This document and contents are extracted from

Materials for Rigid and Flexible Printed Wiring Boards

By- Martin W. Jawitz

Michael J. Jawitz

First of all, I would like to thank the authors for their great contributions. I borrowed a book from National University of Singapore, Central Library for my new job as PWB/PCB certification Engineer at Underwriters Laboratories Inc.

All credits go to the authors and its publishers; I am not purposely distributing the materials. Simply, keep it as personal study notes. The materials and contents covered in the book are very huge and it wouldn't possibly allow me to write down every things. As library borrowing time is limited, I copied down in hand writing on my note book I guess I had more concentration on the content by doing so rather than photo-copying, and then I make effort to write it in words documents.

Please, note that the contents are not in full as in the published book, I just simply took small amount of information for work purpose. Especially, appendix pages described the Tests in real work place PWB certification. If you could find something useful out of this, I will be very happy.

Kyaw Soe Hein

1. Reinforcement Materials, Rigid

GLASS

D-Glass E-Glass S-Glass Quartz

(Commercial Commonly Available)

Most Popular rigid reinforcement for PWB is woven E-glass. This is electrical grade.

There are two types of plastics available thermoplastic and thermosetting.

1. A **thermoplastic** is a material which becomes soft when heated and hard when cooled. **Thermoplastic** materials can be cooled and heated several times. They can be recycled. When **thermoplastics** are heated, they melt to a liquid.

2. A **thermoplastic** is a material which becomes soft when heated and hard when cooled.**Thermoplastic** materials can be cooled and heated several times. They can be recycled. When **thermoplastics** are heated, they melt to a liquid.

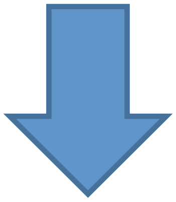
The glass is used to reinforce the *thermosetting plastics (laminates)* in PWB.

Organic resins such as

Epoxy, phenolic, polyester, cyanate ester, polyimide

Low Strength

They are reinforced with *GLASS.*



Durability, high strength, Excellent Insulation

Woven glass fabrics act as restraining force on the resin.

1. Glass do not shrink under extreme temperature or processing stress
2. Immune to organic solvent, bacterial attacks, most acidic or basic solvents/ liquids.
3. No appreciable water absorption or water induced deterioration.
4. High strength to weight ratio
5. Tensile strength and rigidity of glass gives stress resistance to reinforced laminates
6. Excellent electrical insulator with "high dielectric strength" and "relatively high dielectric constant (Dk)".

Glass Composition

Chemical compositions are different in each class of Glass.

Predominant material is SiO2.

Including those materials Al2O3, Fe2O3, CaO, MgO, Ba2O3, Na2O, Li2O.

Physical properties are different as well.

D-Glass

Lower Dielectric Constant (Dk) and Lower Density than E-Glass.

It is developed to improve the electrical performances of the finished material.

Cost of D-Glass = approximately 20 x Standard E-Glass

There is limited supply of D-Glass.

NOT POPULAR

E-Glass

- Primary glass fiber used to make glass reinforced laminates for rigid PWB.
- Fairly high (Dk) dielectric constant
- Low Cost
- Good Electrical Characteristic
- Mechanical properties
- Resistance to heat, water and Acid

Commercial E-Glass

- Tensile strength: 200,000 to 300,000 psi
- Modulus of Elasticity: 10,500,000 psi
- Specific gravity: 2.6
- E-glass can elongate to break at about 3.5%

S-Glass S-2 Derivative

- Strength to weight ratios that exceed those of most metals
- Higher percentage of both SiO2 and AL2O3.
- Lower Dielectric constant (Dk) → Due to High SiO2 content
- Lower Dissipation factor (Df)

Cost of S-Glass = approximately 5 x Standard E-Glass

- Tensile Strength: 650,000 psi
- Modulus of elasticity: 12,400,000 psi

It is used for advanced composite-type printed wiring boards for critical military and aerospace applications.

Quartz

Quartz means fused quartz (Inorganic glass) composed principally of fused silica (SiO2)

- Very low dielectric constant (Dk)
- Very low coefficient of thermal expansion (CTE)

Cost of Quartz = approximately 40 x Standard E-Glass

- High strength to weight ratio.
- Tensile Strength almost equal of the glass
- Excellent chemical resistance except hydrofluoric (HF) & phosphoric acid (H3PO4)

Why use Quartz?

- ✓ Coefficient of thermal expansion (CTE) - x/y plane is less than that of E-glass.
- ✓ Allowing for high solder joint reliability during thermal cycling.

- ✓ Use when you need finished laminate with low (Dk) and low (Df) and low (CTE)
- ✓ For microwave applications

Disadvantage of quartz

Higher cost, processing difficulties (Drilling), quartz is very abrasive.

Properties of Glass Fabric

Moisture and Chemical Resistance

They are inorganic fibers, thus they do not get affected by organic solvents, bacterial attack, or many acidic or basic corrosives.

No appreciable water absorption or deterioration.

Electrical Properties

They are electrical insulator as high dielectric constant (Dk), low dissipation factor (Df)

Heat & Fire Resistance

Being inorganic, glass fabric is incombustible.

At 370ºC, it retains about 50% of initial strength.

At 534ºC, it remains about 25% of initial strength.

Therefore, normal laminating & PCB processing temperature have no effect on glass

Thermal Conductivity

Glass fibers rapidly dissipate heat, particularly in PCB applications requiring dimensional stability and heat-resistance.

Aramids

Non-woven Aramids (Thermount®)

To improve further on woven fabric, we use non-woven aramid.

