Properties

Copper Foils for High Frequency Materials

Copper foils, for the wide range of Rogers' high frequency circuit substrates, are designed to provide optimum performance in high reliability applications.

There are various types of copper foil are offered; in a range of weights (thicknesses). Their characteristics differ, and an understanding of these differences is important to ensure the correct selection of copper foil for each application or environmental condition.

Copper Foil Manufacturing

Standard ED Copper

In an electrodeposited copper manufacturing process, the copper foil is deposited on a titanium rotating drum from a copper solution where it is connected to a DC voltage source. The cathode is attached to the drum and the anode is submerged in the copper electrolyte solution. When an electric field is applied, copper is deposited on the drum as it rotates at a very slow pace. The copper surface on the drum side is smooth while the opposite side is rough. The slower the drum speed, the thicker the copper gets and vice versa. The copper is attracted and accumulated on the cathode surface of the titanium drum. The matte and drum side of the copper foil go through different treatment cycles so that the copper could be suitable for PCB fabrication. The treatments enhance adhesion between the copper and dielectric interlayer during copper clad lamination process. Another advantage of the treatments is to act as anti-tarnish agents by slowing down oxidation of copper.

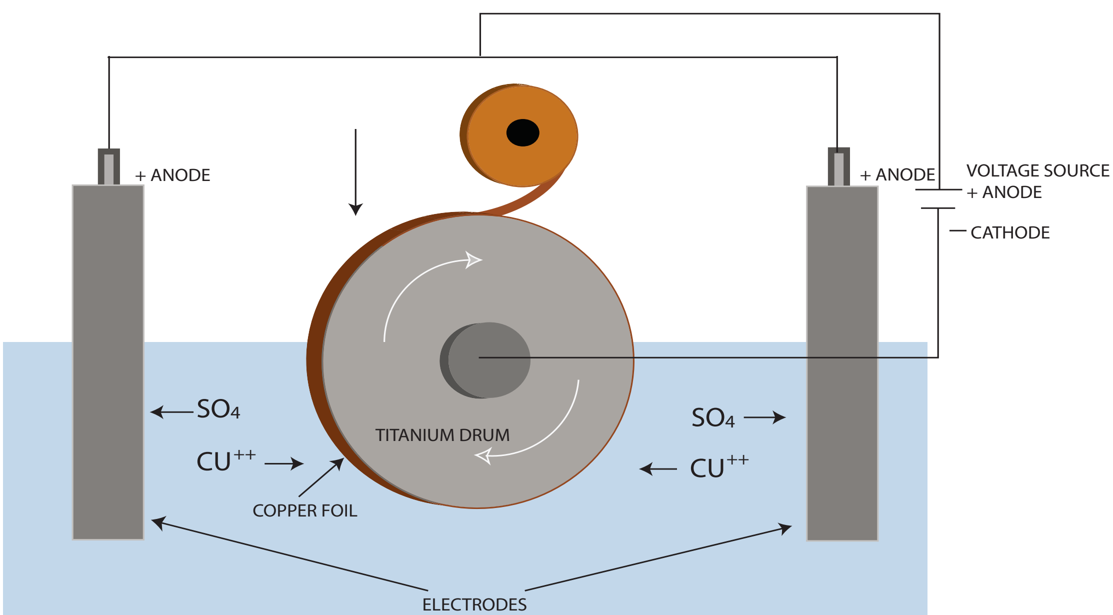


Fig. Electrodeposited Copper Manufacturing Process

Rolled Copper

Rolled copper is made by successive cold rolling operations to reduce thickness and extend length starting with a billet of pure copper. The surface smoothness depends on the rolling mill condition.

