Profile-Free Copper Foil for High Density Wiring and High Frequency Application

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Abstract
Nowadays, the growth of electronic industry is remarkable. All electronic devices are getting smaller with higher performance and data transmission speed. Therefore, we have developed a new profile-free copper foil whose surface roughness (Rz) is less than 1.5 µm with satisfactory adhesion strength. A new original surface treatment of the profile-free copper foil provided affords good peel strength (0.7 kN/m or more) equivalent to that for the conventional roughened foil with sufficient reliability. With the new profile-free copper foil, the conventional subtractive method is applicable to the wiring of 60 µm pitch or less, and the short-circuit fault of electroless Ni/Pd/Au plating, which is prone to occur in fine wiring, will be restrained since the wiring is formed on a smooth surface. Moreover, the transmission loss at 5 GHz will decrease by 8 dB/m since the surface roughness of the conductor line is suppressed.

Introduction
Recently, the demand for smaller size and higher performance of electronic devices has become so strong that higher density wiring of printed wiring boards(PWBs) is strongly required for such applications [1]-[3]. In addition, the request for higher speed and larger capacity communication needs the use of higher frequencies. The conventional subtractive process, which is an easy process widely used for producing PWBs with the conventional copper foil, has proved to be unsuitable for higher density wiring. The conventional copper foil has a roughened surface profile to keep enough peel strength, which will necessitate excess etching time and make it difficult to realize high density wiring. The rough copper surface will also interfere with efficient data transmission because of the skin effect at high frequencies.

We have therefore developed a new profile-free copper foil. This copper foil has a low surface profile or roughness (Rz: <1.5μm) compared to the standard copper foil (Rz:7-8 μm) or low-profile copper foil (Rz:2.5-3.5 μm). Although the profile-free copper foil has the lowest roughness, it can afford satisfactory peel strength of more than 0.7KN/m by applying an original surface treatment to its adhesive side. We have confirmed that this profile-free copper foil is applicable to many kinds of laminate boards with satisfactory practical properties.

The new profile-free copper foil is available in producing finer line/space (L/S) wiring boards easily with reduction in transmission loss. We have achieved L/S=30/30 μm wiring with the 18-μm-thick by the subtractive process and further L/S=15/15 μm with the 3-μm-thick foil by the semi-additive process. If the PWB having finer L/S is obtained by the process using the copper foil, cost effectiveness would also be expected. Moreover, the short-circuit fault of electroless Ni/Pd/Au plating, that is prone to occur in fine wiring should be restrained since the wiring is formed on a smooth surface. Regarding the transmission loss, the value for the profile-free copper foil would be 10% to 25% smaller than that for the standard copper foil at high frequencies.

We are expecting that the profile-free copper foil has a potential to break through the conventional concept. In this paper, we will describe the profile-free copper foil; its features and advantages.

Development concept

The conventional copper foil has a roughened adhesive surface to keep good peel strength. However, this roughened surface will interfere with fabricating finer wiring and reducing the transmission loss. Consequently, we tried to use a new copper foil having very low surface profile (profile-free copper foil) to get rid of these problems. However, to use such foil concerned us about reducing peel strength because the anchor effect would not be expected. To obtain good peel strength, we studied adhesion factors in detail [4]. The key points were interface chemical force, interface polarization and the existence of reactive and contaminated layers. We then attempted to develop a new surface treatment on the basis of these key points for good peel strength.

