Optimization of die attach to surface-enhanced lead frames for MSL-1 performance of QFN packages (part 2)

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This article is part 2 of a two-part series. Part 1 focused on a preliminary assessment of the materials for surface compatibility, fbs.advantageinc.com/chipscale/mar-apr_2017/#36

Quad flat no-leads (QFN) semiconductor packages represent one of the steadiest growing types of chip carriers, and they are predicted to continue growing as original equipment manufacturers (OEMs) strive to put more signal handling into a smaller space. Owing to their low profile, condensed form factor, high I/O and high thermal dissipation, they are popular choices for chip set consolidation, miniaturization and chips with high power density, especially for the automotive and RF markets. As with any package, reliability is critical, and due to their widespread acceptance, OEMs, integrated device manufacturers (IDMs) and outsourced assembly and test suppliers (OSATS) demand continued improvements in reliability of QFNs.

Chemical processes that treat the surface of copper lead frames, to enhance mold compound adhesion, and reduce delamination in chip packages, deliver improved reliability in QFNs. These chemical processes result in micro-roughening of the copper surfaces, while concurrently depositing a thermally robust film that enhances the chemical bond between the epoxy encapsulants and the lead frame surface. Typically, this type of process can reliably provide JEDEC MSL-1 performance.

While this chemical pre-treatment process provides improved performance with respect to delamination, it can create other challenges for the lead frame packager. Increased surface roughness magnifies the tendency for die attach adhesives to bleed (epoxy bleed out or EBO), causing the silver-filled adhesive to separate and negatively impact package quality and reliability. Additionally, any epoxy resin that bleeds onto the lead frame surface can interfere with other downstream processes, such as down-bonding or mold compound adhesion.

Anti-bleed or anti-EBO coatings have been developed to control the amount of bleed, but different adhesives can have different physical properties (surface tension, percent solids, viscosity, etc.) that impact the interaction with the anti-bleed coatings. Consequently, the selection of die attach adhesive can be critical to package performance. This article examines the appropriate methods for optimizing both die attach adhesive chemistry with state-of-the-art lead frame technology.

Performance attributes for achieving MSL-1

In part 1 of this two-part series, we saw the effects of the various factors that could contribute to the MSL-1 performance of the package. The EBO of the die attach was one of the key contributors. The other contributor was the adhesion strength of the die attach and epoxy mold compound to the lead frame and die surfaces. The ATROX® die attach adhesives showed better adhesion strength with cohesive failures in the bulk of the die attach, especially at higher temperatures such as 260°C. This confirms that the material has capability to withstand the reflow process after MSL-1 exposure and not compromise the adhesion strength at the die attach interfaces.

In this article, we will evaluate the different die attach adhesives in an assembled package and test them using MSL-1 preconditioning at 85°C and 85% relative humidity for 168 hours followed by three reflow passes at 260°C. The experiment layout in Table 1 describes the testing plan.

DOE LAYOUT FOR MSL-1 Evaluation				Die Attach		
Leg #	Lead frame	Roughening	Anti-Bleed Concentration (%)	ATROX® DA 1	ATROX® DA 2	Benchmark
1	Cu QFN	PackageBond HT	0.50%	X		
2					X	
3						X
4			0.75%	X		
5					X	
6						X
7			5%	X		
8					X	
9						X
10			7.50%	X		
11					X	
12						X
13			0%	X		
14					X	
15						X
16		Standard – No Roughening		X		
17					X	
18						X

Table 1: DOE layout for MSL-1 evaluation testing.

Properties	ATROX® DA1	ATROX® DA2	Benchmark
Chemistry	Non-Epoxy	Non-Epoxy	Epoxy
Weight loss during cure	0.8%	1.35%	5.3%
Cure profile	175C/60min	175C/60min	175C/60min
Volume resistance	0.00008 Ohm-cm	0.0002 Ohm-cm	0.0001 Ohm-cm

Table 2: Die attach adhesive properties comparison.

