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

Seiya Kido, Tsuyoshi Amatani
MEC Company LTD.
Amagasaki, Hyogo, Japan

Abstract

Development of information and telecommunications network is outstanding in recent years, and it is required for the related equipments such as communication base stations, servers and routers, to process huge amount of data in no 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 equipments. 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 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 type 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

Recently development 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 PCB.

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 ($\tan\delta$)) 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 copper surface. Consequently, the area of current flow is limited (Skin effect loss). Furthermore, if conductor surface are rough, the transmission loss is to be bigger than that of 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 should not be applied to high-speed or high-frequency applications due to transmission loss of signal. To solve these problems of conventional copper surface roughening treatment, we have developed copper surface treatment process as FlatBOND GT process specialized for high-speed PCBs. Even though FlatBOND GT 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.

FlatBOND GT Treatment Process

Figure1 is FlatBOND GT treatment basic process flow.

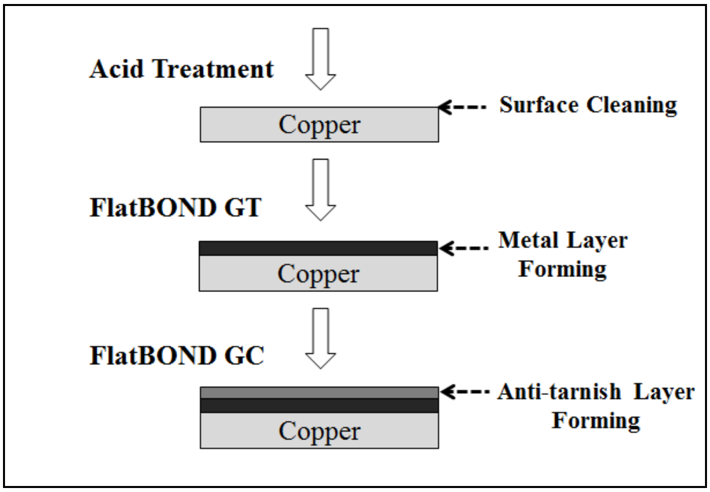

Figure1 - FlatBOND GT treatment process flow

Acid Cleaning

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

FlatBOND GT

By conducting FlatBOND GT treatment, very thin metal layer is formed on copper surface. Figure2 shows the depth analysis result of copper surface treated with FlatBOND GT by X-ray Photoelectron Spectroscopy (XPS). The constituent elements of the FlatBOND GT metal layer are mainly tin, copper and very small amount of metal A. According to Figure2, it is also found that the thickness of FlatBOND GT layer is very thin as 50~100nm. The base chemical of FlatBOND GT treatment is electroless tin plating chemical, nevertheless the FlatBOND chemical can be used more stably in the production condition comparing 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 FlatBOND GT process. In addition, since the chemical can induce copper and metal A into the layer, this FlatBOND GT treatment chemical can be called as ‘functional electroless tin plating chemical’.

