Enabling MSL-1 Capability for QFN and Other Design Leadframe Packages

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Abstract

As the conversion of the electronics industry to lead free soldering materials continues some unexpected negative side effects of higher lead free reflow temperatures have occurred. Defects such as delamination or "popcorning" in surface mount components have increased significantly since lead free soldering has become mainstream. Popcorning is a defect that manifests itself as a fracture between the epoxy based encapsulant and the metal, usually copper alloy, leadframe components used to form a surface mount component. This fracture occurs when moisture in the package volatilizes during reflow processes and forces its way through the encapsulation material and leadframe interface.

Peak reflow temperatures for leaded solder typically run around 215º - 225º C but due to the higher melting point of lead free solders, they require peak reflow temperatures of 240º to 260º C range. This 30º increase in reflow temperatures can have a significant effect on the electronic devices and any resident moisture in the component

The keys to popcorning, or delamination, defect reduction is twofold. The first objective is to enhance the bond between the encapsulant and the copper leadframe materials to form a stronger bond that can resist the vapor pressures induced during reflow. The other objective is to provide a superior bond between the leadframe and encapsulant thus minimizing moisture ingress.

New chemical treatment processes have been developed that pre-treat the copper surfaces of the leadframe and significantly enhance the bond between the encapsulant material and the metal leadframe. The chemical treatment process results in micro-roughening of the copper surfaces and at the same time depositing a thermally robust film that enhances the chemical bond between the epoxy encapsulant material and the copper.

This paper examines the possible issues and the real life successes when comparing standard component manufacturing methods to those that incorporate the aforementioned chemical adhesion promotion process. Components are assembled using both processes and final performance is tested using MLS-1 conditioning protocols, acoustic microscopy analysis (SAM), and final yield improvement.

Introduction

The drive to lead-free solders has increased the reliability testing criteria for semiconductor assembly. The higher temperatures required for reflow can impact a molded component by

1. Mismatch of coefficient of thermal expansion (CTE) between molding compound, die attach adhesive and leadframe surfaces can generate internal stresses and trigger delamination.
2. Moisture ingress along alloy-encapsulant interfaces can volatilize during reflow causing "popcorning" types of delamination.

Processes that micro-roughen the Cu-alloy and apply an adhesion promoting layer onto leadframe surfaces have been shown to improve moisture sensitivity performance at lead-free reflow temperatures[1].

The PackageBond process has been shown to alter the morphology of the copper alloy surface, but to not alter the silver or nickel-palladium-gold plated surface topography. While the generation of these roughened surfaces provides enhanced adhesion to copper alloy surfaces, there are other unexpected effects that can interfere with the assembly of microelectronic packages.

A crucial function of the leadframe is to provide interconnection from chip to board through the leads. An important facet of this connection is the wire bond – the connection from the chip to the lead. Typically, gold wire is chosen as the connection medium in many microelectronic packages, including QFN's. The gold is bonded to the aluminum pads on the semiconductor chip and to silver or nickel-palladium-gold plated leads.

Typically, gold wire is bonded to chip and lead using "thermo-sonic" bonding where heat, force, and ultrasonic energy are used to weld the wire to the surface of interest. An alternative method is thermo-compression bonding which uses only heat and force to generate the bond. Thermo-sonic bonding is more prevalent because thermo-compression wire bonding typically requires higher temperatures (>300º C) to create reliable bonds[2]. This can sometimes negatively impact some of the assembled parts of the package (e.g. die or die attach).

Efficient wire bonding demands extremely clean lead surfaces. The need for a clean surface is three-fold:

1. Contamination can interfere with the bond, reducing both strength and reliability.
2. Some contamination can lead to a reduction in lifetime of the capillaries that guide and apply the wire to the surface. This could translate to a higher cost for assembly both in terms of material and time.
3. Surface contamination on the lead pad can cause delamination. MSL-1 reliability criterion clearly states that no delamination can occur on the lead.

For this purpose, some assemblers utilize plasma cleaning to purge the surfaces of unwanted contamination prior to the wire bonding process. Unfortunately, plasma cleaning equipment is costly and the process can be relatively slow. For high-volume packaging businesses, this can present a productivity bottleneck. One objective of the PackageBond process was to provide silver lead pads that do not require plasma cleaning.

