Advanced adhesion promotor system for IC substrate packaging

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Abstract
In the manufacture of IC substrates the additive production process route results in the joining together of different materials. One example of this would be in the bonding of a structured core layer containing copper traces, with the next build up layer of dielectric material; another case would be in the application of a soldermask material to the finished substrate build.

In both of the examples quoted, typical ways to arrive at suitable adhesion between different materials would be to roughen one of the surfaces. This is most commonly achieved by etching the structured copper traces to produce a strong mechanical bonding between the subsequent layers.

However this mechanism of etching the copper traces to achieve surface roughness can create a number of very specific problems. First as copper features get ever smaller it is not desirable to etch away this structured copper as this can result in a form of dimensional instability. Secondly, we should also consider the influence of a roughened copper surface upon electrical performance of the device, especially in the case of high frequency applications where the path of the electrical signal moves into the outer most skin of the copper track. If the outer layer of the copper track is heavily roughened this will effectively create a barrier for the path of the signal. The result of such roughness is a high and unacceptable signal insertion loss.

The ideal way to overcome these issues would be to use a bonding enhancement system which provides the minimum possible surface roughening. However the challenge here is that any such low roughness system must still offer the best possible bond integrity and functional performance in combination with low signal loss to be compatible with high frequency applications.

This paper highlights the development of a low etching treatment process which meets all of the challenges of Enhanced functional performance together with lowest signal insertion loss to be suitable for so called 5G applications. EXPT NovaBond EX is a system developed to meet these challenges, with the formation of a smooth copper surface with minimal copper loss (less than 200-nm), which is subsequently treated with a coating of adhesion promotor to provide the strongest possible bond strength.

Key words
Adhesion Promotor, Build-up Material, Copper Removal, Etching, Soldermask.

I. Introduction
In the Semi Additive Process build up sequence used in production of IC Substrates one of the key tasks is to form a strong adhesive bond between adjacent layers where there is intrinsically no natural adhesive force. The fundamental challenge here is to form a strong bond between the smooth surfaced copper traces and the dielectric materials used in either build up layers or final soldermasks coatings, with no negative impact upon final product performance.

In former times the most commonly used adhesion promotor systems provided a high degree of roughening of the copper surface; this roughened surface can then act as a key to form mechanical bonds with the resin systems and the copper traces. However this type of system which is based upon a maximum increase in copper surface area for a minimum amount of Copper removed is now no longer acceptable.

As conductor features become smaller and smaller it is ever more challenging to form reliable structures to the desired line and space tolerance, therefore it is totally undesirable to introduce an adhesion promotor step based upon a high degree of surface roughening.

In addition, a second challenge is now faced with the advent 5G systems where there is strong relationship between signal integrity and surface roughening. As the frequency and rate of data transfer of the electrical signal increase, the path of the electrical signal moves into the outer most skin of the copper trace. Obviously if this "skin" has been highly roughened to increase adhesion with buildup layers there is a much higher risk that some of the signal will be lost or slowed down. With any such loss then the ability to perform at the required high frequency range is also impaired.

To overcome these challenges the ideal case would be to develop a totally none-etching adhesion promotor system where there is a strong bond formed between the copper and dielectric materials used. For this best case scenario an adhesion promotor system is required which could form strong Chemical bonds between the two adjacent layers, essentially forming a strong bridge between them.

So far to date no such system based upon a purely Chemical bond is commercially available. However the newly developed EXPT NovaBond EX process from Atotech offers a suitable intermediate process in which the surface of the copper trace is prepared with a low etching pre-treatment step prior to the application of an adhesive coating. The combination of the conditioned copper surface together with a combination of chemical and physical properties of the adhesive coating provide the optimum bond adhesion.

II. Process

The functional properties of organo-silane compounds are well known [1], [2], where by the silane group is able to make a strong bond at the metal surface leaving the active sites in the organic phase to bond with the resin systems in the adjacent dielectric materials. In development of the EXPT NovaBond EX system an unique new adhesion promotor compound has been identified and synthesized for use.

Having identified such a new compound the next challenge is to investigate what pre-treatment of the copper surface is required to give the best possible performance in terms of bond strength for all target applications. During these evaluations a two-step pre-treatment process was identified which when combined with the final application of the adhesion promotor coating gives a three step process as detailed herein; note that the optimum process application is for use in horizontal conveyorized equipment:

A. Cleaner Step

First step is a cleaner (EXPT NovaBond EX Cleaner) which is designed to clean all dirt and traces of oxides from the copper surface in preparation for the next Conditioner step. Surface of Copper trace after this process step is shown here in Fig. 1, which shows that there is no significant roughening of the Copper surface. Note that it is recommended to use spray application for this process step, with typical contact time 20-seconds and an operating temperature of 30-degrees Celsius

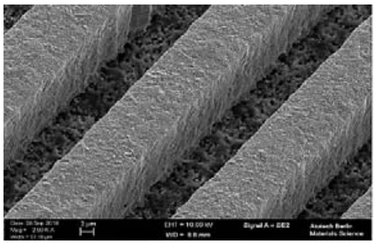

Fig. 1 – Copper Trace after EXPT NovaBond EX Cleaner process step at 2,000x magnification

B. Conditioner Step

The second process step is a conditioner (EXPT NovaBond EX Conditioner) which gives a small degree of copper removal and prepares the Copper surface for application of the Adhesive Silane Coating. Typical copper removal is less than 200-nm and resulting surface roughness is a maximum of 100-nm. Fig 2 shows two examples of Copper trace at different magnifications. As with the Cleaner step it is recommended to use spray application for this process step. Typical contact time is 30-seconds and an operating temperature of 30-degrees Celsius.

