Influence of Copper Conductor Surface Treatment for High Frequency PCB on Electrical Properties and Reliability

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Abstract
Development of information and the telecommunications network has been outstanding in recent years, and it is required for the related equipment such as communication base stations, servers and routers, to process huge amounts of data in short periods of time. As an electrical signal becomes faster and faster, how to prevent signal delay by transmission loss is a big issue for Printed Circuit Boards (PCB) loaded on such equipment. There are two main factors as the cause of transmission loss; dielectric loss and conductor loss. To decrease the dielectric loss, materials having low dielectric constant and low loss tangent have been developed. On the other hand, reducing the surface roughness of the copper foil itself to be used or minimizing the surface roughness by modifying the surface treatment process of the conductor patterns before lamination is considered to be effective in order to decrease the conductor loss. However, there is a possibility that reduction in the surface roughness of the conductor patterns will lead to the decrease in adhesion of conductor patterns to dielectric resin and result in the deterioration of reliability of PCB itself. In this paper, we will show the evaluation results of adhesion performance and electrical properties using certain types of dielectric material for high frequency PCB, several types of copper foil and several surface treatment processes of the conductor patterns. Moreover, we will indicate a technique from the aspect of surface treatment process in order to ensure reliability and, at the same time, to prevent signal delay at the signal frequency over 20 GHz.

Introduction

Background

Recent developments of information and telecommunications network technologies are remarkable. Especially, it is important for related devices such as base station, servers and routers to process large amount of information instantaneously for the development of IoT in the future. With increase in data transfer rates and amounts, signal delay by transmission loss has become a big issue for PCB. Therefore, prevention of signal transmission loss is important to high frequency PCBs.

Factor of Transmission Loss

Transmission loss can be separated into dielectric loss and conductor loss. Dielectric loss is influenced by the dielectric properties (dielectric constant (ε) / dissipation factor (tanδ)) of insulation materials, and it increases in proportion to the frequency (f). Conductor loss is influenced by the size or kind of conductor, and it increases in proportion to the square root of frequency (f). The more frequency increases, the more signal concentrates on the copper surface. Consequently, the area of current flow is limited (Skin effect loss). Furthermore, if conductor surfaces are rough, the transmission loss is bigger than that of the flat surface. It is because current flow is inhibited by the conductor surface roughness (Surface roughness effect loss).

Adhesion Performance for Reliability

To ensure the reliability of PCB product, adhesion between copper conductors and insulation materials is especially important. Generally, conventional copper surface treatment such as chemical roughening has been used to ensure the adhesion by etching (anchoring effect). However, it does not be apply to high-speed or high-frequency applications due to transmission loss of signal. To solve these problems of conventional copper surface roughening treatment, MEC has developed a copper surface treatment process as the flat bonding treatment (FB treatment) process specialized for high-speed PCBs. Even though the FB treatment process contains neither chemical etching process nor chemical roughening process, it can ensure the adhesion between copper conductors and insulation materials with its smooth and profile free surface.

FB Treatment Process

Figure1 is the FB treatment basic process flow.

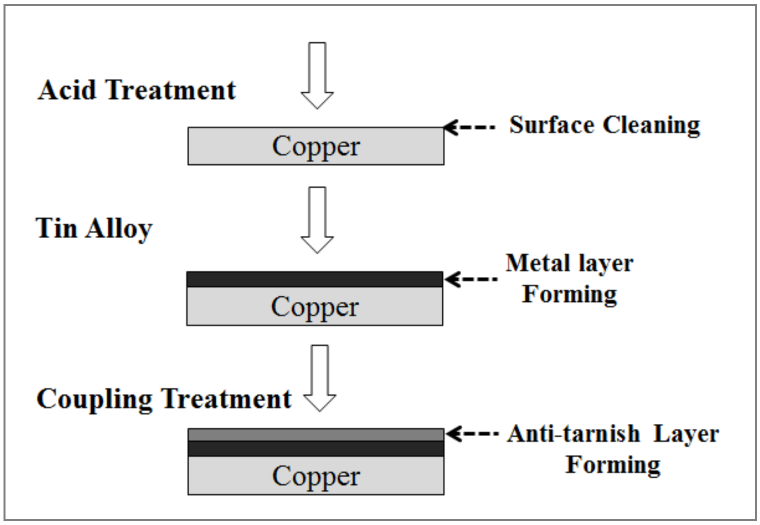


Figure1 – FB treatment process flow

Acid Cleaning

The purpose of acid treatment is a cleaning of copper surfaces by removing foreign materials, stains or oxide existing on the surface to conduct subsequent FB treatment appropriately. Depending on the degree of staining on the copper surface, acid treatment such as sulfuric acid is generally applicable.

Tin Alloy(Chemical-A)

By conducting Chemical-A treatment, a very thin metal layer is formed on copper surface. Figure2 shows the depth analysis result of copper surface treated with Chemical-A by X-ray Photoelectron Spectroscopy (XPS). The constituent elements of the Chemical-A metal layer are mainly tin, copper and very small amounts of metal A. According to Figure2, it is also found that the thickness of Chemical-A layer is very thin at around 50~100nm. The base chemical of Chemical-A treatment is electroless tin plating chemical, nevertheless the Chemical-A can be used more stably in the production condition compared to the conventional electroless tin plating chemical. Because the air oxidization of stannous ion ($Sn^{2+} \rightarrow Sn^{4+}$, which occurs in conventional electroless tin plating) does not occur in the case of Chemical-A. In addition, since the chemical can induce copper and metal A into the layer, this Chemical-A treatment can be called as a 'functional electroless tin plating chemical'.

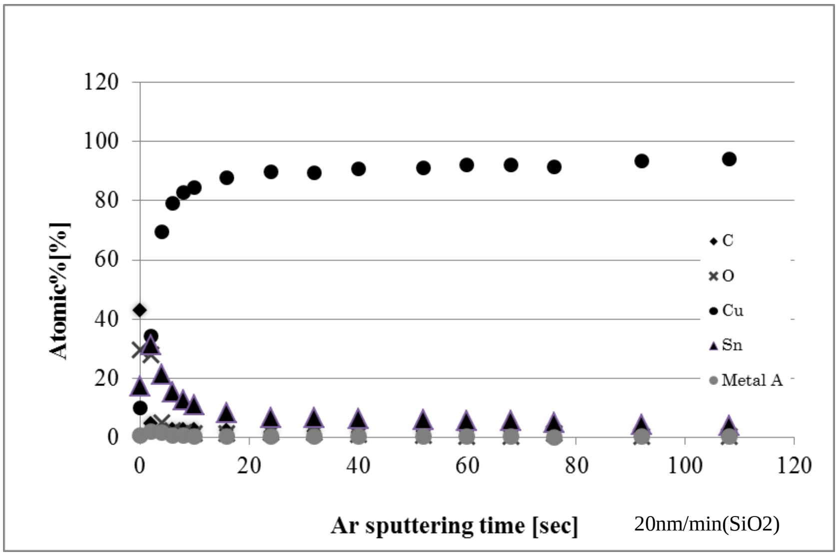


Figure2 - XPS depth analysis of copper surface treated Chemical-A

Coupling Treatment(Chemical-B)

By conducting Coupling treatment(Chemical-B), the anti-tarnish layer is formed on the tin alloy metal layer. This layer can perform as both an anti-tarnish and a coupling effect between tin alloy layer and the insulation resin (Figure3). The coupling layer bonds covalently to the metal surface of the tin alloy layer and also links strongly to insulation resin. This is because functional group R2 in coupling layer reacts with functional group R3 in the insulation resin. Especially, the functional group R2 in coupling layer is important to deliver high adhesion performance. In this way, FB treatment process (Tin alloy+Coupling treatment) can achieve high adhesion performance by choosing the proper functional group to low dielectric resin.

In general, it is known that operating this kind of coupling chemicals stably is difficult due to the self-condensation. In the case of Chemical-B, however, the stability of the chemical is enhanced by its molecular structure. Therefore, the Chemical-B also can be used stably in the mass-production condition.

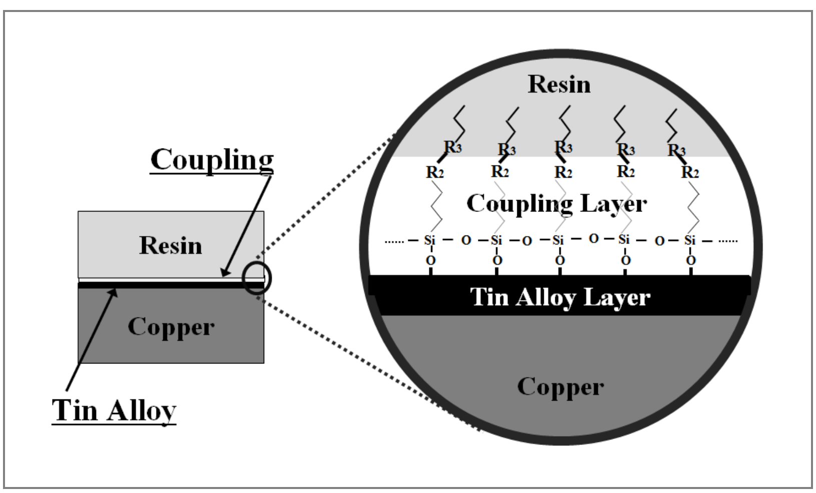


Figure3 - Bonding model of FB treatment layer

Surface Topography of Copper Treated with FB Treatment

We observed copper surface treated with FB treatment by using Scanning Electron Microscope (SEM). Figure4 is the topography images with SEM observation with 3,500 magnification of i) plated copper without surface treatment as a reference, ii) copper surface treated with FB treatment process, and iii) copper surface treated with our conventional chemical which forms a rough copper surface. According to Figure4, the copper surface treated with FB treatment is smoother than that of chemical roughening and as flat as plated copper surface without treatment.

