Materials

1. Introduction

Differing requirements on printed circuit boards make the use of differing substrate materials necessary.Especial emphasis is increasingly being put on the reliability of printed circuit boards.
For many standard applications the classical FR4 material is sufficient, maybe with improved thermo-mechanical characteristics. However, at high frequencies for instance, other materials have to be used.
This technology information sheet should provide you with a basic overview of the types of material commonly available on the market, together with their fundamental characteristics, to make it easier for you to choose the right material for your application.

2. General characteristics of laminates

All of the basic materials mentioned, which are used at CONTAG, comply with the current versions of the following international standards:

Material	Standard
Base material for rigid circuit boards, 1 and 2 sided, multilayer	IPC-4101
Base material for HF applications	IPC-4103
Laminated copper films for flexible printed circuits	IPC-4204
Flexible adhesive coated films for flexible printed circuits	IPC-4203

The characteristics of the base materials can be divided into mechanical, electrical and thermal properties. Apart from electrical characteristics in part needed for special applications, the thermal characteristics mainly determine the usability and reliability of the material.

Thermal characteristics:
The key parameters are less the glass transition temperature Tg, but rather the delamination time at 260°C and 288°C, the coefficient of thermal expansion (CTE) along the X, Y & Z axes, and susceptibility to thermal cycle tests. The increased soldering temperature for lead-free solder means an increase in the thermal stress on the printed circuit board, which increases the danger of cracked sleeves, corner cracks, copper lifting and delamination.

Particularly the reliability of printed circuit boards in automotive applications is increasingly checked using cyclical temperature tests. Typical conditions for this are -40°C to +125°C / >500 cycles or –40°C to +140°C / 1000 cycles. This performance is only provided by materials with limited expansion along the Z axis, in other words with a low CTE (z).

While the Tg can only serve as a guideline for a permanent thermal stress of the printed circuit board (approx. 20°C - 25°C below the Tg), the other characteristics mentioned, especially the CTE(z) are the relevant values when considering the reliability of the circuit. "Modern" FR4 substrates using an FR4 resin system have these characteristics, but only have a Tg of 140°C - 150°C.

Electrical characteristics:
- Dielectric constants (related to a defined frequency, mostly specified at 1 MHz, 1 GHz and 10 GHz)
- Loss angle (related to a defined frequency - see above)
- Proof voltage
- Resistivity
- Surface resistance
- CTI (Conductive Tracking Index), describes the susceptibility to tracking current
- CAF resistance (conductive anodic filament - electromigration between vias)

Mechanical characteristics:
- Adhesion of the Cu foil
- Bending strength
- Elasticity

Other characteristics:
- Water absorption
- Density

Do the base materials conform to RoHS?
All of the common materials on the market comply with the RoHS/WEEE specifications, without restriction. In addition to this, there are also genuinely "green substrates" which completely do without halogens as flame retardants. These also have a very good thermal performance, but could not get established as a standard material owing to significantly higher costs and increased tool wear when drilling and milling.

3. Values for a few selected typical groups of materials

Materials group	Tg °C	CTEz ppm/K	ε_r (1 MHz/1 GHz/10 GHz) -	Proof voltage KV/mm	Surface resistance MΩ	Conductive Tracking Index (CTI) V	Water absorption %	Cu adhesion N/mm
Standard FR4	125°C-140°C	<70	4,7/4,3/-	50	10^7	>200	0,06	1,5
Modified FR4	135°C-180°C	<55	4,6/4,2/-	45	10^7	>200	0,06	1,5
FR4 halogen free	150°C-170°C	<40	5,0/4,8/4,6	50	10^8	>500	0,06	1,5
BT epoxy	Approx. 200°C	<40	4,4/4,1/-	70	10^8	>200	0,05	1,6
CE epoxy	Approx. 250°C	<25	3,9/3,7/3,5	65	10^7	>200	0,05	1,6
Polyimide	220°C-260°C	<55	4,0/3,8/3,8	45	10^8	>100	0,3	1
PTFE (pure)	200°C-230°C	<70	2,6/2,4/2,2	45	10^7	>600	0,04	1,3
RO3000	-	<40	3,0/2,8/2,6	30	10^7	>600	0,1	2,5
RO4000	Approx. 280°C	<45	3,3/3,0/2,8	30	10^9	>600	0,04	1,0

