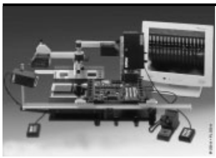
CHAPTER



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Copper Clad Laminates

6.1 Anatomy of Laminates

The basic function of the laminate is to provide mechanical support for electronic components and to interconnect them electrically. Laminates for PCBs are composite materials. They can be simply described as products obtained by pressing layers of a filler material impregnated with resin under heat and pressure. The resulting thin insulating material, which is the mixture of filler (reinforcement) and resin on which all conductors and components are mounted, is called *base material.* This can be either rigid or flexible material.

6.1.1 Fillers (Reinforcements)

Fillers are meant to provide mechanical strength, stability and rigidity to the laminate. The commonly used fillers are a variety of papers, cotton fabric, asbestos sheet, glass in various forms such as cloth and continuous filament mat, ceramic material, molybdenum, etc. However, the most common materials used are paper and glass fibre.

Paper has been used as reinforcement in a vast majority of printed circuit boards. They are low priced and are easily machinable. However, they have a tendency to absorb a lot of moisture.

Fibre-glass as reinforcement has gained popularity because of its high tensile strength and dimensional stability. It offers a high resistance to temperature variation and has a low moisture absorption property.

6.1.2 Resins

Resins are used to impregnate the selected fillers. The commonly used resins in the manufacture of base materials are phenol, polyester, cyanate ester, epoxy and polyimide. Of these, the epoxies and phenolics are used for about 90 per cent of all laminates. They are mostly synthetic types of materials, either thermoplastic or thermosetting, formed by the polymerization process. The selection of a resin takes into account electrical, mechanical, chemical and thermal characteristics. All these characteristics have varying degrees of importance depending upon the specific application of the PCB.

Epoxy resins, which are the most commonly used, are sometimes modified with additives to achieve higher thermal properties or improved chemical resistance. In a composite, the properties of the laminate depend upon the type and quantity of raw materials used, their curing schedules and the procedures used to produce the printed boards. It has to be ensured that there is enough resin to fill all the spaces between the fibres as internal voids may lead to premature mechanical failure of the laminate.

Polyimide is the material of choice when extreme thermal condition exists, such as extended time at high temperature during assembly or use. Another consideration is the need to replace defective components on expensive assemblies. Polyimide maintains its bond to the foil during excursions in order to solder temperature extremely well. Its Tg is greater than 220 °C and is responsible for polyimide's excellent high-temperature performance.

Goosey (2003) describes the characteristics expected from the laminates to meet the present-day requirements of increasing the packaging and interconnected densities of electronic assemblies. New types of laminates have been developed in recent years that have Tg values stretching well above 200 °C and in some special cases, up to nearly 300 °C. Examples of these laminates include those based on cyanate esters, alleylated polyphenylene ethers, and the so-called BT-epoxy and tetrafunctional epoxy systems. Table 6.1 shows the properties of some of the new laminate types.

Table 6.1 Properties of High Tg Laminates (after Goosy, 2003)

Laminate material	Tg (°C)	Dielectric constant (10 GHz)	Dissipation factor (10 GHz)
FR4	130–150	4.5	0.022
Tetrafunctional epoxy	175	4.4	0.020
Polyphenylene ether	175	3.4	0.009
Epoxy/polyphenylene oxide	180	3.9	0.013
Bismaleimidetriazine	180	4.1	0.013
Thermount	220	4.1	0.022
Cyanate ester	240	3.8	0.009

(Contd.)

Table 6.1 *(Contd.)*

Laminate material	Tg (°C)	Dielectric constant (10 GHz)	Dissipation factor (10 GHz)
Polyimide	280	4.3	0.020
Liquid crystal polymer	280	2.8	0.002

A large variety of copper clad laminates are commercially available these days. They have been standardized at national and international levels in terms of specifications which have been laid down for each copper clad laminate grade and the minimum/maximum limits of important properties. In general, the laminates should have good electrical, mechanical and environmental characteristics and meet the standard specifications of the Institute for Interconnecting and Packaging Electronic Circuits (IPC), National Electrical Manufacturers Association (NEMA), Department of Defence Design Standard or Military Standard (MIL), International Electrotechnical Commission (IEC) and the American National Standard Institute (ANSI), among others.