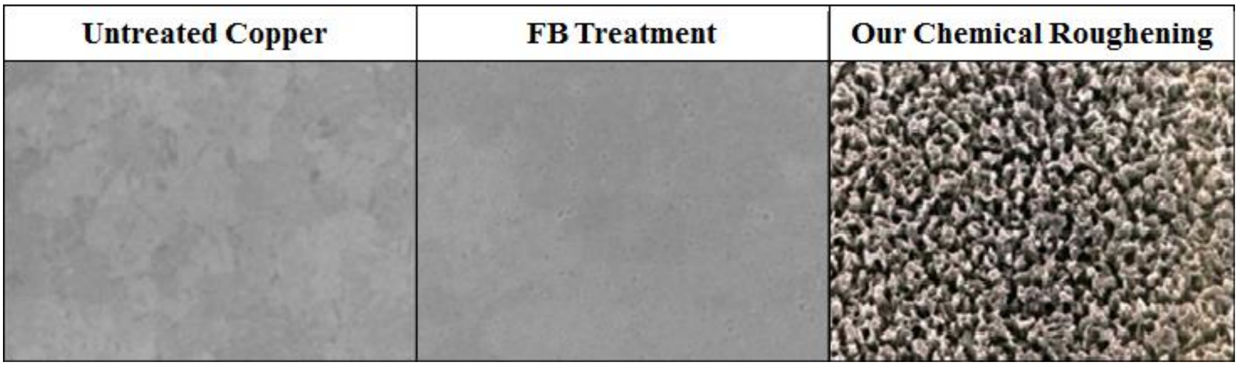


Figure4 - Surface topography comparison

Surface Roughness after FB treatment

Table1 is the surface roughness value (Ra and Rz) of the FB treatment layer. According to Table1, it is confirmed that surface roughness of FB treatment layer is not roughened and almost the same as the plated copper without treatment.

Table1 - Surface roughness comparison

	Untreated Plated Cu	FB Treatment	Our Chemical Roughening
Ra(μm)	0.04	0.04	0.21

Copper Pattern Width after FB Treatment

We also observed the copper pattern before and after the FB treatment by SEM. Figure5 are the observation results of copper conductor pattern L/S = 50/50um. According to Figure5, pattern width hardly changed before and after FB treatment.

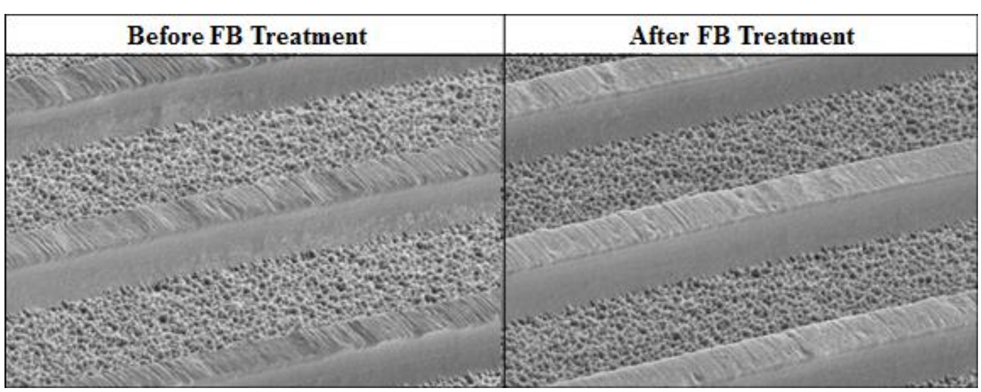


Figure5 - Copper pattern SEM images

Methodology/ Experimental

Transmission Loss Evaluation

To confirm the transmission performance of copper conductor treated with FB treatment, we measured the insertion loss of the signal data of copper conductor treated with FB treatment comparing to that of conventional surface roughening treatment. We used the test coupons which have strip-line structure like Figure6 to measure insertion loss. The details of test coupons are listed as below.

Copper foil: H-VLP foils (35μm thickness)
Inner layer copper surface treatment: 1) FB treatment 2) Chemical roughening treatment
Laminated resin: Low dielectric resin A (PPE type, ε=3.7, tanδ=0.002 at 1GHz, CCL thickness 0.13mm, prepreg thickness 0.06mm×2 sheets)
Circuit length: 200mm
Impedance: 50Ω

For the copper surface treatment, we applied FB treatment and surface roughening treatment. The S21 parameters were measured on a network analyzer up to 50GHz of frequency.

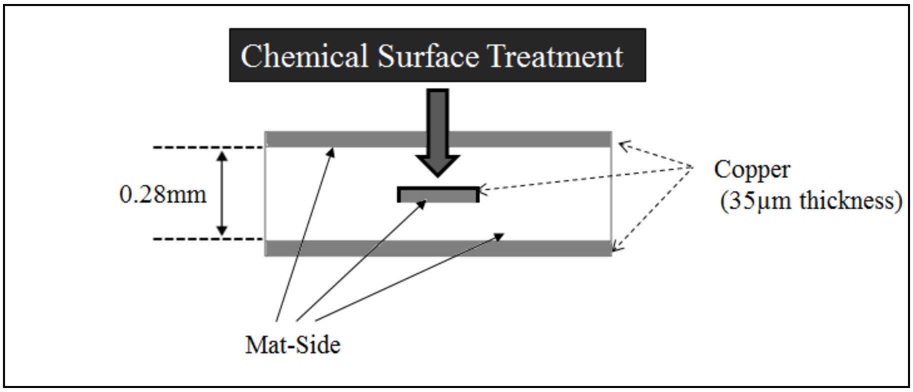


Figure6 - Test coupon design image

Adhesion Performance (Peel Strength)

We used peel strength as a parameter of adhesion between the copper surface treated with FB treatment and the low dielectric resins (prepregs). We measured peel strength according to JIS(Japan Industrial Standard) C 6481. Copper materials were 35um thickness standard copper foils with each chemical treatment. Our copper surface roughening treatment was used for reference. They were pressed with the prepregs by a vacuum-heated press machine, after that the copper foils were peeled in 10mm widths with the peel tester.

(Note: Absolute values of the peel strength vary, depending on the following factors: storage condition of resins, pressing conditions, measuring conditions and so on. We evaluate the peel strength as an inter-comparison between evaluation samples.)

We used two types of low dielectric commercial materials (resin A and resin B) for high-frequency applications (prepregs) in this evaluation. Below are details of Resin A and B.

Low dielectric resin A (<u>PPE type ε=3.7, tanδ=0.002 at 1GHz</u>)
Low dielectric resin B (<u>PPE type ε=3.6, tanδ=0.0015 at 1GHz</u>)

Results

Transmission Loss Evaluation

Figure7 shows insertion loss of signal data of copper conductor treated with FB treatment compared to that of conventional surface roughening treatment. Insertion loss of FB treatment was lower than that of the chemical roughening treatment and almost the same as untreated copper conductor. The difference of insertion loss between FB treatment and chemical roughening became bigger in accordance with increase in frequency. According to this result, it is found that the FB treatment process delivered superior performance for transmission loss over 20GHz. It is because the conductor surface treated with FB treatment is flat and hardly affected by surface roughness effect loss.

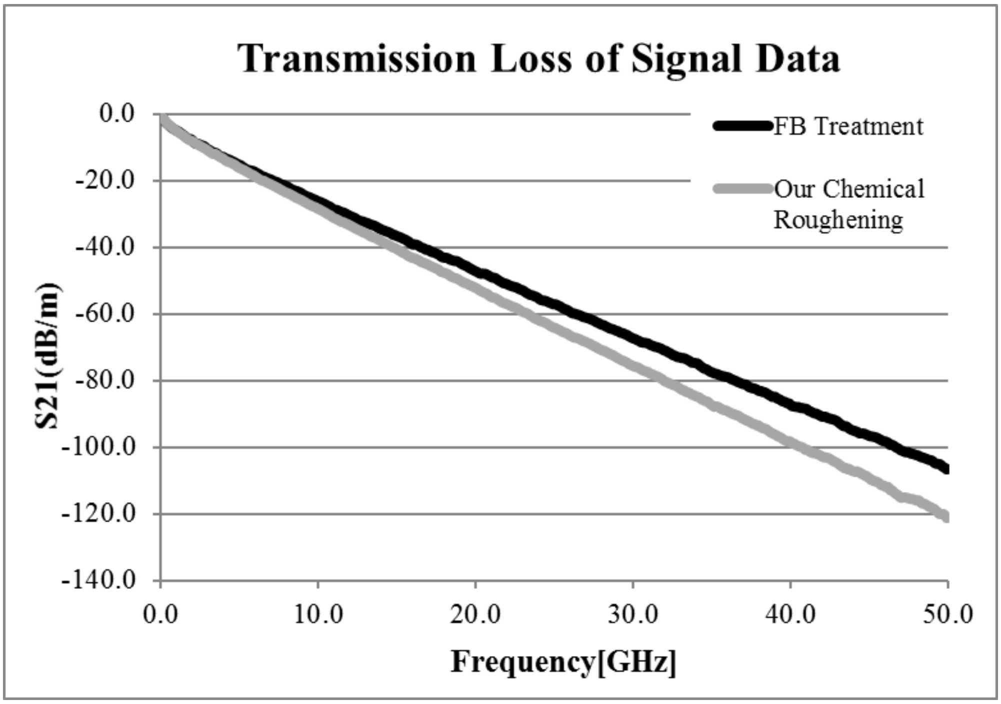


Figure7 - Transmission loss of signal data

Peel Strength

Figure8 is the result of the peel strength measurements. From this result, it is confirmed that the adhesion performance of copper surface treated with FB treatment process for both the low dielectric Resin A and Resin B is higher than that of our conventional roughening treatment even though the FB treatment surface is not roughened or etched.