Another issue with which many assemblers struggle, is called resin bleed or EBO (epoxy bleed out). The die attach adhesives are typically made from epoxy resins filled with silver particles. The liquid epoxy resins can leach away (bleed out) from the silver particles and onto the surfaces to which the adhesive has been applied. The PackageBond process which micro-roughens the alloy surface can lead to higher levels of EBO on copper die attach pads. The roughness provides a very fine topography that acts as a wick and helps to draw the epoxy resin away from the bulk of applied adhesive. Figure 1 illustrates the increase in EBO on C-194 alloy as a result of using the PackageBond process.

Figure 1 – EBO on Untreated and Treated C-194

With many packages now requiring ground bonds – wire bonds to a silver ring on the die attach pad, resin bleed from the die attach adhesive can lead to contamination of the wire bonding surface. In fact, some adhesives can bleed onto the silver surface and be cured during the die attach process. This is shown in figure 2.

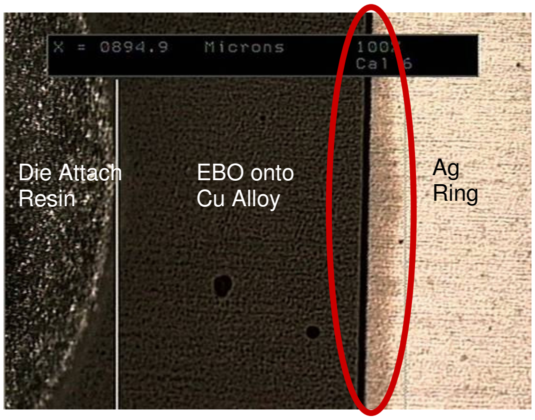

Figure 2 – Bleed of Epoxy Resin Onto Ag-ring

When a ground bond is attempted to a contaminated silver surface, it fails because the silver is not clean. Again, plasma cleaning can be utilized, but the same drawbacks, mentioned previously, exist.

Another way that EBO can impact package reliability is that epoxy cured during die attach can interfere with the bond strength of the molding compound to the die attach pad. This can also lead to delamination defects[3].

To prevent or minimize resin bleed, anti-EBO or anti-bleed treatments are applied to the leadframe surfaces. Typically, these treatments affect the surface energy of the leadframe to provide poor "wetting" by the die attach adhesive. Any anti-bleed treatment must meet several objectives:

1. Must not interfere with die attach or mold compound adhesion.
2. Must not interfere with wire bonding performance.
3. Must reduce epoxy bleed.

TESTING RESULTS AND DISCUSSION

The PackageBond process includes a Postdip step for silver cleaning. When the process was developed, an efficient solution was developed to improve the cleanliness of the silver-plated wire bonding pads. Customer feedback indicated that some issues with wire bonding occasionally occurred. In order to eliminate any wire bond issues, a further step of rinsing while applying ultrasonic energy was evaluated.

The method used to analyze the silver surface for contamination employed Auger Electron Spectroscopy (AES). AES employs the measurement of Auger electrons that escape from a relatively thin portion of the surface layers – the top 0-3.0 nm[4]. Because of the small analysis depth, the analysis is sensitive to very low levels of contamination. Additionally, an ion beam can be used to remove slices of known thickness, and to thus provide a "depth profile" of contamination depths.

Survey spectra were taken before Postdip application and after Postdip with ultrasonic rinsing. The survey results for silver plated lead frames using C-7025 base copper alloy are shown in figures 3 and 4. Contamination from alloy constituents (Cu, Ni, Si) and organic components (C, O, N) can were observed.

