed some corner bumps cracking, Figure 2.

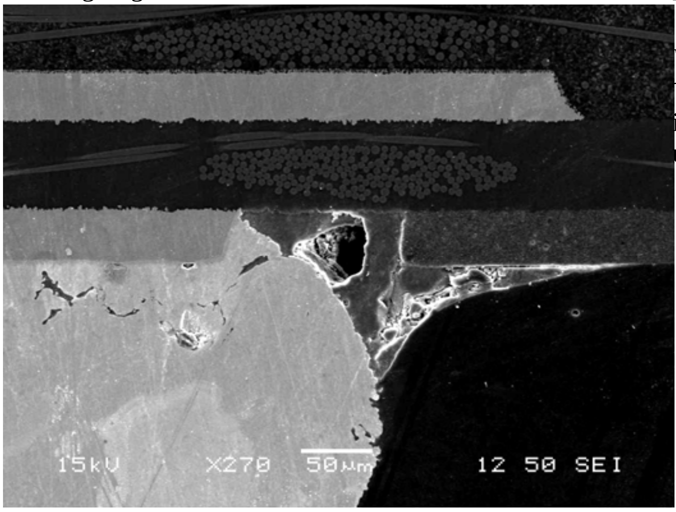

Figure 2. Cracking observed in corner bumps on underfilled 1.0mm pitch packages.

CSP Devices

With this package type, the non-underfilled and the underfill A devices fail early, whereas the components underfilled with underfill B and underfill C don't start to fail until after 1000 cycles, Figure 3.

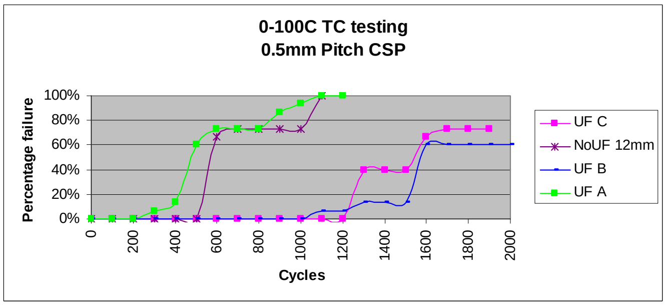

Figure 3. Thermal Cycling Results for CSP components.

Cross-sectional analysis of the component underfilled with underfill A shows delamination of the underfill adjecnt to a solder joint crack, Figure 4.

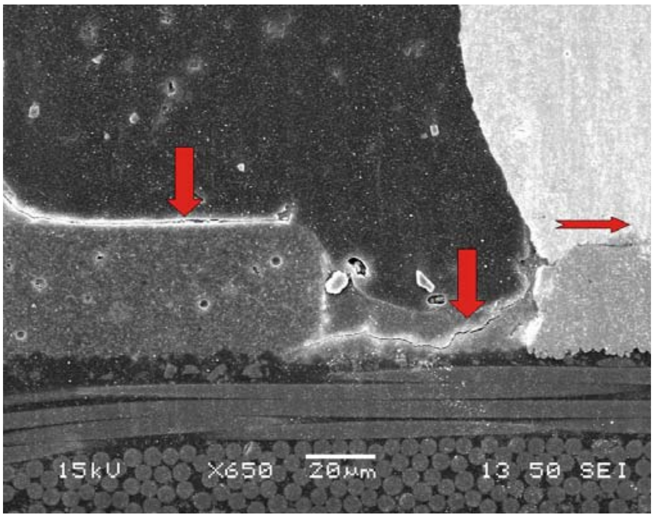

Figure 4. SEM image of UF A component failure.

WLCSP Devices

The 0.4 mm pitch WLCSP devices performed better than initally expected. Once again the non-underfilled and underfill A devices performed similarly, Figure 5.

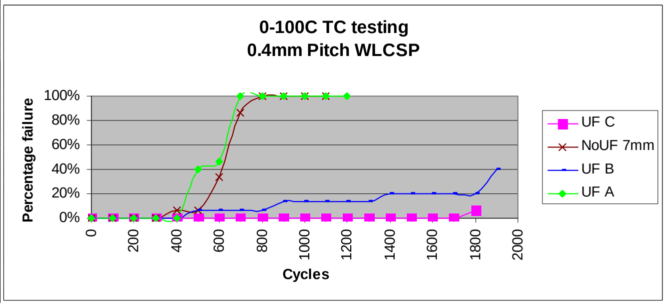

Figure 5. Thermal Cycling Results for WLCSP components.

