Flexible and Flex-Rigid Circuits

Introduction

Most of the boards used in electronic manufacture are so-called “rigid” boards. That is, the only flexibility they possess is a *lack* of sufficient rigidity for the application, which may give problems during reflow soldering, at de-panelling, and occasionally during box build. Where required, flexibility will be provided by the cabling between boards.

But there are other applications where a degree of flexibility is desirable, either a “once-for-all” flexure during final assembly, or extended and repeated flexure during operation, and it is these applications that flexible and flex-rigid circuits seek to address.

In this short topic resource we are focusing first on the applications and the different configurations of flexible circuits that are available, before considering the materials of which flexible circuits are made, and some practicalities of their manufacture and design.

Applications

Of the applications illustrated in our answer, arguably the least obvious is the use of flexible technologies as part of package manufacture. As well as being a component in conventional tape BGA components, flex circuits are the core technology in a number of CSPs, as discussed in our topic paper on *Chip-scale Packages*.

Flex circuits vary enormously in size and complexity. The smallest are probably those used to provide interconnect within components, but very many large flexible structures have been built. It is claimedthat the world’s largest flex largest flex circuits measure 150 feet long, and can be found on the solar panels of the international space station.

Quite apart from their flexibility, flex circuits have two benefits in relation to conventional rigid boards:

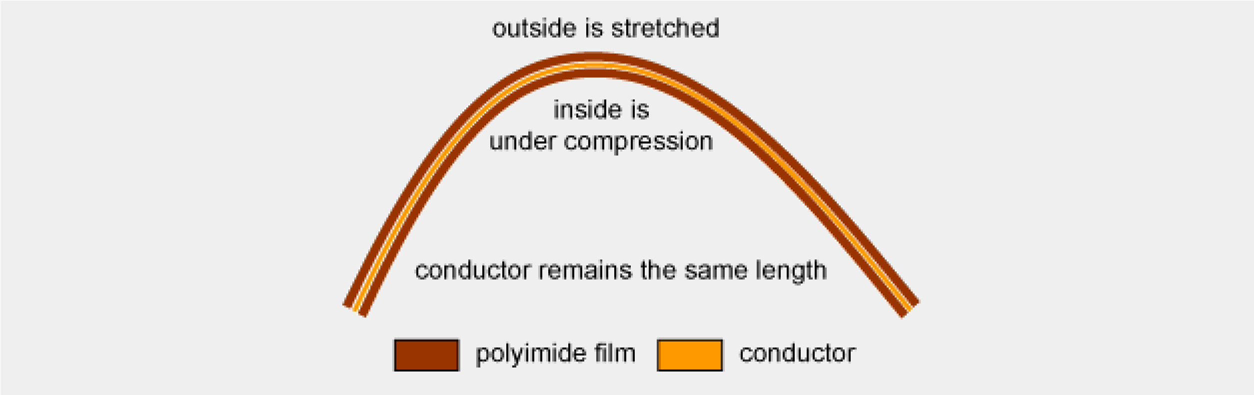
- They are comparatively light, on account of their reduced thickness
- Being laminated with thin copper foil, they lend themselves to the production of high-density patterns.

Configurations

A number of flex configurations are possible, but we need to bear in mind that, the more the layers, the stiffer any multi-component sandwich will be, however flexible the individual layers are designed to be. In consequence, most flexible circuits are comparatively simple, especially as regards the flexible areas. In fact, many flex circuits just comprise a single layer of copper.

Whilst in theory we could use just a single patterned layer of copper on a supporting film, in practice, even single-layer flex will use laminate films on both sides of the copper. This has two purposes, to protect the exposed conductor surface (flex circuits being prone to abrasion) and to move the conductor to the neutral axis.

