

High Strength, Low Profile Copper Foil for High Performance PCBs*

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ABSTRACT — A new high strength, low profile copper foil (AM) has been developed by the authors' company. This foil is designated AM foil, which refers to its advanced metallurgy. The unique attributes of this foil arise from its unconventional processing approach and the resulting microstructure. An extremely small and uniform grain structure enhances the metallurgy and decreases the foil profile. Random crystal orientation and high nucleation density eliminate porosity for all foils of various thickness. Other benefits related to this high strength and low profile foil include good handleability, outstanding etching performance, better control of dielectric thickness, very high elongation to reduce innerlayer cracks, improved oxide adhesion, as well as other advantages.

INTRODUCTION

As printed circuit board fabrication evolves into higher performance and packing density features, more stringent requirements are placed on the copper foil. In general, the desired properties of copper foil in high performance PCBs include:

- 1 *Lower profile* (peak-to-valley) for superior etchability and impedance control while maintaining a strong interface adhesion.
- 2 *Higher strength and hardness* to improve handleability and reduce deformation-related defects in copper foil.
- 3 *Very high elongation at elevated temperature* (180°C) to further reduce innerlayer cracks.
- 4 *Enhanced thermal stability* to inhibit copper foil recrystallisation during lamination and subsequent thermal processing.

In order to meet these criteria, a copper foil with a special combination of metallurgical properties and grain structure was developed using an unconventional electrolytic processing approach.

MICROSTRUCTURE

Conventional copper foils generally display a columnar grain structure with a large grain size. High density (220) crystal orientation and pyramidal-shaped matte side topography are normally associated with foils having this type of grain structure. Theoretically, the grain structure of electrodeposited copper foil is related to the nucleation and grain growth mechanisms during the deposition process. A columnar grain structure and anisotropic crystal orientation in electrodeposited copper foil are merely the result of a preferred grain growth pattern. In the AM foil, however, the anisotropic grain growth is inhibited and nucleation is enhanced. Consequently, a foil of extremely small and uniform grain structure is obtained, and the grains exhibit random crystal orientation. These enhancements are illustrated in Figure 1, which compares the etched cross-sectional views of the foil and conventional Grade 1 (general purpose) and Grade 3 (high elongation at elevated temperature) foils.

Transmission electron microscopy (TEM) was employed to further characterise the microstructure of this foil and conventional copper foils, as illustrated in Figure 2.

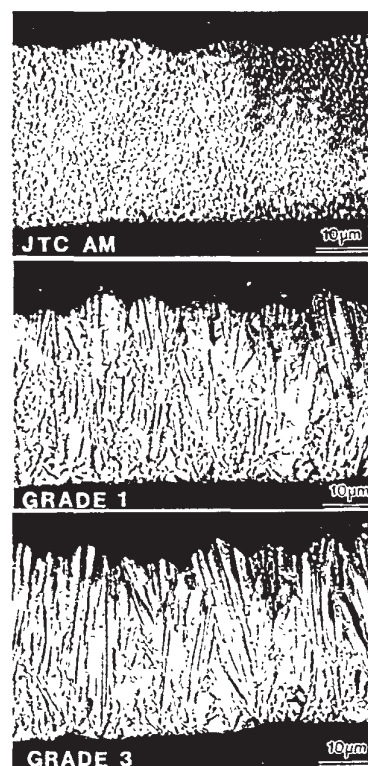


Fig. 1 Microstructure of conventional and JTCAM copper foils (35 µm thickness, etched cross-sectional views).

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Fig. 2 Microstructure of conventional and JTCAM copper foils (TEM planar view images).

TEM planar view images of conventional foil display its complicated microstructure. High density planar defects (twin boundaries), dislocations and subgrain boundaries were all observed within the grains. Using the planar view imaging technique, a typical grain size of 5 to 10 μm was determined for conventional foils. In contrast, AM foil showed an extremely fine grain size. Higher magnification TEM planar images, as shown in Figure 3, illustrated that the average grain size was only about 0.2 to 0.4 μm . In addition, essentially no twin boundaries were observed in the foil.