Woven Fabric can cause

- ✓ Micro cracking
- ✓ Weave Print-through

The problems are eliminated by Aramids

- Increase dimensional stability
- Improved CTE

The result is very smooth surface and flat sheet, but with improved dielectric properties, dimensional consistencies, better drilling and laser and plasma compatibility.

Three thickness of nonwoven Aramid Reinforcement

E-210, E-220, E-230

Aramid Dielectric constant (Dk) = approximately 4.0

Higher modulus, Lower CTE

KELVER: Aramid with Dielectric constant (Dk) = approximately 3.6

It has micro-cracking problem and negative CTE.

2. RESINS

The resin systems vary accordingly

Commercial, consumer, medical, military, aerospace, high-reliability field (high-performance system)

Possible considerations to choose what resin

Processability - should perform well within existing established process and parameters

Flammability – UL 94 V-0 Specifications

Flame retardant chemical (Br, Antimony oxide, phosphorous, etc) must be included.

Results in a compromise of dielectric loss, or long-term thermal stability.

Chemical Resistance Laminates go through chemical process during fabrication and assembly. The resin system selected must be capable of surviving all these conditions.

Minimum deterioration of properties

Electrical Properties Resins with low dielectric electric (Dk) and dissipation factor (Df)

For high speed digital and microwave applications

High breakdown voltages may be required for some types of buried capacitors.

Thermal Stability – Important especially for

1. High-temperature applications
2. High-layer count multilayer boards

Copper cracking in plated through hole can be solved by/ minimized by resin with high glass transition temperature (Tg).

- Tg is the temperature at which the resin begins to act as rubbery solid rather than a rigid solid.
- Td (Thermal decomposition temperature) which is an indicator of long-term serviceability of the resin at elevated temperature.

2.1 Polyester Resin

They may be either thermoplastic or thermosetting behavior.

The basic building blocks are

Polyhydric alcohol such as propylene glycol + polybasic acid + Reactive monomers (styrene)

- ### Epoxy (Modified Epoxy)

They are thermosetting resins

- Resins that cure into a hard final product.

They are rather not thermoplastic which can be re melted many times over. The resins are dissolved in relatively inexpensive solvents and bond well to copper foil and glass fibers.

1. Difuctional Epoxy

Bromine content 18 to 21% weight.

This stage it should meet UL 94 V-0 without further additive.

They have adequate properties of single and double sided circuit application.

In general, they are not adequate for high layer or some critical double-sided boards, due to low glass transition temperature.

"High z-axis expansion, low chemical resistance, higher moisture absorption."

2. Multifunctional Epoxy

They have become the workhorse of PWB industry.

Tg ranging from 130ºC to 190ºC.

As epoxy resins have evaluated, multi-functional additives have been used to generate a higher cross-linked density in the cured matrix, which affords everywhere from a slight to substantial improvement in

- Glass transition Temperature (Tg)
- Chemical resistance
- Z-axis expansion
- Thermal shock resistance

The most commonly used multi-functional additive are

1. Tetra functional Epoxy
2. Gresol novolac Epoxy
3. Epoxy phenol novolac (Increased heat and chemical resistance)

Laminates made with novolac will meet UL 94-V-0.

Multifunctional Epoxies can be broken down into three categories

General-Purpose Systems having Tg between 135ºC and 145ºC

- Improvement in chemical, solvent, moisture resistance compared to difunctional epoxy resins.
- Little change in thermal resistance and z-axis expansions
- These materials tend to be compatible with fabrications processes designed for difunctional epoxy.

Higher-Performance Multi functional Epoxies having Tg between 150ºC and 165ºC

- Additional improvement in chemical, solvent, moisture resistance
- Improvement in z-axis expansion allow sot perform well on thicker boards up to 2.286 mm without lifted pads.
- It is stiffer and harder, may be more difficult to dress.
- The improved chemical resistance requires increased activity of chemical hole cleaning process or use of plasma hole preparation.

Higher-Temperature Multi functional Epoxies having Tg between 170ºC and 185ºC

- Very high chemical, solvent and moisture resistance
- Improvement in z-axis expansion, allowing to perform well on boards up to 0.15 inches.
- Board built with this will usually pass tests requiring up to five solder float tests
- Due to hardness, drill wear will increase.
- These materials used for boards that are extremely thick or subjected to multiple solder assembly operations.

(High-layer count printed wiring boards)

3. Tetra functional Epoxy

FR 4 Laminate

Blends of Tetra functional epoxy + di functional Epoxy

+ Woven glass fabric

- ✓ Better thermal, chemical, moisture resistance & improved electrical properties
- ✓ Still compatible with normal FR-4 processing technology

• Polyimide

Primary Asset >>> High Tg and Thermal Stability

- During drilling process, it virtually eliminates the drill smear caused by heat developed, enable to withstand numerous solder rework cycles.
- Maintain copper bond strength at elevated temperature.
- Excellent Z-axis dimensional stability, minimum through-hole copper cracking
- Polyimide resins Dk & Df less than Epoxy Dk & Df

Disadvantages >>> Absorb water, variable dielectric

Minimize the use of high speed application.

- Best long-term thermal characteristic than any currently available material.
- Originally used for military applications
- Tg high (260ºC to 300ºC), long-term thermal resistance, low CTE (lower than epoxy)
- High thermal degradation temperature result in excellent reworkability

Kermid 701 resin system

Two-component liquid system that does not require a methylene dianiline (MDA)

2..1 Epoxy-Blended Polyimide

Combination of epoxy & polyimide resin

Good mechanical processing advantages. High thermal resistance

Tg of the system as high as 220ºC.

Resin (Cyanate Ester & Cyanate Ester Blend – BT Resin)

Cyanate esters are finding their way into a variety of high-speed applications

- ✓ They have low Dk & low Df over a large frequency range and temperature.
- ✓ CTE of 10 to 12 ppm/ ºC, High Tg (235 ºC)
- ✓ Materials of choice for high-complexity, high layer-count multilayer boards.