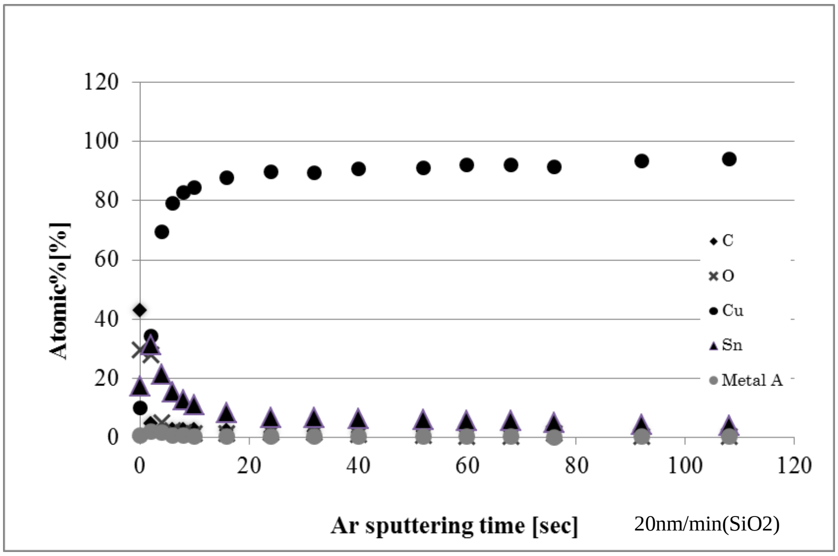

Figure2 - XPS depth analysis of copper surface treated FlatBOND GT

FlatBOND GC

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

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

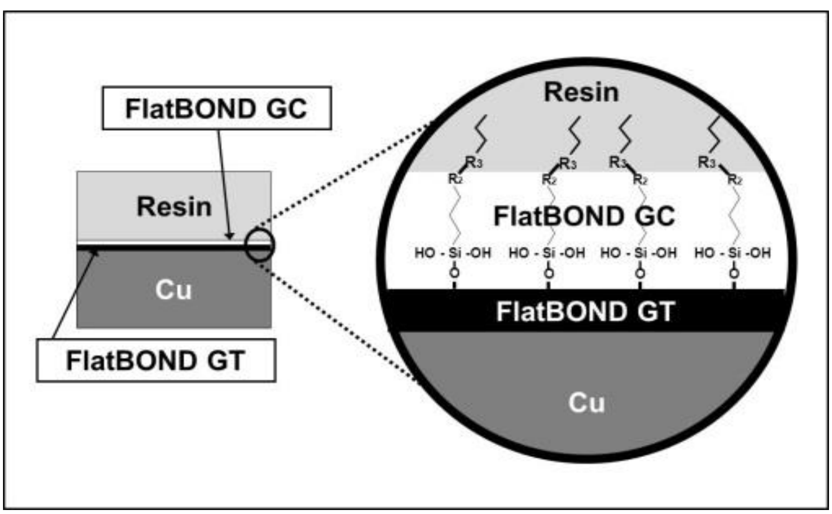

Figure3 - Bonding Model of FlatBOND GC layer

Surface Topography of Copper Treated with FlatBOND

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

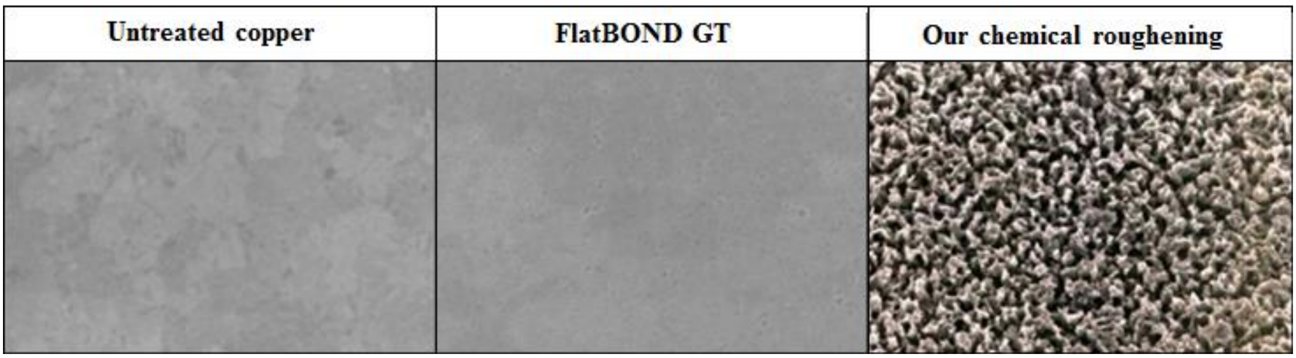

Figure4 - Surface topography comparison

Surface Roughness after FlatBOND GT

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

	Untreated Plated Cu	**FlatBOND GT**	**Our chemical roughening**
Ra(μm)	0.04	0.04	0.21

