Adhesive Enhancement Technology for Directly Metal Plating on EMC

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Abstract

Plating on molding compound is a relatively new field with many possible applications. One major application is magnetic or electrical EMI shielding of active components. This is currently done by metallic cans. However, this technique also increases the space requirements. A second major application, is the formation of build-up circuits on encased components, such as for Fan-out Wafer Level Packaging (FO WLP).

An established method to provide a metallic seed layer is sputtering. However, with respect to cost effectiveness and mass production capability, classical electroless metallization along with an adhesion promoters would a desirable alternative. In this paper we will present a new approach, where components encased by molding compound are directly coated with an electroless copper or nickel layer. By this method spatial requirements are minimized. Also, this process fits into the existing infrastructure within the PCB industry.

Due to the presence of fillers with an extremely high ratio (70-90%wt.) and irregular size (from few µm to tens of µm), classical Desmear followed by electroless seeding can get at best an adhesion of only 2-3N/cm . This is typically insuffient to prevent delamination during further processing. In contrast, with chemically bonding adhesion promoters, as presented in this paper, we are able to get up to 5N/cm of peel strength without any blistering. The plated layer stands up well to reflow shock (260C) and HAST without significant loss of adhesion.

These adhesion enhancement technology is applicable to various kinds of molding compound. Extending this technology to FO WLP (i.e. FO SiP, FO PoP) can be another far reaching application.

Key words

Adhesion, EMI Shielding, Molding Compound, WLP,

I. Introduction

Plating on epoxy molding compound is a relatively new field which could open up new package designs. One such opportunity is the increased need for electromagnetic interference (EMI) shielding for closely spaced components. Currently, this is accomplished mostly by metallic shells or "caps." However, this technique also increases the spatial requirements and reduces flexibility of component layout on the PCB.

An alternative and more space saving approach is "Conformal Self EMI Shielding" using a wet-chemically deposited Cu and/or Ni layer. While in some instances conductive paste and sputtering metallization will provide adequate adhesion – it has the technical drawbacks of poor sidewall coverage and limited metal layer thickness. As a result, scale- up for mass production is relatively difficult and costly. Classical electroless and electrolytic metallization are much more desirable but have been so far limited by insufficient adhesion.

In this paper we will present a new "Adhesion Enhancement" approach based on a chemical adhesion promoter, where components encased by molding

compound are directly coated with an electroless copper or nickel layer. By this method spatial requirements are minimized. Also, this process fits into the existing infrastructure of the PCB industry.

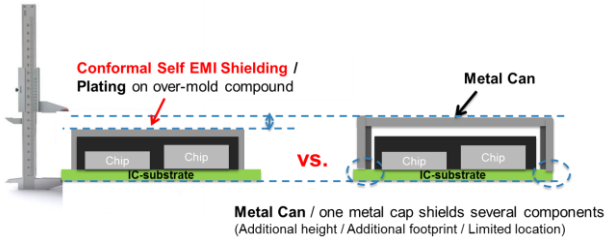

Figure 1: Comparison height and footprint between Conformal Self EMI Shielding and Metal Can [1].

A second possible application is the "direct circuit formation" on top of molding compound. This application aims at replacing standard build-up resins while at the same time embedding components.

This approach has the merit of being comparatively cost effective due to the cheaper substrate materials.

There are several challenges in treating molding compound with wet chemistry. Firstly, molding compound has a high filler content (70-90% wt.) with a wide size distribution ranging from a few nm to tens of µm [2]. The roughness created by the large filler sizes - does not allow for the "direct circuit formation [3] on top of molding compound. Secondly, molding compound, unlike build-up resins have not been optimized for adhesion to plated metal and even contain waxy release agents which counteract adhesion. For this reason, classical desmear followed by electroless seeding can get a maximum adhesion of up to 2N/cm on typical molding compound. This adhesion appears to be insufficient to prevent delamination in the subsequent processes.

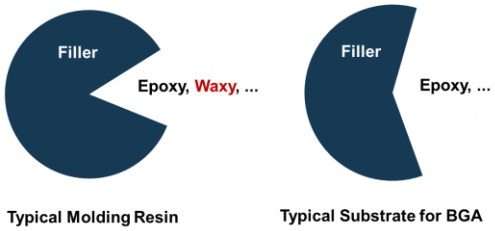

Figure 2: The material component comparison between typical molding resin and typical substrate for BGA.