4. Example materials for various requirements

Standard applications

Name	Reinforcement	Resin	Comment	Examples	Cost factor (reference: FR4 standard) ***
FR2	Paper	Phenol	Low technology, “white goods“, not lead-free solderable	Cobrisol FR2; Aismalibar	0,3
FR3	Paper	Epoxy	Low technology, “white goods“, almost no longer available	Cobrisol FR3; Aismalibar	0,6
CEM1	Paper	Epoxy	Low technology	Cobrisol CEM1;Aismalibar	0,7
CEM3	Glass mat	Epoxy	Low technology	---	0,8
FR4Standard	Glass	Epoxy	Tg 130°C-140°C;conforms to RoHS/WEEE	MC-100 EX*, R-1766; Panasonic	1,0
FR4halogen free	Glass	Epoxy	Thermally very stable,CAF resistant, Tg >= 150°C	DE 156, IS 500; IsolaR-1566W; Panasonic	1,3

Use at high temperatures

Name	Reinforcement	Resin	Comment	Examples	Cost factor (reference: FR4 standard) ***
FR4 medium Tg	Glass	Epoxy	Tg approx. 140-160°C, increased thermal stability, low Z axis expansion, high reliability for lead-free soldering process, often CAF resistant	R-1755C; Panasonic IS 400**; Isola	1,15
FR4 high Tg	Glass	Epoxy	Tg approx. 160-190°C,see average Tg	R-1755S,R-1755T, Panasonic, IS 410**, IS 420**, Isola	1,4
Rigid PI	Glass	Polyimide	Tg approx. 260°C, high performance laminate for high reliability and high operating temperatures	G 200, P 95, P96;Isola N7000 series; Nelco	5
CE	Glass	Cyanate ester	Tg approx. 250°C, use is rapidly declining, replace by high Tg FR4 and PI materials	N8000 series; Nelco	2,5
BT	Glass	Bismaleimide-triazine resin	Tg approx. 200°C, very low thermal expansion, use is rapidly declining, replace by high Tg FR4 and PI materials	N5000 series; Nelco	2,5

Controlled impedance & HF applications

Name	Reinforcement	Resin	Comment	Examples	Cost factor (reference: FR4 standard) ***
Teflon	Ceramic filler	PTFE	Suited for machining, assembly of multilayer and hybrid systems possible with FR4	RO3003®;Rogers	4
Teflon	Glass	PTFE	Very low ε_r values, high CTE (z)	RT5870®, RT5880®; Rogers	3
Polymers	Ceramic filler	Duroplast	Suitability for machining is similar to FR4, assembly of multilayer and hybrid systems possible with FR4	RO4003C®**, RO4350®**; Rogers, 25N**; Arlon	3,5
Various	Glass	Epoxy	Low and constant ε_r values and loss angle, high Tg, thermal performance and suitability for machining are similar to FR4	IS620, IS640; Isola	3

Flexible applications

Name	Reinforcement	Resin	Comment	Examples	Cost factor (reference: FR4 standard) ***
Polyimide with acrylic adhesive	---	---	For dynamic flexible applications, adhesive has a very large CTE(z)	Pyralux® LF/FR series**; DuPont	5
Polyimide with epoxy adhesive	---	---	For semi-dynamic and static flexible applications	Teclam® series*; DuPont Akaflex® series*; Krempel	3
Adhesive free polyimide	---	---	For dynamic flexible applications, good thermal performance	Espanex series*; Nippon Steel AP series®**; DuPont	5-6
LCP (Liquid Crystal Polymer)	---	---	For dynamic, flexible applications, very good thermal performance, low water absorption, also suited for HF applications in the high GHz range	R/flex®3600, R/flex®3850; Rogers	8-10

*) Standard material at CONTAG
**) Various thicknesses in stock
***) The factors always relate to costs in series production. Material orders for small quantities with short delivery times can lead to delays at CONTAG.

5. Summary

There is no universal base material for printed circuit boards. Whether for standard applications, HF, high temperature or other applications: A large number of substrate types is available.

For further technological questions concerning circuit boards, please contact our team of technologists (Tel. 030/351 788 – 155).