Advanced Non-Etching Adhesion Promoter for Next Generation IC Packaging

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ABSTRACT

In this paper findings from the development of a new Non Etching Adhesion Promoter process (NEAP) targeting inner and outer layer bonding are discussed. The herein described approach propagates a nano-scale copper structure that forms a thin anchoring layer with increased surface area, but hardly contributes to the surface roughness. The superb adhesion results obtained to a wide range of dielectrics support the hypothesis of a mechanical type of adhesion mechanism. This paper also outlines detailed examinations on impacts of the adhesion promoter to subsequent processes revealing an unaffected performance generating conductors with excellent geometries for inner- and outerlayer application and clear benefits to the industry.

INTRODUCTION

For the next generation IC-packaging industry, there is an undeniable need to satisfy the demands for finer line and space of conductors. The unquenchable demand for greater computing power and the mission to fulfill Moore's Law have driven such technological advancement.

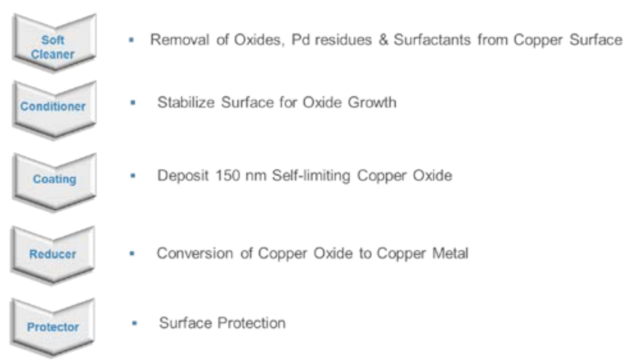
To enable the manufacturing of the state-of-the-art IC-substrates and to meet the technical specifications of the major MPU manufacturers, one of the key technologies is the use of non-etching adhesion promoters (NEAP) for inner and outer layer bonding between conductors and dielectric materials.

While the current POR for adhesion promoters in the packaging industry is still an etch-based system, as the L/S become increasingly finer and even below 8/8µm for the future packaging substrates, manufacturers face a steep challenge to etch such fine tracks. The NEAP systems offer a solution to resolve such difficulty by maintaining the original conductor geometry while reliably providing sufficient adhesion. While most of the commercially available NEAP processes are based solely on chemical bonding that provides the adhesion between the smooth conductor surface and dielectric materials, the potential weakness of such chemical bonding is that its adhesion performance depends highly on the type of material that the adhesive layer is bonded to.

The new NEAP process by Atotech is designed to be one of the technologies that will overcome the obstacles that IC-packaging industry is facing to meet the requirements for future MPU architecture.

PROCESS DESCRIPTION

The herein presented non-etching adhesion promoter concept is based on a nano-dimensional copper oxide structure, adding a superb surface area increase to the conductors, but hardly contributing to the surface roughness. This unique needle shaped structure was thought to mechanically interlock with the correspondent resin favorable associated with a greater variety to various build-up films independent from their functional composition. While the proof of concept was displayed by impressive adhesion values to a wide range of different dielectrics the downside of the surface characteristics was mainly associated with incompatibilities encountered after electroless copper plating or during the selective finishing processes. Therefore, in order to withstand the chemical degradation of the adhesion promoter two additional processing steps were introduced ensuring consistency with inner and outer application enabling NovaBond™ IT to surpass current processes in terms of total performance.



Process	Temp	Time
Soft Cleaner	optional and adjustable	
Conditioner	50 °C	1 min
Coating	70 °C	6 min
Reducer	30°C	1 min
Protector	30°C	1 min

Scheme 1 and Table 1: provides information of the process steps of the NovaBond™ IT process. This includes optional surface cleaning prior to the NovaBond™ IT steps to ensure uniform surface conversion.

i) *NovaBond™ IT Soft Cleaner*: An acidic soft cleaner is used to remove heavy oxides, anti-tarnishes, surfactants from the surface prior to the conversion steps. ii) *NovaBond™ IT Conditioner*: The