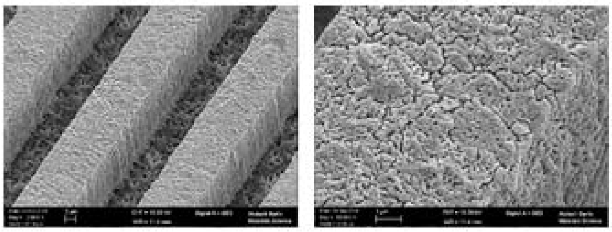

Fig. 2 – Copper Trace after EXPT NovaBond EX Conditioner process step at 2,000x (left) and 10,000x (right) magnification

C. Adhesive Coating Application Step

The final process step is the application of the Adhesive Silane Coating, in which the active compound is made up into an aqueous blend at a chosen concentration to give optimum film coating. Application is then made using either spray or flood immersion application with a contact time of 30 to 60-seconds at a temperature of 30-degrees Celsius. Fig. 3 shows images of the copper trace after application of the adhesive layer. As with previous images it can be seen that there is minimal impact upon the final surface topography.

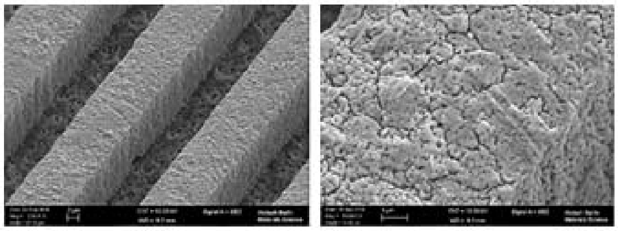

Fig. 3 – Copper Trace after EXPT NovaBond EX Coating process step at 2,000x (left) and 10,000x (right) magnification

III. Methodology

In this section details of the techniques used to evaluate the process performance are given.

D. Measurement of bond strength with build up materials

Copper foils are processed through the sequence under consideration then vacuum laminated [3] with the buildup material under test. The treated foil and laminated build up material is then pressed onto a rigid panel [4] and then routed into 1.0-cm stripes using a bench top router to form stripes which are then used for peel strength measurements according to industry standard procedure [5].

Having made the initial peel strength measurement the test coupon is then subjected to further tests such as highly accelerated temperature and humidity stress tests (HAST) [6], and after processing through twelve passes of a standard IR Reflow test [7]. Purpose of these tests is to show the reliability of the adhesion promoter system under such extended thermal excursion tests.

E. Measurement of bond strength with soldermask

Having treated the copper surface with EXPT NovaBond EX the soldermask under evaluation is applied to the copper surface and cured as per the material supplier's specifications. To evaluate the performance of EXPT NovaBond EX in terms of the adhesion of the soldermask coating two different techniques are used to measure the peel strength as follows:

First is the so called inner layer method in which soldermask is applied to the copper surface treated with EXPT NovaBond EX and cured under standard conditions. The cured soldermask is then bonded to a layer of pre-preg which has been previously laminated to a copper back panel to form a rigid panel (as shown in Fig. 4). Once this rigid test vehicle is formed the desk top router device is once again used to scribe 1.0-cm wide stripes into the back side of the copper foil to give the section for peel strength test.

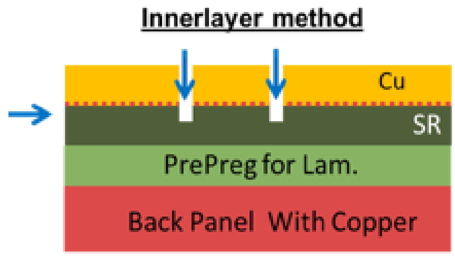

Fig. 4 – Schematic of sample preparation for the Inner layer method of soldermask evaluation

The second technique used for Soldermask evaluation is the so called soldermask method, a schematic of which is shown in Fig 5. In this case the soldermask is applied to a copper foil which has been treated with the Adhesion Promoter coating under test. After standard curing of the soldermask a 1.0-cm strip is routed in the Copper foil to allow peel strength test to be performed.

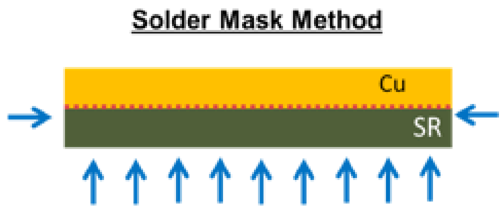

Fig. 5 – Schematic of sample preparation for the Soldermask method of soldermask evaluation

As in the case of the peel strength determinations with build up materials, the initial peel strength is again repeated after HAST and IR Reflow reliability tests.

