No Bleed Die Attach to Roughened Lead frame

Dan Hart, Senthil Kanagavel, Elisia Siow,
MacDermid Alpha Electronics Solutions
CT, USA
Dan.Hart@MacDermidAlpha.com; Senthil.Kanagavel@MacDermidAlpha.com;
Elisia.Siow@MacDermidAlpha.com

ABSTRACT

Alternative oxide processes that roughen leadframe surfaces and leave behind an organo-metallic coating to improve adhesion are considered state-of-the-art prevention for delamination arising from moisture reflow sensitivity, sometimes referred to as "popcorning". An unfortunate consequence of increasing surface roughness imparted by these processes is an expansion in resin bleed during die attach, which is commonly referred to as resin bleed out (RBO) or sometimes EBO (epoxy bleed out). RBO arises because the morphology generated by roughening the surface creates small channels that allow the low surface tension organic resins in the adhesive to flow along the surface via capillary action. The silver filler remains in place, but the resin material bleeds away from the bulk. This leads to a weakening of the overall adhesive deposit because it changes the ratio of silver filler particles to resin.

With the advent of automated technologies, the semiconductor industry requires a new paradigm of reliability. Certainly, autonomous driving, where reliability cannot be sacrificed, provides one of the biggest market incentives. Because reliability requirements for chip packages are continually advancing, packaging houses require die attach alternatives that do not bleed onto roughened leadframe surfaces. Traditional methods to reduce RBO on a roughened surface utilize a chemical treatment to reduce the surface energy of the substrate. These "Anti-Bleed" products work in theory, but variations in different adhesive formulas can lead to variations in the effectiveness of the anti-bleed treatments.

One solution to this issue applies the die attach adhesive to the wafer as a semi-solid film. This adhesive remains on the die after singulation and placement onto the lead frame surface and is cured during reflow. The advantage of this application method is that anti-bleed treatments should not be required. This paper investigates the use of film die attach on roughened leadframes from an adhesion perspective and compares with traditional processes. Since the film die attach must flow into the topography created by the roughening treatment, adhesion can be affected if the flow is restricted by the rheology of the film. Die shear techniques are used to evaluate adhesion as a function of leadframe surface roughness.

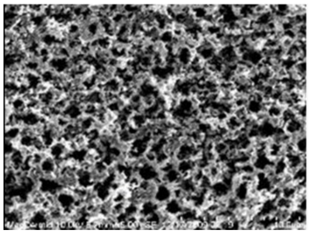
Key words: die attach, conductive film, EBO, RBO, resin-bleed, anti-EBO, anti-bleed, lead frame roughening, alternative oxide

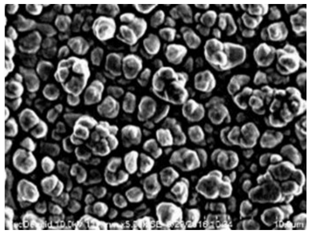
INTRODUCTION

Improvements in reducing moisture-initiated delamination of epoxy mold compounds to roughened, copper-based lead frames have been validated over the past 15 years. There are two primary methods employed to roughen lead frame surfaces – one is subtractive (removes some of the surface to provide a rough morphology), and the other is additive (electroplates a rough copper surface onto the lead frame).

It is generally accepted that adhesion is a function of surface area because increased surface area leads to increased interaction between the two surfaces being adhered. The aggregate of adhesive or attractive forces between the two surfaces increases with surface area. So, increasing the lead frame surface area will lead to improvements to overall adhesion. Additionally, if the method of increasing the surface area of copper-based lead frames is accomplished by generating a surface morphology that will also provide a physical interlock between mold compound and lead frame, the adhesion is further enhanced.

Both subtractive and additive approaches to roughening are currently employed in the semiconductor packaging industry; however, the subtractive approach has the advantage that it can be utilized at either the lead frame factory or in the packaging house. In a packaging house, the additive approach will electrolytically plate copper onto Ag or Ni/Pd/Au bonding pads leading to interference with wire bonding in traditional die attach processes. Figure 1 illustrates the morphology of both subtractive and additive approaches.