Low DK >>> Reduce "cross-talk" between closely spaced signal lines which minimize the needs of extra shielding.

Cyanate Ester (Tri functional) cyanate ester cross-links to form a high temperature polymer (Tg 235 ºC or higher)

Why cyanate Ester Blends (BT resin)?

- In the purest form of cyanate ester, these resins are very brittle and have low peel strength
- To overcome this, these resins are blended with either epoxy or a small amount of polyimide resins

This blend is called BT. Non-toxic to human.
Two Major Components: Bismaleimide + Triazine
Varying ratio of either of Two >>>> Desired Dk
Composition by weight >>> 10% of bismaleimide + 90% of Triazine

(Curing temperature as of epoxy resins)

In most cases, BT resins can be substituted for polyimide resins.

- Desirable electrical performance in microwave frequency
- Can be flame retardant by addition of brominated epoxy, antimony trioxide of fluorine compounds to meet UL 94 V-0 flammability

Polyphenylene Oxide (PPO) Epoxy Blend

- ➢ Thermoset resin that has a Tg of 180ºC.
- ➢ Very low moisture absorption and a cost that is only 20 to 50% more than epoxy.
- ➢ Low Tg (150 ºC)
- ➢ Excellent for high operating temperature or low moisture absorption

- Ideal material for back panels for cellular-based stations and many other wireless applications.

2..1 Getek® Resin

70% high Tg epoxy + 30% Thermoplastic prolyphenylene Oxide

- Low Dk, Df, Low Tg, Low CTE

Getek is UL approved for operating at 150ºC.

• Polyphenylene Oxide (PPO) Epoxy Blend

Teflon® by Dupont

It is an ultra-high-molecular-weight polymer.

The term Tg is not strictly applicable to PTFE resins as it maintains its plastic properties throughout well below zero to very high melting point (327ºC).

- Low Dissipation loss “nonpolar nature”
- Chemical Inertness
- Chemically stable
- Thermoplastic and chemical properties

- The low Dk reduces the propagation delay by approximately 30% when compared to FR4.0.
- Df of 0.00012 at frequency of 10GHz improves signal rise time & attenuation
- PTFE resins are used in microwave applications when the lowest Dk or Df is required.

3. Flexible Film

Materials that are used for finished printed circuit laminates were designed primarily to replace bundles and cables of conventional round insulated wire to both reduce weight and save space.

- Usually, flexible printed circuits are made on non-reinforcement polymeric material.
- They are to be used as interconnects in place of wire harness or in places where connections are needed to a moving part.

TWO ADVANTAGES OF FLEXIBLE PRINTED WIRING

1. Once the flexible circuit layout has been proven, it is almost impossible to make a wrong connection.

2. The thinnest of the flex circuit allows it to be used in locations where the thickness of even a ribbon cable cannot be accommodated.

The original flexible materials were made from thermoplastic dielectric insulation films that were laminated to copper foil with the use of heat.

- Polyimide films offer the best combination of cost and properties for this application.
- Polyester films are a close second, falling short only on thermal resistance.
- Aramid fibers (nonwoven) have unique properties that suggest where cost is important and slight imperfections can be overlooked.
- Fluorocarbon has superior dielectric properties and one suitable for controlled impedance application.

Every Laminate consists of a conductor foil and a dielectric substrate.

Copper is the typical foil of choice while virtually all-flexible circuits are built on either polyimide or polyester substrates.

- Military and high-performance flexible circuits

  Polyimide films

- Best overall performance at an acceptable cost.

- Commercial, cost-sensitive circuits

  Polyester films

- Similar to polyimide but reduced thermal resistance

- Not Weather sensitive application

  Aramid fibers (nonwoven)

  -Inexpensive

  -Excellent electrical & mechanical properties

  but, *Excessive moisture absorption* which limits their use in some hot, humid environment.

- Controlled Impedance Board

  Fluorocarbons

  -Expensive

  -Hard to handle

  - Superior dielectric properties

3.1 Types of Flexible Materials

3.1.1 Polyethylene Terephthalate [PET] polyester

- Low Cost cast film
- Very resistant to solvents
- Tensile strength of 25,000 psi
- Good dielectric strength
- Plastic memory for retractile
- Polyester laminates are built with Thermo-plastic adhesives that facilitate high lamination temperature.
- Polyester film will burn adhesives with sufficient flame suppression properties that are usable even in sensitive applications.

"Low Melting Point (250°), Low Transition Glass Temperature (80°)"

This is the combination of polyester/epoxy.

A unique property of this material is that once it is formed or bent, it can retain the shape due to the low and broad Tg temperature of fully cured material.

3.1.2 Polyethylene Naphthalate [PEN]

It is a close cousin to polyester.

-Performance is similar to [PET] but improved thermal properties including a Tg (glass Transition Temperature) of 120°C melting temperature 12°C (higher than that of polyester)

3.1.3 Fluorocarbon [FEP]

- Unmatched chemical inertness
- High thermal resistance
- Great dielectric properties/ tough mechanical properties
- Very good tear resistance
- Incombustible

Downside [Disadvantages]

Dimensionally unstable at elevated temperature, has memory and requires a special copper foil treatment for bond-ability.

Low Modulus of elasticity

3.1.4 Polyimide

1st >>>>> Kapton ®
2nd >>>>> Upilex ®
3rd >>>>> Apical ®

→ Non Burning + Flame Retardant Adhesive

UL94-V0
Satisfied

-Weak link in polyimide

-Absorb a great deal of moisture (must stored in a dry box)

Tear Resistance They usually have complex outlines with multiple stress concentration points, making tear resistance in which an adhesive can enhance laminate performance.

