

INCREASING IC LEADFRAME PACKAGE RELIABILITY

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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. Component level defects such as delamination and “popcorning” in surface mount IC lead frame components have increased significantly since lead free soldering has become mainstream.

Popcorning and delamination defects often manifest themselves as a fracture between the epoxy based encapsulant and the metal, usually copper alloy, leadframe components used to form a surface mount IC component. This fracture occurs when moisture in the package volatilizes during the reflow process and forces its way through the encapsulation material and leadframe interfaces.

The keys to popcorning, or delamination, defect reduction are twofold. The first objective is to enhance the bond between the encapsulant and the copper leadframe materials to form a stronger bond that is capable of withstanding the vapor pressures induced during reflow. The second objective is to provide a superior bond between the leadframe and encapsulant thus minimizing moisture ingress. In either case, delamination defects may be identified immediately after assembly during ICT, have latent defects that manifest themselves in the field, or a mixture of both.

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 alloy leadframe.

Key words; Leadframe, Delamination, Popcorning

INTRODUCTION

As with any major technical and materials shift there can be unanticipated negative side effects despite best efforts in predictive testing, modeling, and planning. The RoHS mandate was no exception. Since the advent of large scale Pb free soldering a number of new temperature / moisture related issues have arisen, most of them directly linked to the elevated reflow temperatures required to form acceptable Pb free solder joints. Eutectic solder reflow temperatures are typically in the 200C to 215C range

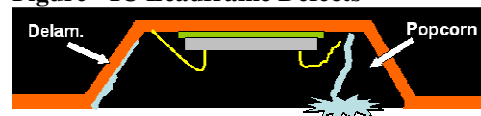
whereby the new Pb free solders require reflowing temperatures in the 240C to 250C range. This 30C to 40C increase in reflow temperatures for Pb free solders has had a wide ranging ripple effect throughout the electronics production supply chain and has effected virtually every material and component used to manufacture a PCBA.

The focus of this technical discussion will be related to the leadframe IC package segment of the electronics supply chain and how this business sector is dealing with new reliability and performance criteria in the Pb free world.

Moisture content in IC leadframe packages has been a defect and reliability issue for quite some time but recently, as assemblers increased reflow temperatures to accommodate Pb free solder reflow requirements, the matter of moisture related defects has been compounded since the vapor pressures in a package have increased exponentially with these elevated reflow temperatures. Vapor pressure, caused by the varying degrees of moisture within a given package turning to water vapor, builds during reflow and once it reaches a pressure level exceeding the chemical and/or mechanical bond strengths of the materials used to form an IC leadframe package, it releases through the path of least resistance. Many assembly, materials, and methods factors play a role in how severe or frequent the popcorning or delamination is and much work has been done to address the issue.

Both popcorning and delamination are defects in an IC leadframe package but their respective effect on the package can vary significantly.

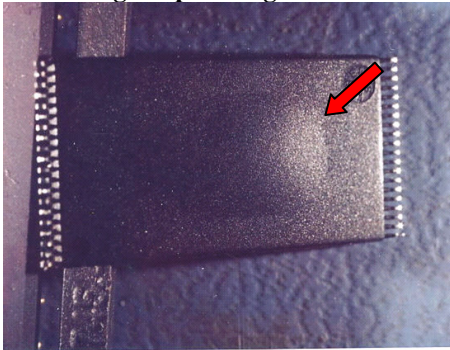
Figure - IC Leadframe Defects



Popcorn cracks, or popcorning as it is often called, earned this interesting moniker via the audible popping sound made when the vapor pressure in the component is released. Popcorn cracks are almost always large and can cause significant internal damage within the package. In many cases the defects are so large electrical interconnects are broken rendering the component non functional. This effect has both a good side and a bad side. The good side is that the defects can likely be identified during ICT testing after assembly and do not escape to the field. The negative side is

that the PCBA requires expensive rework processes to replace the component. **Figure 2** depicts massive deformation of the molding compound on a component that “popcorned”. Note the bulging surface of the encapsulation material.