An unfortunate consequence of roughening lead frame surfaces is that traditional, silver-filled die-attach adhesives will exhibit increased resin bleed out (RBO). These materials are silver filled liquids. The liquid matrix can be epoxide, acrylate, or bis-maleimide, and it can also contain surfactants, wetting agents, and solvents. On roughened surfaces, the liquid matrix will leach out from the deposited adhesive during staging and curing leading to RBO. The increased RBO on roughened surfaces leads to multiple issues, including:

- Changes in the filler to adhesive ratios leading to weaker bonding
- Reactive monomers leaching onto the lead frame surface which, when cured, can block the effectiveness of the surface roughening

For this reason, lead frame roughening treatments include a surface treatment to reduce or eliminate the RBO. Because of the wide variety of die attach adhesives available, it is difficult to provide an all-encompassing solution.

The aim of anti-bleed treatments is to reduce the surface energy of the substrate, thereby reducing the wetting of the surface by the liquids in the adhesive. The relationship between surface energy, interfacial energy, surface tension, and contact angle is described by Young's equation, which can be rearranged as:

$$\cos\theta = \frac{\gamma_{SL} - \gamma_{SV}}{\gamma_{LV}}$$

Where:

γ_{SV} = Surface energy
γ_{SL} = Interfacial energy between surface and liquid
γ_{LV} = Surface tension of the liquid (droplet), and
θ = Contact angle between the liquid and surface

Hence, decreasing the surface energy (numerator in the equation), γ_{SV} increases the contact angle, θ, thus reducing the wettability of the surface.

With the development of conductive film die attach materials, the solution becomes much simpler. These films are silver-filled, semi-solid adhesives that cure to an adhesive polymer. The conductive film is applied to the wafer prior to dicing and is transferred along with the die to the lead frame prior to curing. Because the film is a semi-solid, it will not bleed onto the roughened surface during production staging or cure. While this seems like an attractive solution to the RBO problem, there have been no studies confirming the adhesion of the conductive tape to a roughened lead frame surface. The present paper studies the viability of using conductive film die attach onto roughened lead frame surfaces.

EXPERIMENTAL

Two types of adhesives were tested:

1. Traditional silver-filled liquid (Atrox 590-4HT1; cure profile = 30-minute ramp to 175°C + 60 minutes at 175°C followed by cool down)
2. Conductive film die attach (Atrox CF200-1D; cure profile =45-minute ramp to 200°C + 120 minutes at 200°C followed by cool down)

28-lead QFN lead frames (C-194 alloy) were treated with PackageBond HT-U, a subtractive roughening process, and PackageBond Anti-Bleed 4, an anti-RBO treatment designed for use with the PackageBond HT-U roughening treatment.

Different degrees of etching were used to evaluate how differences in roughness impacted the adhesion of film die attach. Etch depths of 0.75 µm, 1.48 µm, and 2.23 µm for low, normal, and high etch rates. An Anti-Bleed was used to evaluate the conductive film adhesion to a traditionally roughened lead frame surface treated with an anti-RBO coating.

Surface roughness was measured using a Zygo New View 7100, a white-light interferometer equipped with a 20X objective and a fixed 2X zoom. The roughness trends measured were R_A (average roughness) and RSAR (roughness surface area ratio). RSAR is a measure of the proportional increase in surface area compared to an ideally flat surface of the same x-y dimensions.

Details of the experimental legs are described Table 1.

Table 1. Lead Frame Treatment for Experiment

PackageBond HT-U	No	Low Etch (0.75 µm)	Normal Etch (1.48 µm)	Normal Etch (1.48 µm)	High Etch (2.23µm)
PackageBond Anti-Bleed 4	No	No	No	Yes (4%)	No

Die shear was performed using a Dage 4000 Multipurpose Bondtester manufactured by the Nordson Corporation. Shear measurements were made at both ambient temperatures and at 260°C. After shearing, the die/lead frame interface was examined to determine if the predominant failure mode was adhesive failure at die surface, adhesive at lead frame surface, or cohesive

RESULTS

No RBO was observed on any surface using the Atrox CF200-1D conductive-film die attach. The non-roughened sample and the roughened sample with 4% Anti-Bleed 4 exhibited no RBO with the Atrox 590-4HT1 liquid die attach, as anticipated. All other liquid die-attach samples on roughened surfaces exhibited significant RBO. Images are shown in Table 2.