Experiments

The alloy surfaces were treated with MacDermid Enthone's standard PackageBond HT process – acid cleaner, mild microetch, PackageBond Predip, PackageBond HT coating, and alkaline Postdip. The etch rate was maintained in the 1.50-2.00µm/min range to maintain a consistent surface morphology. The surfaces were then treated with the anti-bleed coating as shown in Table 1. Two ATROX® die attach adhesive products (DA1 and DA2), described in Table 2, were evaluated, along with an industry standard die attach product as a benchmark. The die attach adhesives were dispensed followed by die placement and curing. The cured parts were then molded using an industry standard mold compound that is rated to survive MSL-1 performance.

Table 2 briefly describes the die attach adhesives that were tested for this evaluation. After assembly, the devices then followed the standard JEDEC testing procedure for preconditioning of non-hermetic surface mount devices prior to reliability testing as per JEDEC standard JESD22-A113D. Figure 1 shows the scanning acoustic tomography (SAT) scans of the devices prior to preconditioning treatment.

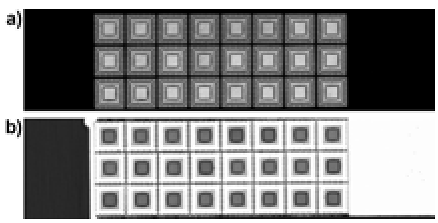

Figure 1: a) C-Scan before MSL-1; b) Through scan before MSL-1.

All parts evaluated with different die attach and anti-bleed treatments were defect-free after SAT inspection prior to MSL-1 preconditioning. Within thirty minutes after preconditioning, the parts were subjected to three sequential reflow passes at 260°C. The reflow profile is shown in Figure 2. After the reflows, the units were again examined by SAT. The delamination results before and after MSL-1 testing are presented in Table 3.

Delamination is observed on all experimental legs involving the non-roughened lead frames. This confirms that the roughening treatment is required for MSL-1 performance. DA1 shows a very wide process window with respect to anti-bleed concentration, which ranges from 0.5-7.5% concentration. DA2 exhibits a narrower window, but within the ranges examined, still possesses a 2.5% (or larger) process window, while the industry standard adhesive doesn't perform well at all anti-bleed concentrations.

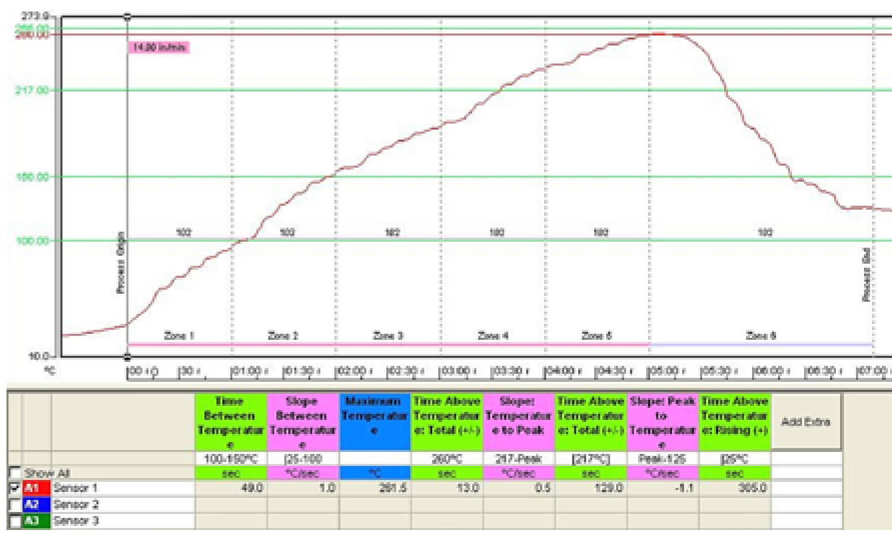

Figure 2: 260°C peak temperature reflow profile.

