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

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This article is part 1 of a two-part series. Part 2 focuses on MSL-1 evaluation of the material combination.

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 semiconductor assembly and test suppliers (OSATS) demand continued improvements in the 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 pretreatment 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 (Figure 1).

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

MSL-1 performance is typically attributed to a number of factors in the semiconductor package. The various materials such as epoxy molding compound, die attach material, lead frame alloy type and surface chemistries, as well as the die type and size, all influence the performance of the package as a whole. The performance and interaction of the individual materials is important in preventing delamination in the package during MSL-1 testing. This article focuses on the key material interactions and their effects on MSL-1 performance.

Conductive die attach typically will undergo stress during the MSL-1 exposure and reflow so it is important it maintains its properties and does not initiate delamination with the lead frame surface or die back side (Figure 1). The other key factor that contributes to the failures is epoxy bleed out or resin bleed out. The resin from the epoxy will bleed onto the lead frame surface. This can cause loss of adhesion to epoxy molding compound and result in delamination during MSL-1 (Figure 2). In addition, as the epoxy bleeds onto the lead frame, the composition of the adhesive under the die changes—less epoxy and more silver. This can impact the adhesion of the die attach to the lead frame or the die, and result in an adhesive failure, as opposed to the desired cohesive failure mode. So, it is very critical for the die attach to not cause any significant bleed out on the lead frame surface.

With the challenges driven by the move to lead-free electronics components, reflow temperatures have increased significantly. This move triggered a reduction in reliability at MSL-1, specifically delamination of epoxy molding compounds (EMCs) and die attachment from the lead frame surface. To improve MSL performance, many semiconductor packagers have turned to different methods for adhesion improvement. The most popular of these is generically termed "brown oxide" or "alternative oxide," which roughens the copper lead frame surface while concurrently applying an organometallic coating.

The brown oxide mechanism comprises an intergranular etching process that selectively etches small gaps between copper grains of the lead frame alloy. The

Figure 1: Typical construction of a QFN package showing EBO from die attach material.

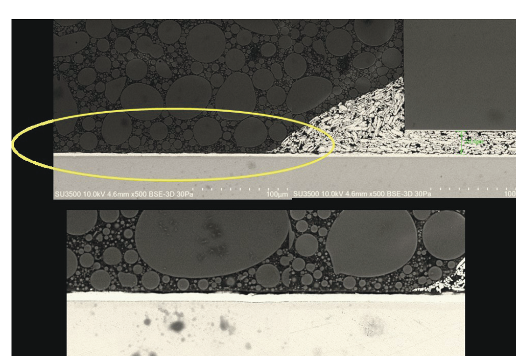

Figure 2: Delamination observed due to EBO from die attach.

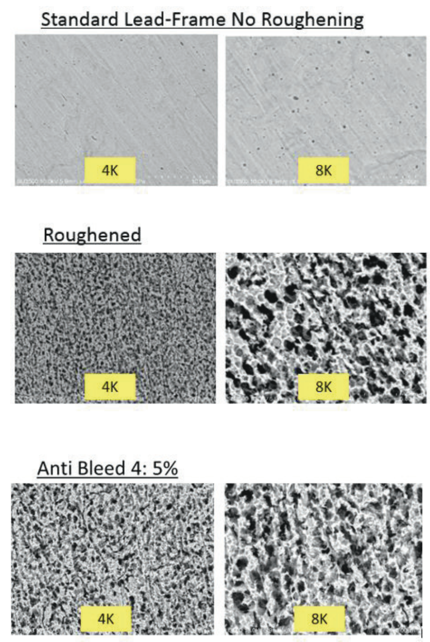

Figure 3: SEM image of a lead frame surface comparison before and after treatment.

etching composition includes organic additives to help define the surface morphology. During the process, etched copper ions react with organic components to form an organocopper coating that is deposited onto the alloy surface. It has been demonstrated that the roughened surface morphology produces improved adhesion, and that the coating is necessary to minimize loss of adhesion during post-mold heating excursions (e.g., reflow) (Figure 3) [1].