Table 2. Images of RBO for all Test Conditions

	Atrox 590-4HT		Atrox CF200-1D
No roughening			
Low etch rate – No Anti-Bleed			
Normal etch rate – No Anti-Bleed			
Normal etch rate – 4% Anti-Bleed 4			
High etch rate – No Anti-Bleed			

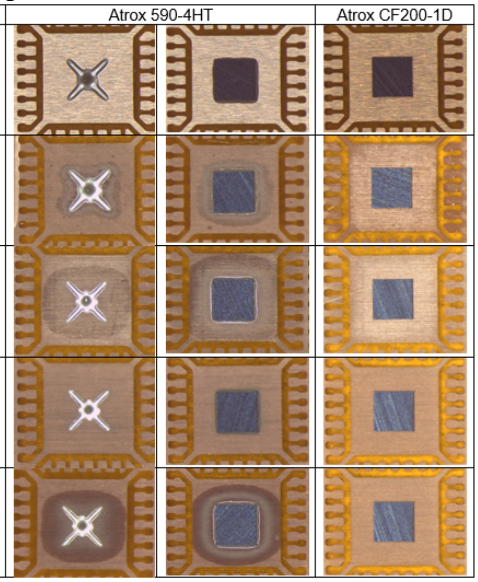


Table 3. Roughness Measurements

	No Treatment	Low Etch No Anti-Bleed	Normal Etch No Anti-Bleed	Normal Etch 4% Anti-Bleed 4	Normal Etch No Anti-Bleed
R_A (µm)	0.13	0.41	0.41	0.41	0.47
RSAR	0.10	0.73	0.77	0.77	0.80

For the purposes of this testing, failure modes were defined as follows:

- Adhesive failure at die surface – no adhesive remains on the die surface
- Adhesive failure at lead frame surface – no adhesive remains on the lead frame surface
- Cohesive failure – adhesive is observed on both lead frame and die surfaces

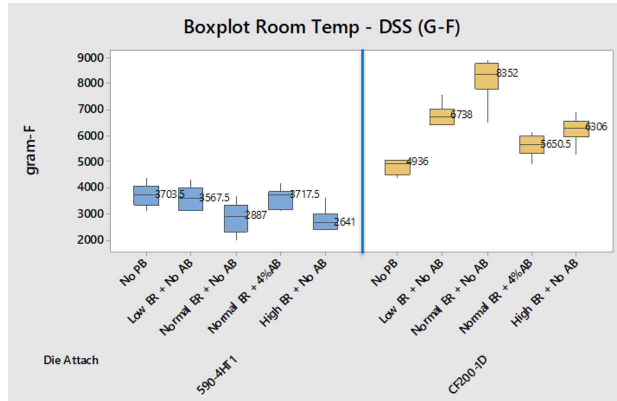


Figure 2. Boxplot of Die Shear after Cure

Table 4. Average Shear Forces and Failure Mode after Cure

Shear at Room Temperature	Atrox 590-4HT1 Shear Force (kg)	Atrox 590-4HT1 Failure Mode	Atrox CF200-1D Shear Force (kg)	Atrox CF200-1D Failure Mode
No treatment	3.7	Adhesive-Die	4.9	Adhesive-Lead Frame
Low etch rate - No Anti-Bleed	3.6	Adhesive-Die	6.7	Cohesive
Normal etch rate - No Anti-Bleed	2.9	Cohesive	8.4	Cohesive
Normal etch rate - 4% Anti-Bleed 4	3.7	Adhesive-Die	5.6	Cohesive
High etch rate - No Anti-Bleed	2.6	Cohesive	6.3	Cohesive