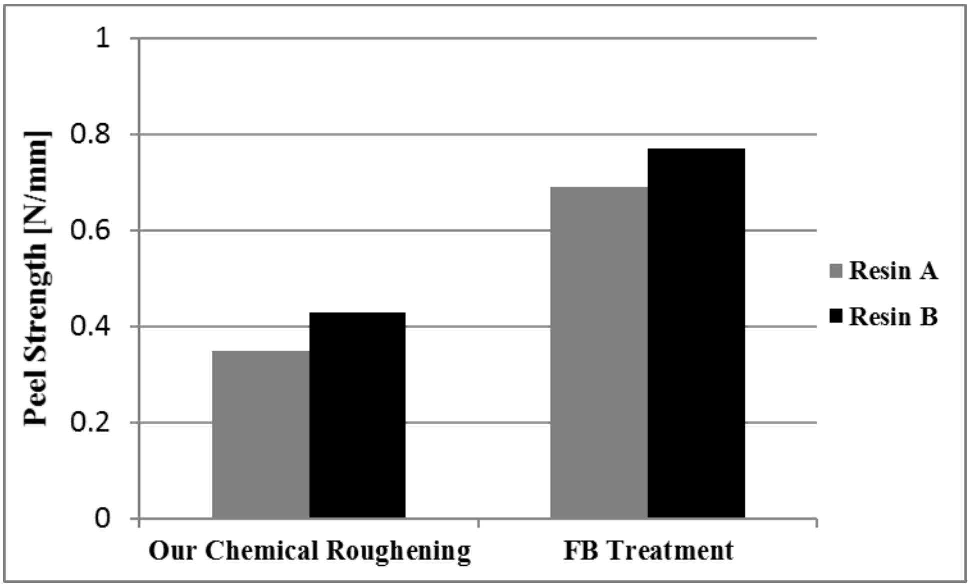


Figure8 - Adhesion performance for low dielectric Resin A and Resin B (Peel strength)

Peel Strength after Multiple Reflow Testing

Figure9 shows peel strength evaluation results of FB treatment process after multiple reflow testing (260℃). According to Figure9, the peel strength of FB treatment does not change even after 10times reflow.

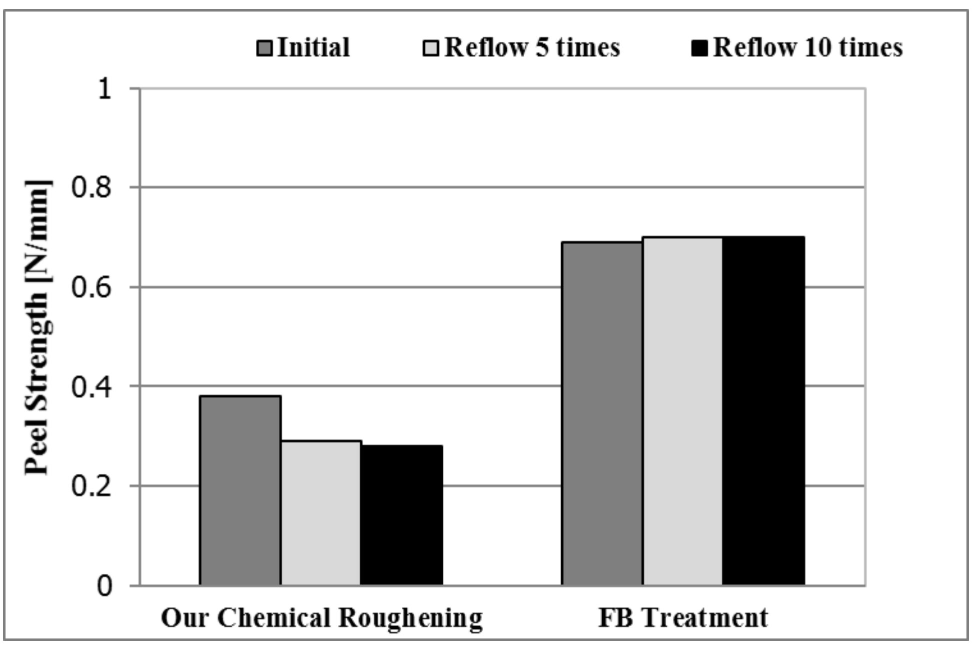


Figure9 - Adhesion performance for low dielectric resin A after reflow testing (Peel strength)

Conclusions

The company developed a new surface treatment process (FB treatment process) on copper conductor for high-speed and high-frequency PCBs. As mentioned above, the FB treatment process achieved superior performance for transmission loss over 20GHz frequency, and its adhesion performance for low dielectric resins was confirmed as superior to that of our surface roughening treatment. FB treatment process improved the transmission loss of signals especially in the high frequency region, in which roughening treatments have problems for transmission loss. Furthermore, it can deliver the high adhesion performance for low dielectric resins with smooth and profile free surfaces. In the future, technologies of electric devices related to base stations, servers and routers will grow more and more for the development of information and telecommunications network such as IoT. Accordingly, the requirement for the high-speed and high-frequency applications should increase more and more. We believe that our FB treatment process will help solve the issues of signal transmission loss and improve the reliability of advanced PCBs.

Influence of Copper Conductor Surface Treatment for High Frequency PCB on Electrical Properties and Reliability

Seiya Kido

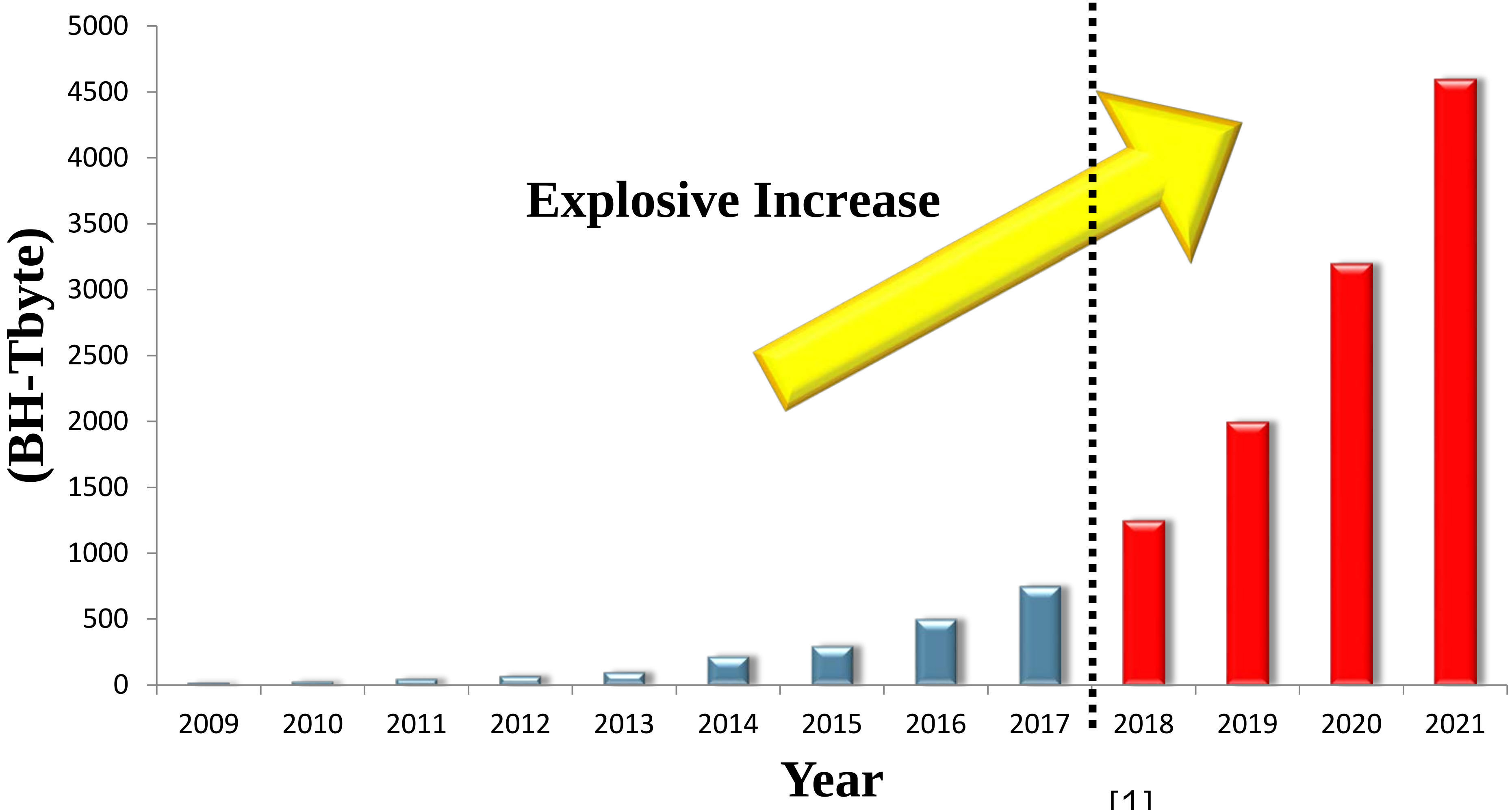
MEC Company LTD.