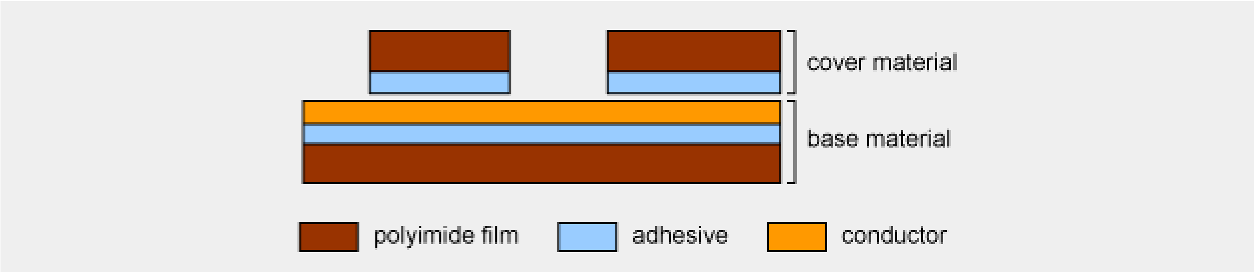
Figure 1: Schematic showing the neutral axis of a bent board



As shown in Figure 1, when a body of any thickness is bent, the material on the outside of the radius is under tension, and that on the inside under compression, whilst the material along the "neutral axis" experiences no enforced change in dimensions. Given that metals are inherently less flexible than polymeric materials, and have a grain structure that makes them prone to fatigue failure, this is beneficial for the life of a flex circuit, particularly one that is subjected to repeated flexure.

A single-conductor flex circuit is often employed as an interconnect, either using connectors, or soldered directly to pads on the board using techniques such as hot bar soldering.

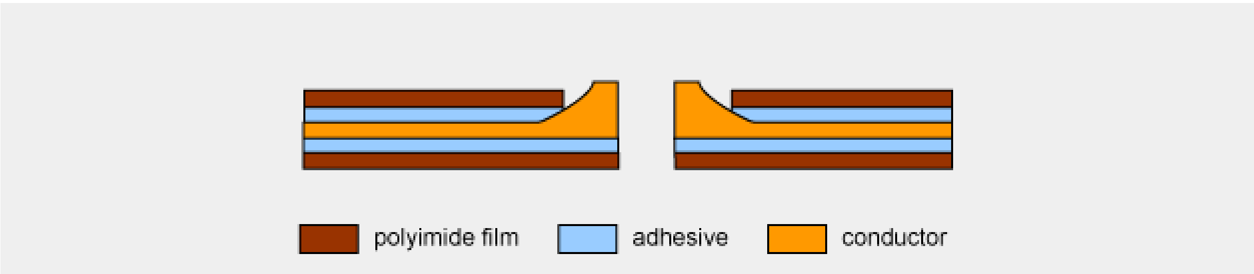
Figure 2: Schematic cross-section of a single-conductor flex circuit



Note from Figure 2 how it is possible to create apertures through the cover material that expose the conductor. This gives access for test or for component termination.

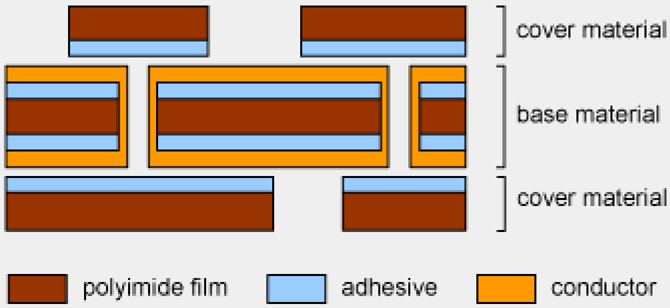
Although less common, selective etching can be used to produce a flexible circuit where the conductor is thin in flexed areas and thick at interconnection points. This enhances the quality of solder joint and the rigidity of the area adjacent to components, but may also be used to create bare metal contacts. This technology, known as "Sculptured flex®" (Figure 3), is licensed by Advanced Circuit Technology.

Figure 3: Schematic cross-section of a Sculptured flex® circuit



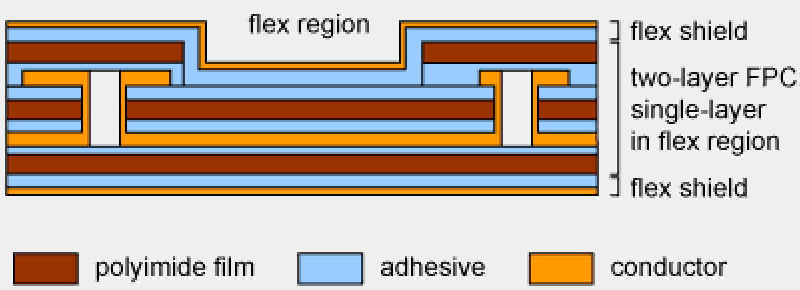
Flex circuits with two conductive layers can be made with or without plated through-holes, though through-holes are usually provided (Figure 4). As with the single-layer circuit, apertures can be cut in the cover layer to allow assembly on one or both sides.

