Copper Foil Elements Affecting Transmission Loss with High Speed Circuits

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Abstract: Large data transmission continues to increase at the rate of 20% worldwide annually due to live video streaming, cloud storage, PDA usage, IOT, and other technologies. Electronic devices are getting smaller yet required to accommodate higher speeds and good signal integrity. With 5G technology on the horizon there is heightened concern for signal loss affecting product performance. It is more important than ever to analyze loss factor at the earliest design stage. This analysis is done for the PCB materials by manufacturing electrical test coupons prior to building the PCB and evaluating the electrical performance. These coupons are designed and built with (TEG, test element group) structures which are ideal for measuring transmission loss. However, often these test PCBs use different lots of raw laminate materials which yield different results. Why? This study examines possible factors for these inconsistencies such as etched signal trace shape, surface treatment, and grain size.

Keywords: high frequency, strip line, transmission loss, surface treatment, copper foil, grain size, skin effect.

1. Introduction

With electronic devices operating at higher frequencies concern for product malfunction due to transmission loss has increased. It is essential for design engineers to analyze signal integrity at early design stage as it could directly impact product sales. Furthermore, the electronics industry foresees more loss related issues with the introduction of 5G technology.

In order to predict transmission loss at PCB design stage typically multiple test boards are built using the TEG (test element group) and loss factors are measured. However, often times the loss data is inconsistent from lot-to-lot, and even with boards built based on the exact same PCB CAD layout. Could it be possible that reasons other than the variance of laminates is affecting signal integrity? In this paper etched signal trace shape, copper surface treatment, and copper grain size are investigated.

2. Etched Signal Trace Shape

1. Trace Cross Section: Subtractive Method

Commonly used imaging and etching methods are subtractive and semi-additive. The subtractive method is more common as there are cost and lead time benefits. Trace width is not as accurate when using the subtractive method compared to the semi-additive process. In this segment traces were processed with varying etching times using the subtractive method and compared.

The subtractive process starts with laminating dry film to the board. Next the photoresist is exposed using the imaging tool. Then the dry film is developed and removed from areas other than right above the trace. Next, the board is exposed to an etchant which removes unwanted copper and leaves just the copper trace which is covered by the dry film. Looking closely at this process on a micro level, the etching starts vertically in the Z axis at the top surface of the copper, but eventually etches down and then on the sides of the trace as well. Through this etching process the trace shape changes from a trapezoid to a rectangular shape. With longer etching and/or modification of other etch parameters the trace shape may become more rectangular but will likely be reduced in size. (Figure 1).

Normally manufacturing engineers will process the trace based on the bottom width of the trapezoid shape to match the trace width specified in the CAD drawing unless noted otherwise.

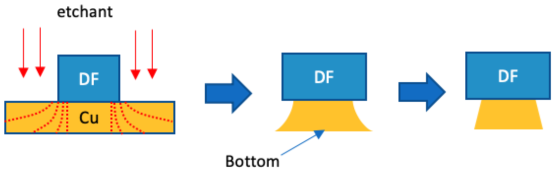

Figure 1 Subtractive method trace formation

Figure 2 shows the difference in trace shape based on etching time. The value m/minute shows the etching line penetration speed: bigger the value, shorter the time exposed to etching liquid, smaller the value longer the time and the trace shape becomes reduced in size but more rectangular/less trapezoidal.

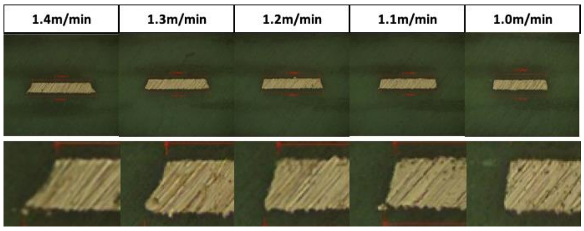

Figure 2 Trace cross section with varying etching time

Figure 2 above shows that longer the etching time the trace shape becomes more rectangular and shorter the time the trace foot is longer creating a trapezoid shape. Next, effect on transmission loss based on trace shape is examined.

2. High Frequency Characteristics

Based on strip lines created in 2.1 (Figure 3), loss was measured up to 50 GHz (Figure 4).