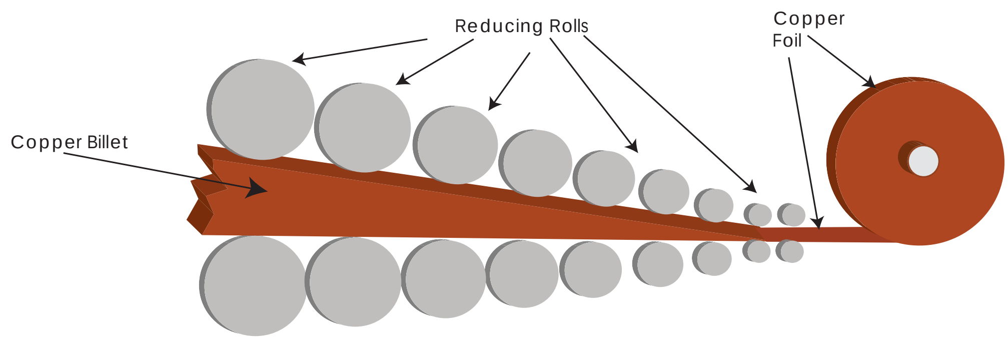


Fig. Rolled Copper Manufacturing Process

Resistive Copper

The matte side of the ED copper is coated with metal or alloy that acts as a resistive layer. The next process is to roughen the resistive layer with nickel particles.

Reverse Treated ED Copper and LoPro Copper Foil

Reverse treated foils involve the treatment of the smooth side of electrodeposited copper. Treatment layers are thin coatings that improve adhesion of the base foil to dielectrics and add corrosion resistance which makes the shiny side rougher than it was before. During the process of making circuit board panels, the treated side of copper is laminated to the dielectric material. The fact that the treated drum side is rougher than the other side constitutes a greater adhesion to the dielectric. That is the major advantage over the standard ED copper. The matte side doesn't need any mechanical or chemical treatment before applying photoresist. It is already rough enough for good laminate resist adhesion.

In case of the LoPro™ copper, a thin layer of adhesive is applied on the reverse treated side of the copper. There is a physical layer of the bond enhancement material. Just like the reverse treated electrodeposited copper, the adhesive treated side is bonded to the dielectric layer for better adhesion. Our RO4000 series material are available laminated with LoPro copper foil.

Crystalline Structure

Electrodeposited copper crystals tend to grow lengthwise in the Z-axis of the foil. Typically, a polished section of electrodeposited copper foil has the appearance of a picket fence, with long crystal boundaries perpendicular to the foil plane. Rolled copper crystals are broken and crushed during the cold rolling operation. They are smaller than the electrodeposited crystals, and have irregular, spherical shapes, nearly parallel to the foil plane.

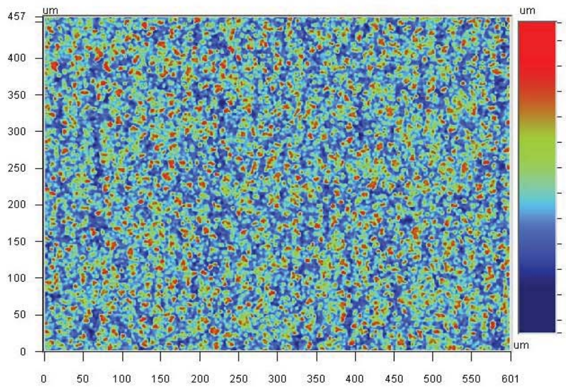
Foil Type	Weight or Thickness	Surface Roughness Rq (µm)		Products
		Dielectric Side	Top Side	
Rolled	1 oz (35 µm)	0.4	0.3	RO3003™, RO3006™, RO3010™, RO3035™, RO3203™, RO3206™, RO3210™ RT/duroid® 5870, 5880, 6002, 6202, 6006, 6010LM, ULTRALAM® 2000 laminates
	½ oz. (18 µm)	0.4	0.3	
Electrodeposited	1 oz (35 µm)	2.1	0.5	RO3003, RO3006, RO3010, RO3035, RO3203, RO3206, RO3210 RT/duroid 5870, 5880, 6002, 6202, 6006, 6010LM ULTRALAM 2000 TMM® 3,4, 6,10, 10i laminates
	½ oz. (18 µm)	1.8	0.4	
	¼ oz. (8.5 µm)	0.8	0.4	
	1 oz (35 µm)	2.2	0.4	RT/duroid 6035HTC laminates
	½ oz. (18 µm)	1.7	0.4	
	2 oz. (70 µm)	3.3	0.4	RO4003C™, RO4350B™, RO4360™ RO4533™ RO4534™, RO4350B-TX laminates
	1 oz. (35 µm)	3.2	0.5	
	½ oz. (18 µm)	2.8	0.4	
Electrodeposited Low Profile Reverse Treated	18 µm	0.5	0.4	ULTRALAM 3000, XT/duroid®, laminates
	12 µm	0.5	0.4	
	9 µm	0.5	0.3	
	1 oz. (35 µm)	0.9	1.3	RT/duorid 6035HTC laminates
	½ oz. (18 µm)	0.7	0.8	
LoPro® Foil	1 oz. (35 µm)	0.6	1.1	RO4003C, RO4350B, RO4533, RO4534, RO4730™ laminates
	½ oz. (18 µm)	0.5	0.6	
Resistive Foil	TCR® Thin Film Resistor Foil ½ oz. (18 µm)	2.2	0.5	RO4003C, RO4350B laminates
	OhmegaPly® Resistor-Conductor Material 25 ohms ½ oz (18 µm)	1.4	0.3	RO4003C laminates
	OhmegaPly Resistor-Conductor Material 25 ohms ½ oz. (18 µm)	1.0	0.3	RO3003 , RO3006, RO3010, RO3035, RO3203, RO3206, RO3210, RT/duroid 5870, 5880, 6002, 6202, 6006, 6010LM laminates