Agenda

- Introduction
- Flat Bonding Process (FB Treatment Process)
- Transmission Property
- Adhesion Performance
- Adhesion Mechanism
- Conclusion

Introduction

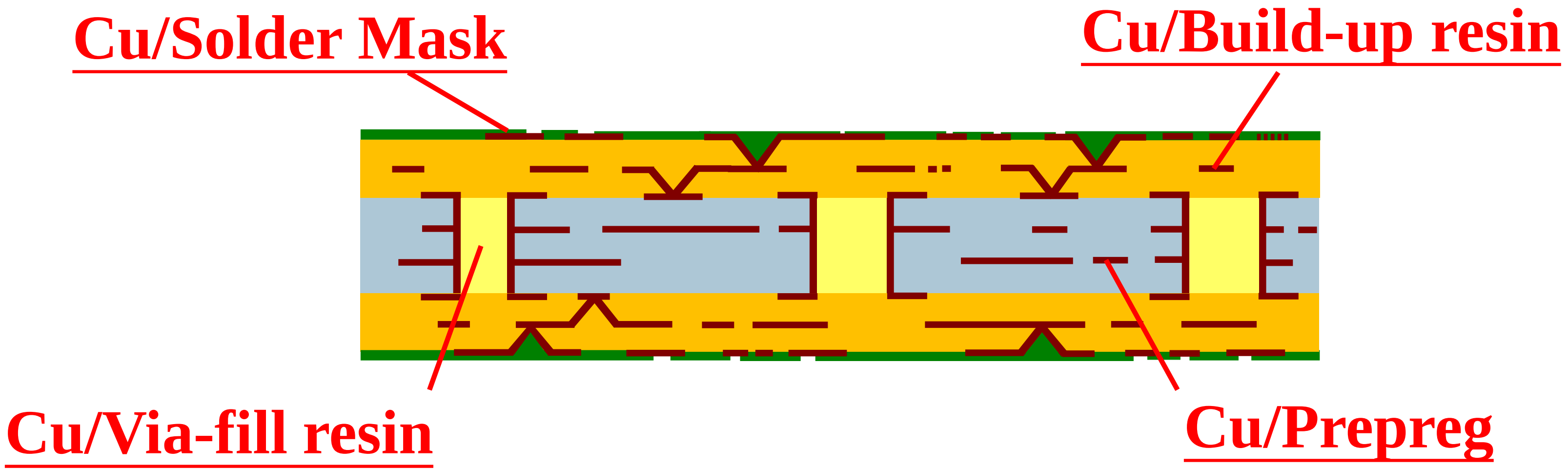
Data Traffic Increase



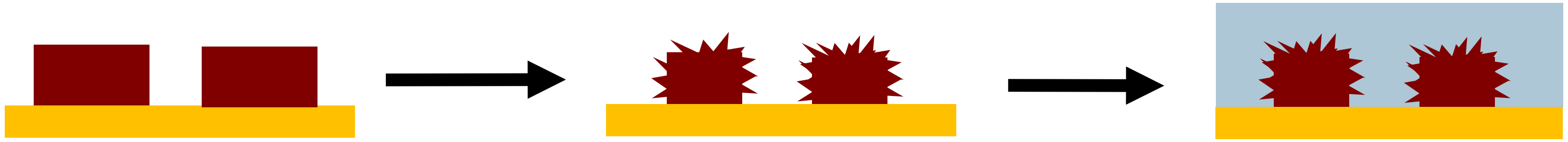
[1]

Development of Telecommunication

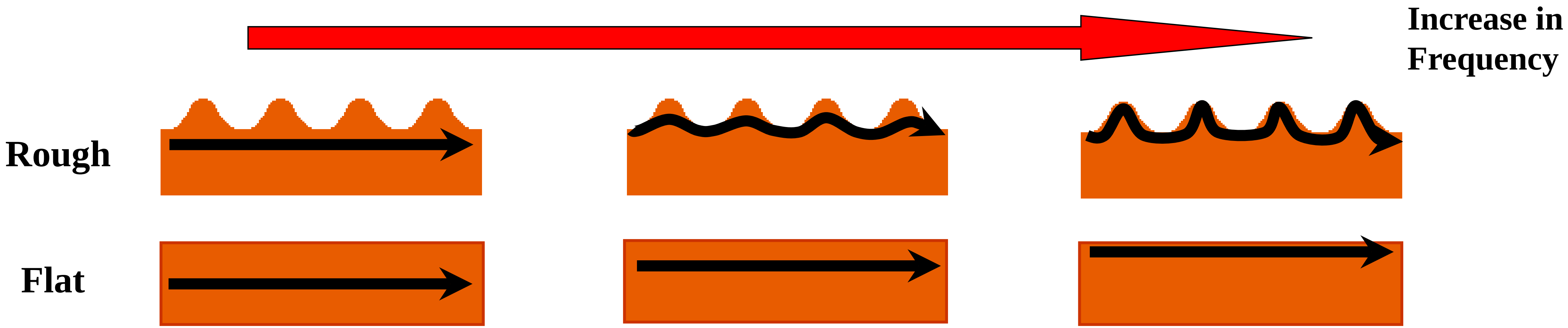
Adhesion Interface between Metal/Resin in PCB



Current Adhesion Technology: Physical Bonding by Roughening Copper Surface



Potential Issues of Current Technology-1

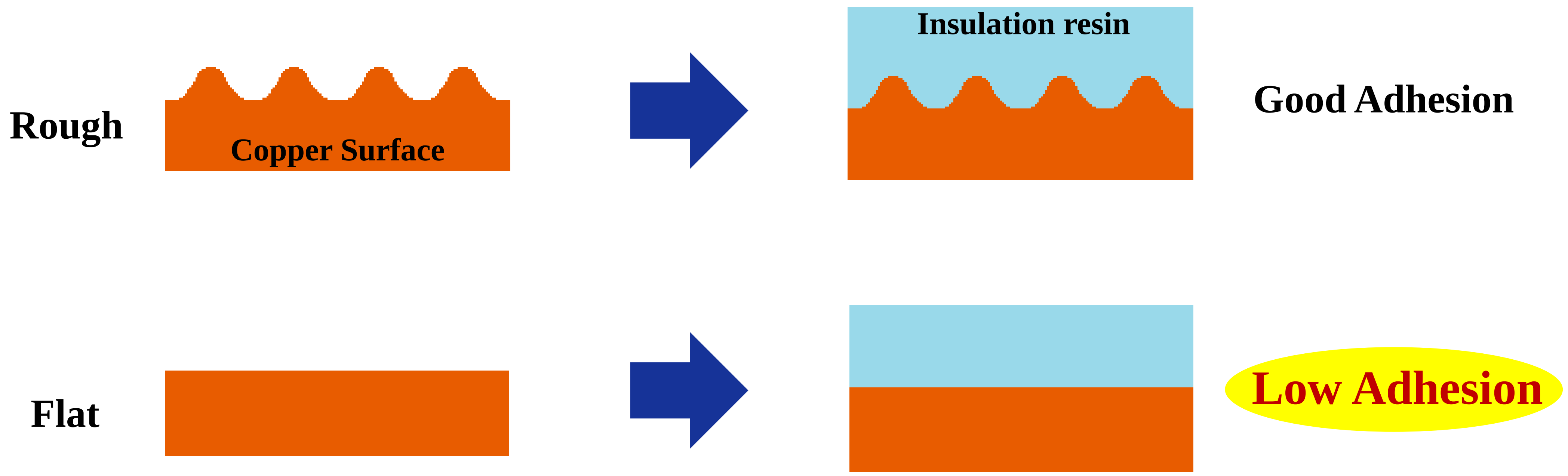


Relation between Frequency and Skin Depth

Frequency(GHz)	1	5	10	30	50
Cu Skin Depth(um)	2.09	0.93	0.66	0.38	0.30

Increase of signal transmission loss by surface roughness

Potential Issues of Current Technology-2



Adhesion with insulation materials become low on smooth copper surface

Development of New Surface Treatment

Current

Physical bonding by surface roughening

Issue.1) Transmission loss of signal by surface roughness

Issue.2) Low adhesion with insulation materials due to smooth copper surface

Future

Profile free surface for high transmission property

&

High adhesion performance with insulation materials

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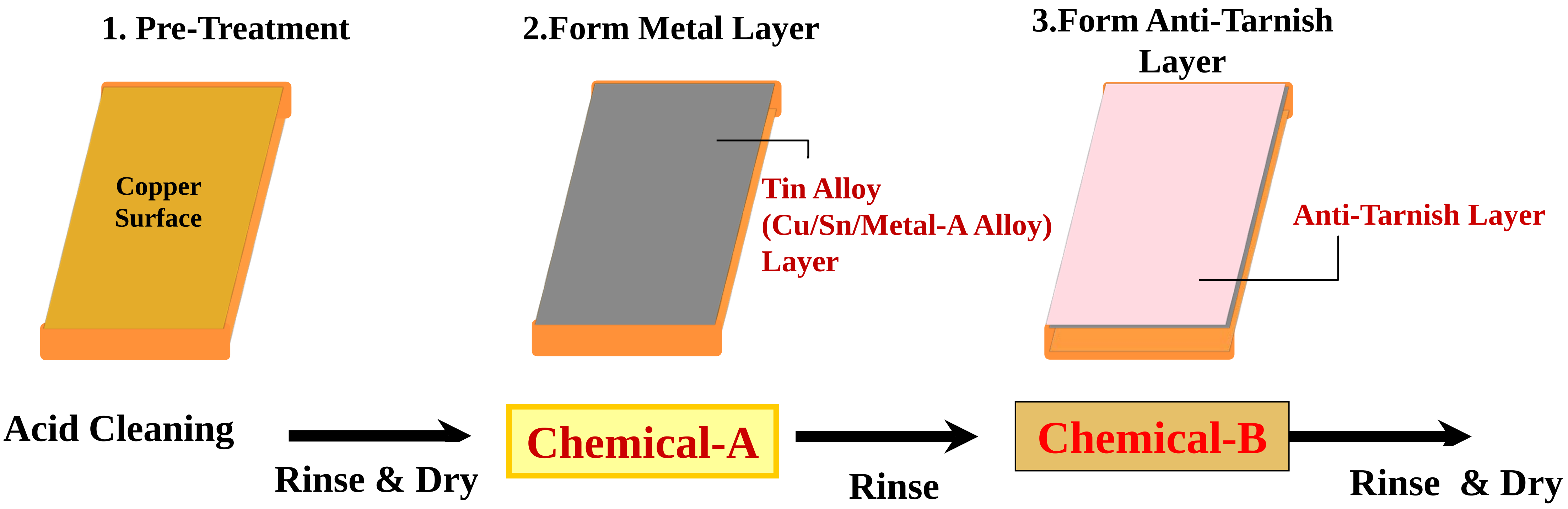
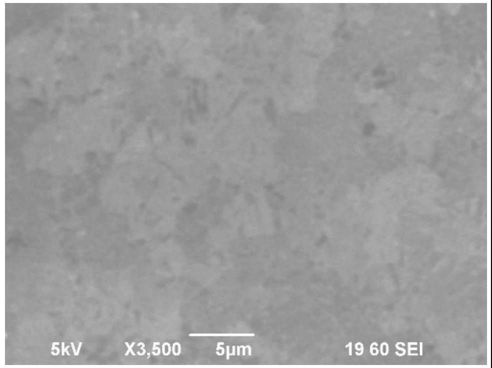
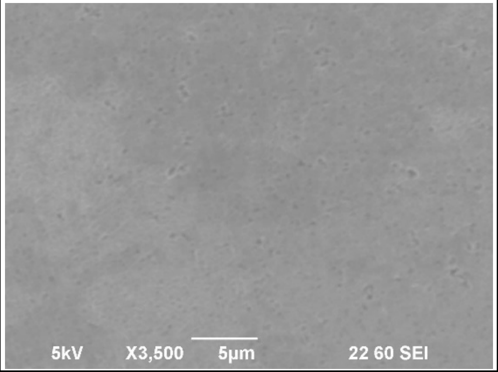
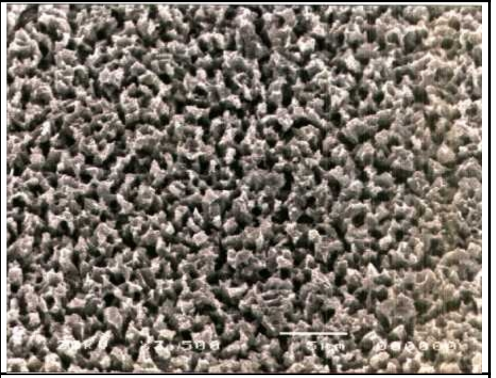
Flat Bonding (FB) Treatment

