Advantage of Non-Etching Adhesion Promoter on High Frequency Signal Loss

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ABSTRACT

In the age where demands for mobile electronic devices are ever increasing, the propensity for an exponential growth of wireless data transfer is inevitable. The massive data exchange is driven by rise in the signal frequency and the trend having high frequency applications is imminent. The prolific examples of high frequency applications include the next generation 4G mobile phones, satellite communications, Wi-Fi LAN, milliwave radars on automotives, CPUs and GPUs.

As the frequency signals carried by electronic devices continue to elevate, there is a greater risk of compromising the signal integrity. The main contributors of high frequency signal loss are the dielectric material and conductor which signals travel on. In order to minimize signal loss, material suppliers have been developing reliable high speed dielectrics with low dissipation factors and dielectric constants. On the other hand, the conductor loss of high frequency signals is largely dependent on the surface profile and roughness of the tracks.

Uneven conductor surface profile and track roughness is a product of using conventional etch-based adhesion promoter. While the conventional etch-based adhesion promoters cause no major functionality issues to the manufacturing of commodity PCBs, the impact on the signal integrity for high frequency applications can be an issue.

As signal frequency escalates, a phenomenon known as the "skin effect" propagates the signals on the track surface. The coupled impact of the "skin effect" and conductor roughness is an upsurge in resistance that results in signal loss. Contrary to the etch-based adhesion promoter, non-etching adhesion promoter (NEAP) can offer a flat conductor surface and a controlled track width. This can in turn reduce the high frequency signal loss significantly.

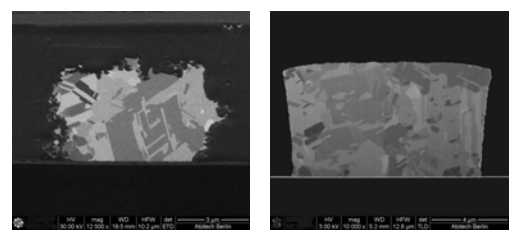
The paper makes use of a commercially available non-etching adhesion promoters and copper foils in order to investigate the influence of surface roughness on high frequency signal loss. The characterization is carried out through the use of computer simulation as well as actual sample measurement in order to determine those factors which dominate the overall loss performance.

INTRODUCTION

The present technology uses a widely accepted copper micro-etchants as surface treatment in order to create a mechanical bonding that ensures sufficient adhesion and thermal reliability between a copper conductor surface and the dielectric layer. An even older adhesion promoter for inner layer bonding is black oxide. This bonding technique is based on the enhanced adhesion due to the surface area increase from copper oxide crystal growth on copper circuitry. However, it is believed that these technologies will eventually be rendered obsolete in the production of future high frequency PCBs.

Studies have shown that high frequency signals travel on the conductor surface, a phenomenon known as skin effect. Consequently manufacturers for high frequency circuit boards are turning their eyes to have smooth surface conductors, as micro-etched or roughened surface will be a cause for signal loss.

Secure™ HFz is designed to enable the adhesion of inner and outer layer while maintaining a smooth conductor surface. The non-etching technology is deemed to be a necessity for the next generation high frequency application. A traditional micro-etch based treatment creates a roughened copper surface that provides the essential mechanical bonding to prepregs with its micro-anchors to ensure excellent thermal reliability.



Etch-Based Process NEAP

Figure 1. Cross Section of 12um Track Treated with NEAP and Etch-Based Process

Figure 1 compares the cross sections between a smooth conductor surface treated by a NEAP and a roughened conductor surface treated by an etch-based process. Unlike the micro-roughening process, Secure™ HFz uses only chemical bonding to provide superior bonding and exceptional thermal reliability without altering the track geometry.

Non-etching adhesion promoters provide smooth conductor surface, as they prevent the change of the conductor profile, it results in the reduction of high frequency signal loss caused by "skin effect." The growing attention to such non-etching technology has prompted manufacturers to consider the use of NEAP to improve the electric properties of the circuit boards.