6.1.3 Copper Foil

The conductive layer on a laminate can be made of copper, nickel, stainless steel or beryllium copper. However, the most widely used substance is copper due its easy availability, cost and functionality. Copper cladding can be on one side or on both sides of the composite, depending upon the need and use.

The quality of PCB depends, to a large extent, on the properties of the copper foil. Therefore, the quality requirements of copper foil are very demanding. The thickness of copper foil is usually expressed in ounces per square foot (oz./ft^2), which corresponds to about 3.052 gram/square cm (g/cm^2) or 305.2 grams/square m (g/m^2).

Table 6.2 Standard Thickness of Copper Foil and Weight

Thickness	Weight			Resistivity
	Basic weight		Tolerance	
	Oz/ft^2	g/m^2		M Ω -max
12 µm	3/8	107	± 10 %	9.3
18 µm	1/2	153	± 10 %	7.0
35 µm	1	305	± 10 %	3.5
70 µm	2	610	± 10 %	1.8

Usually, a layer of very thin copper foil of thickness 17.5 microns, 35 microns or 70 microns is bonded to one or both sides of the base material. 17.5 micron copper foil is also denoted as half ounce since half ounce of copper is used to get 1sq.ft. of copper clad sheet with 17.5 micron thickness of copper. The copper foil is normally available in large rolls weighing 136 to 181 kg (300-400 pounds). Table 6.2 shows the standard thickness of commonly used copper foil. The vast majority of laminates used are with foils of 305 gr./m^2 or lower. The tolerance of weight is usually ±10 %.

Copper foil must satisfy strict quality requirements. Its resistivity should not exceed 0.1594 ohm-gram/m^2 at 20 °C. The foil should be free from pin holes, pits, scratches and nodules. Copper foil is available in two forms: rolled annealed copper foil and electrolytic copper foil. These are detailed below.

6.1.3.1 Rolled Annealed Copper Foil

This is manufactured by melting electrolytically formed copper cathodes into large ingots. The ingots are hot rolled in specially designed rolling mills and annealed to get large copper foil rolls. These foils are available in widths ranging from a minimum of 635 mm to a maximum of 965 mm.

The rolled copper is 99.9 per cent pure and has a good horizontal grain structure. The rolled copper is mainly used in the flexible PCB manufacturing process. Even though foil manufacturing is easier, it has some disadvantages like limited width, poor solderability, and adhesion and ductility problems which are created due to grain structure deformation. The rolled copper foils produced by annealing electrodeposited copper at a high temperature are also called High Temperature Elongator (HTE) foils. HTE is advantageous as it is the most ductile foil available and thus has a niche in some microwave applications.

6.1.3.2 Electrolytic Copper Foil

This is manufactured by the electroplating method. The tank has either a lead or polished stainless steel rotating drum which is used as cathode and pure copper as the anode. Both are immersed into the copper sulphate electrolyte as shown in Figure 6.1.

The deposited copper is easily peeled off because of poor adhesion on the polished drum. The peeled copper has a very smooth shiny finish on one side and dull finish on the other side. The dull side increases its adhesion with suitable adhesives. The grain structure size is vertical in nature and gives excellent bond strength. The dull side is again subjected to further process to enhance roughness by chemical oxidation in order to improve adhesion. The electrodeposited copper foil rolls are available in widths of up to 1970 mm.