Most flexible adhesive tear resistance > the polyimide film

Dimensional Stability Flexible laminates expand and shrink more during exposure to various processing conditions.

3.1.5 Aramids (ACT like Mechanical Backbone)

- Random-fiber aramids and Daoron® epoxies
  - High temperature material that can withstand soldering temperatures very well

Main Draw Back ---→ It is very hygroscopic material & readily absorbs processing chemicals

  - The aramid paper has a very low initiating and propagation tear-strength, but it also has a low Dk (dielectric constant) – about half of that of polyimide.

Aramid fibers (nonwoven) are inexpensive and have excellent electrical, mechanical and thermal properties but feature excessive moisture and residual chemical absorption.

3.2 Types of Flexible Materials

Adhesives are weakest link in flexible PWB.

It holds the structure together.

The adhesive is the dielectric that surrounds the conductive layer and in a typical construction, contributes up to 50% or more of the thickness.

- ✓ Most adhesives support combustion unless they are formulated to include flame suppressors.
- ✓ Adhesives are the controlling factor in critical conditions such as elevated temperatures.
- ✓ Bond Strength is an adhesive property. Selection of the proper adhesive can prevent assembly damage especially during soldering and termination.
- ✓ Chemical resistance is also an adhesive effect.

In selecting an adhesive system,

  - Tensile strength
  - Elongation

3.2.1 Types & Use of Adhesives

Flexible PWB are used in several form.

- Base & cover coat are identical in compositions if not in thickness. Consists of a single-sided adhesive coating on dielectric film & together form the dielectric system of a single-sided flexible PWB.
- Bond-ply and cast-films adhesives are used to join layers of flexible PWB together to form a multilayer structure. Bond piles provide a cast adhesive film that allows for a thinner construction.
- Dielectric barrier between facing etched circuits, acting as a cover coat for both.

Epoxy Adhesive – they have good-high-temp property retention and remain in good conditions after soldering. It has good-long-term stability at elevated temperatures in environmental conditions of up to 121°C.

Polyester Adhesive– the only material that should be used as an adhesive for polyester base laminates and cover film is polyester adhesives.
Major Drawback: Low Heat Resistance

Excellent electrical properties & flexibilities
Heat-resistance can be improved by partial cross-linking.

Acrylic Adhesive- they are most often used when the complex circuits are subjected to high soldering temperature.

- They offer the best heat to short-term high heat exposure.
    - Due to acrylic adhesive thickness and high z-axis expansion, this combination is finding less & less interest among flex users.

      Drawback:
        - ✓ Vulnerable to attack by some solvents in the photoresist process.
        - ✓ Vulnerable to attack by some alkaline solutions that are used in plating and etching process
        - ✓ Absorbed solvents are especially difficult to remove prior to multi-layer lamination. Delamination or blistery can occur if these volatiles are not removed.

Polyimide Adhesive- Polyimide films can be coated with a polyimide adhesives.

Chemical Resistance & Electrical properties > Better/ as good as acrylic

- They offer better heat resistance than any other flexible system
- Used in static flexing applications (not very flex)
- Better dimensional stability, better process ability and lower overall thickness.

Butyl Phenolic- More heat-resistant than polyester adhesive, but their electrical properties are not as good as flexible. The addition of additives to the butyl phenolic adhesive can increase its flexibility.

3.3 Cover Coat/Cover Layer

The etched conductive traces on the flex are usually protected from damage (either mechanical or environmental) by covering these traces with a protective film.

These materials are generally the same polymer as the base material.

- It protects the conductors against the environment
- Defines the solder coating areas for component assembly
- It affords protection against mechanical damage that might occur if a moving flexible circuit touches another part of the equipment.
- It puts the upper on a single-sided flexible circuit on the neutral bending axis.
- It helps to anchor the terminal pads to the base film.

3.4 Bond Plies

They are like double-sided adhesive tape. A bond ply is a cover layer with an adhesive on both sides and could be used as a cover layer or as a joiner in multilayer stack ups, bonding stiffeners or heat sinks into flexible PWB.

3.5 Conductive Materials

Copper foil is far and away the leading choice of conductor material for flexible PWB.
Although Aluminum, Al, is superior in conductivity, it is chemically more active and presents corrosion problems when joined to other metals.
Copper, Cu is the standard material for conductivity and current-carrying capacity.

3.5.1 Electrodeposited Copper (ED)

It produces foil that is very smooth and shiny on one surface (called drum-side), whereas the outside or dull side of the foil has a "tooth" that provides a very good surface for adhesives.

Because of rough surfaces, conventional (ED) copper foils bond very well to the flexible dielectric film, where their flex properties irrelevant.

Used in commercial industrials where repeated flexing is not a requirement.

3.5.2 Rolled Annealed Copper (RA)

- (RA) is very flexible >>> Used in dynamic applications
- It is manufactured by melting the cathode copper and then formed into large ingots.
- (RA) metallurgy provides good flexural endurance but complicated as a result of handling during manufacturing because it is soft and easily distorted.
- Low Temperature Anneal (LTA) foil that offers better handling and flexural properties.

3.6 Copper-Clad Laminates

- ➢ Copper-clad dielectric Films (Polyimide)
- ➢ Copper-clad dielectric films (polyethylene terephthalate & polyethylene Naphthalate)

4. Copper Foils

Two types of foils

1) Electro deposited (ED)
2) Rolled Annealed (RA)

Here, omit the manufacturing processes.