In order to measure the impact of Secure™ HFz on signal loss, an investigation will compare the high frequency signal attenuation between NEAP, etch-based treatment, and reduced black oxide. Attenuation is defined as the reduction in the strength of signal, it is a natural effect of signal transmissions over long distance, with the unit expressed in decibels (dB).

A simulation by modelling software for signal loss was first conducted. The simulated results were then compared with the actual signal characteristic measured.

PROCESS DESCRIPTION

Secure™ HFz uses the following four steps to apply a layer of adhesion promoter. The process is based on first depositing a thin layer of tin on the copper surface. Then the activation step forms an even tin oxide layer where the organo-silane coating can uniformly form hydrogen bond on top. As the Secure™ HFz treated panel is pressed with the prepreg, the functional group of the organo-silane reacts with a variety of functional groups in the dielectric materials to complete the bonding process.

Process	Time	Temp
Acid Cleaner	30s	40°C
Rinse		T_R
Immersion Tin	35s	35°C
Rinse		T_R
Activation	20s	40°C
Rinse		T_R
Silane Filming	30s	30°C
Drying		60°C

Acid Cleaner

A simple cleaning step where oxidation of copper surface is removed along with possible heavy metal residues. The acid cleaner prepares an ideal surface before immersion tin process.

Immersion Tin

A thin tin layer is deposited, 60 – 80 nano meter, on the copper metal surface with the exchange reaction driven by the complexing of copper ions with thiourea in the solution. The immersion tin process produces a very smooth layer with no change in conductor geometry.

Activation

The pre-step to the silane filming is applied to oxidize the tin metal surface uniformly, which in turn provides an interfacial crosslink sites with evenly distributed tin oxide layer. As a result, the silane coupling agent coating can enable a stable adhesion performance.

Silane Coating

The hydrolytic deposition of silane goes through hydrolysis followed by condensation in the silane bath, where the organo-silane results in covalent bonds with the oxygen to form a horizontal chain of silane. As the silane coupling agent is coated on the tin oxide layer, hydrogen bonds are formed on the metal oxide interface.

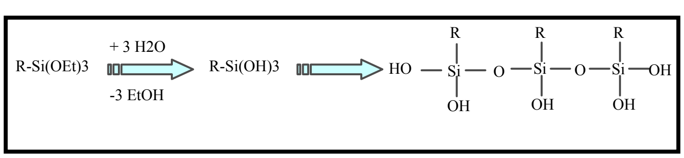


Figure 2. Hydrolysis and condensation reaction occurring as the silane bath is made up

Figure 3 shows that as a result of the heat applied during multilayer layup press, the bonding between the silane coupling agent and functional group from the prepreg polymer is formed, where a strong covalent bond provides enhanced adhesion between the dielectric material and the silane layer.

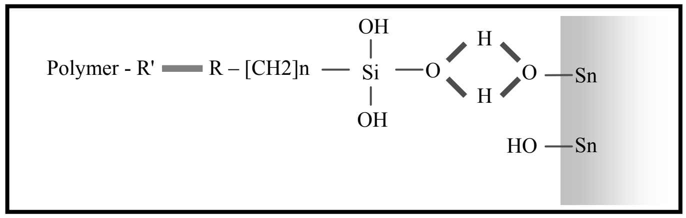


Figure 3. Formation of bond between the silane coupling agent and dielectric material

EXPERIMENT

An experiment was designed to measure the impact etching and non-etching adhesion promoters on signal characteristics. The etch-based treatment was used as reference and the NEAP was based on Secure™ HFz.

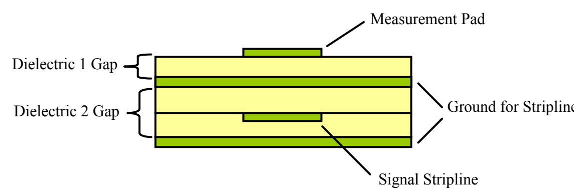


Figure 4. Schematic of the 4-layer signal loss test vehicle with one signal trace stripline

Table 1. Track geometry for the signal loss test vehicle

Test Vehicle Design Parameters	Size
Height of Signal Loss Stripline	10µm
Top and Bottom Width of Signal Loss Stripline	100µm
Length of stripline	200mm
Dielectric 1 Gap	0.50mm
Inner Layer VLP Foil Thickness	12µm
Dielectric 2 Gap	1.0mm
Impedance Value for Signal Loss Stripline	50Ω

The above test vehicle was treated with both etching and non-etching technology and the conductor surface roughness measured with Atomic Force Microscopy (AFM).