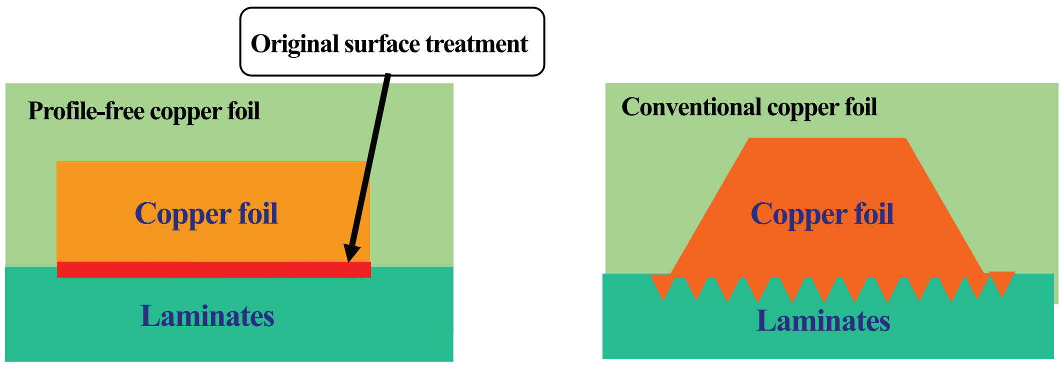
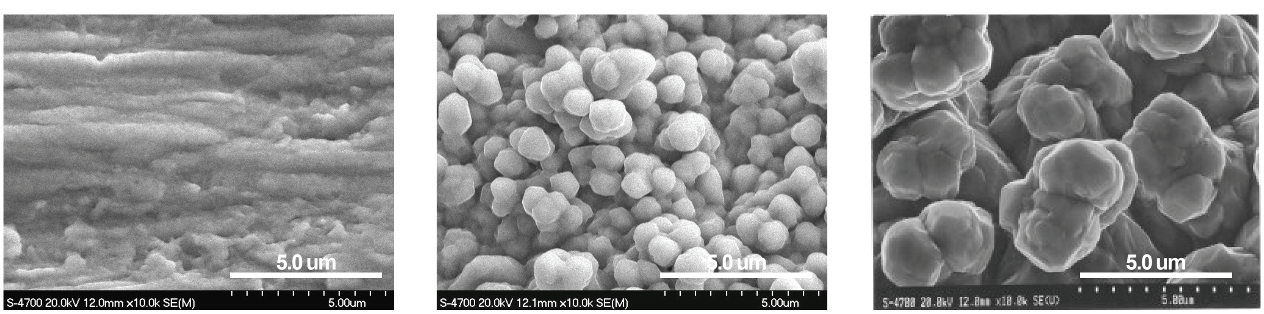


Figure 1 - Conceptual Models for Profile-Free and Conventional Copper Foils

Figure 1 shows the conceptual models for both profile-free and conventional copper foils.

As was shown in Figure 1, the new profile-free copper foil has an original surface treatment layer at the interface, whereas the conventional copper foil has only a roughened surface. The surface profile of the former copper foil is very low because it needs no roughening process on the adhesive surface. These two key points, original surface treatment and very low surface profile, are the features of the new profile-free copper foil.



Profile-free copper foil (Rz=1.0-1.5 μm) Low-profile copper foil (Rz=2.5-3.5 μm) Standard copper foil (Rz=7-8 μm)

Figure 2 - SEM Photographs of the Adhesive Surfaces of Profile-Free and the Other Copper Foils

Figure 2 shows the SEM photographs of the adhesive surfaces of the copper foils.

It is obvious from Figure 2 that the surface roughness of the profile-free copper foil is completely different from those of the other copper foils. The surface profile of the former foil is very low and no nodules were observed. On the contrary, the latter two foils had rough surfaces.

General Properties of the Laminate With Profile-Free Copper Foil

The strong concern for using profile-free copper foil was the reduction in peel strength due to the lack of the anchor effect. So we firstly examined the peel strength between copper foil and laminate. The results are shown in Figure 3.