FB Treatment Process

FB Treatment Process Flow



Surface Topography & Roughness(Ra)

	Untreated Plated Copper	FB Treatment	Our Chemical Roughening
SEM x3,500			
Ra(μm)	0.04	**0.04**	0.21

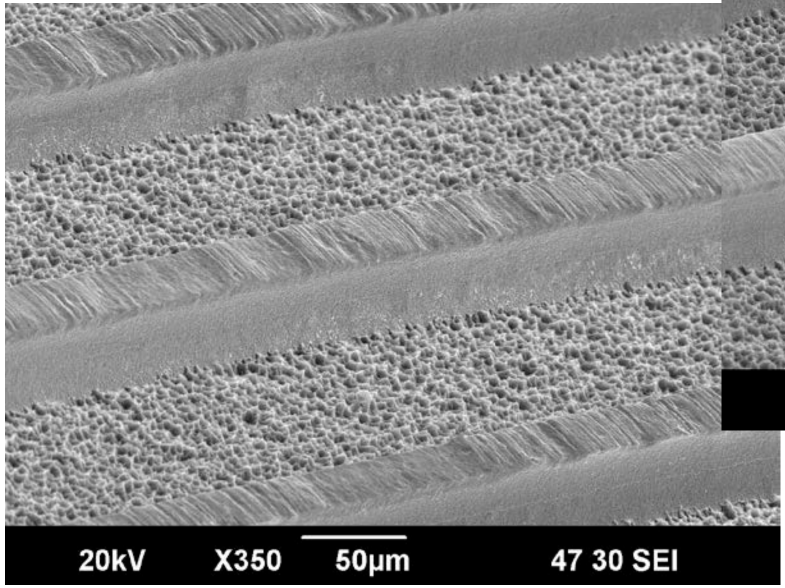
FB treatment provides smooth and profile free surface

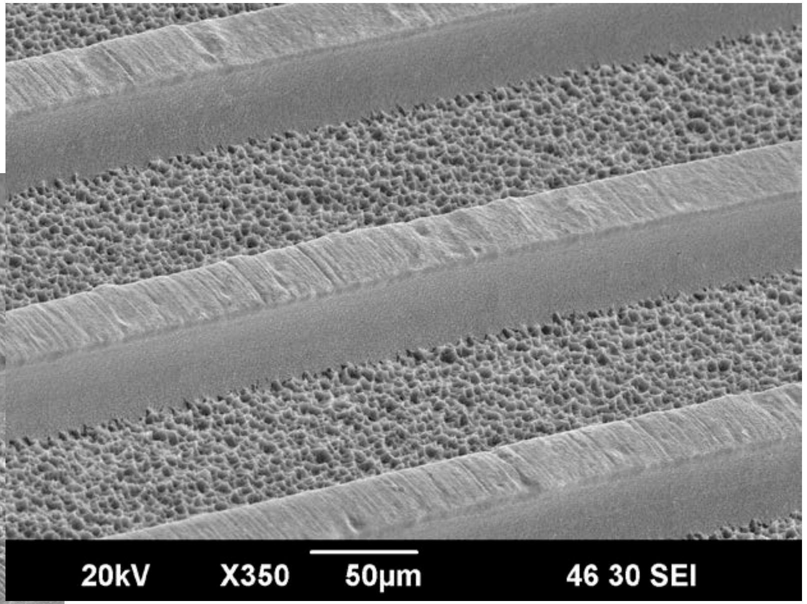
Copper Pattern before/after FB Treatment

Line width = 50μm

SEM (x350 60⁰)

Before
FB Treatment





After
FB Treatment

Transmission Property

Measuring Method

- Base construction

Copper Type : HVLP(35μm)

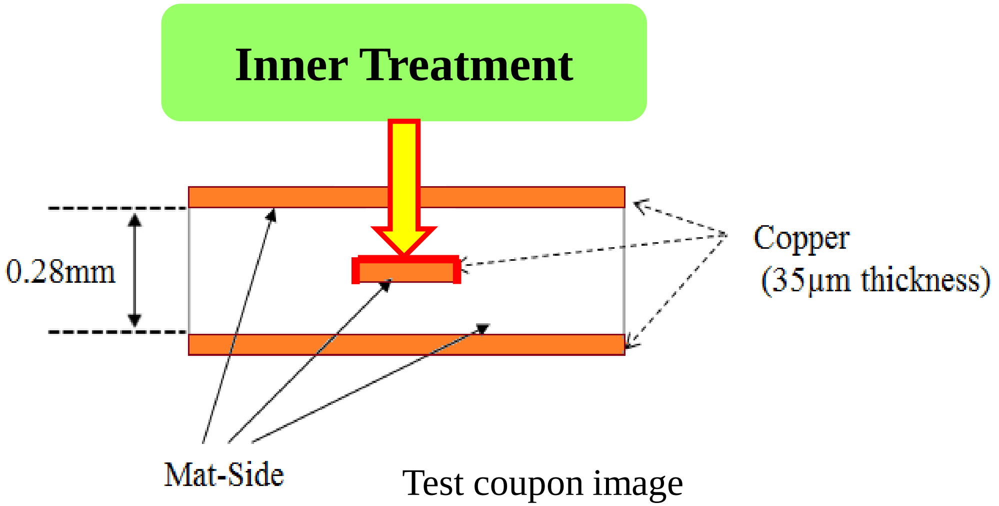
Inner Treatment Type : #1 Untreated Copper

#2 FB Treatment

#3 Black Oxide

#4 Our Chemical Roughening 1.5um

#5 Our Chemical Roughening 2.5um



Test coupon image

CCL : 0.13mmt

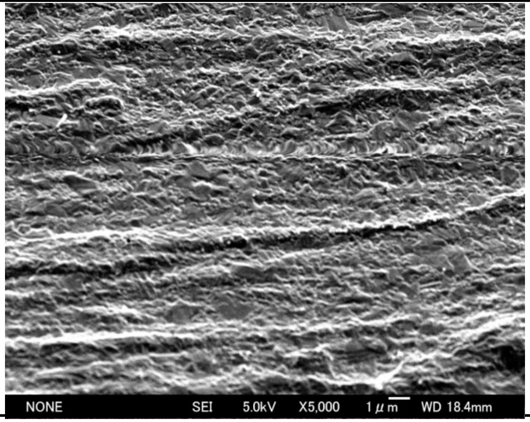
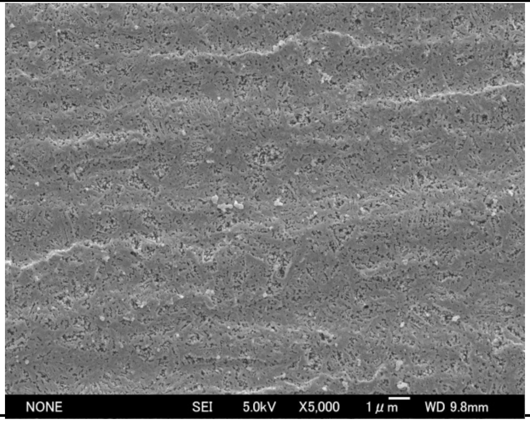
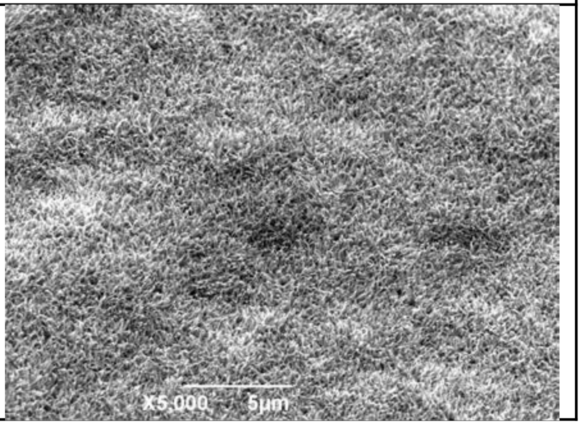
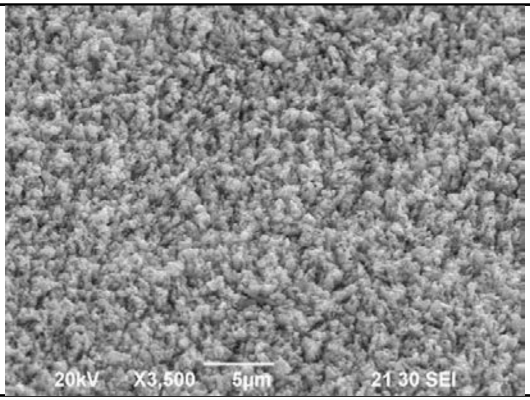
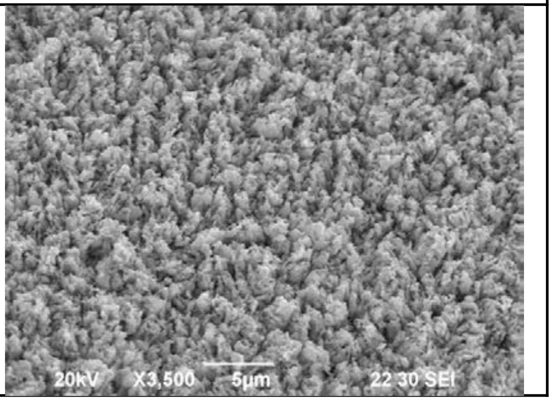
Laminated Resin : Low Dielectric Resin A (PPE type ε=3.7, tanδ=0.002 at 1GHz)

