Application-Specific Surface Finishin g Techniques for Leadframes

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Summary

Efficient and cost effective first and second level electronic packaging requires a number of specific functional characteristics of the materials involved. As a link between the packaging levels, the leadframes are particularly critical. Solderability, wirebondability, corrosion resistance, formability, thermal resistance and other functions with inexpensive materials and processes. We have recognized these needs and have engineered leadframe finishing techniques that meet current industry demands and offer continuous advancements in electronic packaging. Sopme of the most stringent industry standards have been met with this novel processes. In this article we describe our new developments in the field of formability and corrosion protection of leadframe sibstrates.

Background information

Leadframe Application in Electronic Packaging

Leadframes are utilized in the first level electronic packaging to provide mechanical link from IC's to the second level packaging, boards, MCMs, and further to enable the functioning of electronic devices. The leads of the leadframe carry the power and the signals to and from the I.C. In order to complete the first level packaging, the packaging process forms electrical connection between the I.C.s and the leadframes and also provides encapsulation to the package. The process is quite complex and it typically requires many steps including wirebonding, trim-and-forming, thermal aging and encapsulation. Sometimes it involves soldering and other operations even prior to attachment to the boards or MCMs or Hybrid Circuits. Once the packaging is completed, the chips and the leadframe carrier together represent an item that is commercially available and can be either stored on shelf or installed into an electronic device for consumer or specialty market.

The functional performance of the finished product very much depends on the quality of electronic packaging and primarily on the quality of the leadframes. Both, an efficient packaging and product quality can be achieved only if leads have certain functional characteristics including:

- good conductivity
- mechanical strength
- machinability to microscopic dimensions (100 microns or even 50 microns)
- good formability
- corrosion resistance
- good solderability
- low thermal expansion

These properties must be achieved in an efficient and economical process including optimum material selection and fabrication steps. Although nobel metals such as gold, platinum and palladium have their appeal, neither of them can be used as leadframe material, the cost being the first but not the only prohibitive factor.

Substrate materials utilized in leadframe fabrication are typically copper alloys that have been designed to meet the above requirements including the following:

good electrical conductivity,
mechanical strength and flexibility,
machinability, either by stamping or etching and,
can be trim-and-formed without cracking.

The forming property of the leadframe alloys is a very critical parameter in electronic packaging operation. We shall see that, while during the forming process, they do not crack, substrates tend to deform to various degree at the surface causing serious problems in the surface finish.

Typically, the above performance can be met with a variety of copper alloys such as alloy 151 (99.9 Cu/0.1 Zr), alloy194 (97.5 Cu/2.35 Fe/.03 P and 0.12 Zn) and alloy 7025 (96.2 Cu/3.0 Ni/0.65 Si and 0.15 Mg) and other. In addition, the industry is often utilizing exceptional mechanical quality of alloy 42 (Fe58/Ni42 alloy) which has low thermal expansion coefficient and superior mechanical properties.

All functional requirements can not be met with these substrates alone. While they have good bulk material properties and good mechanical strength and conductivity, the surface of these substrates tend to degrade in typical packaging and utility environment. Consequently, low **corrosion resistance,** lack of **wirebonding** and **solderability**, and, to some degree, the **formability** are the functional deficiencies of the current leadframe substrates.

For example, neither copper alloys nor alloy 42 can withstand typical corrosive environment of the electronic packaging process. Furthermore, if exposed to typical storage or, even more so to the atmosphere in a device application which may include underhood or outdoors under inclement weather conditions, these materials would quickly corrode and cease to function.

Since a number of interfaces are being attached to each other in various packaging operation, the surface finish and preparedness for these attachments is quite critical. No wirebonding or soldering can be performed with corroded copper alloy or alloy 42. As a matter of fact, the standards, such as MIL-STD-883 or ANSI-J-001 require that non-activated or at best low activity fluxes be utilized when soldering. This makes the soldering of the above substrates impossible after surface corrosion and oxidation.

For wirebonding there are no fluxes and therefore the surface quality is even more important. The substrate to which the wirebonding is being performed must be clean of organic and inorganic impurities and, it must not interact with the wirebonding material and form brittle bonds or bonds that degrade with time and/or temperature.