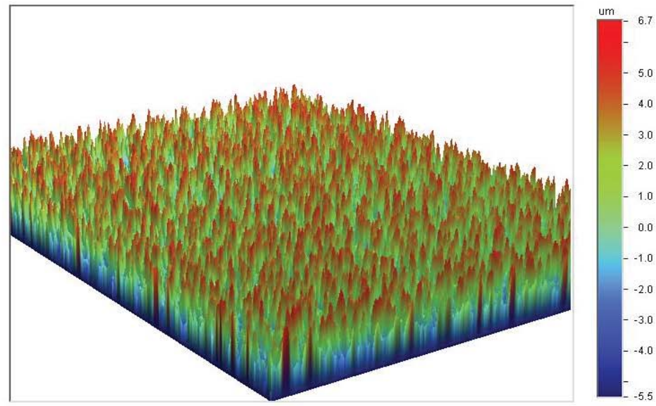
Table 1. Typical Copper Roughness Data

Copper Foil Roughness Measurements

An optical profiler can be used to analyze the three-dimensional surface profile of a copper foil to subsequently determnie its RMS roughness. RMS or Rq is the "root-mean-squared" roughness calculated over the profiled area. The surface morphology of half ounce electrodeposited copper on figure 1 clearly shows that the treated side has granular dendritic structure and the untreated side has a smoother surface.

Title: 1/2 oz EDC Foil
Note: Treated Side





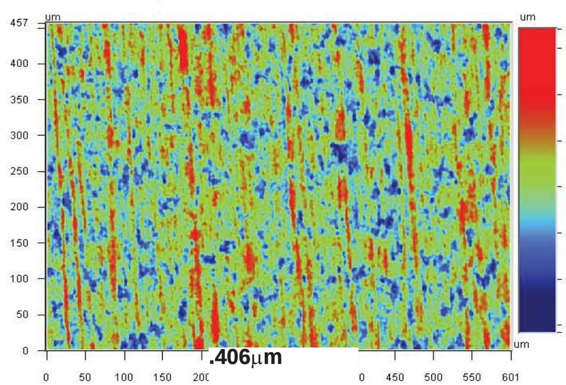
Copper Attribute

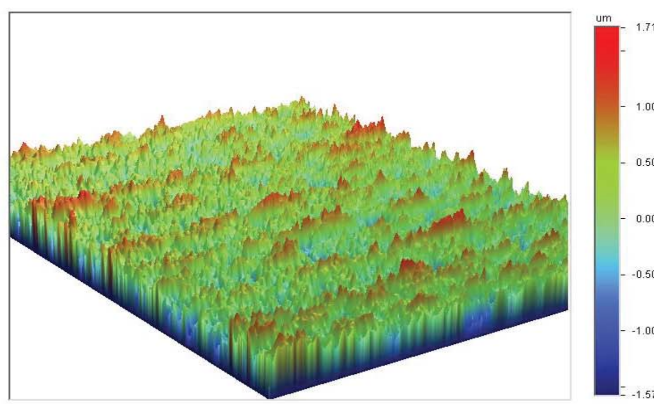
Rq	1.86 um

Measurement Information

Filtering	Low Pass
Filtering	Low Pass
Magnification	10.28
Measurement Mode	VSI
Pixel size	817.12 nm
pixel	736 X 480