Circuit Length : 200mm

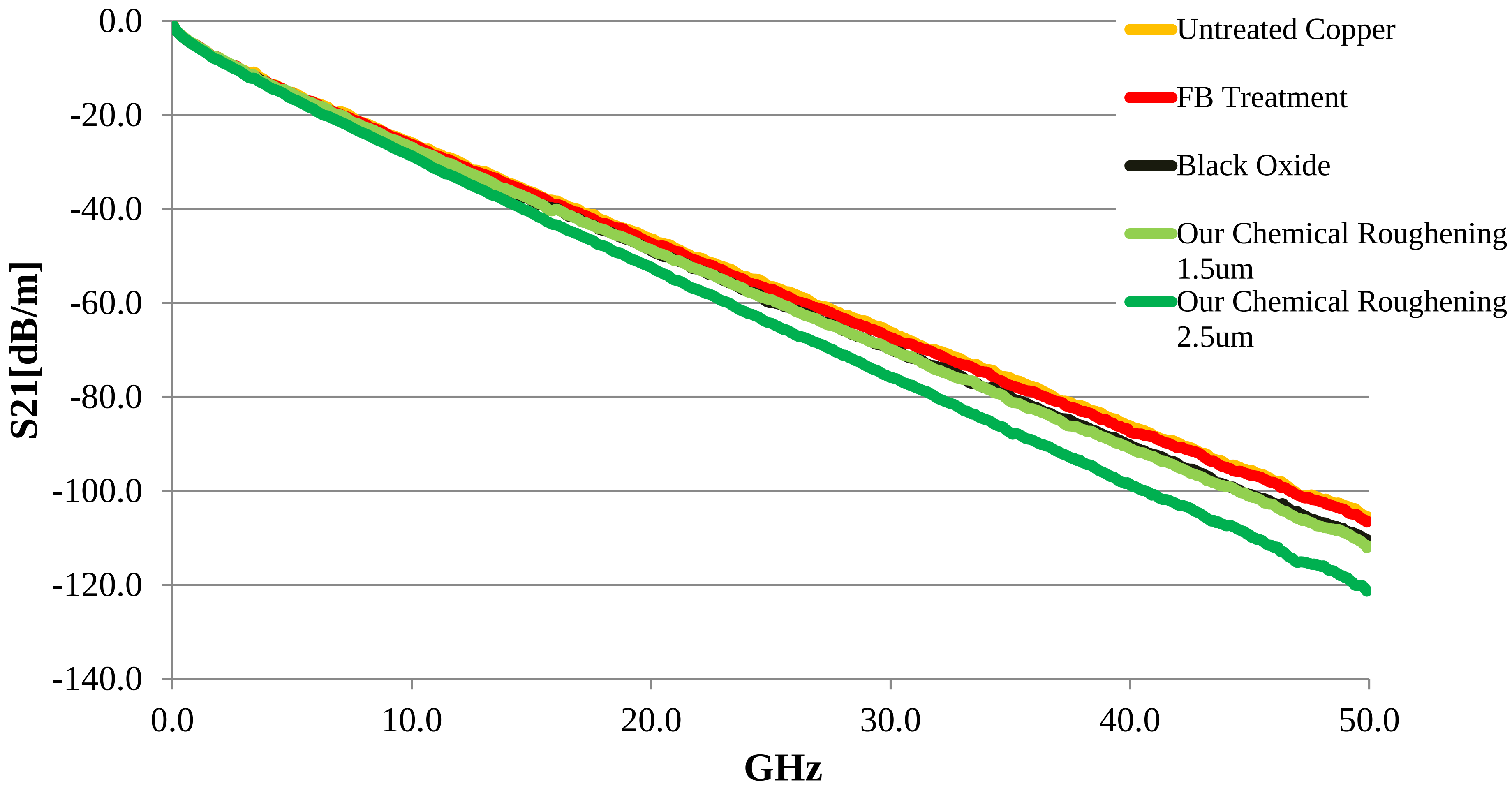
Impedance : 50Ω

Evaluation Method : S21 Measurement by Network Analyzer

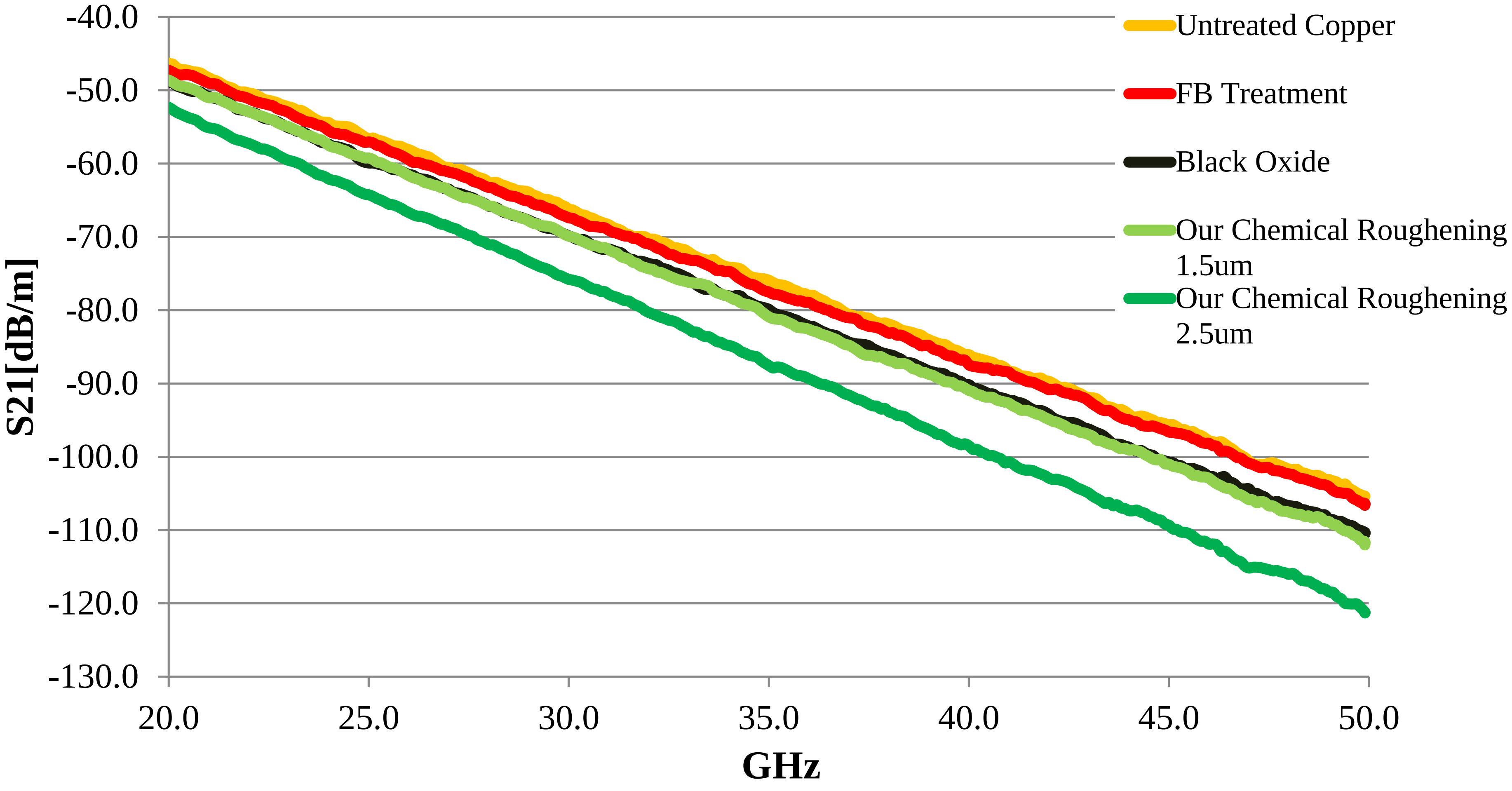
Surface Topography of Inner Treatment

#1 Untreated	#2 **FB Treatment**	#3 Black Oxide
		
#4 Our Chemical Roughening 1.5μm	#5 Our Chemical Roughening 2.5μm	
		

Result of Insertion Loss at 0GHz-50GHz



Result of Insertion Loss at 20GHz-50GHz



Adhesion Performance

Measuring Method

Resin Type: Resin A (PPE type ε=3.7, tanδ=0.002 at 1GHz):

Resin B (PPE type ε=3.6, tanδ=0.0015 at 1GHz)

Copper Foil: Electro-deposited foil (35µmt)