In contrast, with the new approach presented in this paper, we are able to obtain up to 5N/cm of peel strength. The plated layer stands up well to the thermal reliability tests such as reflow shock (260°C) and HAST treatment; there is no delamination or significant loss of adhesion – key requirements for this application.

The technology is based on a new "Adhesion Enhancement" step providing a thin organic layer, which interacts with the molding compound and primes it for plating.

Results obtained so far suggest that these surface treatments are applicable to various kinds of molding compound.

II. EXPERIMENTS AND RESULTS

EMC substrates from various suppliers were investigated. The substrates were first cleaned in deionized water or a standard cleaning bath to remove loose debris and particles from the surface. The "Adhesion Enhancement" chemistry was then sprayed as a thin and uniform layer onto the substrate. During a brief bake, the organic components then selectively interact with the substrate surface.

A permanganate based oxidative treatment finally removes both excess chemistry and treated molding compound surface. Adhesion then results from a combination of mechanical and chemical bonding.

A general process flow is given below:

Adhesion Enhancement

Electroless Metal Plating

Electrolytic Metal Plating (option)

Figure 3: Adhesion and Metallization Process Overview.

Typical process conditions for the new Adhesion Enhancement approach are given below.

Process	Time (mins)	Temp (°C)
Adhesion Enhancer	3 - 4	RT
Baking	4 - 7	80-150
Oxidizer	5 - 35	78 - 82
Reduction	1 - 2	25 - 35

Figure 4: Process Details "Adhesion Enhancement."

The surface is then seeded with Pd activator for electroless copper or nickel plating. The thickness of those

layers is typically in the order of several microns for EMI shielding applications. The exact sequence and thickness depends on the specific shielding requirement.

After electroless metallization the samples are rinsed and dried. This is followed by annealing at 150°C for 30 minutes.

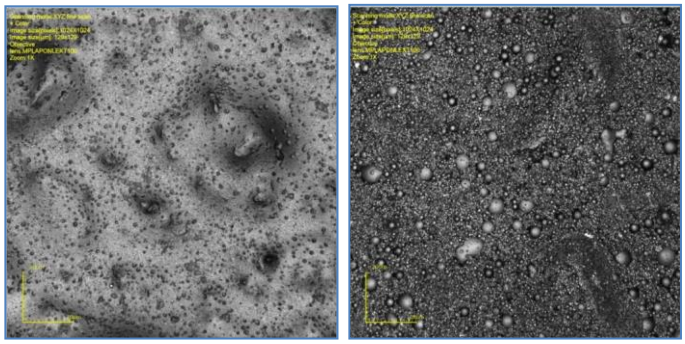

Figure 5: LEXT 4000* image "as- received" (left) and after the Reduction Process (right).

*2D 120x120µm high resolution confocal laser microscope image

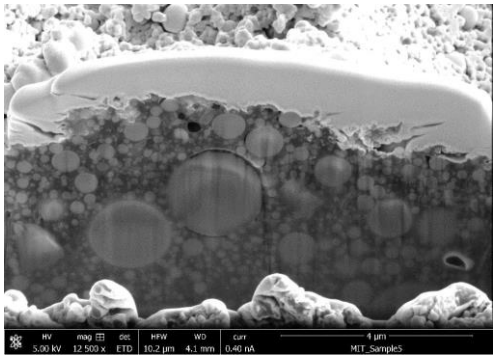

Figure 6: SEM image of FIB X-section after Reduction.

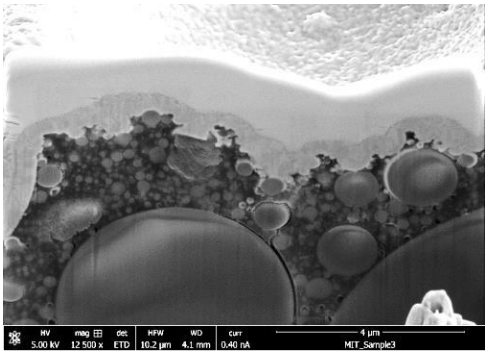

Figure 7: SEM image of FIB X-section after E'less Cu.