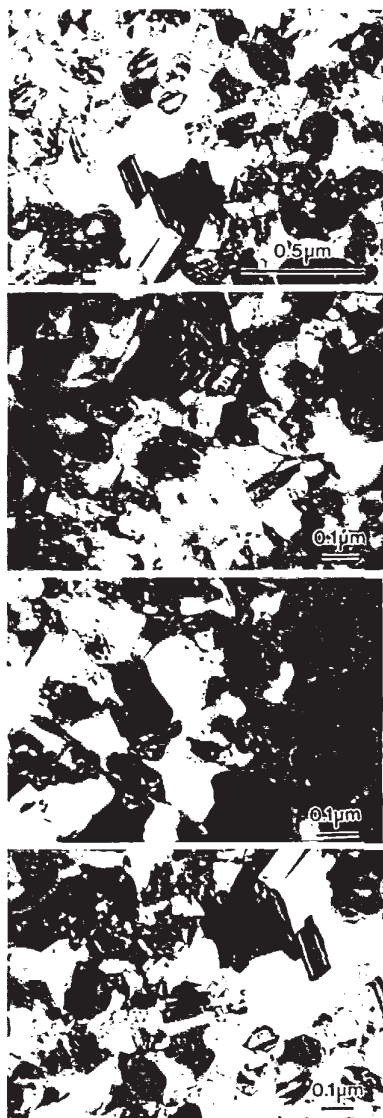


Fig. 3 High magnification TEM planar view images of JTCAM foil.

METALLURGICAL PROPERTIES

Metallurgical properties of copper foil are generally determined by its microstructure. As a result of the dramatic reduction in grain size, a significant increase of tensile strength and hardness is observed in the AM foil. Table 1 shows a comparison of the metallurgical properties with those of conventional foils.

In addition to almost double tensile strength and microhardness, the foil exhibits very high elongation at 180°C. A comparison of the room temperature tensile stress-strain curves of AM foil and conventional foils is shown in Figure 4. This figure further demonstrates that AM foil has a much higher yield strength than Grade 1 and 3 foils. The implication of the increase in tensile strength, yield strength and microhardness of AM foil is the significant improvement of its handleability and resistance to plastic deformation under low to medium

Table 1
Typical Metallurgical Properties — One-ounce (35 μm) Thickness

	Conventional Grade 1	Conventional Grade 3	JTCAM
Room temperature tensile strength (ksi)	55	60	100
Room temperature elongation (%)	11	18	8
180°C tensile strength (ksi)	29	33	29
180°C elongation (%)	2	7	23
Microhardness (KHN) at room temperature	110	130	220

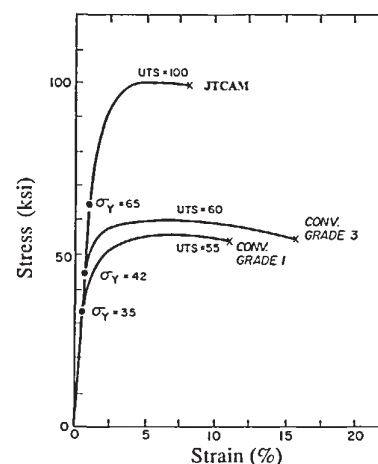


Fig. 4 Tensile stress-strain curves of JTCAM and conventional 1 oz. copper foils.

load conditions. Indeed, fewer wrinkles and other surface defects are being reported by several users of the foil.

The foil elongation at 180°C is another metallurgical property of interest because it is commonly related to the innerlayer conductor cracking phenomenon. The very high ductility of the foil at elevated temperature should eliminate or further reduce innerlayer cracking.

While achieving high strength and high elongation at elevated temperature, another major improvement of AM foil is the stability of the metallurgical properties after thermal annealing. As illustrated in Figure 5, tensile strength of the foil remained relatively unchanged up to temperatures of 225°C. This observation indicates that no recrystallisation occurs in the foil in normal lamination or post-baking operations. This thermal stability is particularly desirable for thin laminates or when dimensional stability or warpage becomes a primary concern.

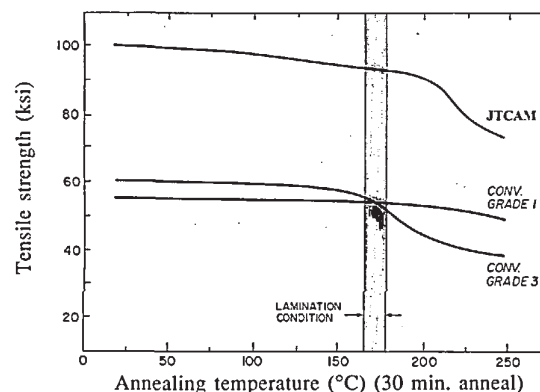


Fig. 5 Tensile strength retention comparison of JTCAM and conventional 1 oz. copper foils after thermal annealing.