Figure 4: Schematic cross-section of a two-layer flex circuit



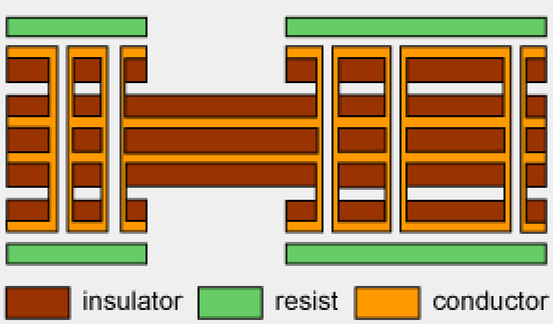
Particularly with high-frequency circuits, interconnections may need to be shielded, and this is relatively easy to do with a flex circuit, as shown in Figure 5. By comparison, providing screens for individual wires is labour-intensive. Typical performance for this type of structure is given at http://www.mektron.co.jp/english/fpc/sh_fpc.html.

Figure 5: Schematic cross-section of a shielded flex circuit



Flex circuits with three or more layers are referred to as multi-layer but, as shown in Figure 6, it is usual to use only a minimum number of layers where flexing or bending is to occur. As with rigid boards, both blind and buried via constructions are possible as well as through connections, albeit at a premium price.

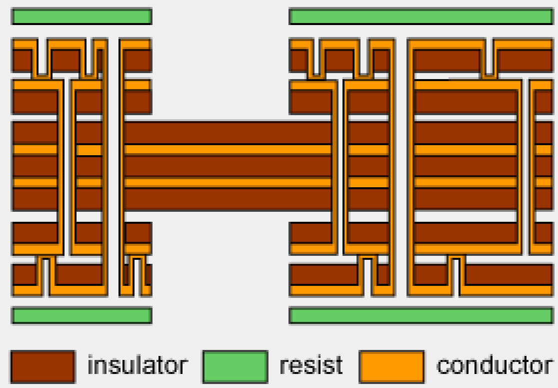
Figure 6: Schematic cross-section of a multi-layer flex circuit



In some cases it may be necessary to have more than a pair of flexible conductor layers, and this can create a problem with stresses during bending. For this type of application it is common to interconnect rigid assemblies with flexible layers of different lengths, reducing the stresses within the system when it reaches it final designed radius of curvature.

Another form of multi-layer is the flex-rigid, which is a hybrid construction of rigid and flexible substrates laminated together and interconnected using plated through-holes (Figure 7).

Figure 7: Schematic cross-section of one type of flex-rigid circuit



Another way of creating desirable rigidity without the cost of a full flex-rigid assembly is to attach **stiffeners** to a less complex circuit, often with only a single conductor layer. Such rigidising parts give a structure that will protect fine pitch components mounted in that area, or can be used to create a mounting piece for attachment to chassis or frame.

The **techniques** used for making flex circuits are broadly similar to those used for multilayer rigid circuit manufacture, provided that due allowance is made for the problems of handling a flexible material, one that is generally less stable than a rigid laminate.

All types of flex and flex-rigid boards may be assembled with **components**, provided that the design will accommodate flexure stresses on the parts, and that the flex materials will survive the soldering process. The techniques used require only modest modifications to the actual soldering processes, but there are practical issues associated with the shape of most flex parts, because flat areas are needed to allow vacuum hold-down during printing and assembly, pin locations may be needed for handling, and some method such as a carrier must be devised to allow conveyorisation or double-sided assembly. Users are advised to discuss the practicalities with their assembly colleagues.