If thicker metallization is required, additional electrolytic plating can be applied again followed by annealing.

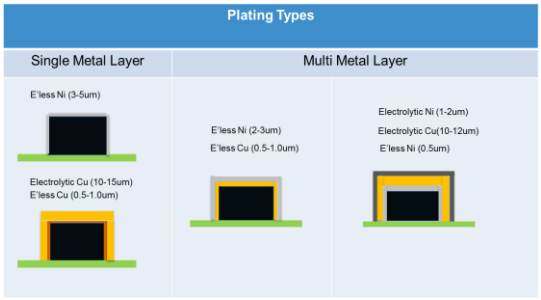

Figure 8: Various types of metal layer build-up on molding compound.

III. ADHESION & RELIABILITY TESTING

Adhesion quality for thin metal layers in the order of several N/cm was determined by Cross Hatching & Tape Testing (IPC-TM-650 Test Method 2.4.1).

As shown below, the use of the "Adhesion Enhancement" allows for the deposition of various sequences of metal layers with passing tape test results.

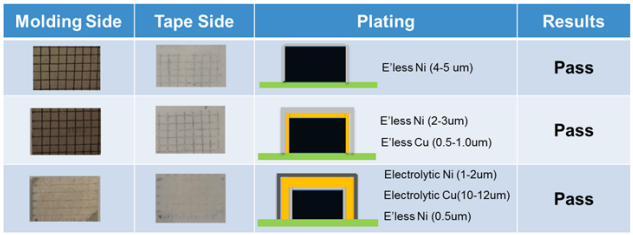

Figure 9: Cross-hatch tape test result on various metal sequences.

For EMI shielding applications, the full manufacturing process has to be considered because the incoming singulated chips / strips (w/ Sub-Diced) generally have solder resist, gold metal finishing or solder balls on their backside (I/O side protection). This side has to be protected from the plating solutions. In manufacturing, this protection is a key requirement and can be achieved for instance by the application of a UV Tape, Peelable ink, PI tape or Gaskets.

By using these tools for backside protection (I/O side protection), Conformal Self EMI Shielding by PLATING can be applied to various types of products (Figure 10).

Figure 11 shows process comparison between metal can and Conformal Self EMI Shielding for Strips (Sub-Diced) manufacturing.

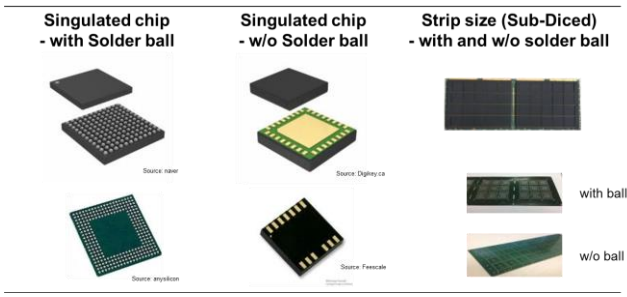

Figure 10: Conformal Self EMI Shielding by PLATING can be applied to various types of Products.

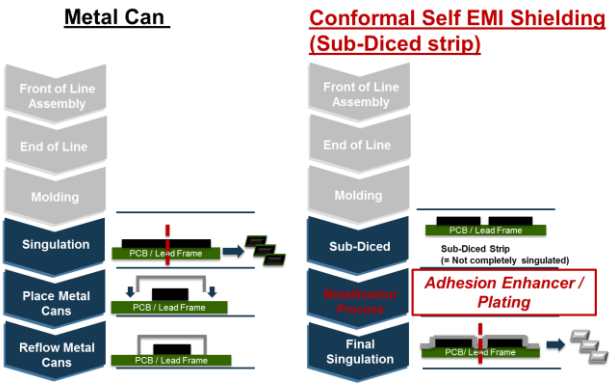

Figure 11: Process comparison between Metal Can and Conformal Self EMI Shielding [4].

Singulated chips with solder balls product is also possible to process (Figure 12) and process was demonstrated (Figure 13 and 14).