TItle: 1/2 oz. EDC Foil
Note: Shiny Side





Copper Attribute

Rq	406.09 nm

Measurement Information

Filtering	Low Pass
Filtering	Low Pass
Magnification	10.28
Measurement Mode	VSI
Pixel size	817.12 nm
pixel	736 X 480

Fig 1. Wyko® Optical Profiler Surface Morphology and Roughness Measurements of Treated and Untreated Half Ounce Copper (not to scale)

As displayed on Table 1, roughness data of electrodeposited and rolled copper foils with different thicknesses was obtained by using an optical surface profiler. It also shows for which products the individual copper foils are used at Rogers Corporation. The rolled copper with no surface treatment is typically the smoothest.

Electric Performance of Laminates

Copper surface roughness can increase conductor loss of a microwave circuit as frequency increases and to the extent that the signal skin depth is comparable or smaller than the scale of the copper roughness. A simple explanation of this effect is that the small skin depth signal must travel along the surface of the rough conductor, effectively increasing the path length and conductor resistance.

There have been many attempts to characterize the relationship between the copper conductor surface roughness and the losses. Morgan[1] published a paper where numerical modeling was done to approximate the losses associated with conductor roughness and in relation to frequency. An example of conductor losses of microstrip transmission lines using different copper roughness and the application of the Morgan rule (labeled MWI) is shown in figure 2.

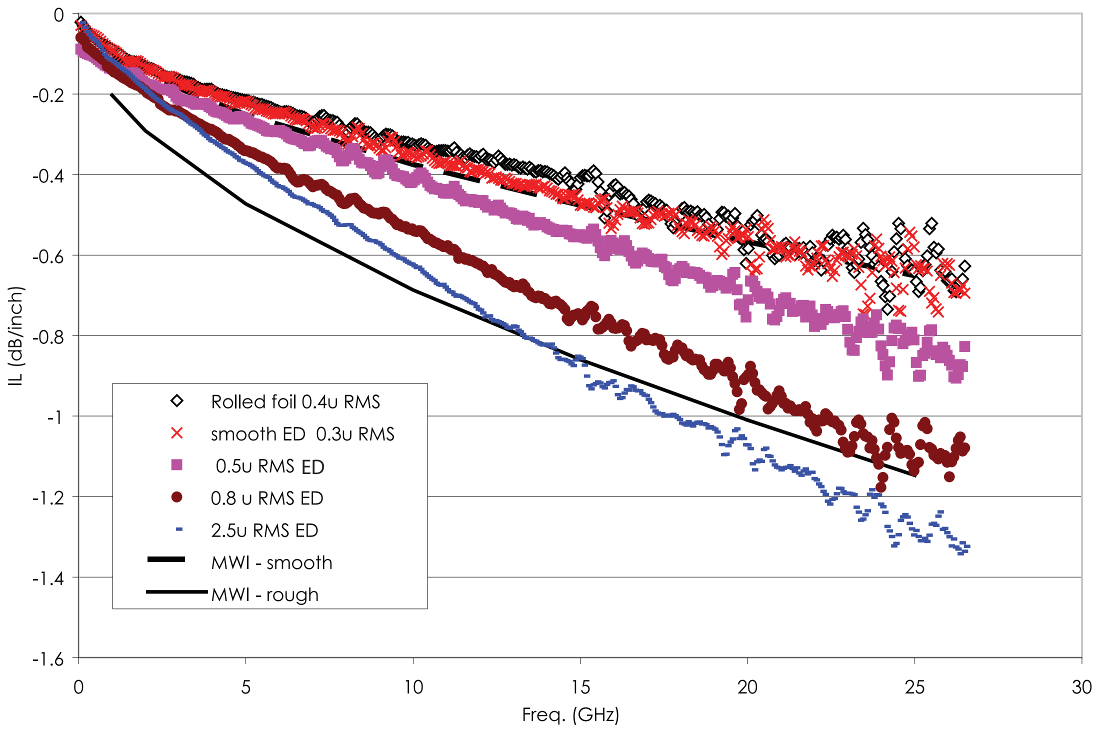


Fig 2. Insertion loss 50 ohm microstrip transmission lines with various copper foils on 0.004" ULTRALAM® 3850 laminates.