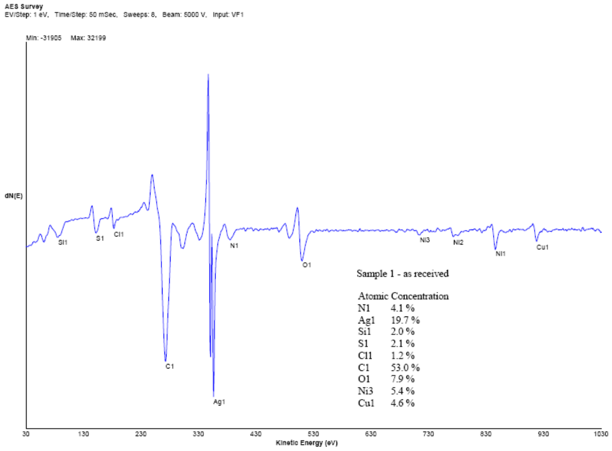

Figure 3 – AES after PackageBond

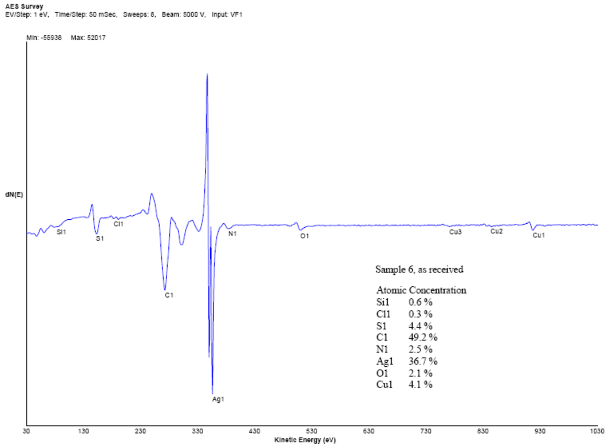

Figure 4 – AES after Postdip and Ultrasonic Rinsing

The samples were then sputtered to remove 5 nm of the surface, and the spectra were again taken. These spectra are shown in figures 5 and 6.

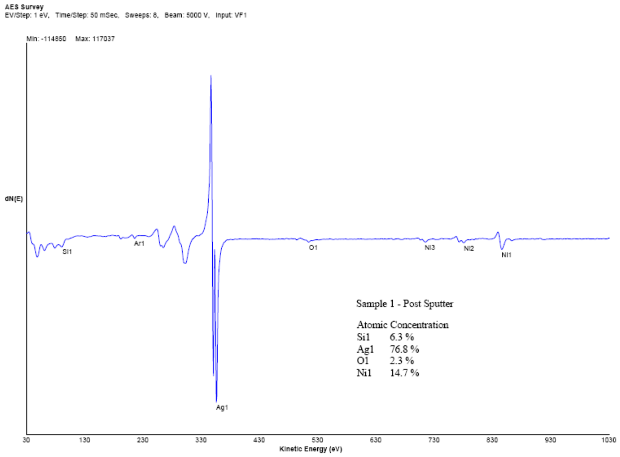

Figure 5 – AES after PackageBond and Removal of 5 nm by Sputtering

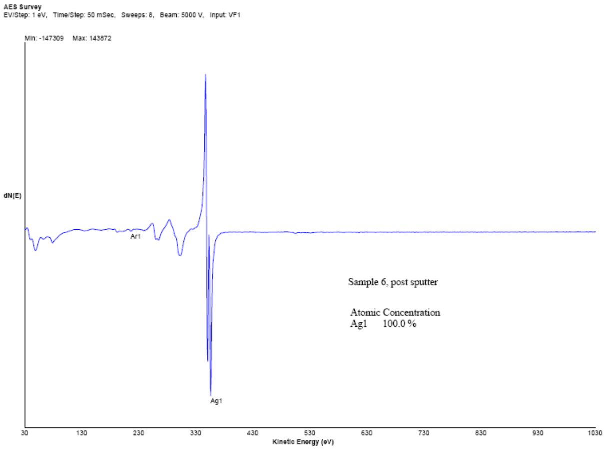

Figure 6 – AES after Ultrasonic Rinsing and Removal of 5 nm by Sputtering

Examination of the silver purity (Atomic %) indicated that ultrasonic rinsing quite effective in removing contamination at a depth of ≤ 5 nm.

Gold wire bonds were made to the silver pads and pull tests demonstrated the improvement seen with the new post treatment regimen. Wire bond application was made under the following conditions:

Equipment:	K&S 4524A Manual Ball Bonder
Wire:	99.99% Au; 1.0 mil diameter, 8 g minimum tensile strength
Ball Bond:	Power=2.5; Time=1.5; Force=0.5
Wedge Bond:	Power=3.01; Time=2.5; Force=1.5
Bond Length:	1.5 mm
Temperature:	125° C

For pull testing a Xyztec Condor 70-3 was used with the following test conditions:

Hook Diameter:	50 µm
Hook Location:	0.75-1.00 mm from wedge bond
Pull Velocity:	100 µm/s
Pass Criterion:	>5 gf

The results (see table 1) demonstrated that wire bonding was good for all samples initially, but after 8-days aging in vacuum at room temperature, the surface that had not seen Postdip and ultrasonic showed significant degradation, and pull strengths were reduced by 60%.