Conditioner step is designed to stabilize the substrate surface in terms of pH and electrochemical potential to ensure an even conversion during the subsequent coating step. iii) *NovaBond™ IT Coating*: In this treatment the unique chemical composition of the reaction solution allows the uniform and self-limiting conversion from copper(0) to copper(I/II) forming a < 150 nm thick needle type structure as basis for the proposed mechanical adhesion mechanism. The total amount of copper which is readily converted during this process is ~ 70 $\mu g/cm^2$ and was calculated by weight loss after dissolving the copper oxide layer. iv) *NovaBond™ IT Reducer*: It is very well known that the conversion of copper oxide to copper(0) already greatly enhances the adhesive stability towards chemical attack from environment and the following metallization processes. Unfortunately this benefit in surface passivation has still not taken up enough to reliably withstand all conditions, so that a further rise in stability is necessary in order to prevent any performance loss. v) *NovaBond™ IT Protector*: The full performance of the NovaBond™ IT process finally unfolds after the NovaBond™ IT Protector step whereby an organic passivation layer is generated enabling the chemical and mechanical stability to provide the excellent properties

SURFACE TOPOGRAPHY

As stated above the NovaBond™ IT process is meant to be the key technology enabling non-etching and non-roughening adhesion between conductors and dielectric materials based on a mechanical anchoring mechanism. Herefrom increased efforts were made to gain insight into the impact of the different process steps upon the copper substrate surface. In this regard SEM and AFM investigations appeared to be best suitable as will be displayed in the following paragraphs.

SEM surface morphology investigation

As it can be extracted from the SEM images (Figure 2) and by comparing the conductor geometry before and after the process treatment the herein presented process reveals to maintain excellent conductor shape characteristics and having no significant impact upon the surface morphology.

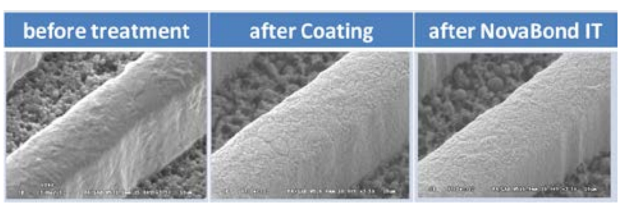


Figure 2: SEM analysis of the surface Morphology before (left), after Coating (middle) and after full Novabond™ IT treatment (right).

These findings are even reinforced by the difference in surface flatness when NovaBond™ IT and etch-based structures are compared (Figure 3). While the etch-based treated surface is heavily attacked and the conductor can hardly be recognized anymore again the NovaBond™ IT surface smoothly follows the contours of the conductor without altering the topography.

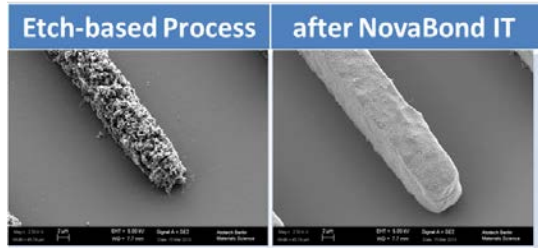


Figure 3: SEM Surface Morphology Images after an Etch based (left) and after Novabond™ IT treatment (right)

In order to visualize though wherefrom the mechanical interlocking of the nano-roughnend surface with the resin raises, samples were NovaBond™ IT treated and laminated into a Ajinomoto GX-T31 dielectric. Add-on analysis by means of FIB-SEM investigation (Figure 4) clearly illustrates the hairy structure of the surface enabling the excellent adhesion performance to a wide range of dielectrics independent from their functional composition as will be discussed in the following chapter.