Figure 2 - Package Popcorning



A less volatile, but an equally concerning IC leadframe defect is called delamination. This defect has the same root cause as popcorning, i.e. vapor pressure, but has more potential for latent defects and field failures. When delamination occurs, the vapor pressure causes a separation between the components material interfaces in its attempt to escape. For various reasons, the mechanical separation of interfaces has a lower release level thus the physical damage to the electrical interconnects within the package is minimal. Therein lies the problem, the IC leadframe package functions properly after assembly but there are now pathways by which moisture can enter the package which can ultimately result in corrosion, metal migration, and other electrical problems eventually ending with device failure. Environmental factors such as temperature, humidity levels, and atmospheric contaminates all play a role in determining when the component will fail. This long term reliability issue can prove quite costly when a device fails in the field and requires PCBA replacement, failure analysis, customer dissatisfaction, and other negative consequences.

The link between IC package moisture content and delamination and popcorning defects is fairly direct. Another factor that has been applying more pressure on the component suppliers is the fact that many OEMs and CEMs are requesting that more IC leadframe components pass the JEDEC MSL-1 test criteria. MSL is an acronym for moisture sensitivity level and has eight different levels, MSL-1 being the highest performance level.

JEDEC is an organization that develops and sets test, measurement, and performance standards for the component industry much like IPC does for the printed circuit board industry. The various classifications used to determine a components MSL correlate with end use and customer requirements. **Table 1** depicts the various JEDEC environmental test parameters and levels for MSL testing of components.

Table 1 - JEDEC MSL Test Levels

Level	Soak Requirements					
	Floor Life		Standard		Accelerated	
	Time	Cond degC/%RH H	Time (hrs)	Cond degC/%RH	Time (hrs)	Cond degC/%RH
1	unlimited	<=30/85%	168+5/-0	85/85	n/a	n/a
2	1 year	<=30/60%	168+5/-0	85/60	n/a	n/a
2a	4 weeks 168 hours	<=30/60%	696+5/-0	30/60	120+1/-0	60/60
3	72 hours	<=30/60%	192+5/-0	30/60	40+1/-0	60/60
4	72 hours	<=30/60%	96+2/-0	30/60	20+0.5/-0	60/60
5	48 hours	<=30/60%	72+2/-0	30/60	15+0.5/-0	60/60
5a	24 hours	<=30/60%	48+2/-0	30/60	10+0.5/-0	60/60
6	TOL	<=30/60%	TOL	30/60	n/a	60/6

With ever increasing end use and customer reliability requirements, combined with the elevated reflow temperatures of Pb free soldering, EMS providers have had to implement strict material handling methods to minimize the environmental exposure of MSD’s (moisture sensitive devices). MSD’s can generally be categorized as IC packages made with organic or plastic materials and their proportional use in recent years has increased dramatically. Though moisture related defects have existed for many years, proper material handling and environmental exposure tracking has become a critical factor in the EMS’s Pb free world. Elaborate and expensive packaging, storage, and time tracking of devices have become common in order to limit the MSD’s from absorbing moisture from the atmosphere. Many EMS providers have even had to incorporate reusable RFID tags and tracking systems just to manage their inventory of MSD’s.

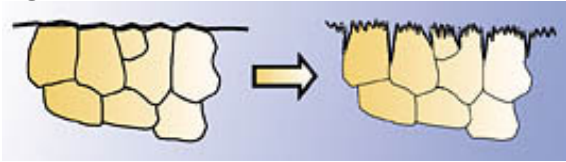
Component manufacturers have also been working diligently to increase the reliability of MSD’s and much work has been done to modify materials, processes, and test methods to make these components more robust. One key area many IC leadframe manufactures have been focusing on is the interfacial bond between the metal surfaces of the leadframe and the plastic encapsulant used in the devices. This interface is a common area of failure during assembly as moisture in the package is superheated during reflow.

Recently new manufacturing processes have been deployed that enhance the bond between the metal leadframe and the encapsulant materials. These chemical processes impart a rough texture onto the surfaces of the leadframe prior to the molding process and have resulted in significant increases in yields at the EMS level, as well as better enabling IC packages to pass the rigorous MSL-1 standards.

The aforementioned roughening process is a multi-step chemical process whereby the metal leadframe is exposed to cleaning and etching chemistry that results in a micro roughening of all the copper metal surfaces of the leadframe. This rough texture essentially increases the surface area of the metal surface and significantly enhances the interfacial bond between the molding compound and leadframe. **See**

Figure 3 for a cross sectional representation metal surfaces before and after treatment. This enhanced bond between the molding compound and leadframe not only prevents moisture ingress along interfacial areas resulting in lower overall moisture content in the MSD prior to assembly, but also resists the vapor pressure stresses generated during reflow.