Table 1 – Wire Bond Testing

Sample	**No Aging**	**After 8 Days**
No Treatment	8.93	9.86
PackageBond but No Postdip and Ultrasonic Rinse	11.09	3.67
After Postdip and Ultrasonic Rinse	10.88	9.87

Installation of the Postdip/Ultrasonic steps in the field has allowed customers that rely on plasma prior to wire bonding to eliminate this costly step, yet still obtain good wire bond yields and maintain capillary life.

While the utilization of a post-cleaning step addresses wire bond performance, it does not provide reduced EBO capability. An anti-bleed chemistry was developed that showed great promise. Application of this solution allowed complete elimination of the unwanted EBO, as shown in figure 7.

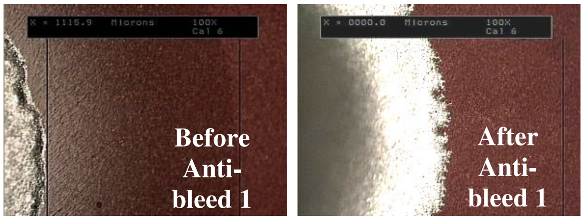

Figure 7 – Effect of Anti-bleed 1

Unfortunately, field trials indicated that there was an issue with some adhesives properly wetting the treated surface.

For further testing, a more precise method for measuring EBO was developed. Previously, a small drop was dropped onto the surface from a syringe, but precision of drop volume was not considered. The use of a pneumatic drop delivery system enabled reproducible application of the adhesive.

Adhesive was applied by resting the dispensing tool on the substrate at a 45° angle. Activation of a valve for a controlled time allowed a known volume of air to force the adhesive through a nozzle and onto the substrate. Drop volume could then be controlled by nozzle opening size, supply air pressure, and activation time. While it was anticipated that this system would provide more uniform results, it also provided an easy way to measure wettability. Poor wetting was observed by inability of the dispensed drop to adhere to the surface. Instead, it remained at the tip of the nozzle. Figure 8 illustrates this test.

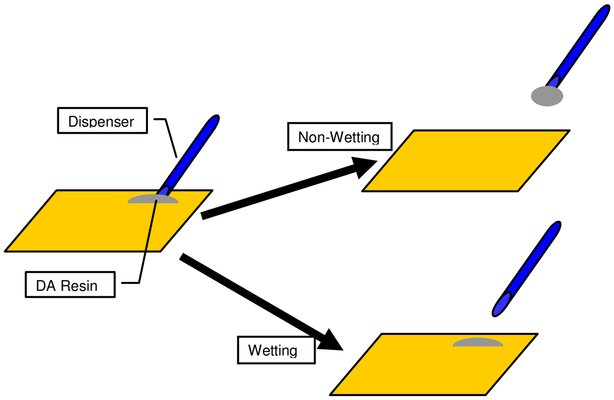

Figure 8 – Schematic of Wetting Test

For all EBO tests, drops were applied using the above method. The samples were then staged for 4-hours at ambient temperature to simulate typical hold times. EBO was then measured. Two die attach adhesives were examined, both manufactured by the Henkel company – Hysol QMI-519 and AbleBond 1 LMI SR-4. EBO and wetting results are presented in table 2.

Table 2 – EBO / Wetting Results

	EBO (mm)	
	Hysol QMI-519	**AbleBond 1 LMI SR-4**
No Anti-bleed	1.30	2.44
Anti-bleed 1	0.0	Did not wet
Anti-bleed 2	0.14	0.0

Wire bond testing was performed on silver-plated lead frame samples treated with both Anti-bleed formulations. The results were compared to an untreated lead frame. The results, shown in table 3 indicate that no deterioration in wire bond performance was observed as a result of either Anti-bleed treatment.