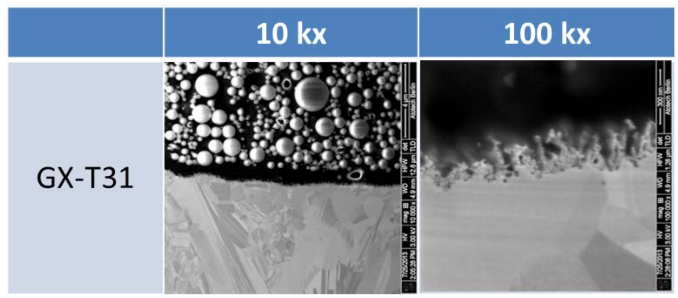


Figure 4: FIB-SEM Images after Novabond™ IT treatment and embedded into GX-T31

AFM surface morphology investigation

As mentioned besides SEM analysis, AFM measurement should be ideal to properly evaluate the true nature of the nano roughened topography of the NovaBond™ IT surface. We herein describe the results which have been obtained by comparing AFM values for DC plated samples

a) before NovaBond™ IT treatment (blue graphs, Fig. 5 & 6)

b) after NovaBond™ IT treatment (red graphs, Fig. 5 & 6)

Measuring window sizes of $(1\ \mu m)^2$ up to $(128\ \mu m)^2$ were selected and the juxtaposition of these roughness values should reveal the process impact upon the overall smoothness of the surface.

As can be depicted from the charts and by correlating the S_A roughness values throughout all measurement window sizes (fig. 5) an impact upon the surface evenness is almost impossible to identify. The difference between the untreated DC reference and the NovaBond™ IT probe is so narrow that the macro- and microscopic roughness is rather attributed to the copper morphology after DC plating and before treatment.

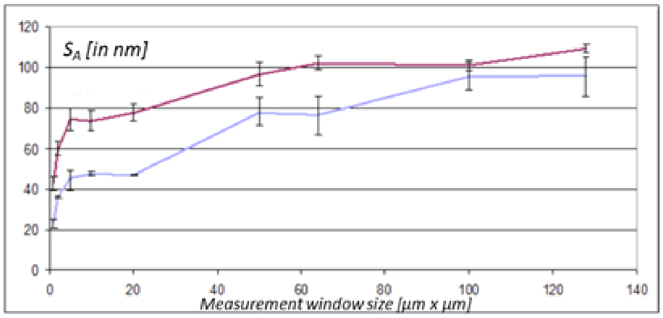


Figure 5: S_a development depending on measurement window

Obviously there must be a distinction between both surface properties in order to rationalize NovaBonds excellent adhesion properties. This is best recognized in the development of the RSAI values (fig. 6) over the measurement window size. In contrast to the SA values there is an immense RSAI enlargement with decreasing measuring window size. This discrepancy is attributed to NovaBonds nano roughness which is more accurately imaged on smaller measuring windows. In accordance with the lower RSAI values the surface of the DC plated reference sample displays no relevant nano roughness.

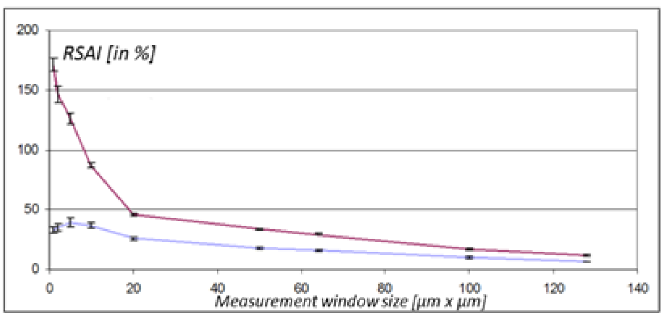


Figure 6: RSAI development depending on measurement window

ADHESION PERFORMANCE

According to the above described properties the new NEAP propagates a nano-scale copper structure that forms a thin anchoring layer with increased surface area. This surface should provide a mechanical bonding to build up films with the significant advantage over the chemically bonded NEAP in its chemical independency from changing types of dielectric materials.

Figure 7 shows the peel strength values of NovaBond™ IT treated samples on different dielectrics. As expected for mechanical adhesion the performance is more or less independent from the resin material. Furthermore other materials, such as Cyanate ester and PPE based resins, to accommodate for the higher frequency specifications, as there is a foreseeable use of the next generation MPUs exhibit excellent results. The slight drop in adhesion e.g. for the PPE resin compared to the GX-92 ABF was assigned to a rupture in the resin itself (cohesive failure mode) as evaluated by fluorescence microscopy (fig. 8).