PROFILE AND ETCHING

As a result of small grain size and random orientation, AM foil inherits a lower profile on the matte side surface. Figure 1 illustrates the shallow and rounded profile of AM foil in comparison with the toothy and pyramid-shaped topography of conventional foils. A further illustration of the surface morphology differences in foils and etched laminates is given in Figure 6.

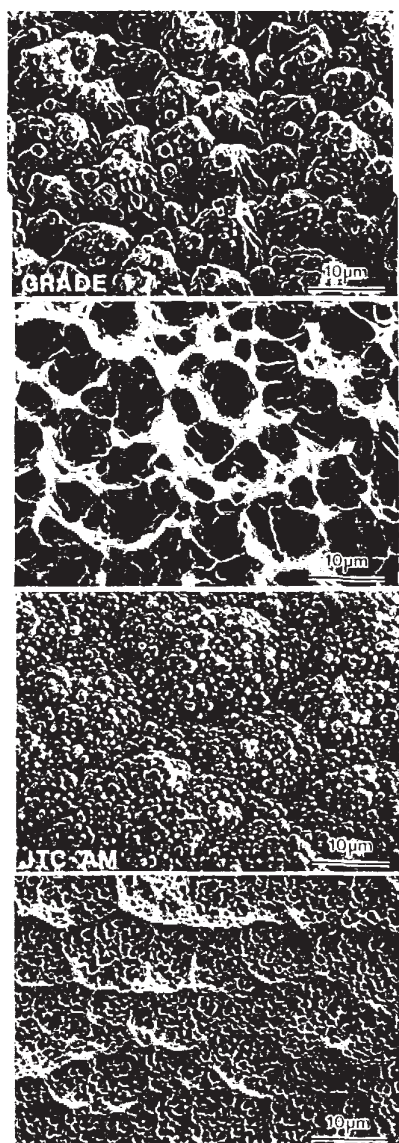


Fig. 6 Surface topography of foils and etched laminates.

Figure 6 shows that a difference in foil matte side topography can make a dramatic difference in the etched laminated surface, which in fact is a replication of the foil morphology. Etched laminate made from AM foil is shallow and smooth with some small rounded holes caused by the foil's nodular treatment. The etched laminate of conventional Grade 1 foil, in contrast, displays much deeper valleys and sharp surface contours. Laboratory etching studies reveal that the significant differences in profile and surface topography are critical to the etching performance and the cleanliness of etched laminate. The shallower and smoother surface morphology of AM foil makes cleaning easier and therefore fewer ionic residues will remain on etched laminates.

A fine line etching study shows that foil profile is one of the most important parameters affecting the etched line geometry. In Figure 7, a comparison of one-ounce AM foil and Grade 1 foils etched with cupric chloride solution shows that the conductor traces etched from AM foil have more vertical sidewalls and higher etching factors.

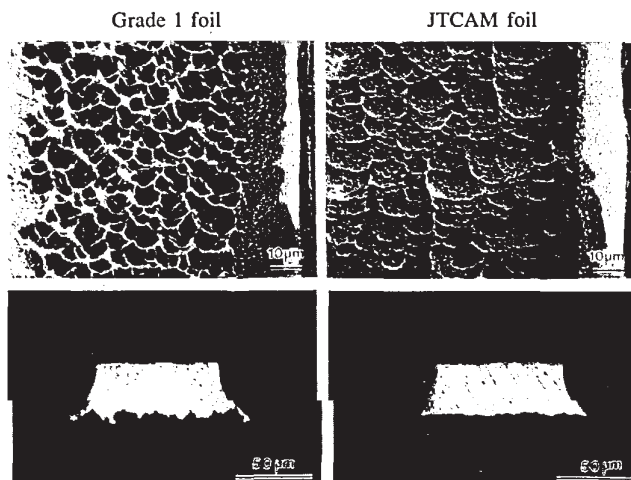


Fig. 7 Fine-line etching comparison of conventional Grade 1 and JTCAM foils.

PEEL ADHESION

Peel strength of copper foil on cured laminate is typically measured to evaluate the adhesion between foil and resin. Generally, peel strength is determined by both mechanical interlocking and chemical bonding. Since AM foil has a lower profile, the contribution to peel strength from mechanical interlocking is expected to be lower than conventional products. However, with an improved adhesion promoter to enhance chemical bonding, the measured peel strength of the foil is still reasonably high and meets military specifications. In Table 2, foils are compared. As can be seen from the table, the roughness of AM foil is only around half that of the conventional foils. Despite the lower profile, AM foil still maintains about 9.5 lb/in. peel on rigid difunctional epoxy laminate and about 9.0 lb/in. on multifunctional thin laminate.