Table 3 – Wire Bond Testing on Anti-bleed Treated Parts

Sample	**Average Wire Pull Force (g)**
No Treatment	7.9
Treated with Anti-bleed 1	8.1
Treated with Anti-bleed 2	8.9

Adhesion testing was performed using the method described in reference 1. Copper alloy lead frame material was laminated to sheets of epoxy resin material using heat and pressure conditions recommended by the resin manufacturer to provide optimum cure and adhesion. After the assembly was cooled, one inch wide tape was applied to the copper alloy and the alloy material not covered with tape was removed by dissolving in a chemical etchant. Upon removal of the tape a one-inch wide strip of copper alloy, laminated to the epoxy resin is revealed.

The cured epoxy material was anchored to the base of a peel testing apparatus. The alloy material was then peeled away from the cured epoxy resin using an apparatus attached to a force gauge to measure the adhesive strength between the two materials. The adhesive force for the untreated control to the epoxy was 82 g/mm, while the adhesive force for treated samples was 91 g/mm with Anti-bleed 1 and 80 g/mm with Anti-bleed 2

Evaluation of MSL-1 performance was evaluated in a test with a customer experiencing delamination issues with a 24-lead QFN. One set of frames was treated with the customer's normal process (no PackageBond). A second set of frames was treated with the PackageBond process and included the process improvements detailed herein. Both sets were assembled – die attach, wire bond, mold compound, and singulation. The units were then preconditioned at MSL-1 parameters (85° C and 85% RH for 168 hours). After three passes through lead-free reflow conditions (260° C), the units were evaluated by scanning acoustic microscopy. The results shown in figures 9 and 10 illustrate the exemplary performance available with the PackageBond process.

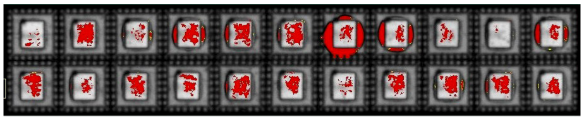

Figure 9 – Untreated QFN

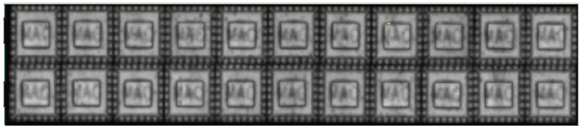

Figure 10 – PackageBond Treated QFN

A second set of QFN frames were similarly tested. While the customer process showed improvement, there was still delamination on some die attach pads and on some leads, representing a failure at MSL-1 conditions. Again, the PackageBond process enabled acceptable performance and MSL-1 conditions.

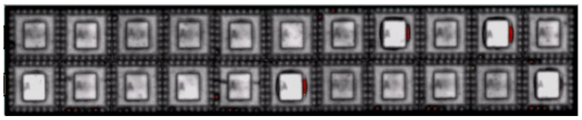

Figure 11 – Untreated QFN

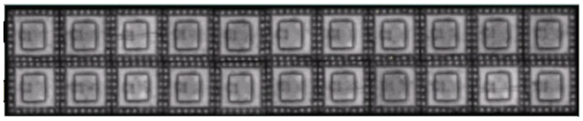

Figure 12 – PackageBond Treated QFN

Conclusions

The challenge of achieving MSL-1 performance with cutting edge design leading to higher functionality in today's chip packages demands continual process improvement at assembly. The drive of industry to the higher temperatures required for lead-free solders compounds the difficulty.

The work contained herein illustrates two of the challenges faced by chip packagers, and describes methods to solve them.

We believe that the work above demonstrates an improved roughening process that can meet the demands of MSL-1 testing criterion, while ensuring reliable wire bond performance and minimizing issues caused by EBO of die attach adhesives.

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[1] Hart, Lee, Ganjei; Increasing IC Leadframe Package Reliability; IMAPS 2008

[2] Harmon; WIRE BONDING IN MICROELECTRONICS; McGraw Hill; 2010

[3] No-Bleed Die Attach Resins; Huneke, Nguyen, Herrington, and Gupta; Henkel Corporation; International Symposium on Advanced Packaging Materials: Processes, Properties and Interfaces, 2005. Proceedings.

[4] Joshi; Auger Electron Spectroscopy; ASM HANDBOOK, VOLUME 10; 1986