The above graph shows insertion loss versus frequency for five different copper foils which were laminated to 0.004" LCP dielectric material. Comparing the treated electrodeposited and rolled copper foils, the rolled (RMS=0.4mm) treated copper has lower insertion loss. The one with the highest insertion loss is the treated electrodeposited foil (RMS=2.5mm) whereas the untreated electrodeposited copper with RMS value of 0.3mm has the lower insertion loss. It can be concluded that the smoother the copper the lower the insertion loss becomes.

More recently a paper[2] disclosed the relationship between copper roughness and the effect on the phase constant as well as insertion loss. As part of this work a sophisticated model was developed which very closely approximates measured circuits of varying geometry. This model was developed by Sonnet Software and is an electromagnetic field solver, using complex impedance. A correlation between this model and measured circuits is shown in figure 3.

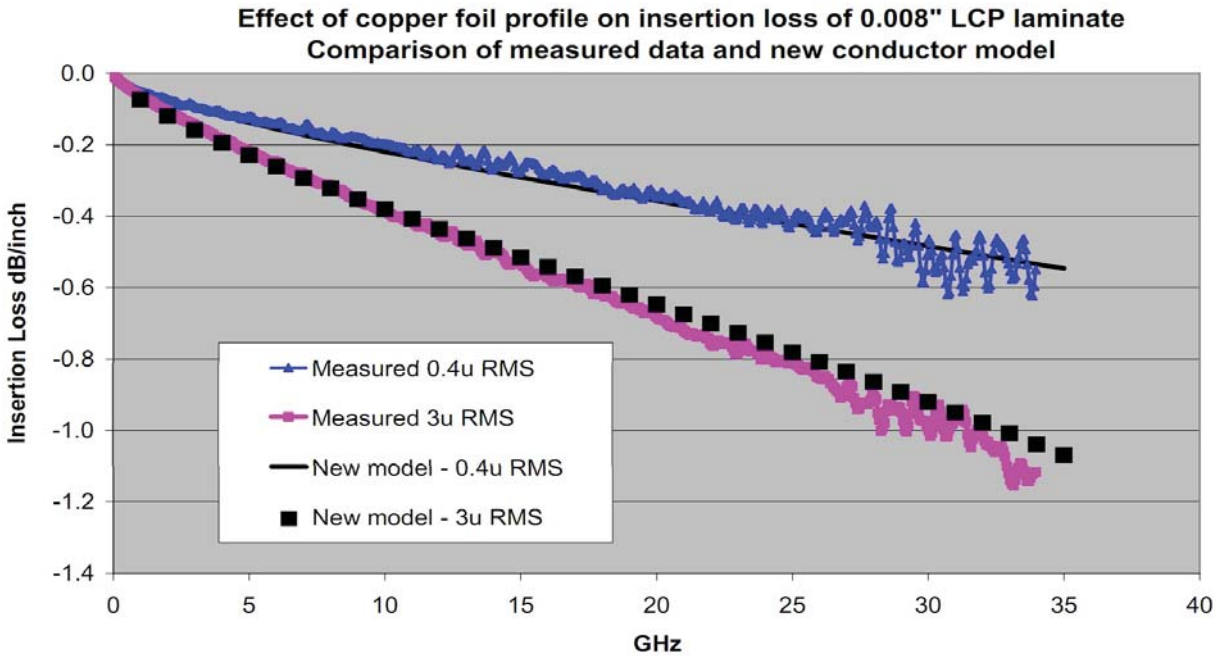


Fig 3. Comparison between EM model and measured microstrip circuits for insertion loss, when accounting for conductor roughness.

This same study found that copper surface roughness impacts the effective dielectric constant of a microstrip transmission line and this is done by the roughness having an effect on the propagation constant. A thinner circuit will be more sensitive to the conductor surface roughness and the effective dielectric constant will increase with an increase in roughness. This is demonstrated in figure 4.

