Metal Foil and Metallic Coatings

While copper is by far the most common metal used in flex construction, a wide range of other metal foils is available for use should special need arise. Virtually any metal that can be produced in foil form or that can be sputtered or plated is a candidate metal foil for flex manufacture. While many choices are possible, only a very few have seen actual volume use. Following are descriptions of a few of the many types of metallic foils available and a review of some of their actual or potential applications.

Copper Foils

Copper foils, as previously stated, serve the vast majority of all flexible circuit applications. Copper's fine balance of cost and physical and electrical performance attributes makes it an excellent choice. There are actually many types of copper foil. The IPC metal foil specification IPC-4562 (formerly IPC-MF-150) identifies eight different types of copper foil for printed circuits, divided into two much broader categories—electro-deposited and wrought—each having four subtypes. (See Table 3-4.) As a result, there are several types of copper foil available for flex circuit applications to serve the varied purposes of different end-products. With most copper foil, a thin surface treatment is commonly applied to one side of the foil to improve its adhesion to the base film. (See Figure 3-4.) Following is a brief examination of some of the most common forms of copper foil.

Copper Foil Type	Number	Designator	Description
Electro-deposited (E) Copper Foils	1	STD - Type E	Standard electro-deposited
	2	HD - Type E	High ductility electro-deposited
	3	HTE - Type E	High temperature elongation electro-deposited
	4	ANN - Type E	Annealed electro-deposited
Wrought (W) Copper Foils	5	AR - Type W	As rolled-wrought
	6	LCR - Type W	Light cold rolled-wrought
	7	ANN - Type W	Annealed-wrought
	8	LTA - Type W	As rolled-wrought low-temperature annealable

Table 3-4 A summary of current copper foil categorizations

Electro-deposited Copper (Standard)

Standard electro-deposited copper is recommended and used primarily for static applications due to its grain structure, which tends to be columnar (see Figure 3-4). This type of grain structure is not well suited to dynamic flexing, owing to the fact that the vertical grain boundaries establish a short path for crack propagation.

Electro-deposited (or ED) copper foil is not commonly used for flex circuit manufacture in the US, but modifications and treatments to such foils could cause them to become more viable candidates in the future. Nevertheless, electro-deposited foils are lower in cost and still quite suitable for some applications and have been readily accepted for use in flex circuit manufacturing in many other countries.

Electro-deposited Copper (Heat-Treated)

One of the variants of standard electro-deposited copper accounted for in IPC-4562 is heat-treated electro-deposited copper foil. This foil type is treated at high temperature to modify the copper grain structure after electro-deposition to create a more ductile foil. The foil may be suitable for certain dynamic applications because of the recrystallization of the grain structure that occurs, approximating the grain structure of rolled and annealed copper.

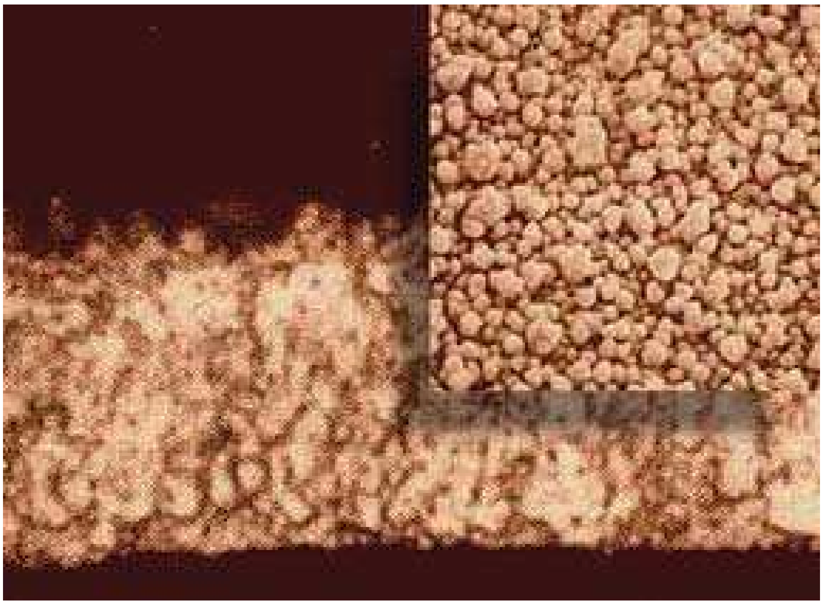

Figure 3-4 Cross-section and top views of low-profile treatment reveal how adhesion is improved.

Wrought or Rolled and Annealed Copper

Wrought or rolled and annealed copper foil, also known as RA copper is produced using traditional metalworking methods. The process involves passing a copper bar through a series of metal rollers until a thin foil is produced. The foil is then heat-treated to bring the copper to a "dead" soft state. This method can create foils economically down to 18μm (1/2 oz.); specialty rollers can make even thinner foils, but the thinner foils are commonly offered only at a premium. As the most commonly used copper-foil type for flexible circuit applications, RA normally affords excellent flexural life due to grain structure.