DOE LAYOUT FOR MSL-1 Evaluation					MSL-1 performance (Failures/Units)			
Leg #	Die Attach	Lead frame	Roughening	Anti-EBO Concentration (%)	Before MSL-1		After MSL-1	
					C-Scan	Through scan	C-Scan	Through scan
1	DA1	Cu QFN	PackageBond HT	0.50%	0/24	0/24	0/24	0/24
2	DA2				0/24	0/24	2/24	14/24
3	Benchmark				0/24	0/24	2/24	8/24
4	DA1			0.75%	0/24	0/24	0/24	0/24
5	DA2				0/24	0/24	8/24	16/24
6	Benchmark				0/24	0/24	2/24	6/24
7	DA1			5%	0/24	0/24	0/24	0/24
8	DA2				0/24	0/24	0/24	0/24
9	Benchmark				0/24	0/24	0/24	24/24
10	DA1			7.50%	0/24	0/24	0/24	0/24
11	DA2				0/24	0/24	0/24	0/24
12	Benchmark				0/24	0/24	19/24	24/24
13	DA1			0%	0/24	0/24	6/24	6/24
14	DA2				0/24	0/24	16/24	24/24
15	Benchmark				0/24	0/24	2/24	24/24
16	DA1		Standard - No Roughening		0/24	0/24	6/24	10/24
17	DA2				0/24	0/24	12/24	12/24
18	Benchmark				0/24	0/24	17/24	24/24

Table 3: SAT analysis results of devices after MSL-1 + 3X reflow at 260°C.

The results show that the ATROX® die attach adhesives outperform the industry standard die attach adhesive on the PackageBond treated lead frames. The reasons for this difference in performance are attributed to the following:

1. Surface roughening treatment to improve adhesion of both epoxy mold compound and die attach adhesive.
2. Reduction of EBO on the roughened surface by the anti-bleed treatment so that the adhesive composition remains consistent and adhesion of epoxy mold compound to the die pad is not affected by cured epoxy bleed from the die attach adhesive.
3. The compatibility of the die attach adhesives with the surface energy of the lead frames resulting from the application of the anti-bleed treatment.

SAT images of ATROX® die attach from Leg 7 after reflow are presented in Figure 3. They confirm that there is no delamination after MSL-1 testing with the ATROX® die attach adhesives. Figure 4 shows microsections of the unit assembled with ATROX® die attach adhesive, and verifies that no delamination is observed. The bond line is consistent and the wetting on the roughened surface is good.

Figure 5 from leg 18 shows the C-scan and Through scan, respectively, for the industry standard die attach adhesive. These SAT scans show delamination after reflow. Delamination occurs at the die attach/lead frame interface, within the die attach adhesive, and at the epoxy mold compound/lead frame interface.

Figure 6 shows microsections of the unit assembled with the industry standard adhesive, and illustrates the delamination observed. Figure 7 from leg 9 is a SAT analysis image that illustrates delamination with the industry standard die attach adhesive that occurs at the surface of the treated lead frame. Figure 8 shows microsections of the unit assembled with the industry standard adhesive, and illustrates that the observed defect was caused by epoxy mold compound delamination that propagated into the die attach.

Results for MSL-1 performance

Delamination is shown to be related to both die attach adhesive and epoxy mold compound adhesion at the lead frame interface. The roughening treatment provides improved adhesion performance after MSL-1 testing for both epoxy mold compound and die attach adhesive. However, even roughening doesn't help to eliminate all delamination unless the anti-bleed coating is applied. Part 1 of this series demonstrated that very high EBO is detected on roughened surfaces without the anti-bleed coating. The current evaluation reveals that delamination can occur at the lead frame interfaces, but also indicates that delamination of mold compound from the lead frame can generate a crack that would propagate into the cured die attach adhesive. These delamination sources are eliminated by roughening the lead frame and eliminating EBO. So, the recommended route to MSL-1 performance is to provide a roughened lead frame surface and a die attach adhesive that wets this roughened surface without generating EBO. To do this successfully, the anti-EBO coating and die attach adhesives need to be compatible. This poses another issue. Most packaging houses prefer the lead frame manufacturer to provide the anti-EBO coating on the lead frames that they supply.

While the solution noted above is easy, it is not always the best unless both the packaging house and lead frame producer

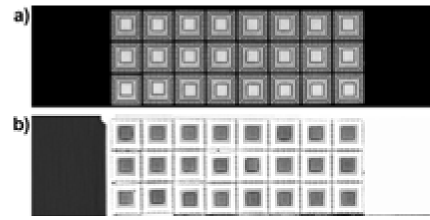

Figure 3: a) C-SAM shows no delamination after MSL-1; b) Through scan shows no delamination after MSL-1.