Figure 3 - Leadframe Metal Surface Treatment



The following descriptions of testing and results using these leadframe treatments will demonstrate the significant benefits yielded from them.

A lead frame can contain several units, depending on the size of individual component and lead frame size. The process of building a lead frame chip package involves forming the metal lead frame, selectively silver (Ag) plating the die attach and wirebond pads, attaching the die (chip) to the lead frame with an epoxy adhesive, connecting the die to the leads of the metal frame by wirebonding conductive (usually gold) wires between the die and leads, encapsulating the package in an epoxy molding compound, then separating the individual units from the lead frame (singulation). These process steps may require high temperatures and physical handling, all of which produce internal stresses on the package as it is assembled. The integrity of the package depends on adhesion of the various components to the surface to which they are attached.

For example, if the CTE's (coefficient of thermal expansion) are not closely matched, elevated temperatures can cause internal stresses that lead to delamination. This is most certainly an issue during the reflow cycling in MSL-1 testing, and becomes even more critical in the move to lead free solders.

Resin and molding compound manufacturers have addressed these issues by developing materials with desired CTE's, Tg's, and the addition of chemical adhesion promoters in the epoxy resins used. However, the critical reliability required for MSL-1 rated components demands alternative methods for reducing delamination defects without compromising other steps in the process.

The aforementioned chemical treatment process provides the bridge to achieving MSL-1 performance on copper lead frames without delamination.

After cleaning the lead frame, a patented coating chemistry (Product PB) was used to roughen the lead frame surface, while simultaneously applying an organic coating to the copper surfaces. The increased surface roughness enhances the adhesion, and the organic coating stabilizes this

improved adhesion at the high temperatures required for processing and lead free reflow at MSL-1 conditions.

The co-deposition of a protective organic layer onto the copper surfaces is a critical function of the chemical treatment process since literature reports that at high temperatures, copper will auto-catalytically degrade epoxy resins¹. The organic coating insulates the epoxy resins used for die attach and package encapsulation from the copper surface and provides the thermal protection from delamination during Pb free reflow.

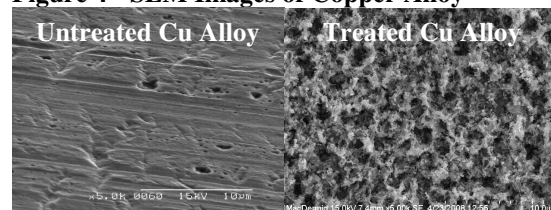
Another critical function of the chemical treatment process, other than the surface roughening and organic coating, is that it must not have any deleterious effects on the silver plated die attach or wire bond pads. This aspect is equally important as any residues or roughness imparted to the silver surfaces could cause defects in the package.

TEST PARAMETERS AND RESULTS

Testing the performance advantages of a lead frame treatment processes in reducing delamination and popcorn defects involved both laboratory scale testing followed by qualification at packaging houses. Laboratory tests comprised surface analysis, and adhesive strength measurements.

SEM (scanning electron microscope) images were taken of copper alloy both before and after chemical treatment of the bare lead frame. The magnification for these SEM images is 5000X and some of the results are shown in **Figure 4**.

Figure 4 - SEM Images of Copper Alloy



SEM images of the silver plated wirebond pads and die attach pads showed no difference before or after treatment, indicating no attack on the silver plating. Verification that the silver plated chip attach pad and wirebond pad surfaces were not contaminated with chemicals from the chemical treatment process was performed using AES (Auger electron spectroscopy) and XPS (X-ray Photoelectron Spectroscopy). Both methods look at the top 5-50 Angstroms of surface depth by detecting electrons having shallow escape depths from the surface. In both cases, silver surfaces were identical to untreated samples thus validating that the use of Product PB did not contaminate the silver surfaces.

Surface roughness of the copper alloy lead frame was measured using a Zygo white-light, scanning vertical interferometer. Average roughness (R_A) and surface area ratio (R_{SAR}) were measured. R_{SAR} is the proportional

increase in roughness with respect to a smooth surface of the same size. Adhesion science dictates that adhesive forces between two surfaces increase as interfacial area increases. **Table 2** summarizes typical roughness results.