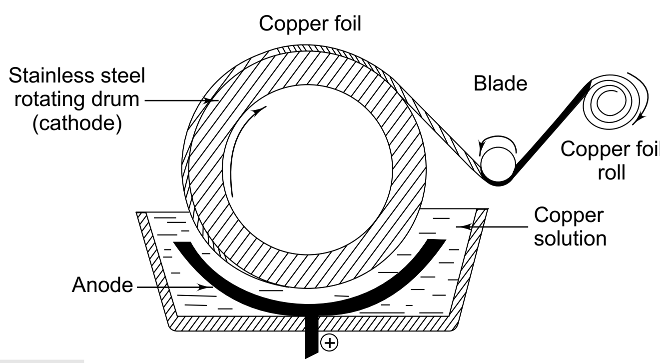

Fig. 6.1 Cell for manufacturing electrolytic copper foil. Cathode is made of stainless steel and anode of copper

The purity of the foil is around 99.5 per cent and its resistivity should be 0.1594 ohms gram/m^2 at 20 °C. Now, thin copper foils with the thickness of 5 microns and 9 microns are available for manufacturing of multi-layers and rigid PCBs. The advantages of thin foils include very rapid etching time, less etchant waste, elimination of bonding treatment prior to photo-resist application and better photo-resist adhesion.

6.2 Manufacture of Laminates

Copper clad laminates are manufactured by pressing layers of filler material impregnated with resin under heat and pressure with copper foil. A hydraulic press is used for this purpose.

Although the following manufacturing procedures can be extrapolated to include any type of laminate available today, the process detailed herein pertains to the industry standard epoxy-glass FR-4 materials.

6.2.1 Materials

The materials needed for the manufacture of laminates are glass fabric (filler), epoxies (resin), solvent and copper foil.

6.2.1.1 Fibre-glass Cloth

Glass cloth acts as the main structural reinforcement in most laminates. The rigidity and strength offered by glass compliments the binding, encapsulating and insulative properties of the epoxy resin. The singular fibre-glass filament is the building block with which glass clothes are constructed. These thread-like fibres are put together to form a yarn or bundle. Subsequently, like weaving of any other type of cloth, numerous yarns are woven together in the manufacture of cloth. Various combination of filament and bundle diameters, filament counts and weave density, among other variables, will resist in a multiplicity of glass cloth thicknesses and weights. Finally, glass clothes are coated with a finish that facilities resin impregnation of and bonding to the cloth.

6.2.1.2 Epoxy Resins

The function of the resin is to act as a ‘glue’ to hold the laminate together. Epoxy resins can be purchased from various vendors at various steps of manufacture. Epoxy resin can be had in a liquid form so that it can be concocted to upstaged resin using proprietary recipes and processes. It can also be purchased in the advanced or upstaged state, wherein the solid resin, complete with hardness and catalysts, is ready for use in treating.

6.2.1.3 Copper Foils

Most foils used in FR-4 manufacture are electrodeposited type foils. These are manufactured by plating copper onto slowly revolving drum-shaped cathodes that are partially immersed in the plating solution. As the drum revolves, the plated copper deposit is removed from the cathode drum at one continuous speed. Varying the drum speed and current density helps to vary the copper deposit and consequently, the resulting foil thickness. At this stage, the ‘raw’ foil becomes available, which is then subjected to various processes designed to increase the roughness of the matte side, thereby increasing its mechanical adhesion to the substrate. In addition, the foil is coated with a micro-thin film of protective coating to prevent oxidation of the copper during lamination and storage.

6.2.2 Process

The three primary raw materials — glass, resin and copper-are pressed at the laminator to give a fully cured final product that is dimensionally stable and resistant to moisture, chemicals and thermal excursions occurring in the PCB manufacturing process. The process utilized in bringing the thin major raw materials together is shown in Figure 6.2.