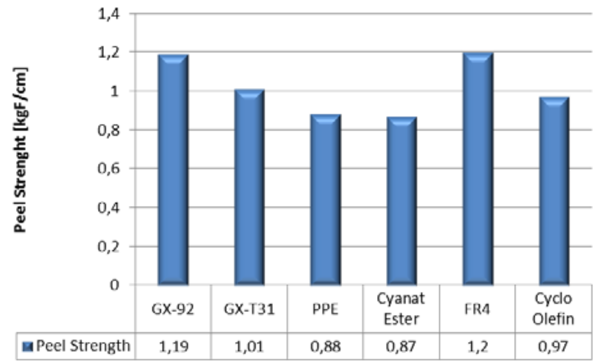


Figure 7: Adhesion Performance on different dielectrics

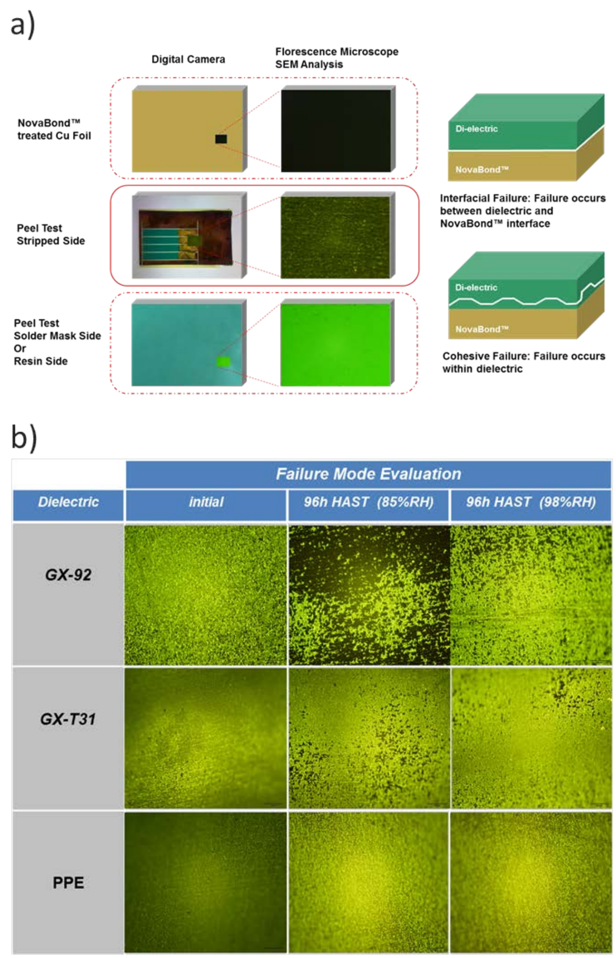


Figure 8: Failure mode analysis by fluorescence microscope analysis a) evaluation method and b) failure mode results

Thermal and moisture stability of the NovaBond™ IT/resin boundary layer was evaluated (herein only the results for GX-92 and GX-T31 are disclosed in fig. 9) exposing the prerouted samples to different HAST conditions (96 h, 130 °C, 85% RH and 96 h, 130 °C, 98% RH). The negligible decrease in adhesion shows that Atotech´s new NEAP process provides a reliable bonding capability even under harsh moisture and thermal conditions. Again the failure analysis points to a cohesive failure mode as analyzed by fluorescence microscopy (fig. 8). These outcomes even become more meaningful by comparing to the results obtained with GX-92 and the etch-based reference system (etch depth = 1.2 µm, fig. 9) whereas values minus

3kgf/cm (initial) and 5kgf/cm peel strength (after HAST) were monitored.