Table1 - Surface roughness comparison

Copper Pattern Width after FlatBOND Treatment

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

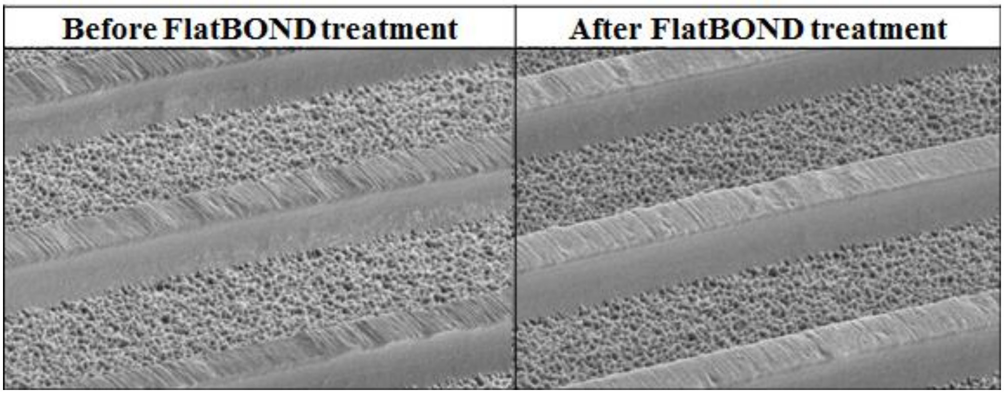

Figure5 - Copper pattern SEM images

Methodology

Transmission Loss Evaluation

To confirm the transmission performance of copper conductor treated with FlatBOND GT, we measured the insertion loss of signal data of copper conductor treated with FlatBOND GT 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) FlatBOND GT 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: 200mmImpedance: 50Ω

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

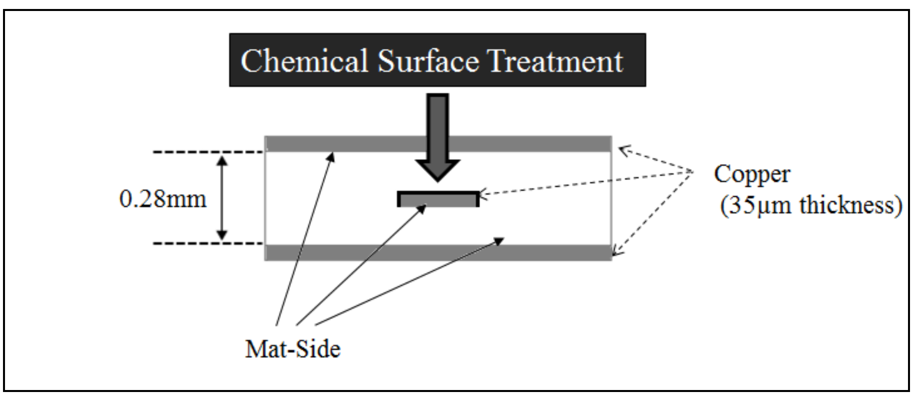

Figure6 - Test coupon design image

Adhesion Performance (Peel Strength)

We used the peel strength as a parameter of adhesion between the copper surface treated with FlatBOND GT and the low dielectric resins (prepregs). We measured peel strength according to JIS 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 vacuum-heated press machine, after that the copper foils were peeled in 10mm width with the peel tester. (Note: Absolute values of the peel strength vary, depending on following factors: storage condition of resins, pressing conditions, measuring conditions and so on. We evaluate the peel strength as 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. The below is detail of resin A and B.

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)