4.3 Grades

Electro deposited (ED) >> Grades 1 to 4 for Rigid PWB
(ED) + Rolled Annealed (RA) >> Grades 2, 5-8 for Flex PWB

4.3.1.1 Grade 1 or Standard Electrodeposited (STD-TYPE E)

- Used for laminates that require heavier copper foils (>3oz, 65g) by weight.
- Used for single & double-sided rigid laminates

4.3.1.2 Grade 2 or High-Ductility Electrodeposited Foils (HDE-Type E)

- Rigid & Flexible laminate industry
- Consumer & automotive industries, which required lower cost and good flexibility for flex to install circuit boards.

4.3.1.3 Grade 3 or High-Temp Elongation Foil (THE-Type E)

- ✓ By far, most common popular grade of copper used in both rigid & thin laminates applications is grade-3 copper foil
- ✓ Greater elongation at elevated temperature than standard (ED) copper foil
- ✓ Most multilayer bonds utilize THE

4.3.1.4 Grade 4 or Annealed Electrodeposited or “Super High Duct” (ANN-Type E)

Although this grade is listed in IPC-4652, there is no know source to obtain this material

4.3.2 Rolled Copper foils

4.3.2.1 Grade 5 or "As Rolled" wrought copper (AR-Type W)

- ✓ Along with grade 8, this is used mainly in the production of flex laminates.

4.3.2.2 Grade 6 or Light Cold Rolled Wrought (LCR-Type W Special Temper)

- ✓ Like Grade 4, this material is also unavailable even though it is listed in IPC-4652.

4.3.2.3 Grade 7 or Rolled Annealed Wrought (ANN-Type W)

- Rolled annealed copper foil are most easily recognized in the flex industry because of their almost exclusive use in producing flexible circuit.
- Most expensive to purchase with comparable thickness.
- Even though it has very good properties, it is gradually being replaced by grades 5 & 8.

4.3.2.4 Grade 8 or "As Rolled" Wrought Low Temp Annealed (Type LTA)

- o Grade 8 is equivalent to grade 5 in requirements and usage
- o Grade 8 flexes are basically used for commercial flex applications where continuous flexing is not a requirement.
- ✓ Like Grade 5, this foil is used in the production of flex laminates.
- ✓ During lamination, some properties change (for the better), which makes this material ideal for flex applications.

4.4 Nickel Foil

- ✓ The development of electro-deposited nickel foils has helped eliminate some of the etching problems experienced with rolled foils.
- ✓ Availability and use of nickel foil are very limited.

5. Laminates, Rigid

5.1 NEMA Grade

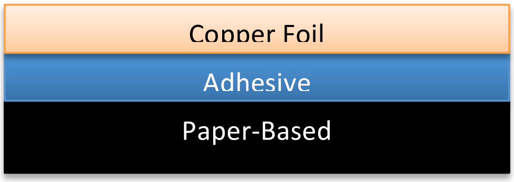
One of the 1st attempts to classify base materials that are used as laminates for PWB was completed b the National Electrical Manufacturing Association (NEMA).

- Copper clad laminates are composed of three basic materials:
  1. Copper foil
  2. Resin
  3. Reinforcement

Some laminates require an adhesive to bond the foil to the reinforcement.

5.1.1 Paper-Based Laminates

- Using layers of a phenolic, polyester or epoxy- impregnated paper
- XPC, XXXPC, FR-1, FR-2 & FR-3
- These are the least expensive and are generally used in low cost consumer products.
- Due to the high z-axis expansion of the paper grade materials, plating of through hole.



Main Drawback

- Lack of physical strength, poor impact resistance, poor dimensional stability, unstable electrical characteristic and breakage.

Chief asset of paper-grade materials is their punch-ability, low-price & electrical characteristic that are adequate for many non-critical applications.

5.1.2 Types of Laminates

5.1.2.1 XPC

- ✓ Made from cellulose-based material that is impregnated with a single coating of a plasticized phenolic resin.

- ✓ XPC laminates are normally brown in color.
- ✓ It shows excellent punching properties and excellent dimensional stability.

5.1.2.1 XXPC

- ✓ Made from cellulose-based paper but is impregnated with two coats of modified plasticized resin
- ✓ Low cost, low performance, low dielectric loss than XPC.
- ✓ When it is wet, it has poor flexural strength & electrical properties.

5.1.2.3 FR-1

- ✓ Made from a cellulose-based paper
- ✓ It is impregnated with a plasticized, flame retardant phenolic resin
- ✓ Normally brown in color and can be punched at room temperature.
- ✓ At slightly elevated temperature, produce cleaner holes and edges if punched or sheared.
- ✓ Used to fabricate single-sided PWB but have extremely poor electrical properties when wet.
- ✓ It can be manufactured with “Green” variants that are halogen-, dioxin- and antimony free.
- ✓ FR-1 laminate has a Comparative Tracking Index (CTI) of over 600V.

5.1.2.4 FR-2

- ✓ It is produced from multiple plies of cellulose-based paper impregnated with an upgraded high-temperature, flame retardant, plasticized phenolic resin.
- ✓ In FR-2, each sheet of cellulose paper is coated twice with resin.
- ✓ FR-2 and XXXPC have similar properties except that FR-2 is flame retardant.
- ✓ This laminate performs better than FR-1 when tested for moisture and insulation resistance (MIR)
- ✓ CTI of over 600V
- ✓ FR-2 mostly for single-sided, some double sided, non-plated-through hole
- ✓ Can also be supplied in “Green” variation, halogen- dioxin- and antimony free.
- ✓ It typically used where dimensional stability & high performance are not requirements.
- ✓ FR-2 is a low cost laminate

5.1.2.5 FR-3

- ✓ It is also made from multiple piles of cotton linter, impregnated with two coats of a modified flame-retardant epoxy resin.
- ✓ Very brittle, should be punched only at elevated temperature.
- ✓ It has better wet electrical properties than FR-2 laminate and is generally used where high insulation resistance is a requirement.
- ✓ Mostly used in single sided boards, some advanced in relatively thin double-sided boards with PTH

5.2 Composite Laminates

- Defined as "consists of two or more form of reinforcing materials bonded together with a suitable resin".
- The emphasis is solely on what type of reinforcement is used. The resin type is not specified.