As well as solder assembly using conventional components, a major use of flexible circuits is for **flip-chip on flex** (FCoF) both for the manufacture of package components and directly for constructing products and shapes that would otherwise be impossible to make economically. See Fritz Byle, *Impact of flip-chip on flex processes*, in *Advanced Packaging*, November 2004.

Materials

Conductors

On account of its inherent ductility, copper dominates the market, but the foils used for flexible circuits tends to be different from those used for rigid circuits, which are typically electrodeposited onto a polished steel drum. This type of copper has a vertical structure, which gives good tensile strength and excellent adhesion. However, a "rolled annealed" type, which is rolled from a hot ingot, has a horizontal grain structure, which gives good flexure performance and improved resistance to fracture in use.

An alternative for flex circuits is a "low temperature annealed" foil, with a long grain structure, as this has a high yield strength and is resistant to damage.

Polyimide has traditionally been the material of choice for flex circuits, and is still preferred for military and high-performance applications. It gives good overall performance at a reasonable cost, and has excellent thermal resistance. For ease of assembly, it can withstand standard soldering techniques. Also, polyimide will not burn, and can be combined with flame retardants to meet UL standards.

Polyimide is intrinsically an excellent insulator, and provides a good high-voltage barrier, but is highly water-absorbent, so needs to be baked and kept dry prior to soldering. Another application problem is that its dielectric properties are poor, so polyimide may not be the best choice where a controlled impedance and low loss are requirements.

Polyester/PET is used for more cost-sensitive commercial applications, such as automotive. Polyester is inferior to polyimide in its thermal resistance, and has a low glass transition temperature. Also it cannot be soldered, so needs to be fitted with special connectors with pressure contacts. However, it has lower moisture absorption than polyimide, and offers lower dielectric constant, higher insulation resistance, with greater tear strength and better dimensional stability.

Fluorocarbons have excellent dielectric properties, which makes them suitable for controlled impedance applications, and good thermal resistance. However, whilst mechanically strong, they are not as dimensionally stable as polyimide, and the need to use very high lamination temperatures (260–288°C) can cause problems over the choice of adhesives. They are also significantly more expensive!

An alternative to polyimide that overcomes some of the inherent limitations is a **liquid crystal polymer** (LCP) material that offers lower dielectric constant and reduced moisture absorption. Details on these films are given in the article *Liquid crystal polymers - A flex circuit substrate option* by Rui Yang in *Advanced Packaging*, March 2002, and Mektron illustrate how a multilayer board can be made with LCP at http://www.mektron.co.jp/english/new/index.html. Note the claim that, because LCP is thermoplastic, they are able to avoid using adhesive for stacking.

Most flex laminates are made with base resins with little filling and no reinforcement, but Aramid™ has been used in some military and specialist applications. It gives high tear and tensile strength, has low dielectric constant and extended temperature capability, and is flame retardant.

As you will know if you have ever picked up an Aramid-reinforced board, the resulting laminate is much lighter than conventional fillers, so Aramid-reinforcement will be important where weight is at a premium. The downsides of the material are that it has high CTE in the Z direction (although low in X and Y) and high moisture absorption. So, like polyimide, it must be totally dry before soldering. And remember that this has an impact during life, should repair be necessary.

Adhesives

With the materials we have considered so far, the normal method of application is to use a separate adhesive, and the choice here affects many of the flex circuit's properties. For example, foil adhesion, thermal ratings, flame retardancy, and resistance to and absorption of both moisture and chemicals. The adhesive also affects electrical properties such asresistivity, dielectric constant, and dissipation factor.

The adhesive needs to match the materials chosen as well as have the desirable application characteristics we have identified :

> **Acrylic** is popularly used on polyimide. It has high heat resistance, good electrical properties and a modulus that is appropriate for flexing. However, its high Z-axis expansion can lead to thickness issues, it is not very resistant to chemical attack, and is subject to smear during drilling.
>
> **Polyimide** and **epoxy** are as good or better than acrylic, except that they have less flexure capability.
>
> For low-cost applications, **polyester** and **phenolic** offer excellent electrical properties and fair heat resistance, combined with good flexibility.

A wide range of materials, both thermoplastics and flexible thermoset adhesives, can be cast onto a release film to give a free-standing adhesive film, or .