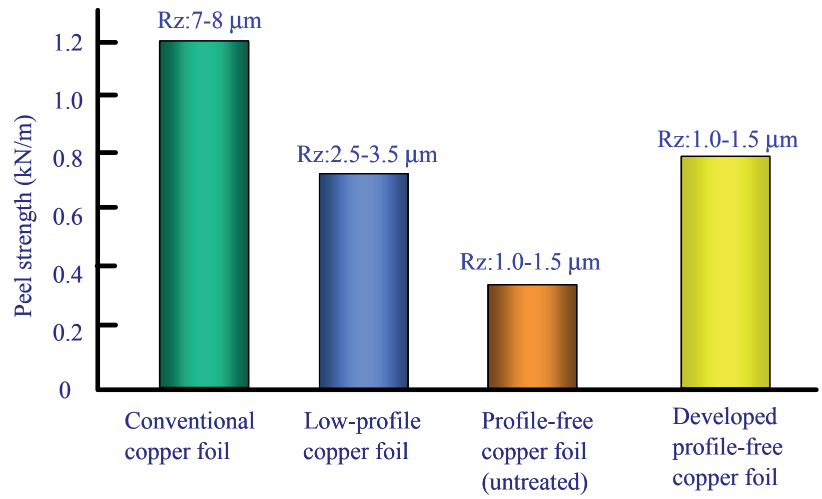


Figure 3 - Peel Strength of Laminates with Various Copper Foils

The peel strength for the newly developed profile-free copper foil was a little higher than that for the low-profile copper foil. The latter foil has already been used widely for such application as package substrates. Therefore, the former foil proved to have satisfactory peel strength for practical use. However, the untreated profile-free copper foil showed such low peel strength as 0.3 kg/N. It is obvious that the original surface treatment contributed to keep enough peel strength.

Table 1 - General Properties of the Laminates Using Profile-Free Copper Foil

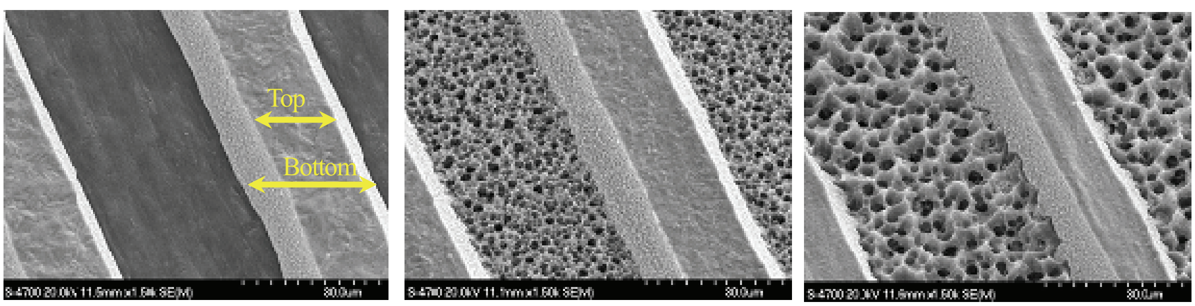
Laminates	Copper foil (18 µm)	Peel strength (kN/m)	Heat resistanace** 260°C	Heat resistanace** 288°C
High-Tg (MCL-E-679)	Low-profile	0.86	2 h OK	1 h OK
	Developed profile-free	0.77	2 h OK	1 h OK
High-Tg and low CTE (MCL-E-679F)	Low-profile	0.69	6 h OK	3 h OK
	Developed profile-free	0.80	6 h OK	3 h OK
High-Tg and low CTE (MCL-E-679FG)*	Low-profile	0.70	6 h OK	2 h OK
	Developed profile-free	0.78	6 h OK	2 h OK
Middle-Tg (MCL-BE-67G)*	Low-profile	1.02	6 h OK	2 h OK
	Developed profile-free	0.75	6 h OK	2 h OK

*:Halogen-free type **After PCT treatment on 4 layer board

Table 1 shows the general properties of various laminates with low profile or profile-free copper foil. By using the new profile-free copper foil, it will be possible to keep stable and satisfactory peel strength. The value of peel strength was independent of the kind of laminates or their resins when the new profile-free copper foil was used. The new profile-free copper foil can afford not only satisfactory peel strength but also good heat resistance. From these basic evaluations, we concluded that the new profile-free copper foil would be suited for practical use. Next we will explain other features of using the new profile-free copper foil.