Combination of core made from			
Paper	*Glass Mat*	*Glass Felt*	*Reinforce Woven Glass*
& Reinforced Woven Glass Outer Layer			
Become	REINFORCEMENT MATERIALS		

Types of Composite Laminate

5.2.2.1 CEM-1

- ✓ A composite grade laminate that is composed internally of either unbleached cellulose paper on cotton linter.
- ✓ Impregnated with plasticized flame-retardant epoxy resin
- ✓ The laminate is a good all-around material with excellent mechanical strength
- ✓ It posses properties of FR-2 and FR-3 and electrical properties approaching that of FR-4.
- ✓ It was developed for single-sided application that requires higher strength and stiffness than can be achieved by all other paper laminates.
- ✓ Better moisture absorption and electrical properties than FR-2
- ✓ Can be obtained halogen and antimony-free
- ✓ CTI values is over 600V

5.2.2.2 CEM-3

- ✓ It is made up of dissimilar materials. The internal layers are composed of a non-woven glass core (also called fiber glass felt) while the outer layers are composed of a woven fiberglass cloth.
- ✓ Both internal and external layers are impregnated with the same epoxy resin.
- ✓ They are mostly used to produce double-sided boards with PTH.

5.2.2.3 CRM-5

- ✓ The internal layers are composed of fiberglass paper core (also called glass mat) impregnated with a flame-retardant modified polyester resin.
- ✓ This is the same basic resin that is used to coat the FR-6.
- ✓ The outer layers are a woven fiberglass coated with the same polyester resin.
- ✓ This composite laminate can be used to produce a double-sided PWB with PTH.

CRM-5 laminate has excellent electrical properties especially under humid conditions.

- CTI of over 600V
- Lower Dk, dielectric constant (3.7) and
- Lower Df, dissipation factor (0.018) than competing paper or composite laminates, which make it an excellent material for high-frequency or high voltage application.

5.2.2.4 FR-6

It is composed of a random fiberglass mat core that is saturated with a modified flame-retardant polyester resin.

- ✓ This laminate has good electrical insulation properties and dielectric properties, especially under humid conditions.
- ✓ With CTI index of over 600V, Dk of (3.6) and Df of (0.016)
- ✓ Maximum flexibility for safety and protection for frequency-sensitive application.
- ✓ Flexural strength is no better than that of paper grade, erratic and low upper peel strength.
- ✓ Thickness variation is about twice that of paper.
- ✓ Die wear is excessive and hole-to-hole cracking could be a problem.

It has lower mechanical properties than CEM-1 or CEM-3 laminates.

FR-6 material is designed for low-capacitance or high impact applications and is designed for the consumer electronics market.

Materials Recommendation

Factors that influence the choosing of proper paper or composite types laminates are processing considerations and intended end use.

- For single-sided boards, using punch-through-hole applications, use FR-6 CEM-1 or CRM-5
- For PTH and single-sided boards, consider CEM-3, CRM-5 or FR-6
- Where electrical characteristics are important, use CMR-5.
- If tool wear is a major factor, use FR-2 or CEM-1
- For layer or heavy loaded boards, consider CEM-1, CEM-3 or CRM-5

5.2 Rigid Laminates (Glass-reinforcement)

Almost any solid insulating resin and glass reinforcement materials can be combined to produce a laminate.

The standard copper-clad laminate and prepreg (FR-4 epoxy/ E-glass) has been available for many years and functions well, but there are some applications in which FR-4/E-glass does not perform well.

In these applications, multi-function epoxies, high-temperature epoxies, bismaleimide resins, cyanate esters, polyimide and polytetrafluoro ethylene are being used.

A rigid printed circuit board consists of a thin copper foil (conductors) and a suitable dielectric material. The latter is basically a reinforced resin.

The characteristic of the laminate (essentially the dielectric material of the resin and reinforcement) is typically divided into two main categories: electrical and mechanical.

To achieve a low CTE value without constant raining cores, low resin content is required. If the resin content is too low, then a dry laminate, weave exposure , etc are possible. Prepreg without enough resin can result in inadequate fill of inner-layer circuitry.

5.4 Laminates, Rigid Glass Reinforcement

5.4.1 Epoxy Laminate (FR-4)

- ✓ Epoxy is the most successful and commonly used resin system that is used with glass reinforcement for PWB.
- ✓ For many non-demanding applications, 130°C to 140°C, glass transition temperature (Tg), so-called tetra-functional modified epoxies have become the material of choice.
- ✓ In high layer count multilayer boards, very thick circuits, and circuits requiring improved thermal properties, 170°C to 180°C, glass transition temperature (Tg), "multi-functional epoxies have become the material of choice.
- ✓ In circuit requiring improved electrical properties, epoxy resins with a low Dk & Df are also available.

- ✓ FR-4 epoxy resin laminates with 130°C (Tg) are cost effective materials for PWB
- ✓ High temperature epoxy materials provide more thermal resistance than standard FR-4 laminates.
- ✓ The primary differentiator between epoxy materials is the (Tg) value. More common are FR-4 materials with Tg value of 130°C to 140°C (tetra-functional modified)
- ✓ 170°C to 180°C, multi-functional
- ✓ Higher-Tg FR-4 materials have better dimensional stability, which is important for complex PWB because the cores do not require heating much above the Tg, as conventional FR-4 would require.