Table 2 – Surface Roughness Measurements

	Cu Alloy		Ag Surface	
	Ra	Rsar	Ra	Rsar
Untreated	0.085	0.030	0.077	0.023
Treated	0.300	0.340	0.068	0.018

Clearly, the copper alloy treated with Product PB is significantly rougher than the untreated control sample, while there is virtually no change in the silver surface roughness.

Peel strength testing was conducted to quantify the relative adhesive values between copper alloy surfaces and epoxy-resin material. These adhesive strengths were measured both at room temperature and after exposure to lead-free reflow temperatures.

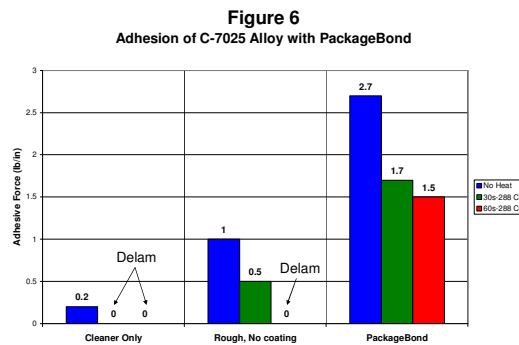
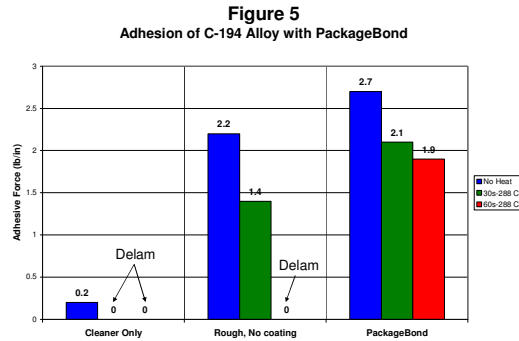
Test methods used to quantify the interfacial bond strength of disparate materials vary widely and many methods exist or are in development². In this case, the copper alloy lead frame materials were laminated to sheets of epoxy resin material using heat and pressure conditions recommended by the resin 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.

These one inch samples were then preconditioned at room temperature, after 30 seconds exposure to 288° C temperatures, and after 60 seconds exposure to 288° C temperature. 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.

To test the efficiency of the PackageBond process, three treatments to the copper alloy surfaces were evaluated:

1. Cleaning with sulfuric acid to remove scale and oxides. The alloy surface was not roughened by this process.
2. Surfaces were roughened using a special micro-etch that attacked the alloy grain boundaries, but did not deposit any organic coating.
3. Product PB was utilized to provide an etch at the copper crystal grain boundaries and deposit the organic coating.

Figure 5 and **Figure 6** illustrate the peel test results using C-194 and C-7025 lead frame alloys. Delamination is indicated by a “zero” force of adhesion.



The samples cleaned with acid only showed only 0.2 lb/in adhesive strength at room temperature and delamination when heated at 288° C. Roughening only provided an improvement in initial adhesion, but delaminated after 60 seconds at 288° C. The Product PB, which roughens the surface and co-deposits an organic layer, provided exceptional adhesion-performance at all thermal conditions.

Another adhesion test used by many lead frame manufacturers and packaging houses is called the Tab Pull adhesion test. In this test, a test sample is produced by attaching a copper alloy strip in the form of a wedge to molding compound. The force required to pull the copper alloy strip from the molding compound is then measured.

In order to quantify how day to day chemical concentration variations in the Product PB process may affect adhesion performance, samples were prepared using C-194 copper alloy lead frame material and processed at three different copper (Cu) concentrations in the chemical processing equipment. Samples treated with the Product PB process were then compared to untreated samples using the Tab Pull test. The three different levels of copper concentrations investigated were – 25 g Cu/L, 35 g Cu/L, and 45 g Cu/L. The results presented in **Table 3** of the Tab Pull testing reveal an increase in adhesive strength by a factor of two, when comparing the untreated sample to the samples treated with the Product PB process and that Cu concentration had no significant effect.