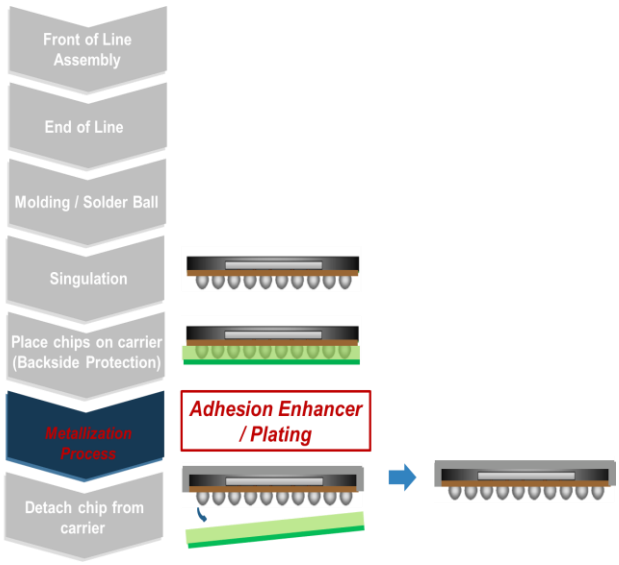

Figure 12: Singulated chips process overview for Conformal Self EMI Shielding.

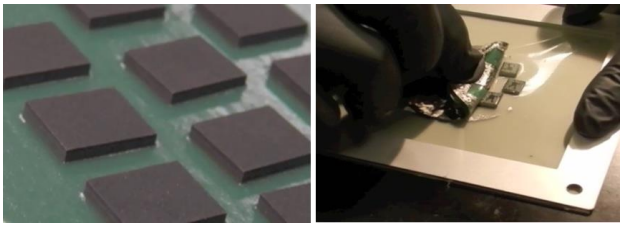

Figure 13: Demonstration for Chips attachment on carrier (left) and Detach chips from carrier after plating (right) for process of singulated chips with solder balls.

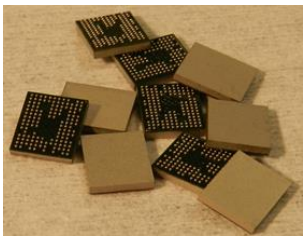

Figure 14: Chips after electroless nickel plating with fully backside (I/O side) protected.

After detach chips from carrier (backside (I/O side) protection tool), the residues of carrier (organic component) on solder balls was inspected by fluorescence microscope. The result shows that no residue of backside protection tool was inspected on solder balls (Figure 15).

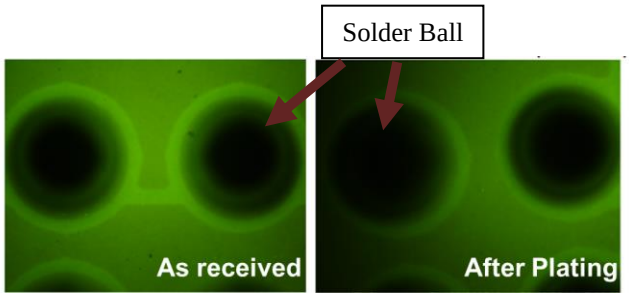

Figure 15: No residue of carrier (backside protection tool) was confirmed by fluorescence microscope inspection. (Green Color: Organic Component)

Also ball shear test (Figure 16 and 17) and cold ball pull test (Figure 18 and 19) were tested to confirm the solder ball reliability between before and after plating with the tool of backside (I/O side) protection. It was confirmed that solder ball reliability was not changed by detach process of the tool of backside (I/O side) protection.

Equipment	DAGE 4000, Cartridge BS5kg
Shear speed	210 µm/s
Shear height	50 µm
No. of balls	30 per condition

Mode 1	Pad pull-out
Mode 2	Intermetallic fracture < 5%
Mode 3	Intermetallic fracture < 25%
Mode 4	Intermetallic fracture < 95%
Mode 5	Intermetallic fracture > 95%

Figure 16: The test condition for ball shear test.

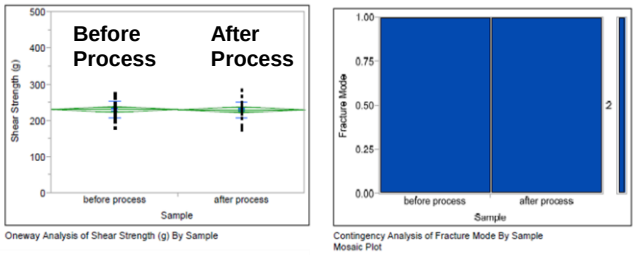

Figure 17: The ball shear test result, compared between before and after plating process.