Rigid FR-4 laminates are copper-clad epoxy glass laminates with high mechanical strength, excellent machinability and consistent drilling properties; they are approved to UL-94-V0 flame retardancy and have good dimensional stability, good electrical and mechanical properties, and good adhesive strength between layers.

The outstanding electrical, mechanical and thermal properties make FR-4 an excellent material for a wide range of applications.

5.4.1.1 Di-functional Epoxies

They are a combination of brominated bisphenol

A epoxy resin using 2-methylimidize as the accelerator and di-cyandiemide (DICY) as the harder.

They are a variety of epoxy resins; they are grouped together by their Tg and fall into Three Categories.

1) Low-End Modified Di-functional with a Tg of 135 to 150°C

- ✓ Compared to standard difunctional epoxies, these systems provide improvement in chemical, solvent and moisture resistance.
- ✓ Little change in thermal resistance and z-axis expansion
- ✓ These materials tend to be compatible with fabrication processes designed for di-functional epoxy

2) High-temperature Multi-functional with a Tg of 170 to 190°C

- ✓ Additional improvement in chemical, solvent and moisture resistance
- ✓ The improvement in z-axis CTE allows these materials to perform well on thicker boards up to 0.09 inches
- ✓ The more highly cross-linked resin matrix is stiffer and harder and may be more difficult to drill.

3) High-temperature Tetra-functional with a Tg of 170 to 190°C

- ✓ Very good resistance to chemical, solvent and moisture resistance
- ✓ The improvement in total z-axis expansion allows these materials to perform well or boards up to 0.15 in (3.8mm) thick.
- ✓ Currently, high temperature multifunctional materials are utilized in applications where the boards are extremely thick or subjected to multiple solder assembly operations.

5.4.2 Cyanate Ester

The tri-functional cyanate ester cross-link to form a high-temperature polymer (Tg 230- 240$°C$ or higher) with dielectric properties which make it of special interested in the high-frequency (RF) PWB.

These are a number of issues with this system including high rates of moisture pick-up, extreme sensitivity to processing caustics, brittleness under suboptimal processing conditions.

- A low Dk (2.8 for the neat resin) is the main feature of the cyanate ester resin system.
- In applications requiring high Tg combined with low Dk and Df, quartz fabric can be used.
- Cyanate ester is a good option for high-complexity, high-layer-count multilayer boards where its low Dk is of value for two reasons.
- Lower Dk materials permit impedance requirements to be met with thinner individual spacing than would be possible with higher Dk materials such as FR-4.
- Lower Dk materials help reduce “cross-talk” between closely spaced signal lines and minimize the requirements for extra shielding lines.

5.4.3 Polyimide Laminates

5.4.3.1 Polyimide/Glass

The base resin system is a pure polyimide resin that provides a low z-axis expansion through the most severe process & thermal excursions resulting in good plated-through-hole integrity.

- This laminate is ideal for many different applications due to its low z-axis expansion. It improves the PTH reliability or high-layer-count multilayer board.

5.4.3.2 Polyimide Glass and Copper-Invasion-Copper

- ✓ CTI has low CTE (4.6 ppm/ $°C$) and higher modulus (20,000,000 psi)
- ✓ Laminates containing CIC are significantly lower in CTE than their non-constrained counterpart.
- ✓ Even at 8% copper, a CTE of 12 to 13 ppm/ $°C$ is obtainable at normal resin contenet range if about 10% by volume of CIC is used.

5.4.3.3 Polyimide Quartz

- ✓ It offers the advantage of a low CTE combined with a low Dk (3.65 @ 10GHz) and Df (0.005)
- ✓ A CTE of 11.7 to 12 ppm/ $°C$

Quartz is the best selected if its properties are also important. Laminates and materials made from quartz fibers exhibit high-strength, low expansion, excellent chemical resistance, and attractive electrical properties.

Physically, polyimide quartz has a number of excellent properties including a low-CTE, low water absorption, high flexural strength, high peel strength, good dimensional stability (xy) and relatively low density.

On the downside, quartz-based laminates are abrasive and will use drill bits much faster than will glass-reinforced products with the same resin system.

5.4.4 Polyphenylene oxide (PPO®)

Epoxy + Polyphenylene oxide resin and Glass reinforcement yields a low Dk of 3.6 to 4.3 @ 1MHz.

-A PPO/ Epoxy system has a low Dk and is stable over a wide temperature range.

These materials are hybrid polyester-based laminates that compare favorably to PTFE but process and assemble like FR-4.

They are very suitable for wireless applications.

5.5 Aramid Laminates

5.5.1 Epoxy Thermount ®

It consists of a non-woven aramid reinforcement coated typically with high-temperature epoxy or (alternatively, polyimide with higher Tg or 250°C resin.

The result is a material having a Tg of 170°C with typical CTE values of 10 to 12 ppm/ °C.

- The Dk at 3.8 to 4.0 is lower than that of FR-4.
- The absence of woven fiberglass reinforcement allows for the formation of vias by use of lasers.
- The Dk of nonwoven aramid reinforcement is consistent across all constructions and thickness but over a wide frequency range.
- This relates to predictable and stable performance for impedance control for almost any design.

5.5.2 Epoxy on Woven Kelar®

It was developed by DuPont Company in mid 1970s as a high tensile , high modulus, low density reinforcement material.

The use of Kevlar cloth impregnated with resin as PWB material can be used as an alternative to glass/epoxy.

Light-weight, low-loss Dk, high modulus & negative CTE make Kelvar an excellent choice for CTE-controlled Boards.

Kevlar reinforcements and many high-performance resin systems are sensitive to humidity, moisture may be absorbed as a result of uncontrolled storage conditions or during wet processing.