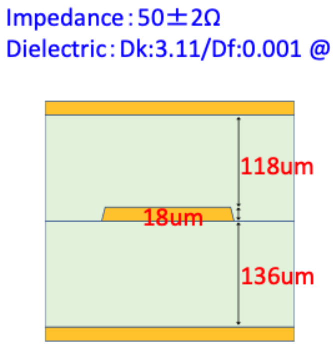

Figure 3 Stack-up

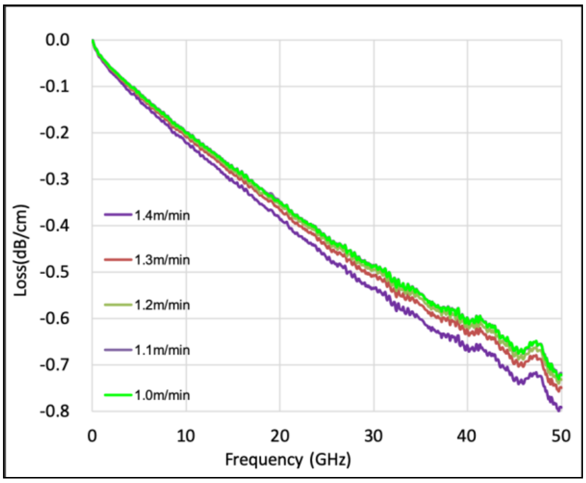

Figure 4 S21 measurement result

Frequency	Penetration Speed				
	1.4m/min	1.3m/min	1.2m/min	1.1m/min	1.0m/min
20GHz Average	-0.39	-0.37	-0.36	-0.35	-0.35
50GHz Avetage	-0.75	-0.71	-0.69	-0.68	-0.68
					dB/cm

Figure 5 Average loss

The measurement result shows loss is lower with the rectangular shaped traces and higher with trapezoid. As could be seen on the average loss in Figure 5, maximum difference close to 0.07 dB/cm was observed.

3. Effects of Surface Treatment

3.1 Brown Oxide

Multiple boards with strip line design are processed through a chemical treatment to add roughness to the circuit side of the copper in order to strengthen mechanical bonding. In the past black oxide treatment was the standard. Today, brown oxide treatment which is more environmentally friendly or organic treatments are used. The surface roughness after the brown oxide treatment improves the peel strength. Additionally, at high frequencies where skin effect is prevalent it is thought to increase transmission loss. Figure 6 shows SEM image of copper surface before and after treatment.

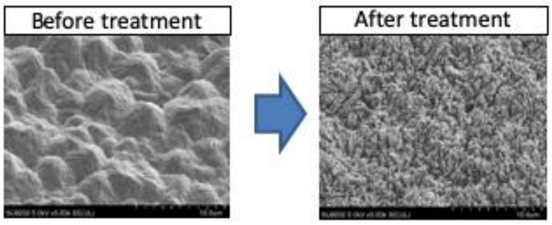

Figure 6 Copper surface SEM before and after treatment

3.2 Correlation Between Brown Oxide Treatment and Grain Size

Brown oxidation used for roughness treatment to enhance the mechanical bond and reduce unwanted tarnish on the copper is also thought to be influenced by the base copper grain structure. Here 4 different grain types are compared. Copper was laminated to dielectric material and difference in surface roughness pre and post brown oxide treatment were observed (Figure 7).

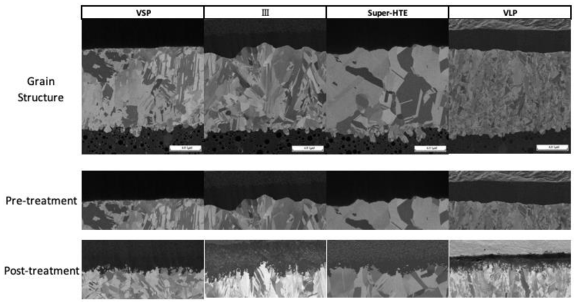

Figure 7 Before/after surface treatment cross section FIB *Post press (190°C, 1.5 hours)

3.3 Transmission Loss Measurement

Transmission loss for strip lines discussed in 3.2 were measured. The conditions were the same as Figure 3. Figure 8 shows S21 before treatment, Figure 9, S21 after treatment.