A disadvantage of the roughening process is that it leads to an increase in resin bleed out (RBO), sometimes referred to as epoxy bleed out (EBO). The sponge-like morphology of the alloy surface after treatment produces a capillary action that triggers a leaching or bleeding of the fluids in the die attach adhesives away from the adhesive deposit.

Methods to control epoxy bleed out

There are two key methods to control the EBO on a lead frame surface. The first is to tailor the die attach adhesive to the lead frame surface. The die attach formulation has added anti-bleed agents that minimize the flow out of resin and other organics onto lead frame surfaces. Each anti-bleed agent has a different response to the surface chemistry of the individual lead frame surface, thereby necessitating a compatible combination that will have delamination-free performance during MSL-1 testing.

The second method uses compatible anti-bleed coatings on the lead frame to match the chemistry of the die attach and minimize the EBO. From a surface treatment perspective, the key to limiting EBO is to control the surface energy on the lead frame. Application of a coating to the lead frame that reduces the surface energy will reduce the degree of capillary action and reduce/eliminate EBO. Theoretically, this can be seen from Young's contact angle equation (**Eq. 1**; see Figure 4 for additional details):

$$\Upsilon_{SV} - \Upsilon_{SL} - \Upsilon_{LG} (\cos\theta) = 0 \qquad \textbf{Eq. 1}$$

Where: Υ_{SV} = Surface energy
Υ_{SL} = Interfacial energy between surface and liquid
Υ_{LV} = Surface tension of the liquid (droplet), and
Θ = Contact angle between the liquid and surface

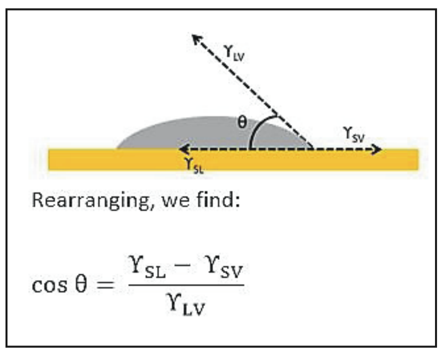

Figure 4: Relationship between the parameters in Young's contact angle equation.

Rearranging the equation, we find the following observations. As the surface energy (Υ_{SV}) decreases, the numerator increases and the term cos θ decreases. This situation occurs when the contact angle θ increases. So decreasing the surface energy increases the contact angle, thereby decreasing wetting of the surface. This can also be accomplished without adjusting the surface energy by increasing the surface tension (Υ_{LV}) of the liquid.

On the contrary, if the surface energy is reduced too much, the resin will resist wetting the surface and can "shrink" away or dewet from the surface. In a worst case, the adhesive will not wet the surface. Therefore, optimization to control EBO while maintaining the enhanced adhesion and thermal resistance properties is critical.

The combination of surface anti-bleed coatings on the lead frame and their compatibility with specific anti-bleed agents in die attach is studied and hereby presented as a compatible combination for delamination-free MSL-1 performance.

Experiments

The alloy surfaces were treated with MacDermid Enthone's standard PackageBond HT process: acid cleaner, mild micro-etch, PackageBond Predip, PackageBond HT coating, and alkaline Postdip. Etch rate was maintained in the 1.50-2.00µm/min range in order to maintain a consistent surface morphology. The surfaces were then treated with the anti-bleed coating as shown in Table 1.

DOE LAYOUT FOR RBO & DSS				Die Attach		
Leg#	Lead-Frame	Roughening	Anti-EBO Concentration (%)	DA1	DA2	Benchmark
1	CuQFN	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 EBO and adhesion testing.

Two ATROX epoxy die attach products were evaluated with an external benchmark die attach product. The die attach adhesive was dispensed in a standard asterisk pattern and then staged for four hours before measuring the EBO on the different surfaces (Figure 5).

Figure 5: EBO results

All die attach products showed EBO on the roughened lead frame surface as expected. The two ATROX die attach products showed minimal epoxy bleed out on the lead frame surfaces treated with an anti-bleed coating, indicating good compatibility with the surfaces. Table 2 compares the die attach materials in terms of key properties.

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	0.0002 Ohm-cm	0.00008 Ohm-cm	0.0001 Ohm-cm

Table 2: Comparison of die attach materials in terms of key properties.