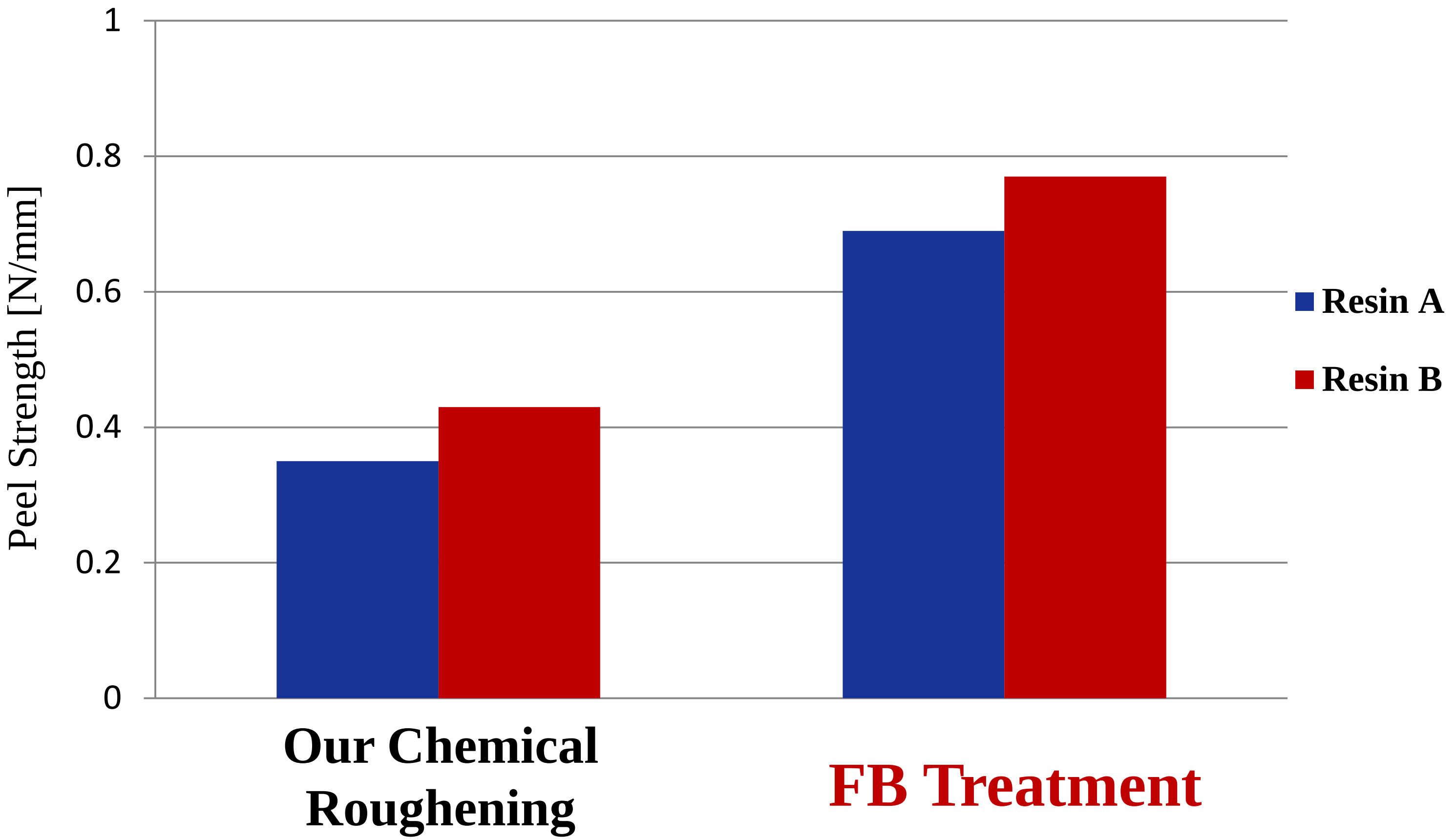
Surface Treatment: a) Our Chemical Roughening Treatment

b) FB Treatment

Evaluation Item: Peel Strength, Delamination

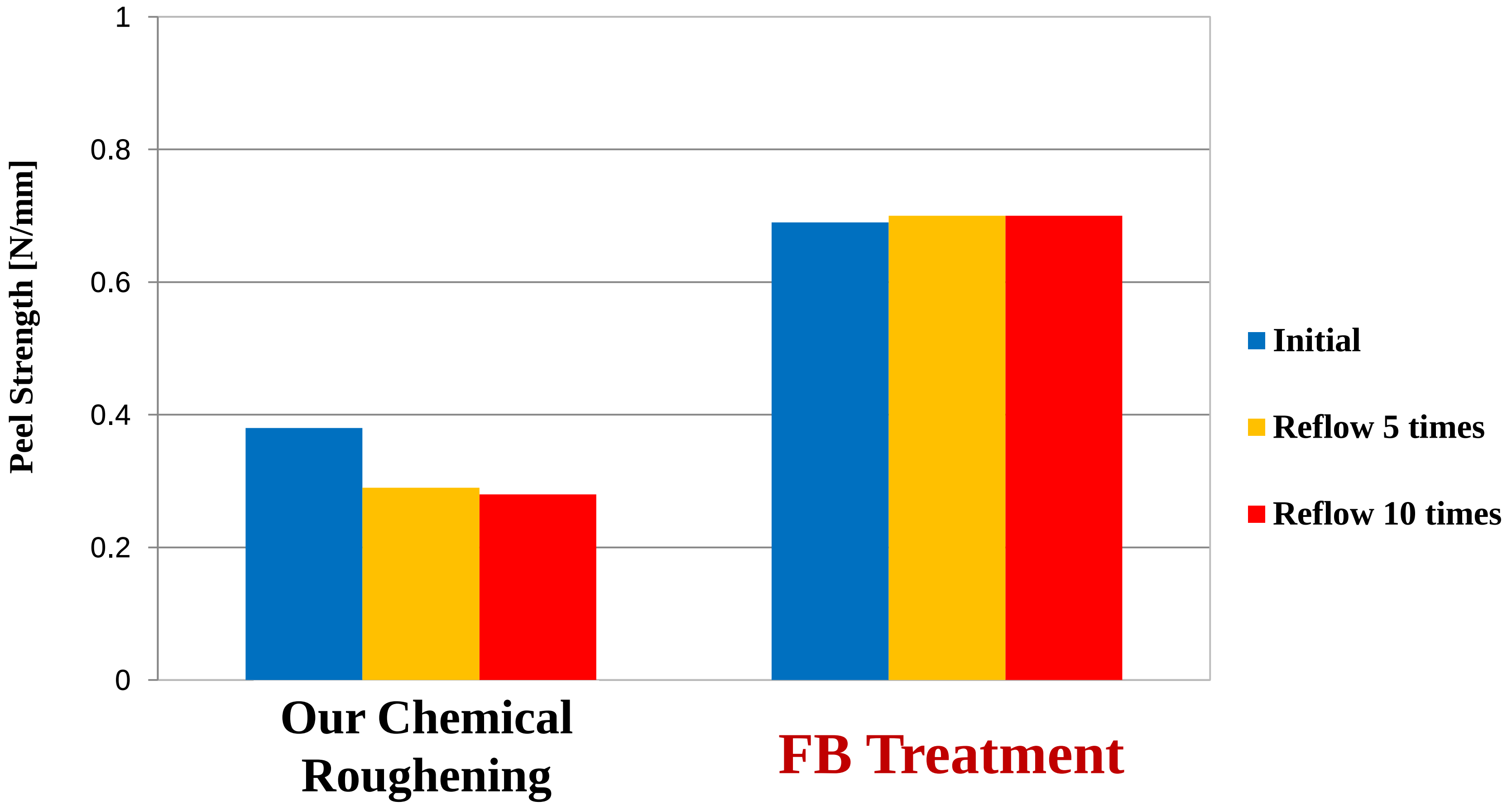
Adhesion Performance

Low Dielectric Resin A (PPE type ε=3.7, tanδ=0.002 at 1GHz)
Low Dielectric Resin B (PPE type ε=3.6, tanδ=0.0015 at 1GHz)



Adhesion Performance After Reflow (260℃)

Low Dielectric Resin A (PPE type ε=3.7, tanδ=0.002 at 1GHz)



Delamination TEST

Low Dielectric Resin A (PPE type ε=3.7, tanδ=0.002 at 1GHz)

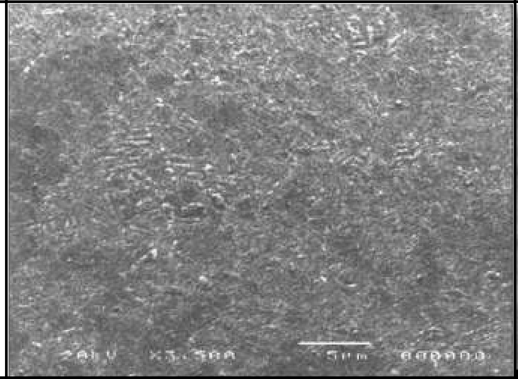
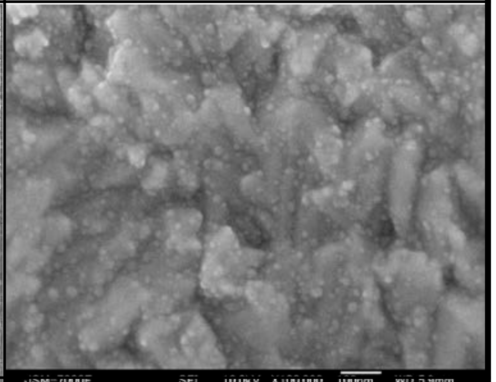
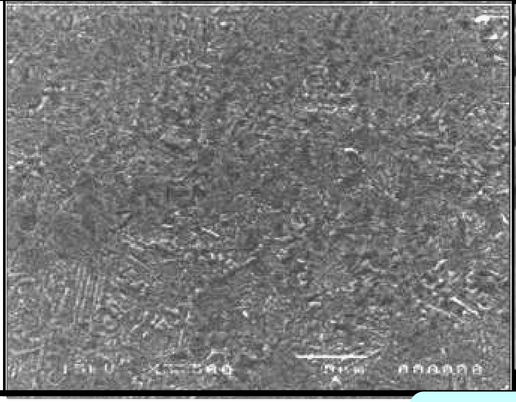
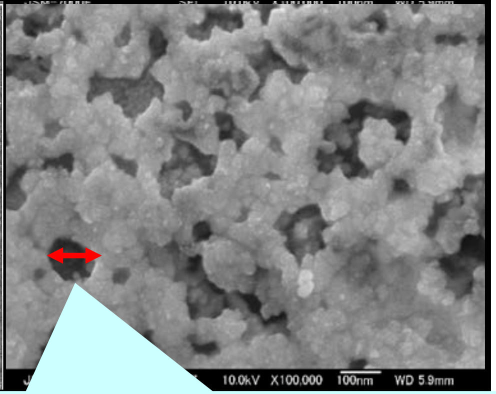
PCT(121˚C, 100%RH, 2atm) 8 hrs ⟶Solder Dip 30sec

	260°C	270°C	280°C	290°C
Our Chemical Roughening				
FB Treatment				

Adhesion Mechanism

Q: Why can FB treatment process deliver High Adhesion Performance with its Smooth Surface?