Finer Circuit Formation

There have been three main circuit formation methods: subtractive, semi-additive, and full-additive methods. In the subtractive method, the circuit is formed by etching using etching resist. On the other hand, the normal semi-additive method and full-additive method need a chemical roughening process for insulation material to form a plated layer by electroless plating. It is known that the additive processes have an advantage in forming fine circuits. However, they have not been used widely and conventionally, because they need specific materials and facilities. In addition, it is difficult to get a lower surface profile because they need a roughening process. Therefore, it will be better if we can make finer circuits by the subtractive process. Recently, a semi-additive method using ultrathin copper (2-3 μm) foil was proposed by a copper foil supplier [5]. The method has some advantages over the conventional semi-additive method. Both the subtractive method and this method have no limitation of insulation materials and no need for the roughening process. We then studied both the methods. The results of circuit formation by the subtractive method are shown in Figure 4.



Profile-free copper foil (Etching time ratio: 0.71) | Low-profile copper foil (Etching time ratio: 0.83) | Standard copper foil (Etching time ratio: 1.0)

Figure 4 - Results of Circuit Formation by the Subtractive Method Using Various Copper Foils

(Copper thickness: 18 μm, L/S specification: 30/30 μm, Etchant: Ferric chloride)

Figure 4 shows the better circuit formation with the profile-free copper foil than with the other copper foils. It is possible to obtain satisfactory circuit line width by using the profile-free copper foil. Moreover, we found that we can reduce the etching time by using the profile-free copper foil. The surface after etching was very flat for the profile-free copper foil depending on its lowest surface profile. The conventional roughened copper foil requires longer time for the circuit formation to get rid of some defects like short-circuit faults: the profile-free copper foil required only 71%, and the low-profile 83% of that time for the conventional copper foil. It means that the profile-free copper foil has the potential not only to reduce the etching time but also to increase fabrication amounts.

We think this shorter etching time will make a satisfactory circuit width. Figure 5 shows the measurements of the top and bottom line widths formed with various copper foils. The profile-free copper foil was able to keep wider lines than the other copper foils. We think circuit design will become easier by using the profile-free copper foil.

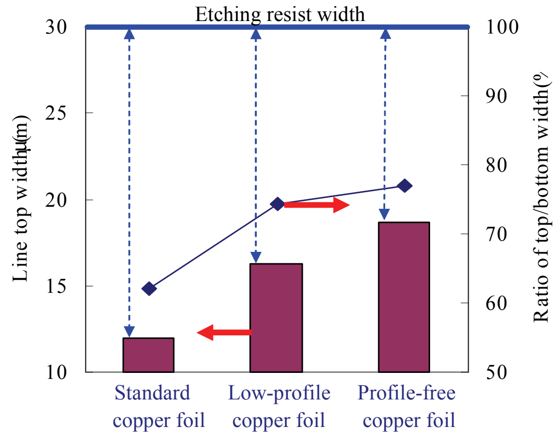


Figure 5 - Line Width Formed by the Subtractive Method (Copper Thickness: 18) □m

The semi-additive method using the profile-free ultrathin copper foil was also studied. Figure 6 shows the circuit board fabricated by the semi-additive method with 3-□m-thick profile-free copper foil. The circuit of a line/space of 15/ 15 □m was successfully fabricated. An advantage of using the profile-free ultrathin copper foil is no limitation of insulation materials. Since the conventional semi-additive method needs a roughening process to afford satisfactory peel strength, the insulation material is so designed as to be easy to roughen with chemical etchant. Many kinds of insulation materials can be used with the profile-free copper foil,

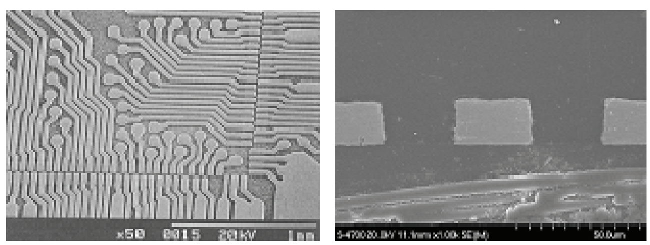


Figure 6 - Circuit board Example Fabricated by the Semi-Additive Method Using Ultrathin Profile-Free Copper Foil

The electroless Ni/Pd/Au plating process was also studied. In general, a circuit board of a line / space of 30 /30 □m level can easily fail in the electroless Ni/Pd/Au plating process [6]. Figure 7 shows the circuit board fabricated with both the profile-free and conventional roughened foils. It is obvious that using the profile-free copper foil will suppress short-circuit faults of electroless Ni/Pd/Au plating. The rough insulation surface from the roughened copper foil had some copper-like substances remaining after the etching process. And after the electroless Ni/Pd/Au plating process, there were some clusters (circled) that could cause short-circuit faults.