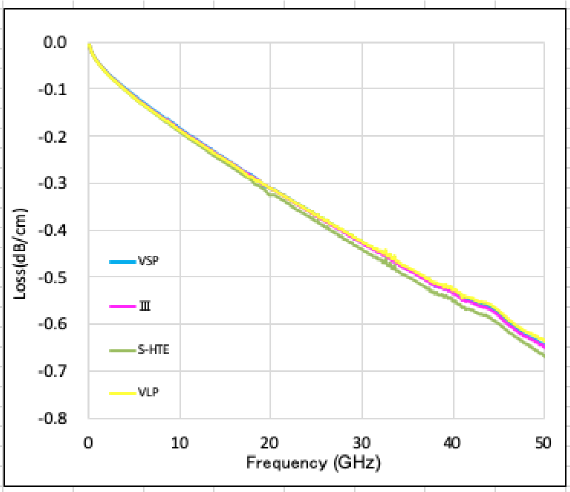

Figure 8 S21 measurement before treatment

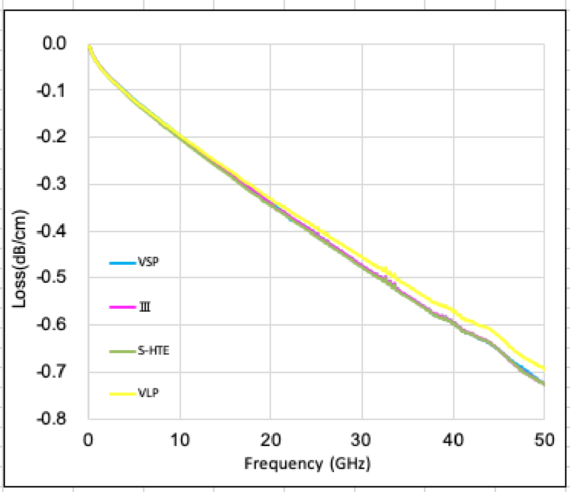

Figure 9 S21 measurement after treatment

20GHz Average	Copper Type			
	VSP	Ⅲ	S-HTE	VLP
Before	-0.312	-0.311	-0.322	-0.311
After	-0.341	-0.342	-0.346	-0.333
Difference	**-0.029**	**-0.031**	**-0.025**	**-0.022**

50GHz Average	Copper Type			
	VSP	Ⅲ	S-HTE	VLP
Before	-0.614	-0.615	-0.631	-0.604
After	-0.688	-0.691	-0.692	-0.661
Difference	**-0.073**	**-0.076**	**-0.060**	**-0.058**

dB/cm

Figure 10 Average loss comparison

Based on the results shown in Figure 8 and 9, there is more transmission loss after roughness treatment. At 20 GHz averaging 0.02 to 0.03 dB/cm more loss, at 50 GHz averaging 0.06 to 0.07 dB/cm. VLP and S-HTE type have less loss compared to VSP and Type III. However, the main objective of brown oxide treatment is to improve bonding to the PCB prepreg or laminate. A better way to minimize transmission loss whilst maintaining bonding strength needs to be determined.

4. Observation

1. Effects of trace shape

If the trace shape is more trapezoid and the trace foot is longer the signal loss increases. As the frequency increases, due to skin effect, the current will try to flow through the tapered section. This tapered section of the trace is where there is less magnetic field. The result is that it increases current density in trace foot area causing overall bigger loss.

2. Transmission loss and grain size

There were differences in loss based on grain size but no trend was found. VLP copper has longer treatment period, whereas the HTE has bigger grain size (not as dense). The result is that the VLP surface treatment area is smaller. Figure 11 shows medium grain size has the most loss meanwhile small and large have similar loss, less than that of the medium. As mentioned above, it is important to find a good balance between peel strength and loss.

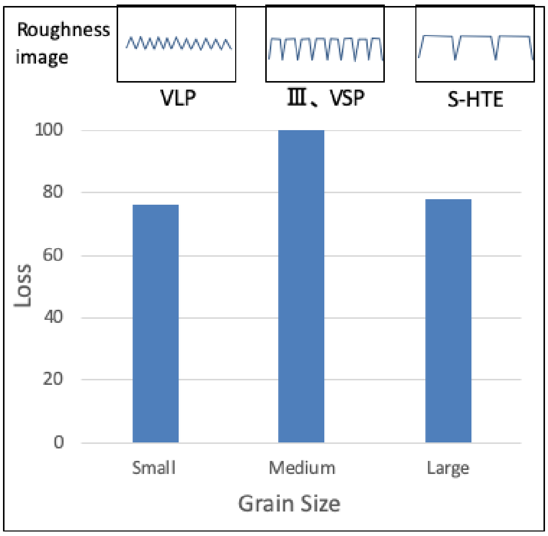

Figure 11 Grain size and loss

5. Conclusion

It was found that issues that were not as problematic when device operating speed was in the few GHz range are now critical with speeds going up to 10 plus GHz. Impact of skin effect is prevalent at higher frequencies and effects of materials and inconsistencies in processing can no longer be ignored. As far as trace shape there are 4 sides and both the contributing factor of the circuit and bonding sides need to be taken into account. Thus, finer treatment than brown oxide and ways to bond without roughness treatment would be required in the future. As these areas are not addressed in the PCB CAD drawing, design engineers working on high speed applications need to understand the importance of these factors and select materials as well as control the manufacturing process.