Equipment	DAGE4000, TP5kg
Pull speed	5 mm/s
No. of balls	30 per condition

Mode 4	Bond failure	Process or material problems
Mode 3	Ball extruded	Jaw cavity too big, jaw closing force too low or very soft solder.
Mode 2	Ball failure	Good bond. Maximum test force possible or jaw cavity too small.
Mode 1	Pad failure	Good bond. Possible pad design problem.
Mode 0	Mixture of Mode 1 and Mode 4	

Figure 18: The test condition for cold ball pull test.

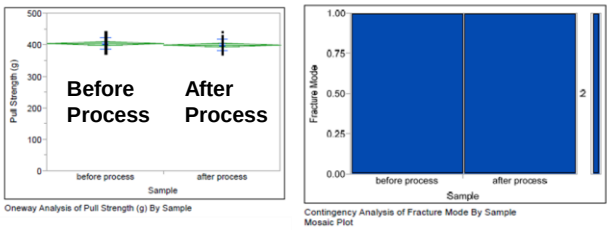

Figure 19: The cold ball pull test result, compared between before and after plating process.

The adhesion between molding compound and plating layer after aging test (PCT and TCT) was also confirmed (Figure 20).

Test Conditions	Tape Test Results
MSL1+ PCT96	Pass
MSL1 + PCT192	Pass
MSL1 + TC500	Pass
MSL1 + TC1000	Pass
MSL1 + TC2000	Pass

MSL1 Precondition: JESD22-A113F [8]
PCT: JESD22-A102-C [9]
TC: JESD22-A104D, Test Condition H[10]

Figure 20: Tape test results after PCT and TCT

Furthermore, for direct copper trace formation on the molding compound surface, an optional "Adhesion Booster" has been developed to even further enhance adhesion to the EMC. The "Adhesion Booster" is a chemical adhesion promoter. Typical process conditions for the new Adhesion Enhancement approach are given below. For surface activation, plasma or wet chemical conditioner can be applied to this process.

Process	Time (mins)	Temp (°C)
Chemical Adhesion Promoter		RT
Baking	8-12	80 - 150

Figure 21: Typical Booster process conditions.

For this application, a total copper thickness in excess of 25 microns was applied. Adhesion of such metal layers is typically evaluated by a 90° Peel Strength (IPC-TM-650) test whereby a 1cm wide strip of the plated layer is peeled from the substrate while recording the force.

This peel strength measurement tool is widely used in the PCB industry to check the adhesion strength between substrate and plated copper layer. Adhesion values above 3-4N/cm are considered to indicate adequate adhesion - that is the ability to survive thermal stress applied during component attachment or "reflow" without delamination or significant loss of adhesion.

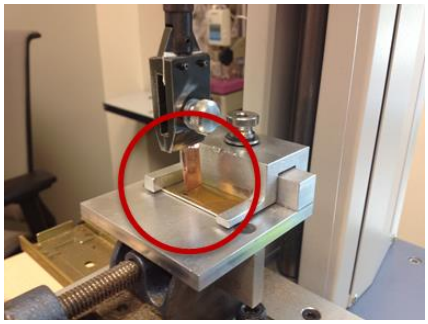

Figure 22: Peel Strength Measurement Tool.

On several molding compound intended for circuit formation, peel strength values of 4-5N/cm could be consistently achieved and maintained after (solder) reflow. Reliability of adhesion was tested by "solder-reflow" heating to 260°C /30secs (repeated 5 times)

Material	(N/cm)			
	Mean	Max	Min	Pst Rfl
Supplier A - Type 1	4.3	4.6	3.9	4.8
Supplier A- Type 2	4.6	5.0	4.0	4.9
Supplier B - Type 1	4.0	4.2	3.7	3.8
Supplier B - Type 2	3.4	3.6	3.2	3.5
Supplier B - Type 3	3.7	3.8	3.6	4.1

Figure 23: Peel strength evaluation of different molding compound types.

Also highly accelerated stress humidity testing (HAST: 96h, 130°C, 85% RH) was tested and no delamination or significant peel strength degradation occurred.