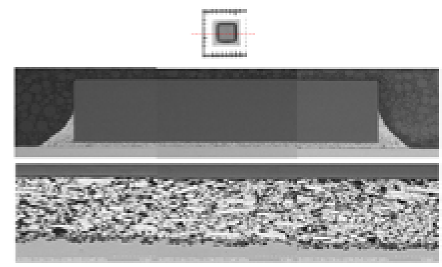

Figure 4: Microsections of a unit assembled with ATROX® die attach adhesive.

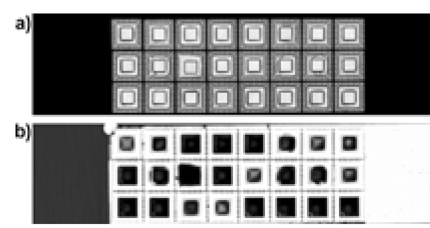

Figure 5: a) C-SAM shows delamination after MSL-1; and b) Through scan also shows delamination after MSL-1.

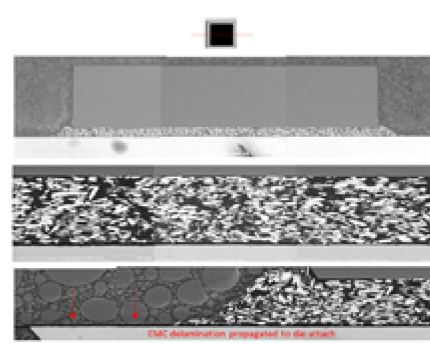

Figure 6: Microsection images of a unit assembled with an industry standard die attach: a) (top panel) Microsection image of a unit assembled with an industry standard die attach; b) (middle panel) Magnified image of the unit showing delamination; and c) (bottom panel) Epoxy mold compound delamination propagated into the die attach.

agree on die attach adhesive and anti-EBO treatment. In general, lead frame companies desire an anti-EBO treatment that will work with all die attach adhesives. The work presented here illustrates the difficulty of achieving MSL-1 performance without considering the anti-bleed and die attach adhesive compatibility. Perhaps a more effective solution would be for the packaging house to install the anti-bleed application so that they can be matched to the die attach adhesive(s) that are used in-house.

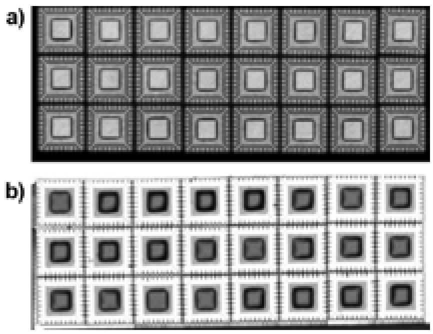

Figure 7: a) C-SAM shows no delamination after MSL-1; b) Through scan shows delamination after MSL-1.

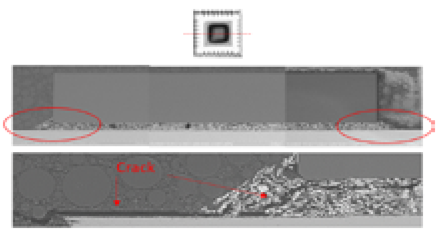

Figure 8: Delamination on lead frame paddle area propagating into the die attach layer.

Summary

The key finding from this study was that the use of roughening processes is critical for enhancing adhesion strength to lead frame surfaces, however, what is also critical is to choose a compatible anti-bleed material that reduces/eliminates EBO on the lead frame surface and doesn't interfere with adhesion of mold compound or die attach adhesive to lead frame surface. This combination of treatments maintains the joint integrity during high stress such as MSL-1 performance followed by a 260ºC reflow process. The two ATROX® die attach adhesives, although different in properties, are shown to be compatible with the MacDermid Enthone PackageBond HT roughening and PackageBond Anti-Bleed surface treatments, which lead to high MSL reliability.

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