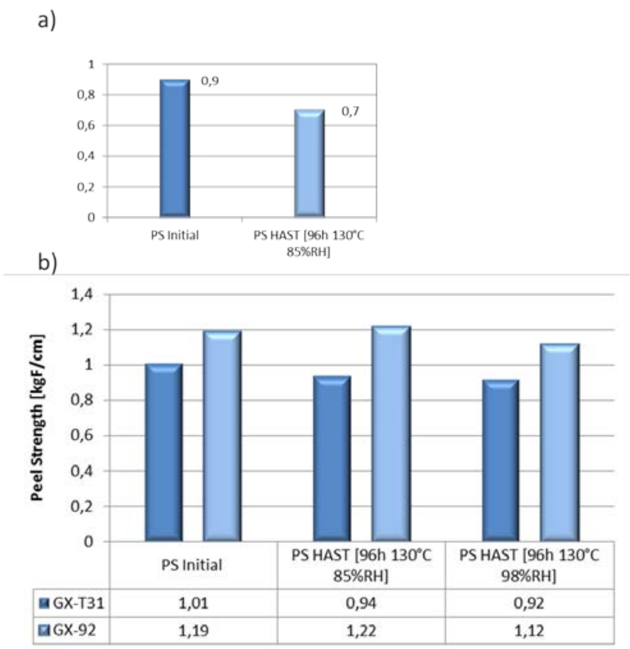


Figure 9: Adhesion Performance a) Etch-based process with GX-92 and b) NovaBond™ IT with GX-T31 and GX-92

To simulate the thermal stress which copper-resin composites are exposed to during manufacturing, test vehicles were prepared whereas NovaBond™ IT treated DC plated samples were processed according to SAP process (fig. 10). Afterwards the test panels were subjected to different annealing conditions in order to figure out if the boundary layer suffers from delamination or blistering.

- 1 h @ 150°C followed by 1 h @ 180°C and followed by 1 h @ 200°C

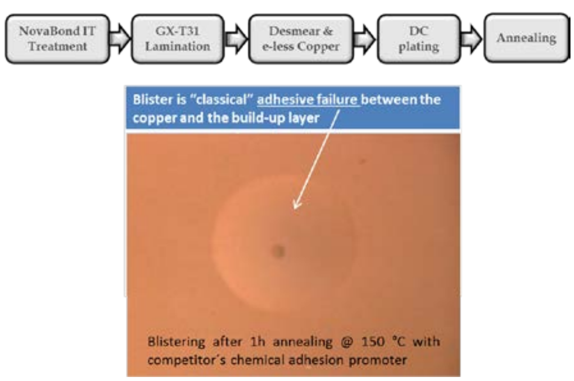


Figure 10: "Blister" test sequence and failed test result obtained with competitor´s chemical adhesion promoter

Optical inspection and cross-section analysis did not reveal any issues regarding the stability of the NovaBond™ IT adhesion performance (fig. 11) unlike competitor´s chemical adhesion promoter (fig. 10), emphasizing again the thermal reliability of the NovaBond™ IT/ABF interface.

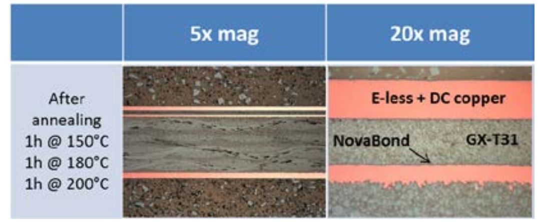


Figure 11: Blister test cross section analysis

The excellent results and the same behavior were also observed while evaluating NovaBond™ IT with different solder masks (fig. 12) regarding their adhesion performance. While the only significant impact upon the peel strength was the use of a liquid type solder resist (SR1) with a superb increase in adhesion (0,83 kgf/cm) all other resins exhibited more or less the same performance with very good values even after HAST and 5 x reflow cycles (@ 288°C peak temperature). Again all failure analysis points to a cohesive failure mode as analyzed by fluorescence microscopy (fig. 12).