Wrought alloys of copper can also be used in flex-laminate construction. These foils can offer greater strength and toughness, making handling in manufacture easier. They also have an advantage in low-strain/high-cycle-life flexing applications and may be a superior choice for some of these applications.

Electroplated Copper

With some flex materials, the copper is plated directly onto the base substrate using combinations of electroless and electrolytic plating. Electroplated copper is differentiated from electro-deposited copper by virtue of the fact that its as-plated properties can be vastly different from those produced by normal foil deposition processes. Some electroplated foils exhibit properties equivalent to RA copper and, under some conditions, give superior results. This is due, in part, to the nature of the process, which, because of the special additives used, allows the production of an amorphous or equiaxed grain structure. (See Figure 3-5.) The foil produced is much less sensitive to grain orientation effects than RA type foils.

Sputtered Copper Films

Another approach to getting thin copper onto flexible base materials is to sputter or vapor-deposit seed metals and plate up. The method has been in use for roughly two decades, but only in recent years has it gained the attention of a broader audience, owing to the need for finer lines and traces. One of the historical problems with the method was obtaining a foil that was consistently pinhole free ***and*** had sufficiently high peel strength.

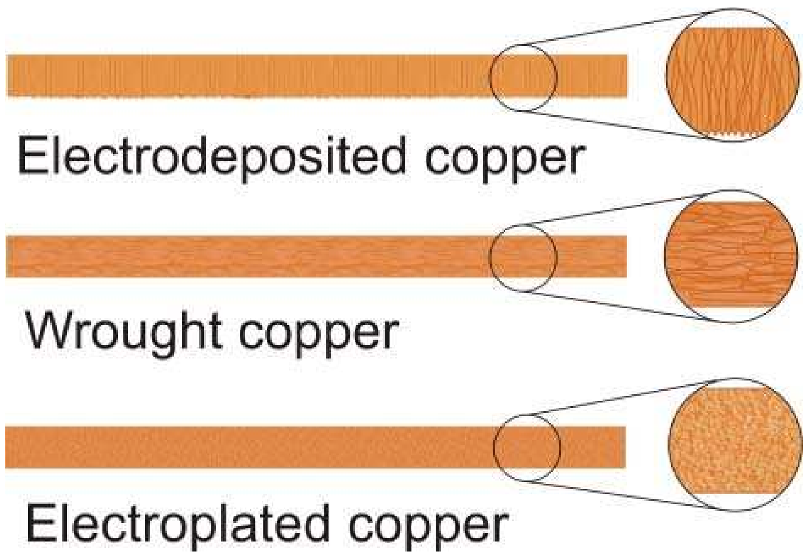

Figure 3-5 Copper foil grain structures vary with the process used to create the foil. Shown above are vertically ordered grain, horizontally ordered grain, and amorphous or equiaxed grain.

Similar to electroplated foil, sputtered copper provides very thin (typically less than 1μm) copper film deposited directly onto base films over a much thinner adhesion promoting layer of nickel, chrome, nichrome or Monel. The thin sputtered copper film serves as a seed layer for subsequent electroplating.

Such films are extremely useful in fabricating very fine line circuits and certain unusual constructions or applications. For example, the thin copper film is ideal for cryogenic applications where electrical conductivity is sufficient but thermal conductivity is relatively poor for the thin film. Beyond such esoteric applications, sputtered copper films are proving quite suitable for high cycle life dynamic applications such as disk drives, provided the plating process is well controlled.

Other Thin Copper Options

The never ending drive to reduce the size of electronic products and systems has resulted in the need for thinner copper foils to produce the finer circuit lines and traces required. Making thinner copper foils that can fulfill the requirements for flexible circuits is no mean task. The foil is expected to be pinhole free and to provide the adhesion so important for reliable manufacture and use. Some foil and material suppliers have devised and implemented a number of new and improved methods for meeting the requirements. A brief review will, hopefully, help clarify the choices.

As noted earlier, traditional rolled and annealed foils have found favor with flexible circuit material suppliers and users; however, rolling copper foils to values less than 17µm in thickness, while possible, tends to be expensive. To extend the role, foil suppliers such as the Somers division of Olin Corporation have developed technology that will allow for 3µm and 5µm copper foils to be bonded to flex circuit base materials. The "trick" is creating the thin foils on a rolled copper foil carrier of normal 35-micron thickness. The product is uniformly thick and pinhole free. The adhesion treatment, common on copper foils, is desirably low profile for flexible circuits. This attribute improves etch characteristics, allowing finer features with some (preferably minor) penalty in peel strength.

For the new Olin copper foil material, a proprietary inorganic release layer is used between the rolled foil carrier and the thin copper foil. The force required to remove the carrier foil after lamination is reportedly is very low (about 1-2 grams/centimeter or approximately 0.1 oz/in), even after lamination at temperatures required for flex circuit materials. Gould and Oak Mitsui have similar ultra thin copper foil on carrier foil solutions in the market, also targeted at very fine line circuit applications.