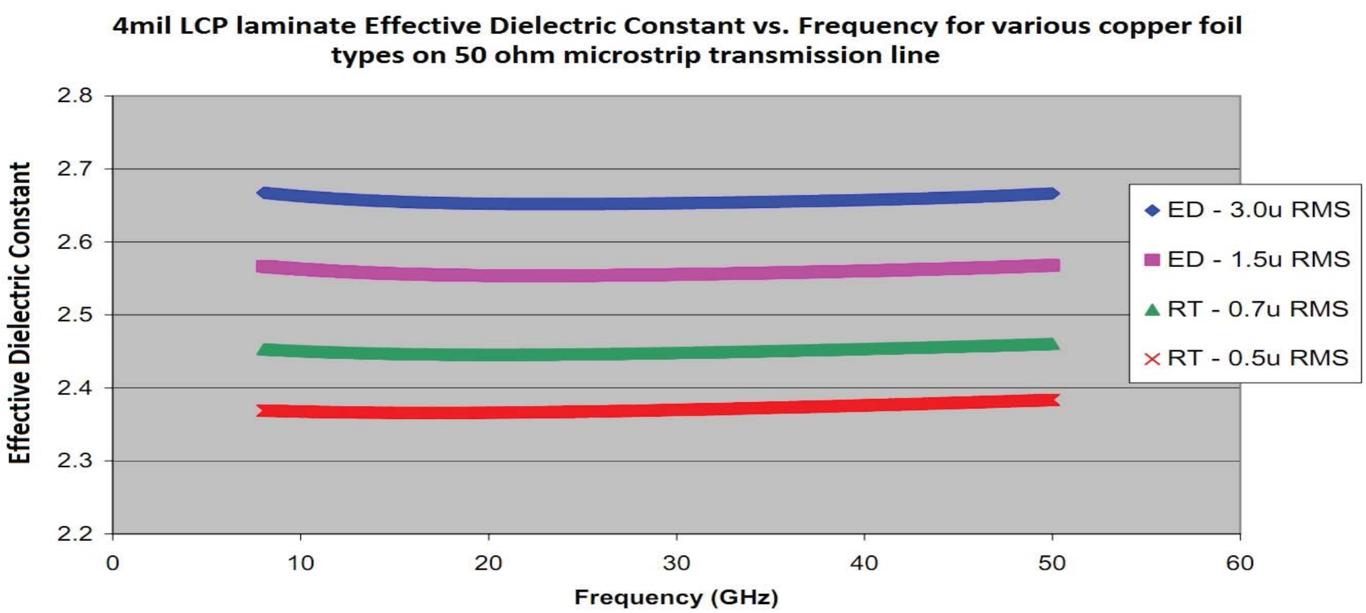


Fig 4. Comparisons of different copper roughness on the effective dielectric constant of microstrip transmission lines.

Mechanical Performance of Laminates

A. Thermal Shock Resistance

Under some extreme conditions of rapid thermal cycling, electrodeposited copper may exhibit thermal stress cracks in narrow conductors. Under similar conditions, rolled copper has significantly improved resistance to cracking. Although electrodeposited copper has greater tensile strength and elongation before breaking, rolled copper has better elastic elongation before reaching permanent deformation.

B. Foil Adhesion

Because the adhesion of resin systems to metals is mechanical, bond strength is directly related to the surface roughness of the treated foil side. Typical peel strengths after thermal shock for 1 oz. copper foils to

C. Bondability of Stripline Assemblies (PTFE Substrates)

The SEM photographs below illustrate the differences in topography and roughness between copper types and etch dielectric surfaces. If the boards are to be adhesive bonded, then for electrodeposited copper, sodium etch or plasma etch of the dielectric surface is not necessary, provided that care is exercised to preserve the surface topography. However, for rolled copper-clad circuit boards, the surface roughness of the dielectric will give a poor mechanical bond, and surface treatment is necessary for reliable chemically bonded assemblies.

