Hybrid Multilayer –
Cost-effective solutions for high packaging densities

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Possible Constructions

Base materials made from PTFE (Teflon®)/woven glass are being used in larger and larger volumes. The reason for it is based the continuously increasing operating frequencies of electrical appliances. All of a sudden the dielectric properties of FR4 are not adequate any longer to ensure functionality: Dielectric Constant (DK) incl. tolerance, dielectric loss, etc. The correct conclusion lies in the use of PTFE base material, which is manufactured according to applications, even in Europe.

Multilayers made of PTFE have been virtually unknown until about one year ago, but total system cost analyses have changed the rules: Multilayers made entirely from thermoplastic materials are being used as well as hybrid multilayers composed of PTFE and FR4. In all-RF multilayers thermoplastic bonding films made of CTFE (e.g. HT 1.5) or FEP are used to bond the inner layers instead of prepregs. As with FR4 multilayers, increasing packaging densities of printed circuit boards are the decisive factors. It is also possible to obtain coupler structures, whereby PTFE inner layers of different thicknesses and dielectric constants can be bonded together.

A further important aspect for the use of multilayers lies in space saving, whereby one multilayer pcb is used instead of several printed circuit boards. This automatically leads to cost savings for cables, connectors, etc. Hybrid multilayer have the additional benefit of combining the RF function of a printed circuit board with the digital function in ONE printed board. Cost savings are also possible through the thickness selection of PTFE base materials: Instead of 0.76 mm or 1.52 mm base material thickness for double-sided printed circuit boards, only the required dielectric thickness of the RF part will be used; Rigidity for SMT assembly is achieved through the FR4 section.

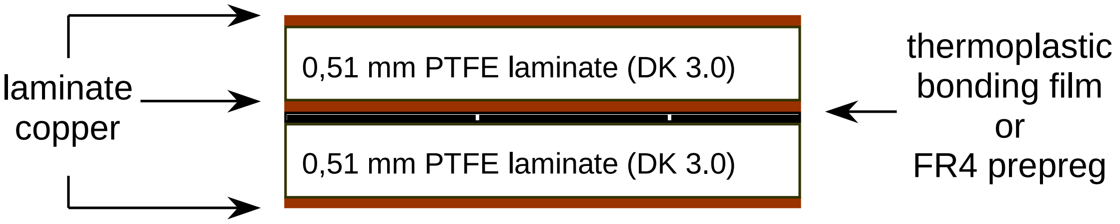

Fig. 1: 3 layer PTFE multilayer

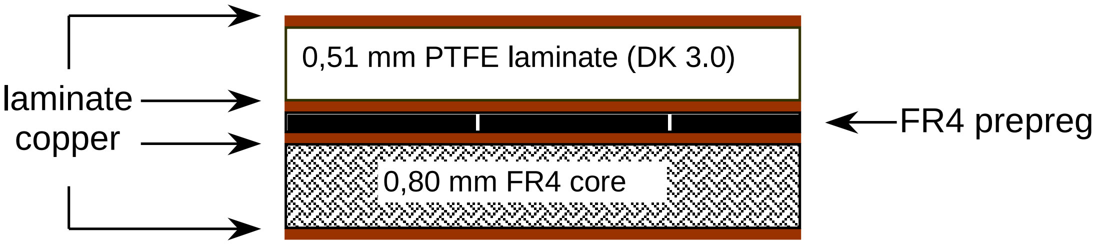

Fig. 2: 4 layer hybrid multilayer FR4/PTFE

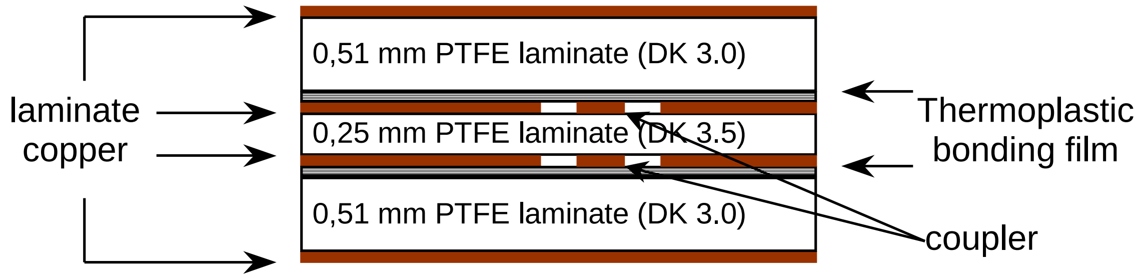

Fig. 3: 4 layer PTFE multilayer with coupler structures and different PTFE laminates