Trim and Form Operation-Formability of Leadframes

Concerning forming of the leadframes, the JEDEC standard describes the lead design and the type of trim-and-form that may be applied to the device while being fabricated. The forming angle is 90-98 degrees and the forming radius 20 mils, Figure 1. This standard has evolved as a result of the consumer demand for high density packaging. It has imposed one of the most serious challenges to the packaging process.

Typical copper alloy substrates as well as alloy 42 can be formed to meet above requirements. Though the current industry practices vary from plant to plant, it is evident that in either case the surface of these materials undergoes considerable deformation. Figure 2 shows the plane view and the cross section of a lead after forming. One can observe the surface deformation that appears as groves. In the industry this change is often refered to as "orange peel" effect. The cross section, magnification 1000X, shows that the "orange peel" in nature is an undulation of the surface (not cracking) with the troughs being 2-3 microns bellow the top. Clearly, this flow of material at the surface will force the finish to either flow with it or to crack. Thus, the surface finish that was applied for the purpose of meeting other requirements such as corrosion resistance, solderability or wirebonding can easily be damaged. As a result, the parts fail the standard solderability tests following the trim-and-form step.

Deficiencies of the State-of-the-art Processes Utilized in Leadframe Finishes

Current leadframe finishes typically utilize nickel electroplate over the substrate to form a barrier to prevent copper or iron and other base metal impurities to migrate to the surface. While these impurities can cause severe deficiencies in processing, the nickel finish alone is not a solution. Nickel readily reacts with the atmosphere and forms oxides. These oxides are detrimental in packaging operations. To overcome this the industry is utilizing noble metal finishes, such as silver, palladium or gold, over nickel. While applied in economically small amounts, these layers preserve the leadframe finish and allow for a more efficient packaging operation.

The leadframe finish with palladium in the top layer has been a more recent development in the industry. Example of this application is a commercial finish, where the nickel electroplated leadframes are coated with 0.075-0.15 microns of palladium to form a solderable finish. While this finish permits marginal processing of leadframes, it is quite inefficient in processing leadframes that undergo trim-and-form steps after plating.

Figure 3 shows the effect of trim-and form on the surface finish. The specific example is a 3.75 microns thick commercial Nickel coating with 0.15 microns of Palladium on top. The commercial surface finish is not designed for these deformation and it can not conform to the flow of matter underneath. As a result the finish cracks, which is apparent by clear discontinuities in the Nickel plate.

The cracking in the surface finish is typically disastrous to the electronic packaging. Now, both types of substrate materials, copper alloys and alloy 42, migrate to the surface and form oxides or other undesirable impurities which inhibit the packaging process. This is particularly apparent from the electronic packaging design standards such as JEDEC. In SOP applications the bent portion of the lead is tipically 1 millimeter from the tip. The cracking in the finish causes serious deficiencies in the solderability of these packages. With the cracks in the heel of the formed lead, the surface finish is ineffective in providing the electronic packaging process with the necessary performance.

Concerning the Alloy 42 substrate material the problem caused by cracking of the surface finish is even more pronounced than in the case of copper alloys. As the least corrosion resistive component, iron tends to migrate to the surface through pores or cracks in the surface finish. There, it forms thick layers of rust. This rust inhibits any functional performance of the component in an even mildly corrosive environment.

Thus, the current leadframe finishes with palladium or other noble metal in top layer have an inherent deficiency caused by inadequate plating chemistries and processes applied. To meet the need for a better performance, we have developed an improved finishing process including better plating chemistry and appropriately designed layers in the leadframe substrate finish.

Experimental and Results

A. The Conformal Nickel Coating for Electronic Packaging with Leadframes

A novel leadframe finishing process provides solutions to the problems caused with non-conformal nickel plating utilized in commercial leadframe finishing processes. We have developed a surface finish that includes nickel plate which conforms to the flow of the substrate and maintains the superior performance of the leadframe finishes throughout the packaging process and thereafter.