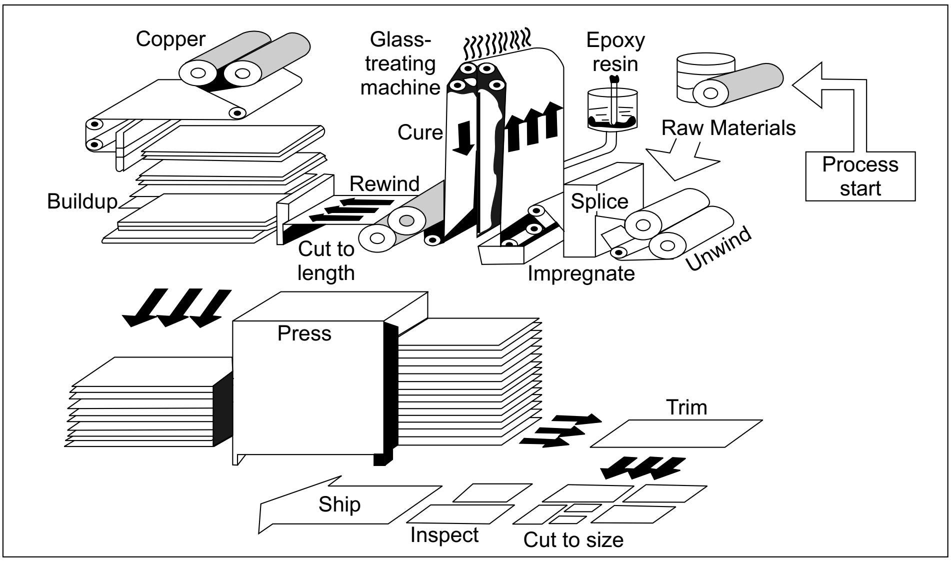

Fig. 6.2 Process for manufacturing laminates (Courtesy GE Electromaterials, 2001)

6.2.2.1 Treating

Treating is the process whereby the liquefied resin is applied to the glass cloth, usually via a combination of immersion and metering rollers. The treated cloth is then subjected to a controlled heat source to semi-cure the resin. The heat source is a drying oven, which is air-circulating or infra-red type and can be up to 40 m long. Most of the volatiles are driven-impregnated glass sheet is now dry to the touch, and in this stage, it is generally referred to as prepreg or 'B' stage.

Rigid process control is necessary during treating as the immersion and metering process are critical. Thorough wetting of the glass cloth by the resin, as well as precise control of the resin quantity absorbed are of utmost importance to the laminate consistency and quality. Practically, the ratio of resin to base material, the final thickness of the prepeg and the degree of resin polymerization need to be monitored.

6.2.2.2 Lay-up

Lay-up is the process wherein treated prepegs and copper foils are assembled for pressing. In this operation, the copper foil is first laid against a large polished stainless steel press plate. Then, a number of sheets of prepegs are laid on top of the copper. The number of layers depends upon the desired thickness of the laminate. The final sheet of copper foil is placed on top of the prepeg if the material is to have copper on both sides. If copper is desired only on one side, a release film is used to replace one of the sheets of copper.

6.2.2.3 Pressing

Pressing is the process wherein simultaneous heat and pressure are applied to the packs or books (prepegs, copper foils and release film, if any) to produce fully cured laminates. This operation is carried out in a press which is hydraulically operated and capable of developing pressure up to 1000 psi. Steam is a typical heat source. Packs or books are loaded into each press, with the typical process being capable of moulding 80 sheets 36×48 inches or 250 sheets of 48×144 inches, 1/16 inch thick.

During pressing, the semi-cured epoxy resin liquefies and flows, expelling any entrapped air or gases. This flow acts to encapsulate the treatment side of the foil(s), facilitating foil adhesion, and also to homogenize the resins in each laminate. After a certain period of time, the epoxy groups in the liquefied resin begin to form cross-links, leading to curing of the resin. Thermocouples are placed in several sheets to monitor and control temperature, while a timer automatically records time against a pre-set cure cycle.