Table 2. AFM analysis on conductor surface after etch-based and non-etching treatments

	Before Treatment	After Etch-Based Process	After Secure™ HFz
R_a (µm)	0.03	0.41	0.05
R_{ms} (µm)	0.04	0.39	0.06
R_z (µm)	0.28	2.94	0.30

As expected, the non-etching treatment gave virtually no alteration of conductor roughness in comparison with the surface profile before treatment. On the other hand, the conductor roughness with etch-based process showed a typically surface roughness after a micro-etchant treatment.

Simulation software, Polar Instrument Si9000, was first used to investigate the impact of conductor surface roughness on the signal loss. The computer modelling uses a field solving PCB transmission line design system that is suitable simulation for transmission line loss can be achieved. The electrical properties of the dielectric material were inputted into the simulator to generate the signal attenuation.

Table 3. Dielectric constant and dissipation factor of high frequency material based on PPE

Conditions	Dielectric Constant	Dissipation Factor
2 GHz	3.40	0.0020
4 GHz	3.40	0.0030
6 GHz	3.40	0.0030
8 GHz	3.40	0.0040
10 GHz	3.40	0.0040

Condition: C-96/20/65, Test Method (IPC TM-650): 2.5.5.1 and 2.5.5.5

Polyphenylene Ether (PPE) based material is widely used for high end high frequency application due to its superior electrical properties. The dielectric constant and dissipation factor of a representative PPE-based material was used for the simulation work. The dielectric constants shown on Table 3 were applied.

DISCUSSION

The signal loss was simulated between the frequency range of 1 – 20GHz. A stripline with the same geometry as the test vehicle was used and the values of roughness resulting from the two surface treatments were entered.

As expected the simulation results showed greater signal loss on the roughened track compared to the non-etched smooth track. The crucial question was how much of the signal loss would be reduced by keeping the conductor contour smooth.

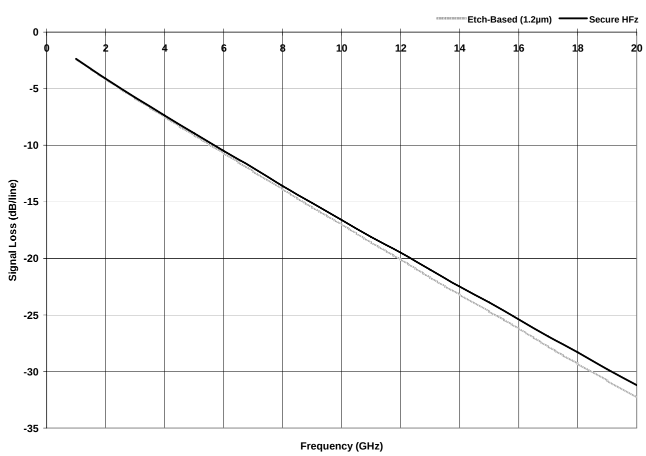


Figure 5. Simulated results comparing the signal loss between conductors treated with etch-based and Secure™ HFz

Table 4. Simulated signal losses with different surface treatment

Frequency (GHz)	Signal Loss (dB/line)	
	Etch-Based (1.2µm)	Secure™ HFz
3	-5.85	-5.77
5	-9.12	-8.95
10	-17.00	-16.60
20	-32.30	-31.20

The predicted difference in adhesion promoter between the etch-based and non-etching process have exhibited a signal loss difference of 1 – 4%. Although the discrepancy in signal loss between the two surface treatments may not seem that significant, the simulated results certainly showed that there is a trend of increasing signal loss difference between etch-based and non-etching adhesion promoters as the operating signal frequencies move into an even higher range.