We have prepared two sets of substrate with advanced surface finishing processes. The two specific examples were composed of electroplated proprietary Nickel and Palladium layers. The two examples are:

Example A.1.
Five mils thick copper alloy 194 leadframe was plated as follows:

1. Nickel plate*	1.5 microns
2. Palladium Strike*	0.025 microns
3. Palladium/Nickel plate (80% Pd)*	0.075 microns
4. Palladium plate*	0.075 microns

Example A.2.
Eight mils thick alloy 151 substrate was plated as follows:
1. Nickel plate* 3.0 microns
2. Palladium Strike* 0.025 microns
3. Palladium/Nickel plate (80% Pd)* 0.075 microns
4. Palladium plate* 0.075 microns

*Proprietary PallaTech products (Conformable Nickel and PallaTech Palladium)

This type of finishes have a superior performance in electronic packaging. The results of the comparative testing of the commercial finish and the finish subject of this development are shown in the Table 1. MIL-STD-883 and J-STD-002 were applied for the basis of comparison in triplicate for each data point.

The samples were bent with a specially designed equipment for bend testing of leadframes to the JEDEC standard of 10 mil radius and 90 degrees. The parts were submitted to the tests as in Table 1. The parts passed all standard tests applied.

Table 1. A Trim-and-Form Comparative Solderability Study of Commercial and New Conformal Finish, Example A2

Test Type	Commercial finish	Lucent finish
MIL-STD-883, TM 2003*	fail, less than 95% cov.	pass, over 95%
MIL-STD-883, TM 2022*	fail, over 1 sec	pass, less than 1 sec
J-STD-002, Category 2**	fail, over 1 sec	pass, less than 1 sec
J-STD-002, Category 3**	fail, over 1 sec	pass, less than 1 sec

*Tests performed with 8 mil substrate with surface finish bent at 10 mil radii for 90 degree, followed with 8 hours steam aging, and, utilizing non-activeted flux, as specified in MIL-STD-883.
**Test for Leaded Surface Mount Devices at 20 degrees inclination. Category 2 and Category 3 finish require 1 and 8 hours respectively steam aging prior to solderability testing.

Figure 4 shows two cross sections of the conformable Nickel after bending asper JEDEC requirements. The thin plate, 1.5 microns Nickel (Example A1), shows the typical deformation observed with this novel plating process when the thickness is insufficient. The plated layer stretches beyond its elasticity limits. It elongates and becomes thinner and it breakes. The plated Example A2 has sufficient plated thickness and it remains continuous across the lead, following the trim-and-form operation.. In the Figure 4 in both cross sections there are clearly visible zones with expanded surface finish as a result of substrate deformation. However, in contrast to the Figure 3, the breaks in the coating are completly absent when the conformal Nickel of similar thickness is utilized.

B. The Surface Finishing Process for Alloy 42 and other Corrosion Sensitive Substrates for Electronic Packaging (Conformal Nickel/Copper Combination)

A novel process for Alloy 42 and other corrosion sensitive substrates has been developed. A combination of a proprietary underplate with conformal nickel produced a finish with unique properties. Standard test for Alloy 42 is the ASTM B-117 which calls for a NaCl solution exposure at 35°C for 24 hours or longer. The part must be free of rust following the test.

We have prepared three sets of finishes. One set was designed to emulate commercial finishes. Typical commercial finish utilizes thin copper strike (0.125-0.175 microns) and a non-conformal Nickel layer followed by the palladium coating of 0.125 microns. Two sets were prepared with a new proprietary processing sequence including conformal Nickel plate. The plating sequences were as follows.

Example B.1. Commercial Finish
Six mils thick alloy 42 leadframe was plated as follows:

1. Ni Strike	0.5 microns
2. Sulfamate Nickel*	2.5 microns
3. Palladium Plate	0.175 microns

*Allied Kelite.