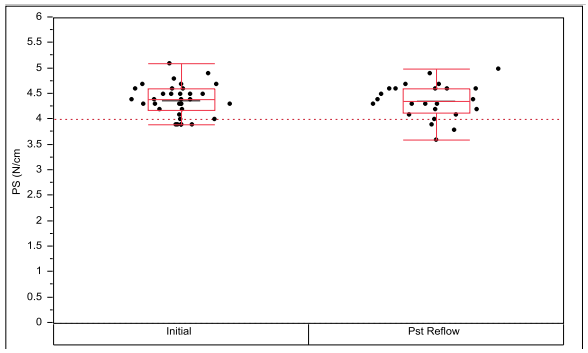

Figure 24: Peel Strength - initial and post reflow.

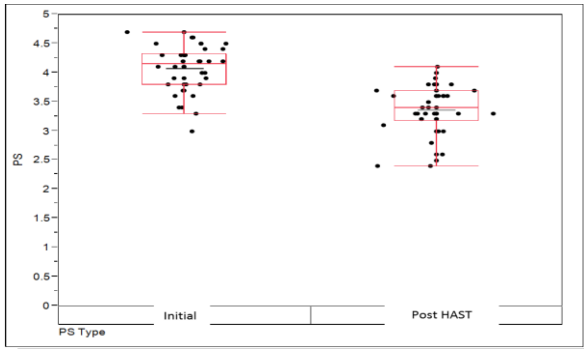

Figure 25: Peel Strength - initial and post HAST.

By this process, relatively lower surface roughness can be obtained, which is similar roughness to PCB substrate for BGA.

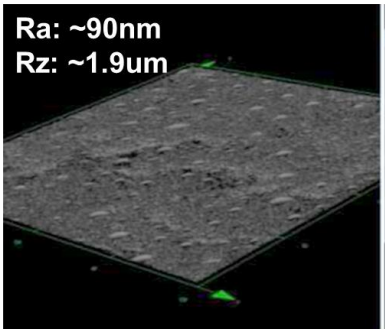

Figure 26: Laser microscope (LEXT 4000) 3D image. *after plasma activation + adhesion promoter

To determine the failure modes of the "Adhesion Enhancement" and "Adhesion Booster" processes, the peeled off copper and resin layers were investigated. Typically, cohesive failure is observed, which is the preferred mode over interfacial. For cohesive failure, resin and filler and filler fragments are observable on the peeled copper foil.

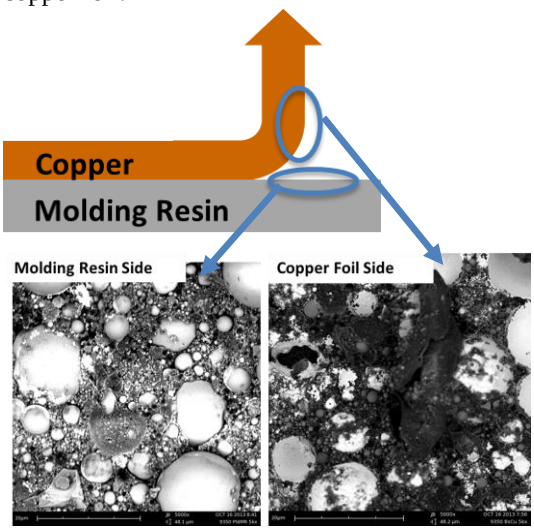

Figure 27: Peeled strip image – resin and copper side.

Figure 27 shows resin filler on the peeled copper foil consistent with cohesive failure. For reference, an image of the copper foil (Figure 28) is shown after interfacial failure. There is only little resin and filler residue present. Interfacial failure typically indicates low adhesive strength.

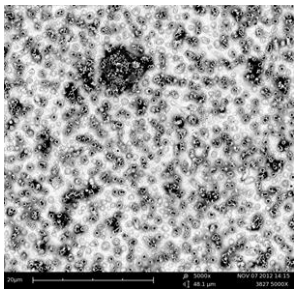

Figure 28: Copper foil after peeling with interfacial failure and low adhesion (<1 N/cm).

One major concern with respect to the adhesion of the plated metal to the EMC is the internal stress of the metal layer. High internal stress reduces the peel strength and can even cause local delamination or blisters. To release the internal stress of the metallic layer, typically an annealing step of 100 - 200°C is applied.