Table 2

Typical Roughness and Peel Adhesion — One-ounce (35 µm) Copper

	Conventional Grade 1	Conventional Grade 3	JTCAM	MIL Specification
Roughness (Matte Side)				
Ra (µm)	1.3	1.4	0.8	-
Rtm (µm)	11.1	11.8	5.8	-
Peel Strength (lb/in.)				
Difunctional epoxy (0.060 in.)	12.2	12.8	9.5	8.0
Multifunctional epoxy (0.005 in., 140°C Tg)	10.0	10.0	9.0	6.0

Excellent interface adhesion between AM foil and epoxy resin laminate is further demonstrated by examination of the peel back samples. As shown in Figure 8, SEM images of AM foil and laminate surface after peel back show that the peel fracture is a cohesive failure. Peel fracture propagates through the resin layer instead of along the interface between foil and resin.

OTHER IMPORTANT FEATURES

The high strength and improved handleability make free-standing thin copper foil more realisable. Also, the high nucleation density during deposition and the extremely small grain size provide copper foil free of porosity, which is one of the most desired attributes of doubletreat foil. The combination of thin free-standing and porosity-free characteristics allows AM foil to fulfill the demands of future applications, as well as those of today.

Finally, better photoresist adhesion and improved oxide treated surfaces have been reported in PCB production facilities. This result, again, is attributable to the small and uniform grain structure which results in more uniform surface roughening and higher surface area after microetching.

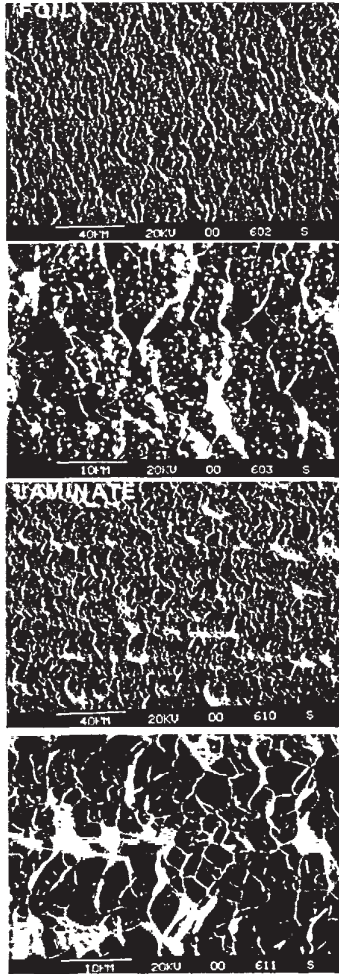


Fig. 8 Cohesive failure of peel-back samples of JTCAM copper foil on tetrafunctional epoxy laminate (SEM at 200x).

SUMMARY

Extremely small grain sizes and a grain structure that is essentially free of twin boundaries are the major microstructure characteristics of

AM foil. As a result of the microstructure features, this foil displays a lower profile, no porosity and possesses very high strength and microhardness. These attributes improve thin foil handleability and yield, as well as enhancing etching, dielectric control and electrical performance.

A summary of proven or expected benefits for high performance laminates and PCBs from AM foil is listed in Table 3.

Table 3

Proven or Expected Benefits of JTCAM Foil

<i>Metallurgical/ Physical Property Advantages</i>	<i>Laminate and PCB Benefits</i>
Higher UTS	Fewer wrinkles of thin foils Improved stiffness and handleability Improved laminate surface quality
Smaller and more uniform grains, lower profile	No porosity Improved etchability Improved photoresist and black oxide adhesion Better impedance control Dielectric thickness control Fewer lamination voids Reduced measles Fewer white spots after etching Improved dimensional stability
Higher elongation at elevated temperature	Resistant to stress cracking in multilayer boards
Thermally stable	Resistant to foil recrystallisation Less warp and twist
Greater hardness	Improved MLB drilling
Adhesion promoter	Improved adhesion Extended shelf life Peel retention after high humidity Enhanced oxidation resistance
Grade 1 and Grade 3 properties combined	Less inventory

ACKNOWLEDGEMENT

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