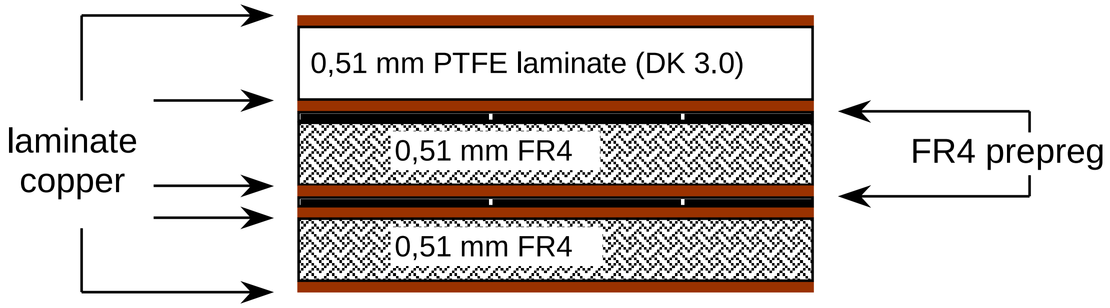

Fig. 4: 5 layer hybrid multilayer FR4/PTFE

Base Material Selection

Standard **FR4** base materials and **FR4** prepregs are used for hybrid multilayers, because the cost of total bill of materials are the lowest once FR4 is involved. In the case of higher layer count multilayers with a built-in RF multilayer it has to be noted that FR4 might start to decompose at the required high press temperatures for bonding films. In such cases the RF multilayer has to be bonded first, in order to use the FR4 press cycle in a second step.

Circuitry of 35 micron copper cladding on **PTFE** base material can be used for lamination with FR4 prepregs; for thermoplastic bonding films with considerably lower dielectric thickness this should be reduced to 18 microns.

Base Material Grade	**Dielectric Constant at 10 GHz**	**Tolerance**	**Dielectric Loss at 10 GHz**	**Water absorption (%)**
RF-35	3.50	± 0.07	0.0018 **	< 0,02
TLC	2.75; 3.0; 3.20	± 0.05	0.0030	< 0,02
TLE	2.95; 3.0	± 0.05	0.0028	< 0,02
TLT	2,45; 2.50; 2.55; 2.60; 2.65 *	± 0.04	0.0006 *	< 0,02
TLX	2,45; 2.50; 2.55; 2.60; 2.65	± 0.04	0.0019	< 0,02
TLY	2.17; 2.20; 2.33	± 0.02	0.0009	< 0,02
CER-10	10		0.0035	< 0,02
FR4 Epoxy/Glass	4.2 – 4.5	± 0.2	0.012	< 0.35

* at 1 MHz
** at 1.9 GHz

Table 1: Characteristics of PTFE base materials vs. FR4

Thermoplastic bonding films are differentiated by either dielectric properties at required frequencies or possible lamination temperature of a multilayer manufacturer (table 2).

	HT1.5	**FEP**
Dielectric Constant	2.35 (@ 10 GHz)	2.00 (@ 1 MHz)
Dielectric Loss	0.0025 (@ 10 GHz)	0.0007 (@ 1 MHz)
Lamination temperature (°C)	225	290
Lamination pressure (bar)	8 – 15	8 - 15

Table 2: Characteristics of thermoplastic bonding films

Multilayer Manufacture

The following overview provides important leads for the manufacture of hybrid multilayers. There are no earth-shattering differences in comparison to all-FR4 multilayers, however information about the small differences can result in higher yields.