In order to confirm the simulated signal loss results, an actual measurement on signal characteristics were measured using the test vehicle presented on Figure 4. The signal loss was measured between the frequency range of 1 – 10GHz.

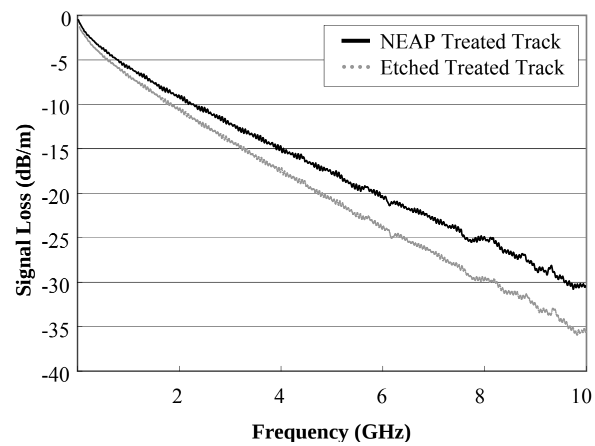


Figure 6. Actual Signal Loss Measurements For 100um Track With Etching And NEAP Treatments

The simulated results have correctly shown the trend of NEAP reducing the signal loss in comparison with etch-based technology. At an operating signal of 10GHz, the track treated with etch-based treatment was observed to have signal loss of approximately 14% more than the smooth track. The test results have shown that the combination of superior dielectric materials, very low profile copper foils, and non-etching adhesion promoter can enable the manufacturing of a printed circuit board with significant improvement in electrical properties.

By comparing the total attenuations shown on Figure 5 and Figure 6, it can be observed that the actual measurement of signal loss is greater than the predicted values. Although the simulation is useful in determining the trend of how surface treatments can influence the signal integrity, absolute readings can vary quite significantly from actual measurements.

The difference between the simulated results and the actual measured signal loss can be accounted for by the computer modeling not taking the roughness on the interface between the conductor and dielectric material into consideration. While the test vehicle was constructed using VLP copper foil, there was still enough roughness to contribute to signal loss.

The investigation has found that the nature of different surface treatment can indeed have a significant impact on the signal integrity. However, in order to manufacture circuit boards with superior electrical properties, it has to be constructed in combination with dielectric material with low dielectric constant and low-profile copper foils.

The manufacturing of such high frequency panels can be expensive and there are proposals of meeting the specified level of electrical properties with lower cost by using NEAP. One of the potential solutions is to couple the non-etching adhesion promoter with a middle grade high speed dielectric material, where an electrical property similar to the high grade dielectric material can be achieved. This can potentially result in a reduction of overall cost but obtaining similar signal integrity and panel makers are seeking such option.

NEAP has been shown to give improvements on the signal loss from the current technology, this has been confirmed by both simulated and actual measurements. There is a also a possibility of using cheaper high speed materials in combination of NEAP to offer the same grade of electrical properties as the high-end dielectric materials. This will be part of the next studies to compare how cost effective can coupling NEAP and a medium grade dielectric be in comparison to the best dielectric materials available in the market.

SUMMARY & CONCLUSION

As the advancement of information technology and mobile devices continue, there is an increasingly stringent requirement for signal integrity. Where roughness used to be permitted in the high frequency panels, manufacturers can no longer afford to compromise the signal loss associated with surface treatment processes.

While adhesion promoters such as reduced black oxide and micro etchants are still the process of record, the time when roughening of conductors will no longer be part of the board design specification is imminent.

Simulation results and actual measurements of signal loss have confirmed that the use of non-etching adhesion promoter can significantly improve the overall electrical properties of circuit boards. The application of NEAP can also offer the possibility of reducing manufacturing cost when used in combination with cheaper high speed dielectric materials to match similar electrical properties as the high-end materials.

Therefore, non-etching adhesion promoter is the future of surface bonding technology for circuit boards to enable the continuous evolution of high frequency applications.

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