When the curing is completed, the steam is automatically cut off, press cool down begins and the press books are cooled to a temperature (80 °F) at which they may be handled. After removing the material from the press, the edges are trimmed from the sheet to remove the irregular excess resin flow areas. At this stage, the laminate sheets are sheared down to the desired sheet or panel size.

During the manufacturing process, several quality control checks need to be implemented to ensure uniformity in thickness of the laminate, lamination integrity (endurance of extreme thermal, mechanical and chemical abuses) bow and twist, surface quality and dielectric variations. Knowledge of the laminate manufacturing process is helpful for designers, fabricators and assemblers in understanding the capabilities and laminations of this critical building block of PCB manufacture.

6.2.2.4 Quality Control

After the laminate has been formed, it undergoes various tests. They are conducted to check for the following:

- Cleanliness;
- Dents;
- Scratches;
- Thickness;
- Water absorption
- Solder float test (Solder resistance);
- Bonding strength;
- Warp and twist;
- Flame resistance;
- Dimensional stability;
- Resin content;
- Volatile content;
- Resin flow and gel time;
- Printability;

- Flexural strength;
- Peel-off test;
- Drillability; and
- Punching and shearing qualities.

6.3 Properties of Laminates

The properties of laminates vary from grade to grade, depending upon resins and fillers. The electrical, mechanical, chemical and thermal characteristics are of laminates mainly depend upon the selection of the resin. The properties of laminates are:

- Dielectric constant;
- Dielectric breakdown strength;
- Dielectric strength;
- Dissipation factor;
- Arc resistance;
- Loss factor;
- Absorption of water;
- Tensile strength;
- Compression;
- Shear;
- Flexural strength;
- Impact strength;
- Environmental resistance;
- Fungus resistance;
- Flammability characteristics;
- Self-extinguishing characteristics;
- Laminating difficulty;
- Copper adhesion;
- Heat resistance;
- Machinability; and
- Dimensional stability.

The electrical and mechanical properties of laminates are affected by environmental factors such as humidity, temperature, corrosive atmosphere, etc. Table 6.3 lists the important properties of laminates commonly used for PCB construction.

Table 6.3 Important Properties of Base Materials

Grade	Composition	Remarks
XXXPC	Paper/phenolic	High moisture resistance
FR-2	Paper/phenolic	Similar to XXXPC but flame retardant
XXXPC	Paper/phenolic	Best mechanical characteristics of paper/phenolic grades
FR-3	Paper/epoxy	High mechanical and electrical characteristics, flame retardant
FR-4	Glass/epoxy	Flame retardant, chemical resistant, low water absorption
G-3	Glass/phenolic	High flexural strength and dimensional stability
G-5	Glass/melamine	High resistance, high impact strength
G-9	Glass/melamine	Same as G-5 but better electrical characteristics
G-10	Glass/epoxy	Same as FR-4 but not flame retardant
G-11	Glass/epoxy	Same as G-10 but higher flexural strength under heat

(Contd.)

Table 6.3 *(Contd.)*

Grade	Composition	Remarks
G-30	Glass/polyimide	High dimensional stability under heat, flame retardant
FR-5	Glass/epoxy	Same as G-11 but flame retardant
GPO-1	Glass/polyester	General purpose mechanical and electrical grade
GPO-2	Glass/polyester	Similar to GPO-1 but lower flammability

6.3.1 Electrical Properties

The electrical properties of a laminate depend upon the electrical properties of the filler, cured resin and the by-products of the curing reaction.

Laminate absorbs moisture to some extent when exposed to high humidity conditions. Consequently, this absorbed moisture adversely affects the electrical properties. For 1.6 mm thick laminates, the appropriate water absorption values are as follows:

a) Papmer phenolic
Example: NEMA grades X, XX, XXX, etc. 0.75 to 6 %

b) Glass epoxy
Example: NEMA grades G10, G11 0.23 %

c) Glass PTFE (polytetrafluoroethylene)
Example: NEMA grades GTE 0-0.68 %

6.3.2 Dielectric Strength

This is the ability of an insulating material to resist the passage of electric current of a disruptive discharge produced by an electrical stress. It depends upon a large number of factors pertaining to the material such as chemical composition, molecule structure, degree of moisture, thickness cleanliness and roughness of surface and material ageing.