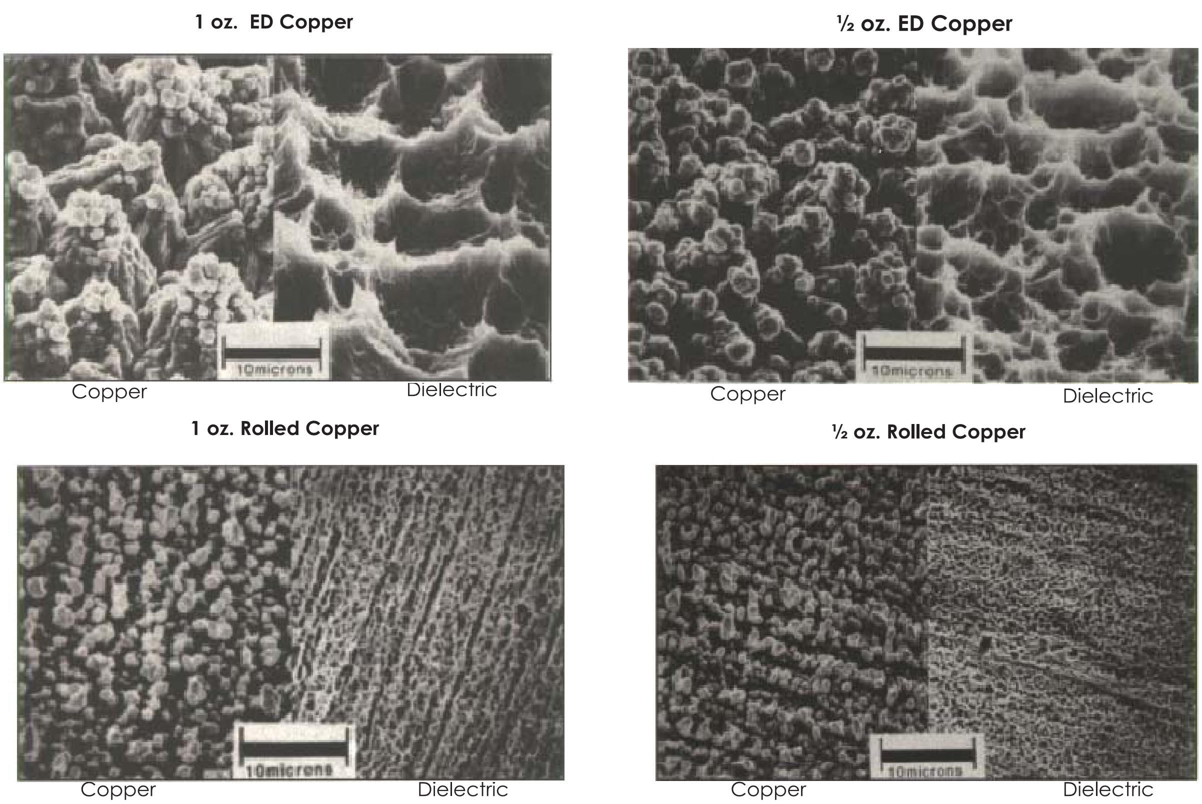


Fig. 5: SEM images of copper and dielectric

Properties

The different manufacturing methods of the two types of foil lead to differences in the electrical and Mechanical properties. The primary differences are listed in Table 2.

Property	Electrodeposited				Rolled		
	¼ oz 8 µm)	0.5 oz (18 µm)	1 oz. (35 µm)	2 oz (70 µm)	0.5 oz (18 µm)	1 oz. (35 µm)	2 oz. (70 µm)
Tensile Strength, kpsi	15	33	40	40	20	22	28
Elongation, %*	2	2	3	3	8	13	27
Vol Resistivity Mohm•cm		1.66	1.62	1.62	1.78	1.74	1.74

Table 2. Typical Foil Properties

* Values represent properties after lamination to a PTFE laminate.

Table 3 lists the recommended copper foil type for specific applications or environmental conditions.

	Copper Type		
	Electrodeposited	Rolled	Reverse Treated
High Frequencies (Low PIM 20 GHz)		X	X
Thermal Shock Environment		X	
Mechanical Stress	X		
Bonded Assemblies	X		
Fine Lines Circuit (< 5mil traces)	¼ oz. (8.5µm)		X

Table 3: Application Recommendations

References:

1. S. P. Morgan, "Effect of surface roughness on eddy current losses at microwave frequencies," J. Applied Physics, p. 352, v. 20, 1949
2. Allen F. Horn III, John W. Reynolds, Patricia A. LaFrance, James C. Rautio, "Effect of conductor profile on the insertion loss, phase constant, and dispersion in thin high frequency transmission lines", DesignCon 2010

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