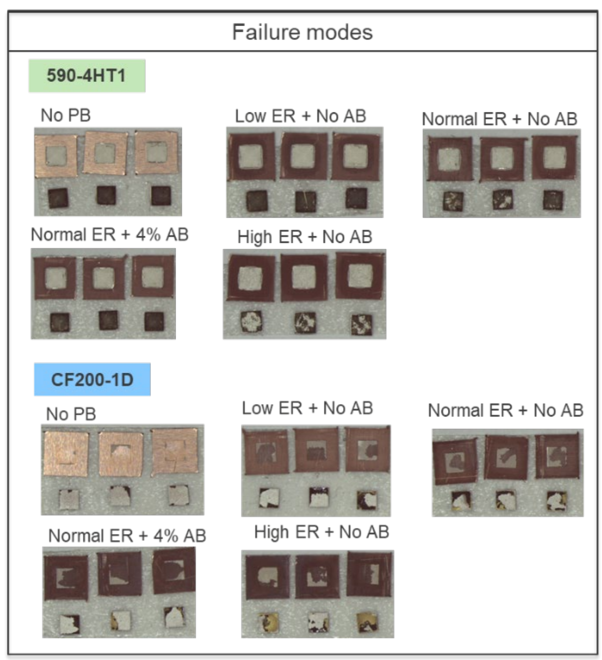


Figure 3. Failure Modes at Room Temperature

A second set of sixteen dies was sheared with the stage temperature set to 260°C. This simulates adhesion at lead-free reflow temperatures. Experience has shown this to be a good predictor for delamination performance during MSL testing. These results are shown in Figure 4 (boxplots), Figure 5 (failure mode images), and Table 5 (summarized results).

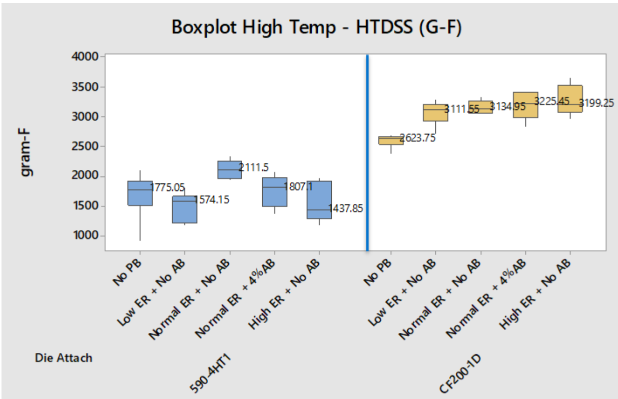
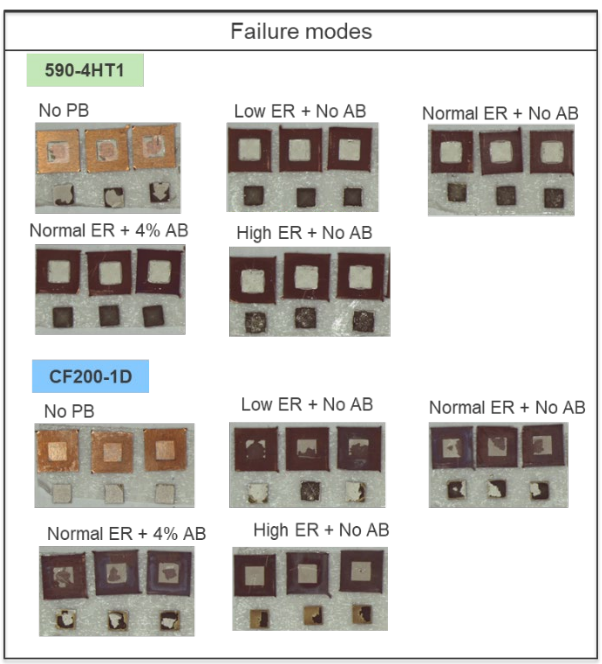


Table 5. Average Shear Forces and Failure Mode at 260°C

Shear at 260°C	Atrox 590-4HT1 Shear Force (kg)	Atrox 590-4HT1 Failure Mode	Atrox CF200-1D Shear Force (kg)	Atrox CF200-1D Failure Mode
No treatment	1.8	Cohesive	2.6	Adhesive-Lead Frame
Low etch rate - No Anti-Bleed	1.6	Adhesive-Die	3.1	Cohesive
Normal etch rate - No Anti-Bleed	2.1	Adhesive-Die	3.1	Cohesive
Normal etch rate - 4% Anti-Bleed 4	1.8	Adhesive-Die	3.2	Cohesive
High etch rate - No Anti-Bleed	1.4	Adhesive-Die	3.2	Cohesive



One unexpected result of the testing was the enhanced performance of the film die attach film compared with the liquid die attach adhesive. This suggests that in addition to a better adhesive property for the conductive film, the flow of the film adhesive into the lead frame's surface microstructure is as good or better than for the liquid adhesive.