A final option in this review is an adhesiveless tie coat-free flexible copper clad laminate from Fractal. The lack of a tie coat is made possible by an innovative micro-mechanical bonding technology, the resulting peel strength of which reaches an amazing 2-2.5 kilograms/centimeter (~ 12-17 lbs/in).

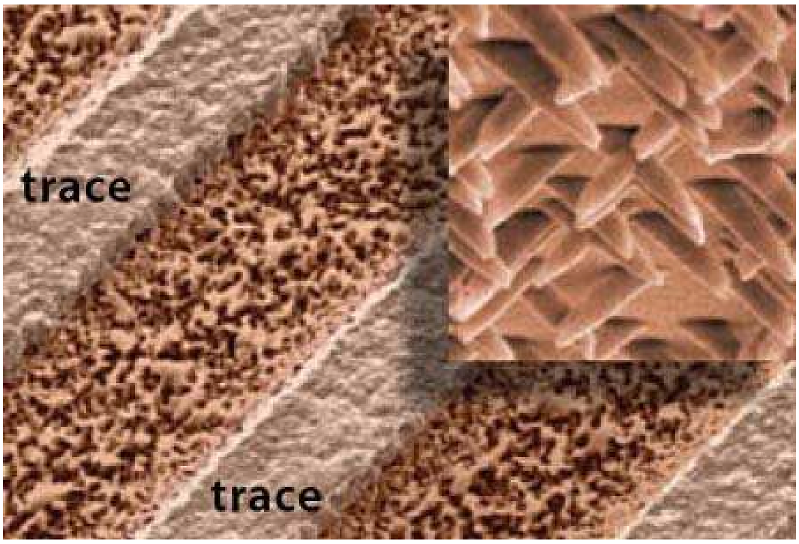

Figure 3-6 A top view of fine-line etched circuits, on which is overlaid a greater magnified image of the copper foil with the polymer removed to reveal the unique micro-mechanical structure to improve peel strength. (Photo courtesy Fractal AG)

The manufacturing process reportedly involves an unusual technology in which polymer films are irradiated by heavy high-energy ions and then treated chemically to "develop out" the irradiated spots, and then plated. A photomicrographic comparison to traditional treatments is offered in the attending images. Single- and double-clad copper-polyimide flexible circuit laminates with foil thicknesses from 5-18μm are being offered. With such high peel strengths, the materials are likely to withstand the rigors of gold plating very well.

In summary, the demand for high density circuitry on flexible substrates has driven the foil manufacturing industry to develop some very innovative solutions. Those solutions are making possible leading edge products of today and securing the future for next generation opportunities. Each solution has merit, and having more than one solution is a blessing to both design and manufacturing.

Metal Foil	Resistance Ω/cm x 106	Thermal Conductivity W/m*K	Tensile Strength (psi)	% Elongation (annealed)
Copper Rolled annealed	1.67	393	32,000	20
Copper Electro-deposited	1.77	393	25,000	12
Aluminum	4.33	225	16,000	30
Stainless Steel	75	6	90,000	40
Beryllium Copper	~8	83	60,000* 200,000**	35 - 60* 1 - 4**

* Annealed Dead Soft ** Heat-Treated Full Hard

Table 3-5 Comparison of selected properties of metal foils

Beryllium Copper

Beryllium copper is a useful choice when good conductivity, mechanical strength and/or spring-like qualities are simultaneously sought. While beryllium copper is not as conductive as copper (with approximately 25% the conductivity of copper), the metal is one of the standards of the electrical connector industry due to its unique blend of properties.

One of the concerns registered on occasion is the fact that beryllium is a toxic metal, but because the metal is not used in its native state but rather in an alloy, this has been shown to be a low order concern. In machining, the dust should be well controlled, but etching is not a general concern.

Aluminum Foil

Aluminum foil has been used in special applications where reduced weight or cost is sought and the design will accommodate its use. Aluminum foils have proven particularly successful in simple flexible shielding applications. When plated with electroless nickel/gold, the terminations become both separable and/or solderable.

Iron Alloy Foils

Various iron alloys (stainless steel, Iconel, etc.) have been used and proven of value in applications where low thermal conductivity requirements were coupled with the need to pass electrical signals. A prime example is in the interconnecting of instrumentation in cryogenic devices, however, as noted earlier, very thin sputtered films of more conductive metals may also serve this function, provided that the electrical currents are not too high. Because such foils are so resistive, they have proven very useful in creating flexible heaters.

Other Conductor Materials

Beyond traditional metal foils for creating conductors, other products and processes can serve to provide conductive (or resistive) pathways on flexible base laminates. Following are descriptions of some common and not so common alternative conductor materials.

Polymer Thick Film Flex Circuits

This is a special subset of flexible circuits, where specially formulated conductive and resistive inks are screen-printed onto flexible substrates to create circuit patterns. The conductive inks are normally silver filled polymers, and the resistive inks are filled with carbon or mixtures of silver and carbon.

Polymer thick film technology (PTF) is an extremely popular method for producing a range of cost effective products—from membrane switches