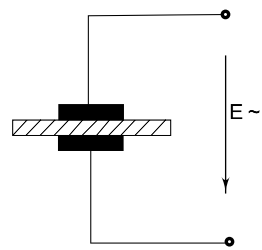

Fig.6.3 Schematic electrode arrangement for testing dielectric strength

The test is performed by applying 50 Hz ac voltage on a piece of laminate whose copper surface is etched off before it is placed between two electrodes as shown in Figure 6.3. The test is carried out under oil in the following two ways:

- *Short-time Test:* In this test, the voltage is increased at a uniform rate of 0.5 KV/s.
- *Step-by-step Test:* Initially, 50 per cent of the short-term breakdown voltage is applied. The voltage is then increased in increments according to a pre-determined schedule at 1-mm interval. The test values of dielectric strength vary with the form and size of the electrodes, the frequency and shape of the voltage waveform and the surrounding material.

6.3.3 Dielectric Constant

Dielectric constant is the ratio of the capacitance of a capacitor with a given dielectric to the capacitance of the same capacitor with air as dielectric (Figure 6.4). It is calculated from the capacitance as read on a capacitance bridge, the thickness of the sample and the area of the electrode.

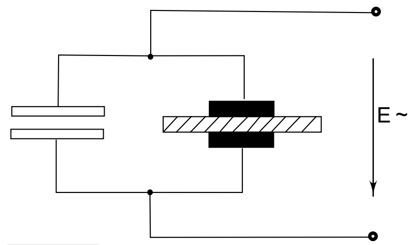

Fig. 6.4 Electrode arrangement for testing dielectric constant

The dielectric constant is also referred to as *Permittivity* and being a ratio, is a dimension-less entity.

The dielectric constant measures the ability of an insulating material to store electrostatic energy. It varies with the thickness, temperature, humidity and frequency and chemical composition of the material. The effects of temperature and frequency variations on the dielectric constant vary for different materials.

6.3.4 Dissipation Factor

The dissipation factor of an insulating material is the ratio of the total power loss (in watts) in the material to the product of the voltage and current in the capacitor in which the material is the dielectric. It varies with frequency, moisture, temperature, etc. and is a dimension-less entity.

Expressed in another way, the dissipation factor is the ratio of parallel reactance to parallel resistance. It is measured with the electrode arrangement as shown in Figure 6.5 whereas Figure 6.6 shows the vector diagram of the equivalent parallel circuit.

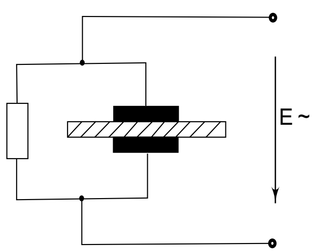

Fig. 6.5 Electrode arrangement for testing dissipation factor

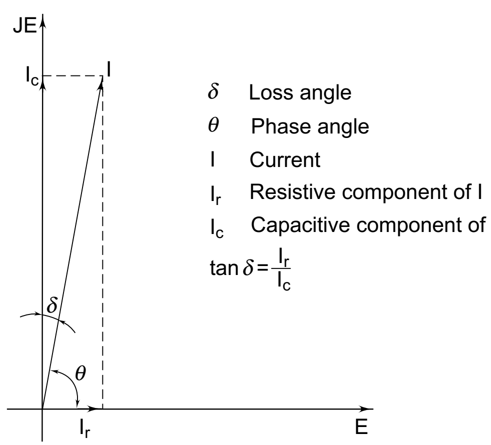

Fig. 6.6 Vector diagram of equivalent parallel circuit for a laminate