5.6 Prepreg

Prepreg (i.e, Pre-imPREgnated glass fabrics) are woven glass fabrics that have been impregnated with a partially reacted resin. The creation of the prepreg is a complex process requiring the selection of the right resin system for the required physical function, environmental performance and electrical properties.

This process involves impregnating the glass with resin and then applying heat to advance the resin to its partially cursed or “B” stage (as it is commonly called).

APPENDIX

A1. *Arc Resistance*

It measures the resistance to formation of conductive traces when exposed to high voltage, low current (less than 0.1A) and clean conditions (no dirt or moisture). This is a measure in elapsed time until tracking ; therefore the units are in "seconds" applicable to both thick & thin laminates.

A2. *Coefficient of Thermal Expansion (CTE) and Thermal Coefficient of Expansion (CTE) (Same Meaning)*

It is a characteristic thermo-mechanical property of a material or a composite.

It is the tendency of the material to expand when heated. If there is no restraining fabric in the laminate, the resin could expand the same amount in each direction and xy- and z- axis expansion would be roughly one third of the volume expansion coefficient.

The volume of resin expansion is in compressible, which means that when the resin is constrained from moving in the plane of the laminate by the high-strength fiber-reinforcements, the resin will expand in the constrained z-direction.

A2. *Comparative Tracking Index (CTI)*

Comparative Tracking Index measures the resistance of a laminate to electrical failure in a contaminated environment as a result of electrical tracking (formation of conductive paths) in circuit surfaces. The comparative tracking index provides a comparison of the performances in insulating materials under wet and contaminated conditions.

A8. *Dielectric Breakdown Voltage (DBV)*

DBV measures the resistance of electrical failure in the x-y axis of the laminates as might occur between PTH. Electrodes are placed in part through holes drilled in the laminate. Because the distance between the holes is fixed, the measurement is in kilovolts (kV)

DBV is a measure of an insulator's ability to withstand the stress of high voltages placed across it.

A10. *Dielectric Constant (Dk/permittivity)*

The Dk is the property of the insulating material that determines the relative speed that the electrical signal will travel in the material. It is also a measure of the degree to which the EM wave is slowed down as it travels through the insulating material.

The higher the Dk, the slower the Signal travels on the wire.

Signal speed is roughly inversely proportional to the square root of the Dk.

The Dk of nearly all PWB's dielectric materials changes with frequency and usually goes down as frequency goes up. Given a choice, lower Dk is nearly always better.

A11. *Dielectric Strength*

IT is also called "Electric Strength" measures the resistance to electrical failure in the z-axis by high voltage. The voltage at failure is divided by the laminate thickness in mils, yielding a measure in "V/mil".

A13. *Dissipation Factor (Df – loss Tangent)*

It is the measure of the percentage of the total transmitted power that will be lost as power dissipation from the laminate material.

The higher the Df of the insulating material the greater the heat generated by the circuit board.

The heat itself is not an issue in most applications but in systems where Dk is significant, the heat can change the capacitance properties of the circuit.

Teflon is the best material for Df, capable of values as low as 0.0008.

Standard epoxies & polyimides have values between 0.01 & 0.04.

A17. *Flexural Strength, Flexural Modulus*

It measures the load a laminate will carry without breaking. In terms of the copper-clad laminates, FS determines the ability of the laminate to support the weight of electrical components.

It is the measure of the stiffness of the laminate. It means that the force required per unit of deflection in bending. Flexural strength predicts the amount of laminate will sag particularly during wave soldering.

Flexural strength & Flexural modulus are both measured in the length and cross-dimensions.

Values are reported in pounds per square inch (psi).

A18. *Glass Transition Temperature (Tg)*

The Tg is the temperature at which a polymer changes from a hard, brittle, glassy solid to a soft, rubbery solid.

Note: It is not the melting point of the polymer or laminate.

The combination of a low Tg & high CTE can lead to barrel cracking in the PTH in circuit board.

In general, the higher the glass transition temperature, the better the resistance of the laminate is to moisture, chemicals and measling.

(Measling = destruction (white spots) of the weaver interior)

A20. *Insulation Resistance*

It measures the combined resistance (Volume and Surface) to current flow in the laminate material.

Normally, the insulation characteristic of a laminate is adequately described by surface and volume resistivity; therefore, resistance is not a requirement.

When carried out for information purposes only, the test results are reported in mega-ohms.

A21. *Loss Tangent*

It is a measure of flow to the EM field through a dielectric that is absorbed or lost in the dielectric. This property is the least understood of all the properties that go into the characterizing the laminate.

A22. *Moisture Absorption*

All resin systems absorb some moisture or water when exposed to high-humidity environmens.

This absorption affects the PWB in two ways. Water has a Dk of approximately 7.3.

If laminate absorbs a significant amount of water, the resulting relative Dk will be higher than 4.1 that are used to calculate impedance and can cause impedance mismatch.

A more important effect of moisture absorption is increased leakage current. Materials with high moisture absorption may exhibit leakage in excess of what in the circuit housed on them can withstand.

To use high-absorption materials in such applications, it is often necessary to seal them with a special coating after first baking them dry.

A23. *Peel Strength*

Peel Strength is the measure of the physical attachment between the copper foil and the dielectric material.

It is important that the copper foil layer remain securely attached to the laminate during physical, chemical and thermal excursion during board fabrication.

As the width of the copper traces becomes narrower, the peel strength must be consistently high across the laminate.

A24. *Surface Resistivity*

It measures the resistance of the material between traces on a plane. Surface resistivity vary widely with the test conditions used prior and during the test. The values are reported in mega ohms-cm.

A27. *Volume Resistivity*

It measures the resistance of the material from trace to trace through the laminate as might be found between PTH.