IV. Results and Discussion

For the sake of convenience the three main functional performance factors will be discussed separately herein

A. *Results of peel strength with build up materials*

A range of different build up materials were considered in this evaluation, results for which are shown here in Fig. 6

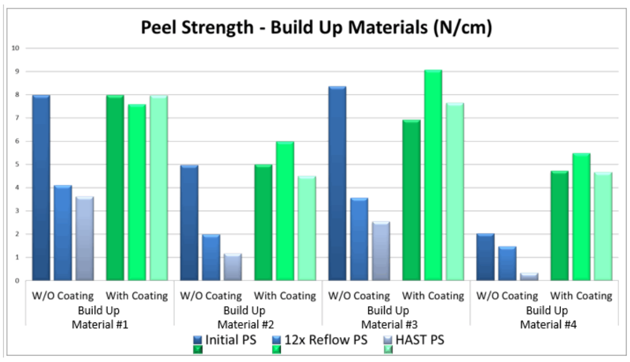

Fig. 6 – Peel Strength Data with and without EXPT NovaBond EX Coating

In Fig. 6 a comparison should be made between the blue and green data sets for each build up material, with particular emphasis being placed upon the results in the reliability tests. In all four cases it can be seen where there is no coating of EXPT NovaBond EX applied there is a very significant fall off in peel strength after HAST or reflow test. However after application of the adhesive coating no such fall off in peel strength is observed. This is a strong indication that the application of the adhesive coating has a positive effect upon bond strength.

B. *Results of bond strength with soldermask*

In this case data with and without application of the Adhesive Silane Coating is compared with the adhesion of soldermask upon a surface treated with an Atotech internal reference. This reference process used, CupraEtch FH, with an etch depth of 0.6-microns, is a process that is based upon the highest possible inter granular etching with highest possible RSAI, Ra and Rz values.

Data from soldermask tests is shown in Fig. 7 where excellent performance is once again exhibited with the use of EXPT NovaBond EX Coating:

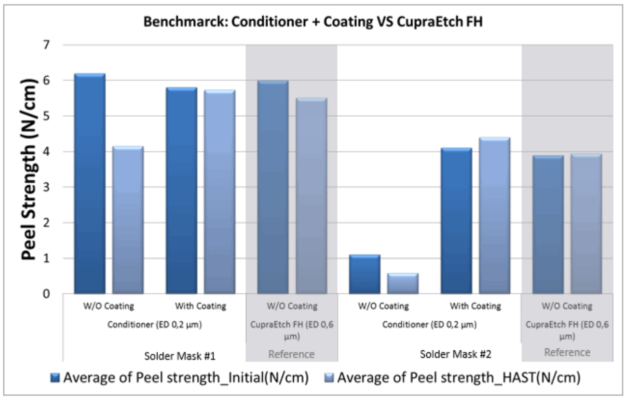

Fig. 7 – Peel strength data after application of Soldermask

In the case where soldermask #1 is applied it can be seen that where no coating is used there is a significant fall in peel strength after HAST test. However when EXPT NovaBond EX process is applied the adhesion shown before and after is comparable with the high etching reference process, CupraEtch FH.

Where soldermask #2 is applied the data shows an even greater improvement where the EX coating is applied. The example with no coating has relatively poor peel strength yet the example where the coating has been applied gives a performance very similar to that seen with the high etching reference, CupraEtch FH.

Next, the performance is compared with the two different solder mask test methods. In the example shown in Fig. 8 a comparison is made for Solder Mask #1:

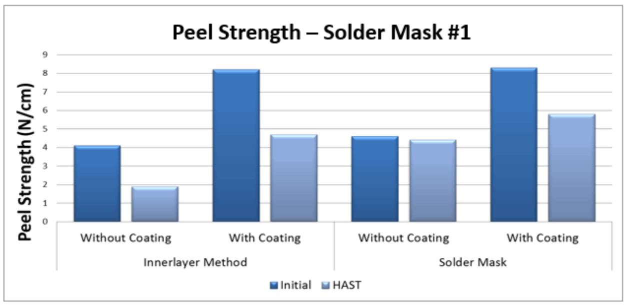

Fig. 8 – Comparison of soldermask test methods

In both examples it can be observed that after application of the EXPT NovaBond EX Coating there is a significant increase in peel strength, this applies to both the initial peel strength and also when repeated after the HAST reliability test. These observations once again indicate the positive effect of the applied coating upon the adhesion between copper and solder mask.

V. Conclusion

In manufacture of IC Substrates treatment processes are required to facilitate a strong bond between materials which would not typically bring good adhesion. In this paper a new process has been introduced which is able to give excellent bond strength between circuitised copper features and the resin systems found in various dielectric materials. EXPT NovaBond EX is shown to enhance the bond strength between commonly used soldermask and build up materials with minimal copper removal and roughening of the copper trace. These enhanced adhesion properties are the result of the application of a unique organo-silane material with a tailored pre-treatment process.

Acknowledgment

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