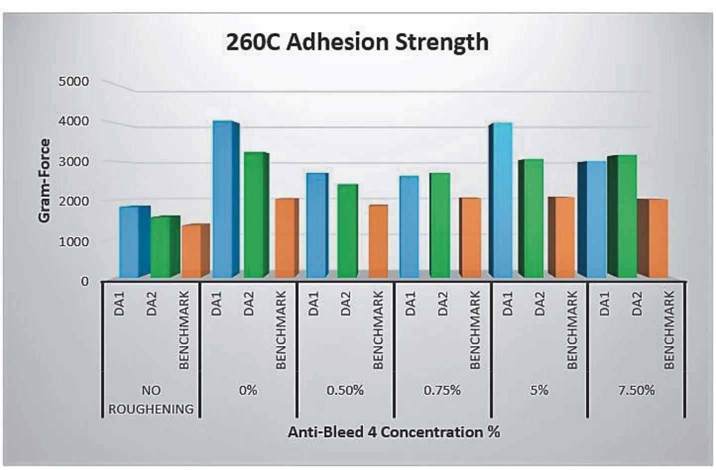

Figure 6: High-temperature adhesion results.

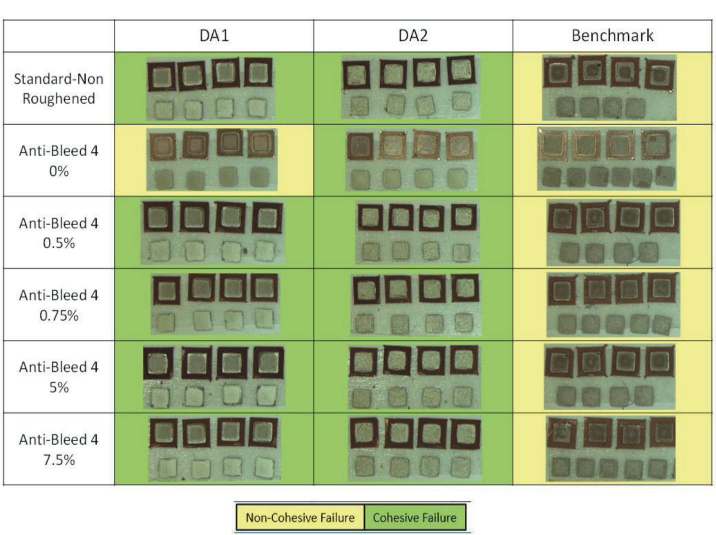

Figure 7: Failure modes of die shear adhesion results.

Experiment results for adhesion

Different die attach materials are tested on copper lead frames with different coatings to evaluate the adhesion strength and failure modes to determine the most compatible combination. Adhesion strength is measured by die shear at elevated temperature (260°C) (Figure 6). The failure mode is evaluated by inspecting both the die and lead frame surfaces after shear. The desired failure mode — cohesive — is indicated by adhesive remaining on both die and lead frame surfaces.

The benchmark product showed significantly lower adhesion on all conditions evaluated, indicating that the material does not possess high adhesion strength at high temperature. However, the samples treated with the brown oxide process exhibited improved adhesion strength for all adhesives, including the benchmark. The other important finding was that the two ATROX die attach products showed a very low drop in adhesion with untreated lead frames while using 5% of PackageBond Anti-Bleed 4. This demonstrates that both improved EBO resistance, in addition to increased adhesion strength at high temperatures, can be achieved with the proper combination of EBO reduction techniques (Figure 7).

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, it is also critical to choose a compatible anti-bleed material that reduces/eliminates EBO on the lead frame surface and doesn't interfere with adhesion of die to the lead frame. This combination of treatments maintains the joint integrity during high stress such as MSL1 performance followed by a 260°C reflow process.

The two ATROX die attach materials, 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.

Acknowledgment

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Reference

1. D. Hart, B. Lee, J. Ganjei, "Increasing IC lead frame package reliability," 41st International Symp. on Microelectronics 2008, IMAPS Conf. Proc., 533, 2008.

Biographies

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