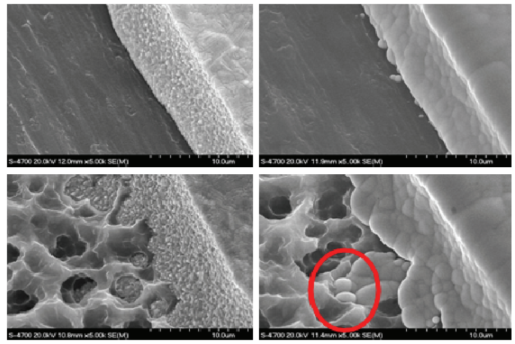


Figure 7- Deposition Defect of Electroless plating

Transmission loss

In order to reduce the transmission loss, we have tried to apply materials having low dielectric constant and loss factor. This general kind of approach reduces the dielectric loss that is a part of the transmission loss. The transmission loss basically consists of the conductor loss and dielectric loss. The conductor loss has not been studied enough in the circuit board field so far. At higher frequencies, the conductor line with a rougher surface will tend to have higher resistance because of the skin effect [7]-[9]. The surface roughness then becomes very important for high frequency applications. However, no good solution has been proposed so far, it was difficult to apply smoother copper foil without degrading peel strength. Since the profile-free copper foil has very low surface profile and satisfactory peel strength, we expected it to lower the transmission loss at higher frequencies.

To measure the transmission loss, PWBs having strip lines of 50 Ω impedance were fabricated using the three kinds of copper foils. The transmission loss was calculated from the scattering parameter (S21) measured using a Network Analyzer 8753ES of Agilent Technologies. The measurements are shown in Figure 8.