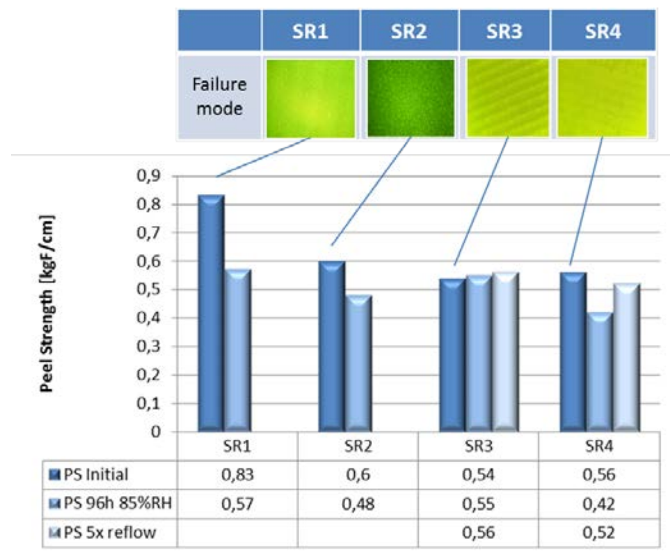


Figure 12: Adhesion Performance and failure mode analysis with different solder resists

Inner and outer layer compatibility

As NovaBond™ IT is designed for permanent inner and outer layer application, subsequent processes such as laser drilling, de-smear and electroless copper deposition and/or respectively exposure, development and selective finishing must not be affected by the process. In this regard a special focus was set on potential residue formation at the surface interfering with the adhesion of the base copper to the electroless copper layer (innerlayer application) or respectively to the ENiG layer (outerlayer application).

We herein present the results obtained from a representative experiment evaluating the laser drilling-, desmear-, and via-filling compatibility (innerlayer application). For this purpose suitable test vehicles were build (fig. 13), separated into stripes (5 mm) and then submitted to the copper strip lifting (fig. 14).

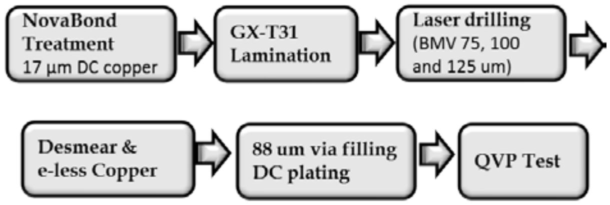


Figure 13:Build up sequence for the QVP test vehicles

Depending on the outcome of the cross section analysis two different main scenarios are thinkable (fig. 14):

a. The test is failed when the capture pad remains in the hole, pointing to residues in the interface causing copper/copper separation.

b. The test is passed when the capture pad is torn out of the hole, showing that no residues are affecting the copper/copper junction.

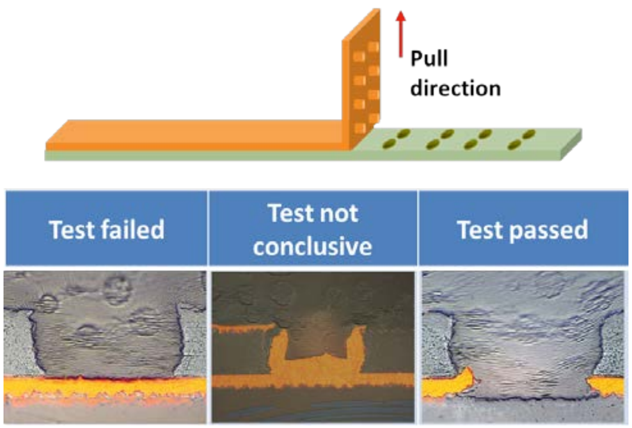


Figure 14: QVP test evaluation

Figure 15 depicts the results from the QVP evaluation (75 µm openings) for NovaBond™ IT and two reference surfaces a) an etch based process, and b) Black oxide. It can be concluded that all conditions passed the test requirements pointing to their -but in this case especially- NovaBond™ IT ´s compatibility with the innerlayer application.