Example B.2. Lucent Application Specific Finish #1
Six mils thick alloy 42 leadframe was plated as follows:

1. Proprietary pre-plate	2.5microns
2. Conformal Nickel plate	3.0 microns
3. Palladium Plate	0.175 microns

Example B.3. Lucent Application Specific Finish #2
Six mils thick alloy 42 leadframe was plated as follows:

1. Proprietary pre-plate	4.0 microns
2. Conformal Nickel plate	3.0 microns
3. Palladium Plate	0.175 microns

The samples were bent at 10 mil radii for 90 degrees and exposed to salt spray for 8 and 24 hours as per ASTM B-117 standard test. The quality of finish was evaluated by the visual determination of the percent of rusty discoloration over the parts. Attached photos in Figure 5. show minor rust for Example B.2. and complete absence of discoloration in Example B.3. for Lucent samples after 24 hours. In contrast to this, severe rusting of three samples of Commercial Finish were observable even after 8 hours of test. These samples completely desintegrated after 24 hours.

Table 2 shows the results of our comparative tests of the standard commercial finish and the surface finish subject to this development.

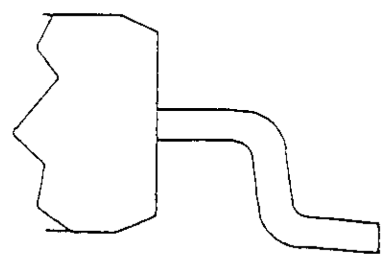
Table 2. ASTM B-117 ComparativeTest Results of Commercial and Lucent Finish for Alloy 42

Finish Type	8 hours Salt Spray	24 hours Salt Spray
Commercial Finish	fail, over 50% area rusted	fail, 100% rusted/powdery
Lucent Appl. Spec. Finish	pass, less than 5% rusted	fail, over 5% rusted
Lucent Appl. Spec. Finish	pass, less than 5% rust	pass, less than 5% rust

Conclusions

The main scope of this invention is the Nickel plating process that is applicable to typical leadframe alloys which cause "orange peel" deformation during trim-and-form operation. Depending on the type of substrate and specific standard test requirements, we have developed two types of finishes. Both include a new conformal Nickel plate critical to the finish performance. With it, it was possible to fabricate leadframes that can be trim-and-formed to the JEDEC specifications and remain solderable across the bend. For iron containing leadframe materials, we have demonstrated that a combination of proprietary underplate and conformal Nickel plate offers electronic packaging fabrication that can meet stringent standards such as ASTM-117-B salt spray in duration of 24 hours.

Figure 1. JEDEC Specifications for SO Packages Gull-Wing Bend



R: 10-30 mil, Angle: 90-98°

Figure 3. Commercial Nickel Plate on SO Leadframe

Cracked Nickel plate, 3 microns thick
Cross Section, 1000 X

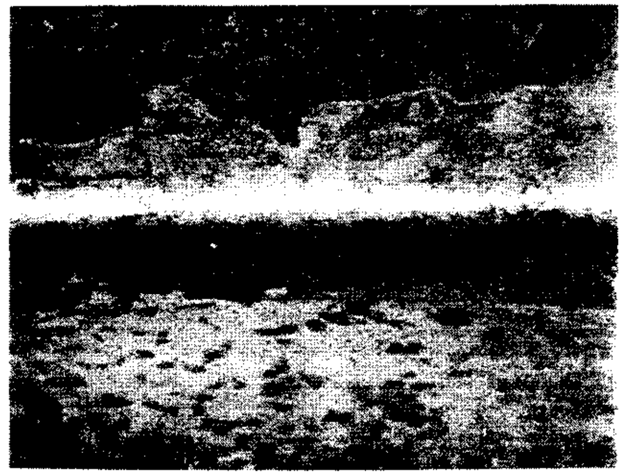
Figure 4. Conformal Nickel Plate on SO Leadframe

Thin Conformal Nickel, 1.5 microns,
Exceeded Elasticity Limits, 1000 X

Conformal Nickel plate, 3 microns
Continuous Coverage, 1000 X

Figure 5. Salt Spray Test Results on Alloy 42 Substrates (ASTM B-117)

Nickel Strike, Sulfamate Nickel Palladium Plate, 8 hours Salt Spray



Preplate 2.5 microns, Conformal Nickel Palladium Plate, 24 hours Salt Spray

Preplate 4 microns, Conformal Nickel Palladium Plate, 24 hours Salt Spray