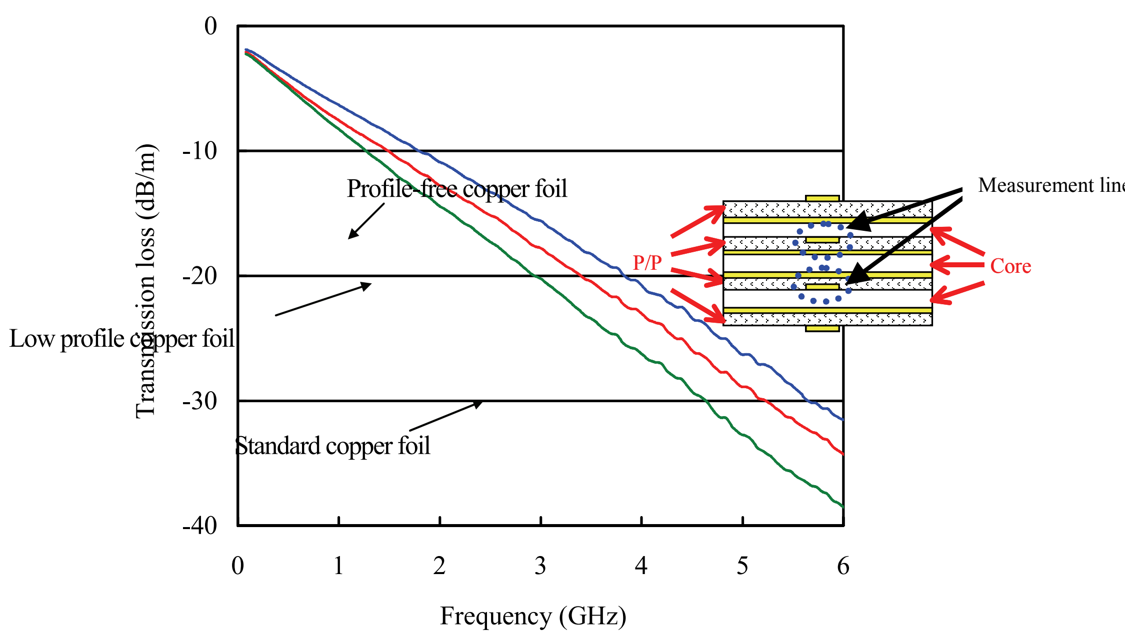


Figure 8 - Transmission Loss of the Circuits Made With Various Copper Foils

In this study, we used a low dielectric constant material (MCL-LX-67Y, Hitachi Chemical) as insulation material. Although the transmission losses for the three copper foils were nearly the same below 1 GHz, a large difference in the loss value appeared above 3 GHz. The transmission loss for the profile-free copper foil at 5 GHz was -25 dB/m; those for the low-profile copper foil and standard copper foils were -28 dB/m and -33 dB/m, respectively. The advantage of the profile-free copper foil over the standard copper foil was -8 dB/m at 5 GHz, and would be more at the higher frequency region.

We also estimated the effect of surface roughness on the transmission loss by using a simulation technique of the Advanced Design System of Agilent Technologies. In this simulation, microstrip lines were used as the circuit structure . As shown in Figure 9, the transmission loss for 0 □m surface roughness is -15.8 dB/m at 10 GHz; those for 0.5 □m, 1.0 □m, and 3 □m were -20 dB/m, -24 dB/m, and -26 dB/m, respectively. It was demonstrated that the transmission loss would strongly depend on the surface roughness of the conductor line. The combination of high loss factor (Df) material and profile-free copper foils can afford lower transmission losses than that of low Df material and the roughened copper foil.

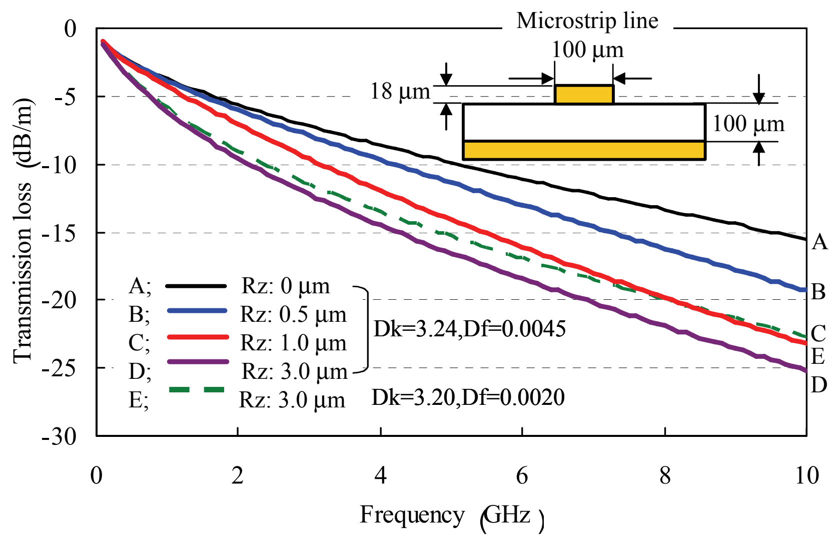


Figure 9 - Simulation Results of the Transmission Loss for Differently Roughened Copper Foils

Conclusions

1. We have developed a new profile-free copper foil whose surface roughness (Rz) is less than 1.5 □m with enough peel strength.
2. The technical key point of the development is the adoption of an original surface treatment on the adhesive side of the foil.
3. The laminate using the foil proved to have satisfactory peel strength and heat resistance.
4. Finer circuit formation by the subtractive method and circuit design will become easier by using the foil.
5. It is possible to reduce deposition defect of electroless Ni/Pd/Au plating by using the foil.
6. The very low surface roughness of the foil will reduce the conductor loss caused by the skin effect at high frequencies, leading to the reduction of total transmission loss.

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