To examine the interaction of the conductive film with the lead frame surface morphology, High magnification SEM (Scanning Electron Microscopy) was used to evaluate microsections of the lead frame/die attach film interface. Figure 6 illustrates the surface topography prior to treatment with the roughening process.

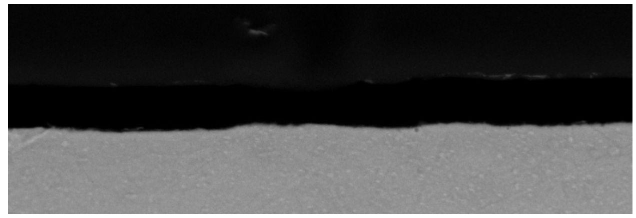
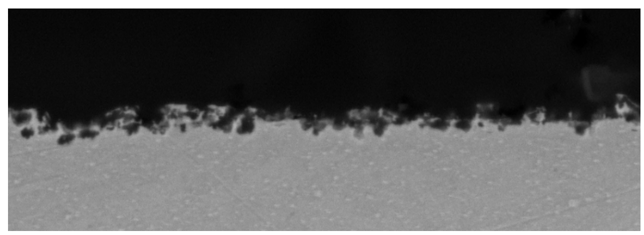
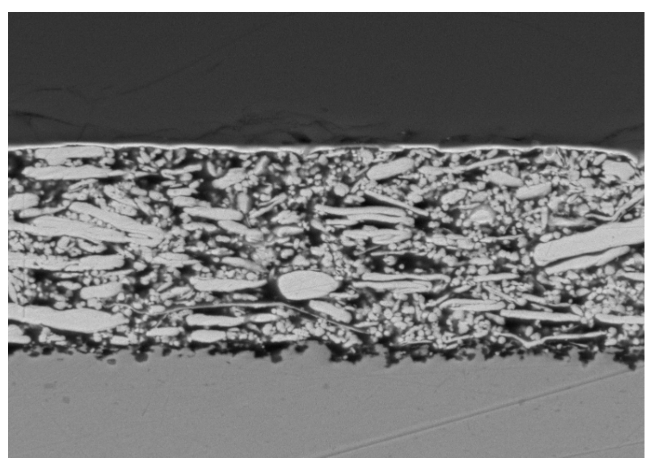
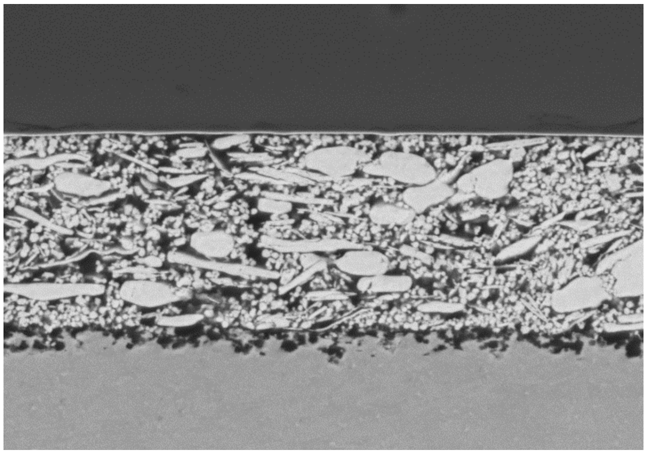


Figure 7 illustrates the increase in surface roughness and, ultimately, surface area as a result of the normal roughening process.



Micro-sections of the conductive film/lead frame interface were initially difficult to interpret using traditional micro-sectioning techniques (Figure 8), so ion milling was used to provide a clean, undistorted surface for SEM imaging (Figure 9).





The distribution of conductive silver particles from the film die attach adhesive can clearly be observed within in the lead frame surface structure after ion milling. This indicates exceptional flow of the conductive film into the lead frame topography during the die attach cure.

DISCUSSION AND CONCLUSIONS

The primary goal of the roughening process is to provide a surface that will reduce or eliminate delamination of epoxy mold compound under MSL-1 testing protocols. Traditional liquid die-attach adhesives, while suffering from RBO issues on roughened surfaces, typically do not have the same moisture sensitivity adhesion issues that are associated with epoxy mold compounds. However, the issues resulting from RBO can lead to significant failure at lead free testing conditions. The present work was undertaken in an effort to develop a no bleed process that delivers exceptional MSL-1 performance.