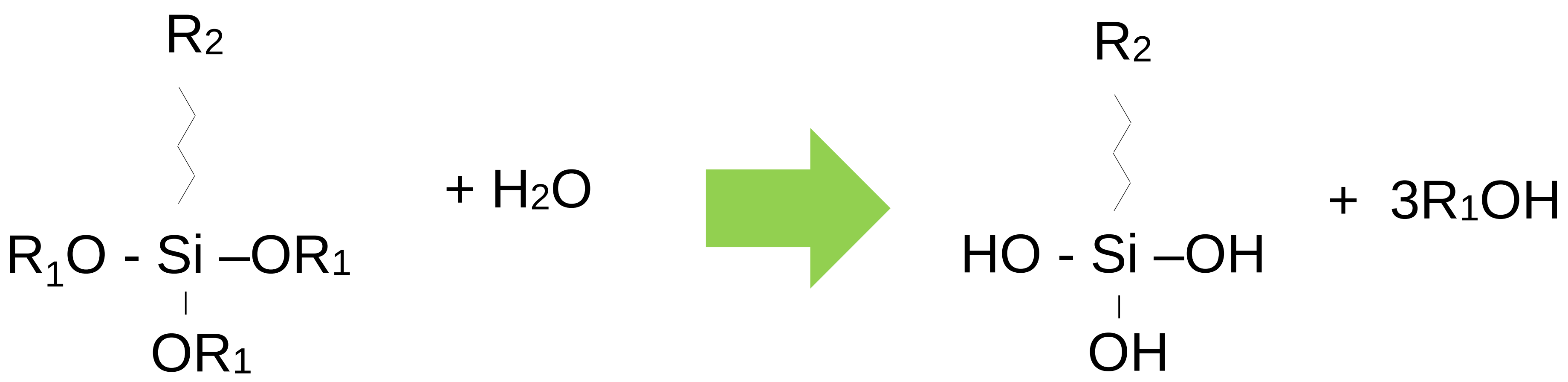
Surface Observation by FE-SEM

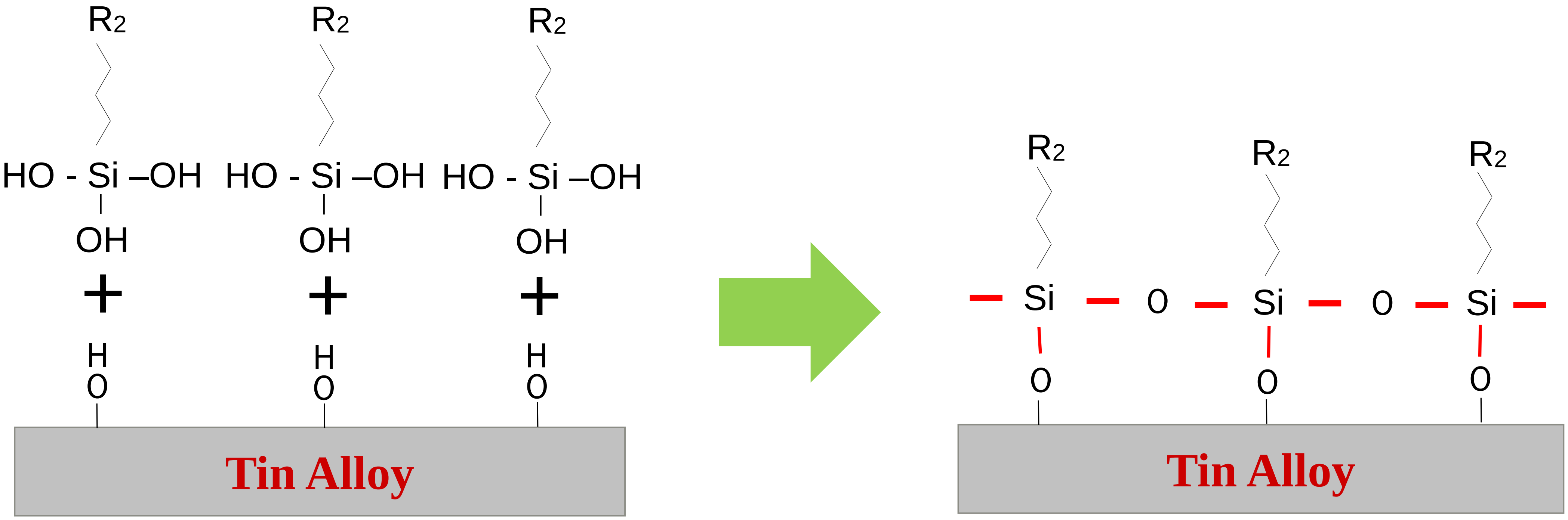
	SEM (x3,500)	FE-SEM (x100,000)
Untreated Plated Copper		
FB Treatment		

Physical Bonding

~100nm Minute Holes

Chemical-B contains Silane Coupling Agent

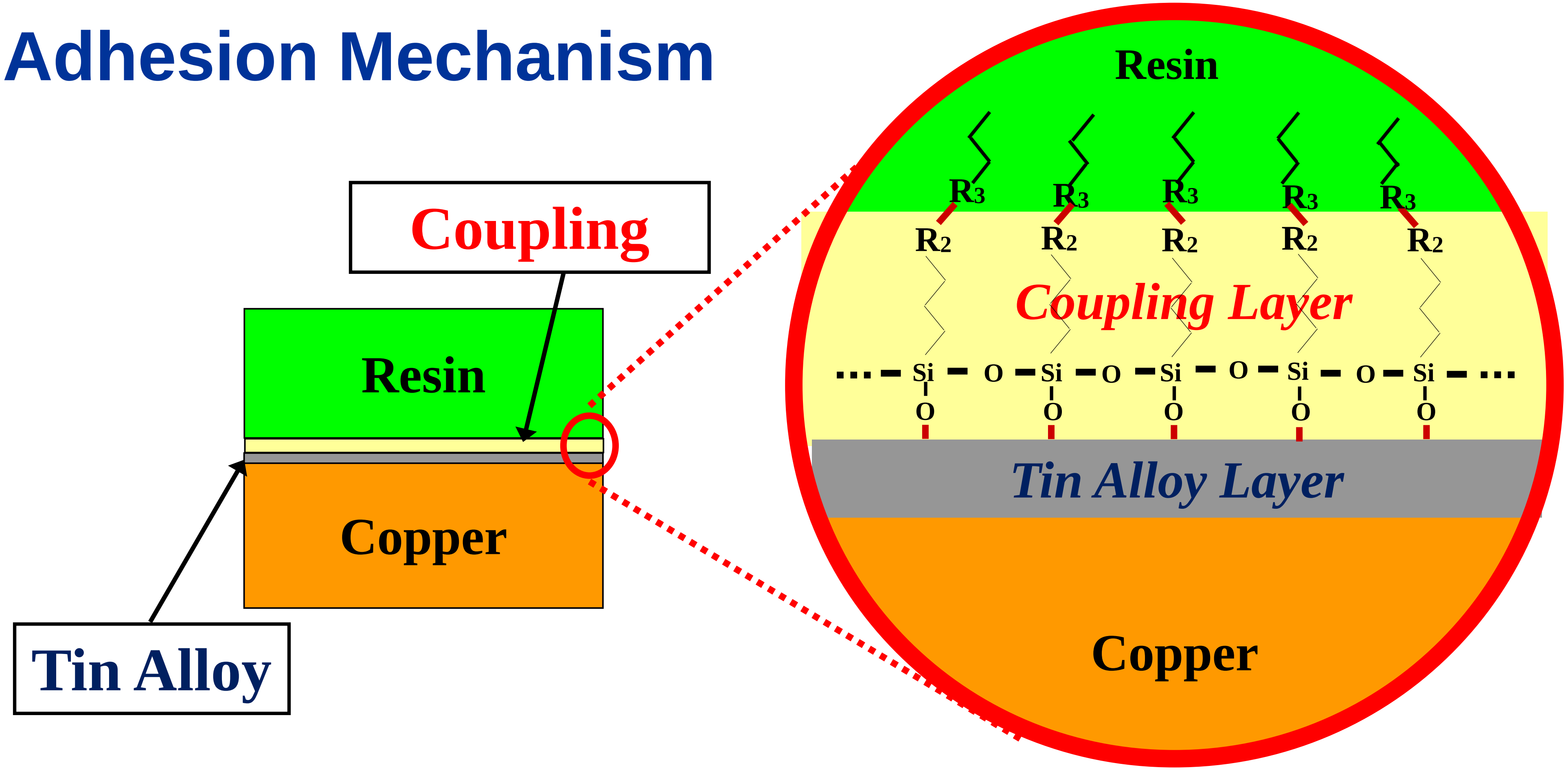




Before Chemical-B Treatment

After Chemical-B Treatment

Adhesion Mechanism



Chemical Bonding

Functional groups, R_2, in Coupling layer bonds covalently with functional groups R_3 in resin=> High adhesion performance

Conclusion

Conclusion

New Surface Treatment <Flat Bonding (FB) Process>

- **Profile free surface.**
- **Copper pattern reduction is very limited.**
- **High adhesion performance with insulation materials.**

Performance of FB Treatment

- ***FB treatment*** **process can decrease the signal transmission loss at high frequency region because of its profile free surface.**
- ***FB treatment*** **process can deliver sufficient adhesion strength for low dielectric resin, even though the treated surface is flat.**
- **Both chemical bonding and physical bonding are contributing for the high adhesion performance, which are derived by the covalent bonding of coupling effect and the nano-scale minute structure.**

Thank You!

Q & A

References

1. Trends of 5G mobile communication systems and activities, SoftBank Co.