Cross-section analysis of devices show significant solder joint cracking

Figure 6. Solder joint cracking on WLCSP devices.

In the 0^0C to 100^0C thermal cycling testing, it is evident that one unfilled reworkable system (underfill A) performs poorly, where as another similar system (underfill B) performs better. In previous studies, these two materials were evaluated in both drop testing and a more rigorous s thermal cycling condition (-55°C to 125°C thermal shock).

Drop testing on these materials was evaluated using the 0.5mm CSP devices. Drop condtions were conducted at 2900Gs with a 0.3ms pulse. Drop test results are shown in Figure 7.

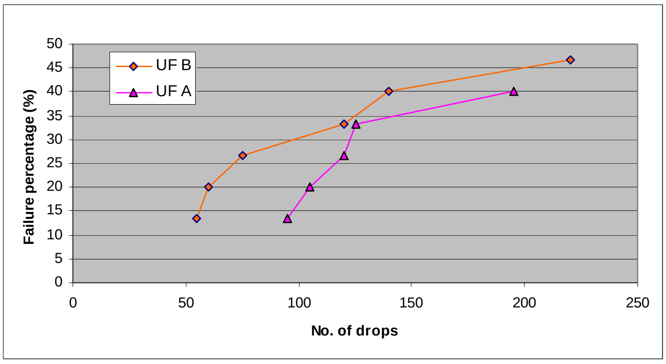

Figure 7. Drop test results comparing underfill A and underfill B on 0.5mm pitch CSPs.

Failure analysis on these devices show evidence of underfill delamination and some substrate cracking, but no solder joint cracking was observed, Figure 8.

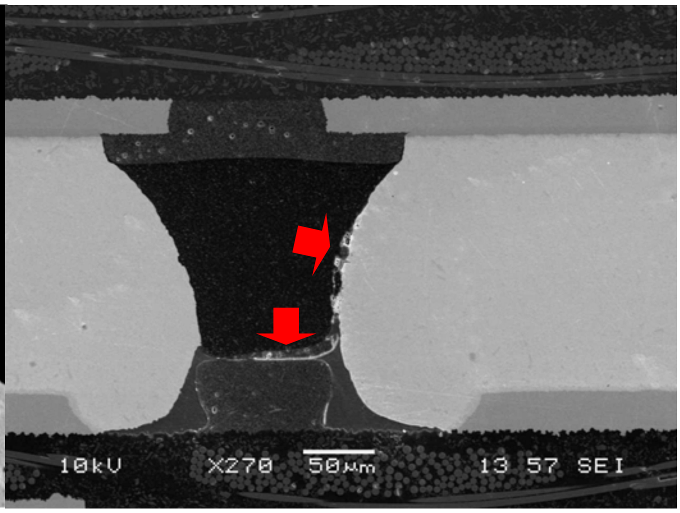

Figure 8a. Underfill delamination from solder bump.

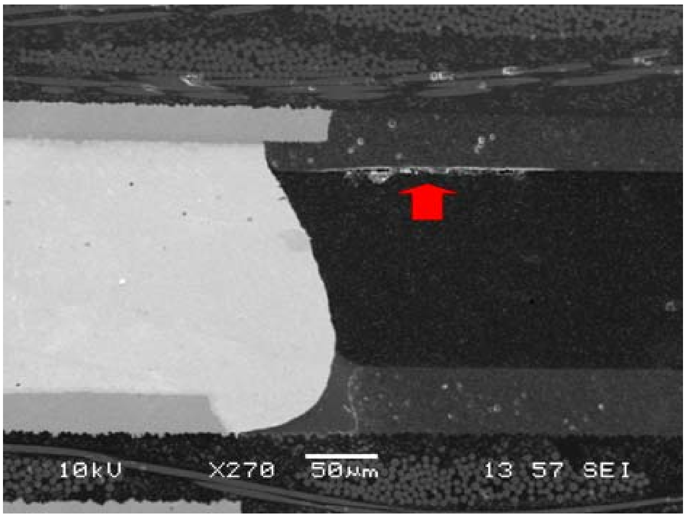

Figure 8b. Underfill delamination from package bottom.