Table 3 - Tab Pull Test Results

Untreated Cu	8.8 kg
25 g Cu/L	16.8 kg
35 g Cu/L	16.7 kg
45 g Cu/L	17.3 kg

The impact of any surface on treatment on the die attach areas need to be evaluated for changes in wetting properties of die attach resins which are usually silver filled epoxy resins. If the epoxy resin bleeds away from the initial application area, to a large extent, there can be issues in downstream processing. Typically, chip packagers prefer <10-mils of EBO (epoxy bleed out).

To perform this test, a small droplet of die attach resin is applied to the surface, cured as normal, and the amount of spread of the droplet is measured. **Table 4** lists the measured EBO for some typical die attach resins and copper alloy lead frame materials with and without treatment.

As can be seen from the data, there was an increase in EBO across both alloys, as well as all three die attach materials from baseline, but are still well within acceptable standards. The increase in die attach flow can be explained by the increased capillary effect of the roughened surface.

Table 4 - EBO Test Results (mils)

	Ag Surface			Cu Surface		
	Resin 1	Resin 2	Resin 3	Resin 1	Resin 2	Resin 3
Untreated C-194	0	0.3	0	0.7	0.7	0.5
Treated C-194	0	0.9	0	1.3	1.6	1.1
Untreated C-7025	0	0	0	0.6	3.9	0.6
Treated C-7025	0	0.5	0	5.2	6.7	3.5

Resin 1 = Ablestik 84-1 LMI SR4

Resin 2 = Ablebond 8340A

Resin 3 = Sumitomo CRM-1033BF

Some of the additional qualification testing at packaging assemblers involved treating actual lead frames with the Product PB process, and then using these treated lead frames to build functional chip packages. These packages were subsequently exposed to MSL -1 preconditioning followed by three simulated Pb free reflow cycles, and then evaluated for delamination using C-SAM (C-mode Scanning Acoustic Microscopy) and T-SAM (T-mode Scanning Acoustic Microscopy). The IC lead frame packages depicted in **Figure 7a** and **Figure 7b** are 24-lead QFN packages and had a history of delamination issues for this customer.

Figure 7a – SAM for Untreated QFN Sample

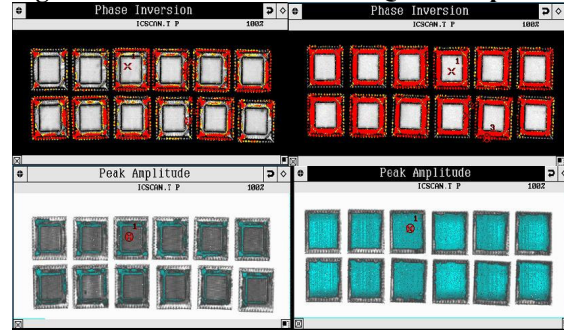
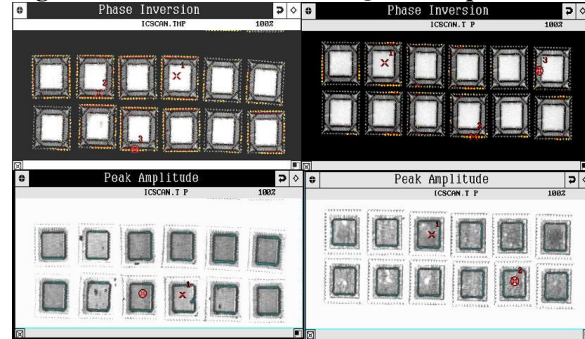


Figure 7b – SAM for Treated QFN Sample



The C-mode scan in **Figure 7a** shows delamination (red areas) at the molding compound / copper alloy interfaces of a standard untreated control sample. The T-mode scan shows delamination (blue) between resin and the die attach pad (copper alloy) on the same untreated sample. **Figure 7b** depicts the same lead frame design with the addition of the Product PB lead frame treatment. It is apparent that the treatment of the lead frame with Product PB had the desired result in eliminating delamination at MSL-1 levels.

CONCLUSIONS

With the demand for MSL-1 capability greater than ever, along with the increasing use of MSD’s in the electronics industry worldwide, new process materials and methods must be developed and marketed to meet the industry needs. Based on the aforementioned evidence, combined with real world production results, we believe the addition of a lead frame treatment technology in the IC packaging fabrication sequence will allow IC lead frame manufacturers to meet these ever increasing quality and reliability demands.

ACKNOWLEDGEMENTS

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