Cover coat

Flex circuits use a cover coat to

- protect the circuit against corrosion and contamination
- protects from mechanical damage
- provide a level of electrical insulation
- provide a neutral bending axis for single-conductor applications
- help anchor terminal pads to the base material.

Cover coat materials include polyimide/acrylic, polyimide/epoxy, polyester/polyester and aramid/acrylic, and are matched to the substrate material and to the thickness and environmental requirements.

[Note that, whilst screen-printed solder mask can be pressed into service as a cover coat it does *not* provide the same mechanical strength.]

The adhesiveless approach

As you will have seen from the preceding diagrams, adhesives have traditionally been applied separately from laminate and foil, but advances have been made by introduction of "adhesiveless" laminates. These make it possible to have a thinner and more controlled dielectric thickness, and are thermally more stable. They are also mechanically stronger since there are fewer layers to delaminate.

A number of approaches have been taken to the challenge of combining the adhesive with one of the surfaces, or otherwise circumvent the need for an adhesive:

1. In the “cast to foil” process a liquid solution of polyamic acid is applied to the foil, which is heated to evaporate the solvent and imidize the acid, resulting in a polyimide film on the foil. This is usually employed for single-layer flexes, but it is possible to add a second foil.

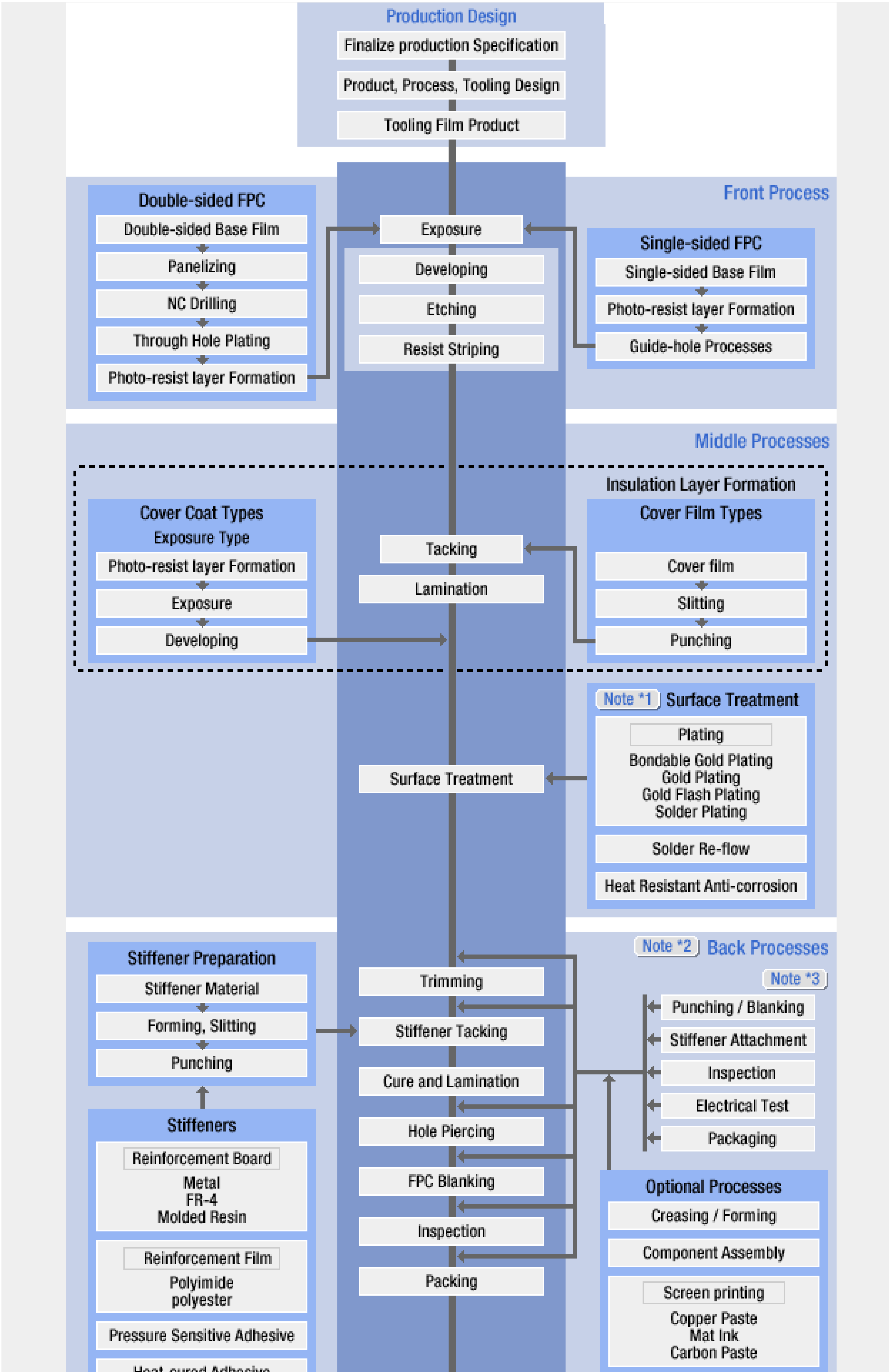
2. The converse process is to apply a metal surface to the polymer film, and plate up the thickness if required. This requires vacuum processing, depositing metal either by evaporation or by sputtering from a copper cathode. As with all such thin-film processes, adhesion can be poor, depending both on the deposition conditions and the environment for the final product. Especially where the laminate is exposed to high humidity, an intermediate metal layer (typically chromium or nickel) will be needed to enhance adhesion.