Thermal cycling these devices from -55°C to 125°C at two cycles per hour reveals a similar trend to that observed at more mild conditions: once again, underfill B outperforms underfill A, Figure 9.

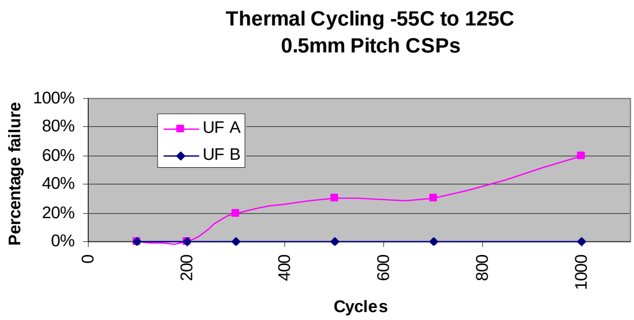

Figure 9. Thermal cycling results comparing underfill A and underfill B.

Failure analysis of these devices showed crack initiaion for underfill B even with no failures detected, Figure 10. Significant damage accumulation on parts underfilled with underfill A can be seen in Figure 11.

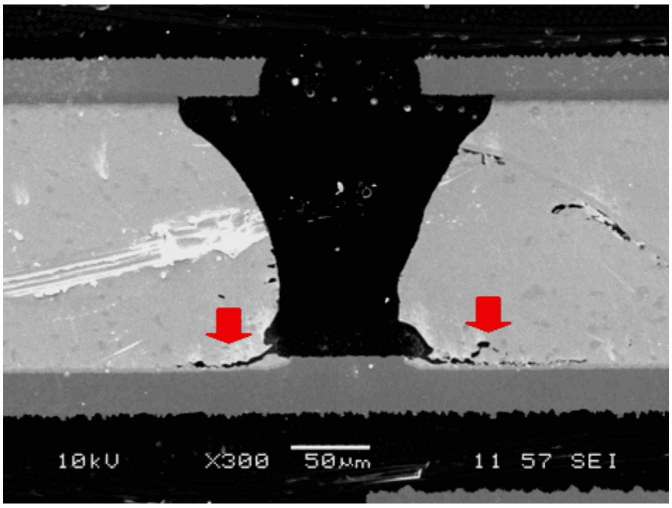

Figure 10. Crack initiaion at 1000 cycles for underfill B, no failures detected.

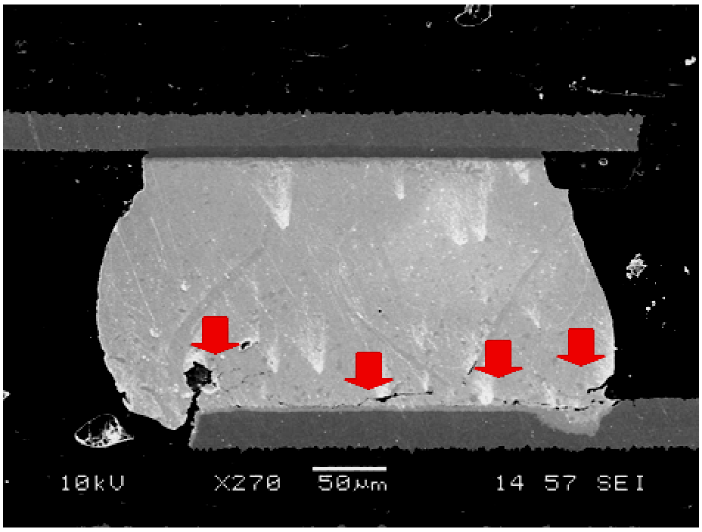

Figure 11. Solder joint cracking on underfill A after thermal cycling.

CONCLUSIONS

With the variety of underfill systems available in the market, choosing the correct system for the reliability required is critical. In this study, two materials who have similar physical properties were evaluated. Both have low T_g and are reworkable, but perform very differently in reliability testing.

While underfill A performs poorly in thermal cycling testing, it outperfoms underfill B in drop testing. Ideally, the material of choice would perform the well in both types of testing.

Future work includes more studies that evaluate drop testing on package-level underfill systems and investigating new systems that strive to provide good thermal cycling performance as well as provide drop test enhcancement.