The optimal annealing process temperature depends on the targeted performance, the resin Tg, or the acceptable level of oxidation. An example is given in Figure 28 exploring annealing temperatures and times vs. adhesion.

In this example, annealing at 160°C provides the tightest peel strength distribution. Above 180°C, gradual degradation of adhesion as indicated first by a widening distribution and eventually by a significant drop of adhesion becomes apparent.

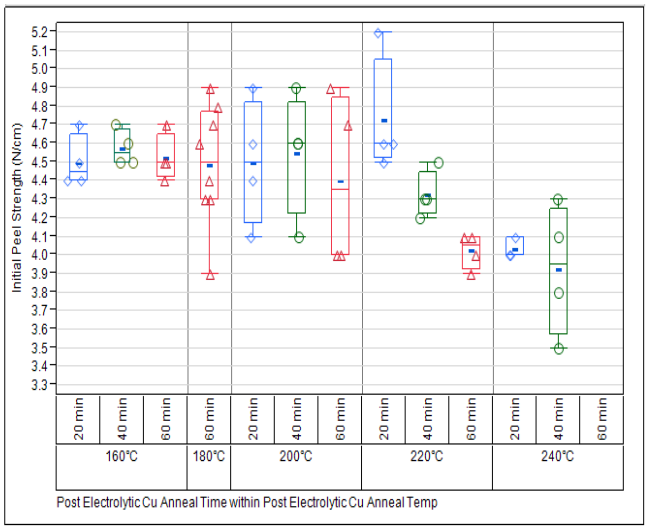

Figure 29: EMC annealing study – peel strength vs. temperature and time.

Another parameter impacting adhesion for plating on molding compound is the PMC (Post Mold Cure) level. Below, three different levels of PMC (A: 85% PMC level, B: 90%, PMC level, C: Over cure) have been evaluated with respect of their effect on adhesion.

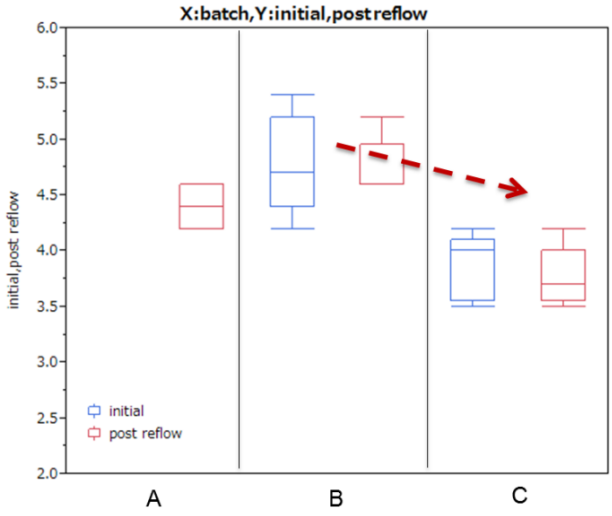

Figure 30: PMC level v.s. Peel strength

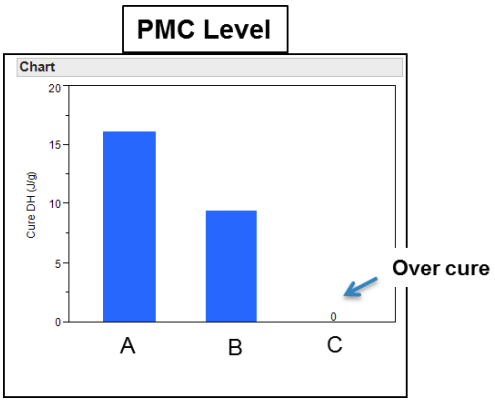

Figure 31: PMC level vs. adhesion performance - A: 85% PMC level, B: 90%, PMC level, C: Over cure

Best adhesion is obtained in this case for 90 % PMC level, while over cure leads to a significant decrease in adhesion.

Conclusions

It has been shown that with the new "adhesion enhancement" process, the wet-chemical processing and the seeding of plated metal on molding compound becomes feasible. This allows the facile application of EMI shielding to closely space active components as well as the "direct" creation of conductive traces on EMC embedded chips.

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