3. An alternative process for applying copper directly to film is electroless plating, using variants of the processes developed for rigid boards. The advantages compared with vacuum processing are that conventional equipment and processes are used, and no thermal stresses are induced by the process. However, getting good adhesion with polyimide, polyester and fluorocarbon materials requires suitable surface preparation and process control.

Process and design issues

As indicated in the figure below, the processes involved in flex manufacture are extended, particularly for the more complex stiffened types or flex-rigid constructions. As always with such diagrams, one must bear in mind that there will be variations between suppliers, depending on the processes available and local preferences.

Figure 8: Generic process flow diagram for flex manufacture


Production Design
Finalize production Specification
Product, Process, Tooling Design
Tooling Film Product
Front Process
Double-sided FPC
Double-sided Base Film
Panelizing
NC Drilling
Through Hole Plating
Photo-resist layer Formation
Exposure
Developing
Etching
Resist Striping
Single-sided FPC
Single-sided Base Film
Photo-resist layer Formation
Guide-hole Processes
Middle Processes
Insulation Layer Formation
Cover Coat Types
Exposure Type
Photo-resist layer Formation
Exposure
Developing
Tacking
Lamination
Cover Film Types
Cover film
Slitting
Punching
Note *1
Surface Treatment
Surface Treatment
Plating
Bondable Gold Plating
Gold Plating
Gold Flash Plating
Solder Plating
Solder Re-flow
Heat Resistant Anti-corrosion
Note *2
Back Processes
Stiffener Preparation
Stiffener Material
Forming, Slitting
Punching
Trimming
Stiffener Tacking
Cure and Lamination
Hole Piercing
FPC Blanking
Inspection
Packing
Note *3
Punching / Blanking
Stiffener Attachment
Inspection
Electrical Test
Packaging
Stiffeners
Reinforcement Board
Metal
FR-4
Molded Resin
Reinforcement Film
Polyimide
polyester
Pressure Sensitive Adhesive
Optional Processes
Creasing / Forming
Component Assembly
Screen printing
Copper Paste
Mat Ink
Carbon Paste

Source: Mektron

Note 1: Additional masking processes (material preparation, lamination and removal) are necessary for multiple surface treatments.
Note 2: Back process may vary depending on product specification.
Note 3: Thermoset adhesive needs to be applied before pressure-sensitive adhesive when a product requires both.

Patterning for flexible circuits uses either screen printing or etching depending on the fineness of pitch. Whilst etching is a process capable of producing very fine features using thin foil, an alternative is the laser direct printing process described by Dieter J. Meier et al, *LDP for low-cost flex*, in *Printed Circuit Design and Manufacture*, October 2005.

You will notice from that reference the possibility with a flexible substrate of achieving

Source : http://www.ami.ac.uk/courses/topics/0263_flex/index.html