Initially, there was concern that the semi-solid film would not flow into the microstructure provided by the PackageBond HT-U. Prior to the testing, the consensus among the experimenters was that the liquid die attach would perform better than the film, but it was hoped that the conductive film attach would provide adhesion to the treated surfaces at least as good as the attach to a non-roughened lead frame surface. In fact, the results demonstrated that the film die attach performed better at both ambient temperatures and at lead free soldering temperatures. The tests demonstrate the effectiveness of the conductive film die attach.

Die shear results on the untreated surface indicate that the conductive film die attach provides a 30% improvement in adhesion at room temperature compared to the liquid die attach adhesive. At 260°C the improvement is about 40%.

Combining film die attach with surface roughening delivered a 130% adhesion improvement at room temperature versus the optimum process for liquid die attach (normal etch rate + 4% AntiBleed 4). At 260°C the improvement is75%.

Comparing the improvement on untreated lead frames to the treated frames suggests a 90% improvement for the best film die attach result compared to the traditional liquid adhesive during 260°C testing.

SEM imaging indicated that this behavior resulted from excellent flow of the adhesive into the high-topography, surface structure formed by the roughening process. The combination of roughening with the conductive film die attach provides exceptional adhesion at both room temperature and high temperature die shear testing.

It is noteworthy that the conductive film die attach exhibited poor adhesion on surfaces treated with the anti-RBO process. This means that the use of an anti-RBO treatment is not only unnecessary, but in fact, detrimental to adhesion performance with film die attach. Thus, the use of conductive film die attach eliminates the constantly nagging RBO issue on roughened lead frames for chip packagers.

High reliability chip packaging applications require new approaches for improving performance under stress. As the need for error free performance in these applications grows, the development of methods to overcome known weaknesses in packaging is essential. RBO has long been considered a weak link in the packaging process. Many solutions have been tried. Adhesive suppliers try to adjust surface tensions to minimize RBO while maximizing stability of the silver filler within the liquid matrix. Lead frame manufacturers request anti-RBO treatments that provide reduced RBO with all adhesives used by their customers. The problem here is that both approaches are only band-aids to the real solution.

Table 6 lists some of the significant benefits of film die attach compared to the liquid die attach process. These benefits provide the package designer the ability to provide the higher I/O with higher reliability required for today's advanced package solutions.

Table 6. Benefits of Conductive Film Die Attach

Liquid Die Attach	Conductive Film Die Attach
RBO on roughened surface requiring anti-RBO treatment	No RBO - No anti-RBO needed
Normally requires UV dicing tape	Uses non--UV dicing tape
Adhesive must be thawed and then dispensed onto lead frame using pressure and time	Adhesive is attached to die prior to dicing, so no need to dispense adhesive onto lead frame
Bond line is controlled by pick and place equipment	Uniform bond line
Depending on the dispense pattern and curing profile, voids can occur under the die	No chance for void formation within the adhesvie
Fillet formation undesirable for tight tolerance designs	Minimal / No fillets with conductive film
Adhesive creep onto thin dies can cause contamination	Film offers a contamination-free solution for thin dies
Open / Staging time must be controlled	No open /staging time concerns with conductive film

It has been demonstrated that RBO can lead to delamination on the die pad which propagates into the die attach bond. Use of liquid adhesives requires that the surface energy of the lead frame be tuned to the adhesive being applied. The "no-bleed" adhesive also provides improved adhesion which translates into better reliability. This increased reliability is one of the technology advancements that needed for today's critical applications, such as:

- Devices needed for autonomous driving in modern automobiles
- Critical medical sensors that can be implanted in the human body
- Aerospace devices that must survive temperature-pressure changes encountered in space
-

REFERENCES

I. Hart, Lee, Ganjei; Increasing IC Leadframe Package Reliability; IMAPS, 2008

II. Hart, Ganjei, Kapadia; Enabling MSL-1 Capability for QFN and Other Design Leadframe Packages; IMAPS, 2010

III. Hart, Kanagavel; Optimization of die attach to surface-enhanced lead frames for MSL-1 performance of QFN packages (part 2); Chip Scale Review; July-August 2017