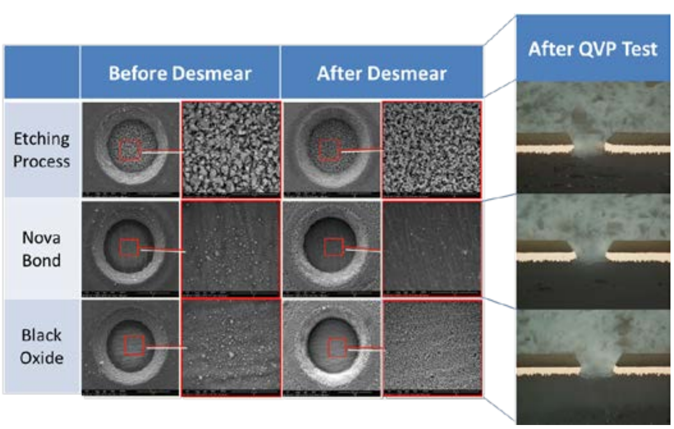


Figure 15: QVP test results

Referring to the outerlayer compatibility, correspondent tests were conducted in order to display that no residues remain on the surface (fig. 16) affecting a perfect selective finishing processing. Besides cross section analysis and adhesion tests (tape test before and after ENiG) we herein want to focus on FT-IR investigations before and after a micro-etch cleaning step (1 µm etch depth) (1st step in the ENiG process). We strongly believe that these investigations reliably demonstrates that the NovaBond™ IT process does not cause any kind of residues responsible for later skip plating issues or poor copper/nickel adhesion.

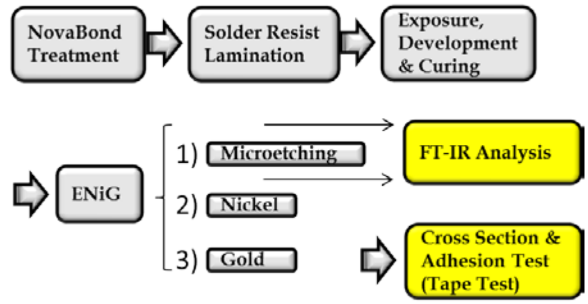


Figure 16:Residue evaluation and outerlayer compatibility test

In figure 17 the FT-IR investigation of NovaBond™ IT treated samples with 4 different solder resists are summarized. While the spectra immediately after development step still exhibit adsorption frequencies (red areas) which are assigned to solder resist residues, these signals completely disappear whenever the surface is cleaned by means of a micro-etch cleaning step (as used for all selective finishing processes) pointing to absolutely clean and even copper superficies. These results in combination with the previously shown excellent adhesion performance, the passed taped test before and after ENiG and the missing undercut after ENiG clearly demonstrate that NovaBond™ IT fulfills so far all tested requirements for its outerlayer application and these results could already be confirmed by major manufactures.

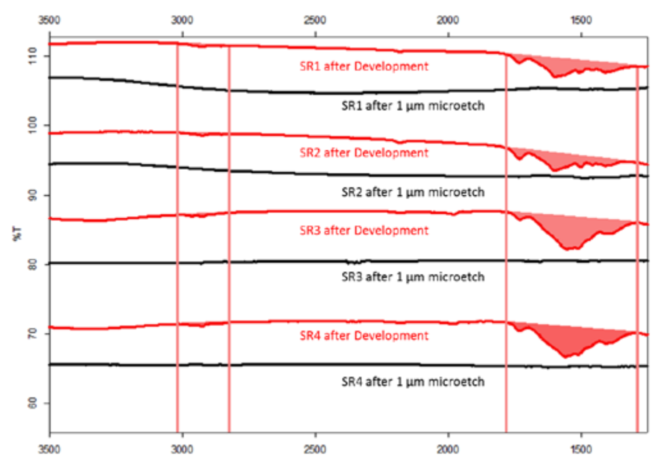


Figure 17: Residue evaluation via FT-IR investigation

SUMMARY & CONCLUSIONS

NovaBond™ IT is a simple process and provides manufacturers with a non-etching adhesion promoter for inner and outerlayer application. The new NEAP propagates a nano-scale copper structure that forms a thin anchoring layer with increased surface area, but hardly contributes to the surface roughness. As the new NEAP provides a mechanical bonding, one of the significant advantages over a chemical bonded adhesion promoter is its variety on dielectric materials. The obtained adhesion results supported the conclusions. Further examinations on impacts of the adhesion promoter to subsequent processes revealed an unaffected performance generating conductors with excellent geometries for inner- and outerlayer application.

ACKNOWLEDGMENT

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