Results

Transmission Loss Evaluation

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

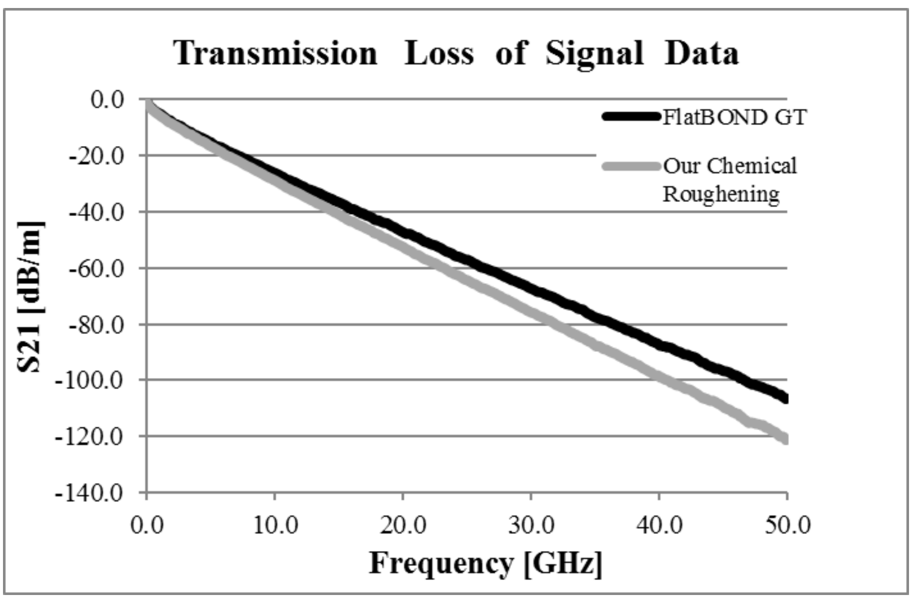

Figure7 - Transmission Loss of Signal Data

Peel Strength

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

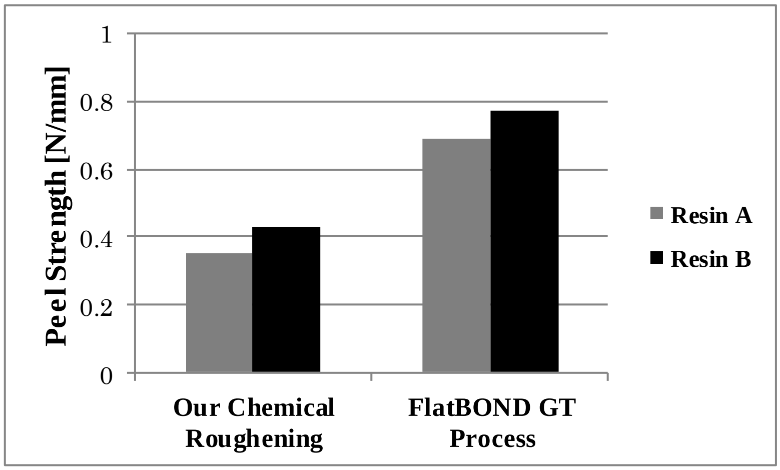

Figure8 - Adhesion performance for low dielectric resin A and resinB (Peel strength)

Peel Strength after Multiple Reflow Test

Figure9 shows peel strength evaluation result of FlatBOND GT process after multiple reflow test (260℃). According to Figure9, the peel strength of FlatBOND GT does not change even after reflow10times.

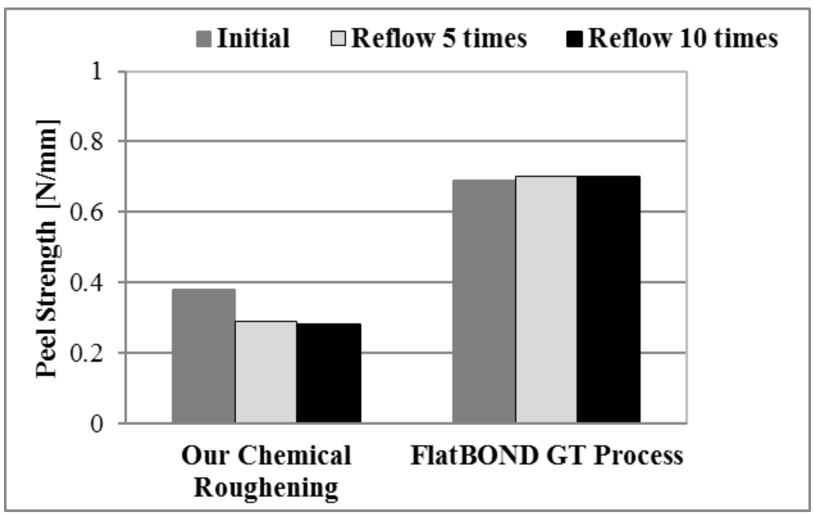

Figure9 - Adhesion performance for low dielectric resin A after reflow test (Peel strength)

Conclusion

We developed new surface treatment process (FlatBOND GT process) on copper conductor for high-speed and high-frequency PCBs. As mentioned above, the FlatBOND GT process achieved superior performance for transmission loss over 20GHz frequency, and its adhesion performance for low dielectric resins was confirmed as superior than that of our surface roughening treatment. FlatBOND GT process improved the transmission loss of signal especially at high frequency region, on 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 surface. In the future, technologies of electric device related to base station, 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 firmly believe that our FlatBOND GT process solves the issues of signal transmission loss and improve the reliability of advanced PCBs.