Generation of Inner Layers

Like thin FR4 base materials, PTFE base materials should only be micro-etched before photoresist lamination, since mechanical processing, e.g. brushing, leads to stretching.

After etching an expansion in x/y direction is observed, which can be compensated by smaller artwork. As with FR4, the exact value of the expansion is dependent on various factors, such as construction of the base material (dependent on dielectric constant), base material thickness, cladding, amount of copper to be etched off, etc.

Recommendations of table 3 are indicators only. They demonstrate however that PTFE base materials with DK values of 2.75 – 3.5 should be used primarily, because the glass fabrics used for those types are thicker and therefore dimensionally more stable.

Base Material	**Expansion (ppm)**
RF-35	200 – 400
TLC	200 – 400
TLE	200 – 400
TLT/TLX	400 - 600
TLY	400 - 800

Table 3: Expansion of PTFE/glass base materials

Exposed PTFE surfaces after etching should not be touched in order to prevent a levelling of the negative profile of the etched copper foil in the PTFE surface. This eliminates an additional surface preparation by means of plasma. Contrary to myth stories, SEM photographs confirm that this large surface area remains intact even after many days, in spite of the so-called „cold flow“ of PTFE.

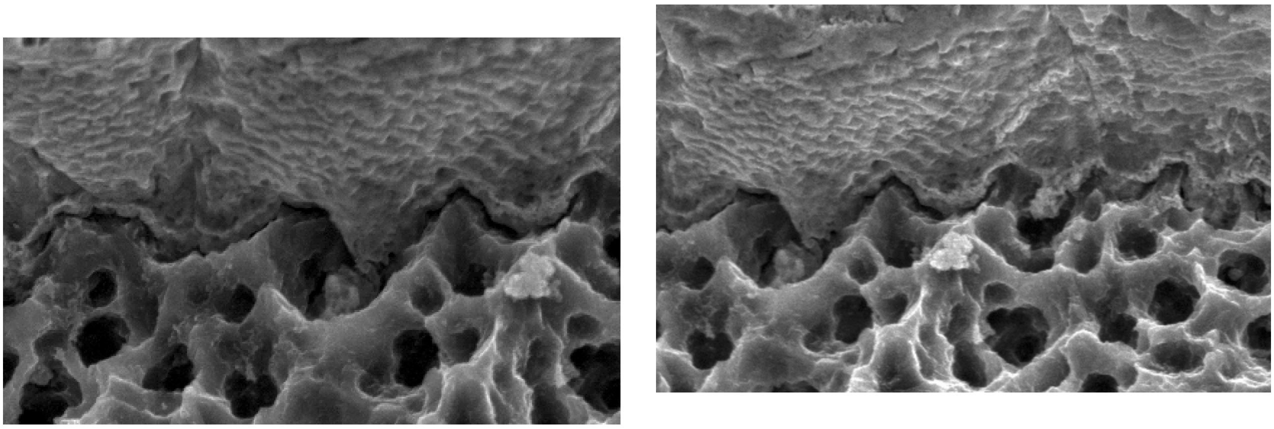

Fig. 5: Etched off PTFE surface a) just etched, b) after 10 days (source: Circuit Foils)

Brown oxide or reduced oxide is recommended to enlargen the surface area of the copper for the interphase with FR4 prepreg. When using CTFE or FEP bond films for all-RF multilayers, reduced oxide is oxidised again under the required lamination temperatures of > 225 °C so that brown oxide is suitable as well. Some pcb manufacturers also use nickel/gold or immersion tin.

Lamination

The most cost-effective multilayer option uses FR4 prepregs under standard FR4 lamination conditions (minimum hold time of 45 minutes at 175 °C.

Thermoplastic bond films (such as HT1.5) soften only, unlike FR4 prepregs, and also do not flow and do not require any cure time. A bonding temperature of 225 °C is reached within 30 minutes, and should be kept for the same time period. A very low cooling rate of approximately 1,5 °C/min until room temperature is reached (fig. 6) yields highest planarity of the multilayers.

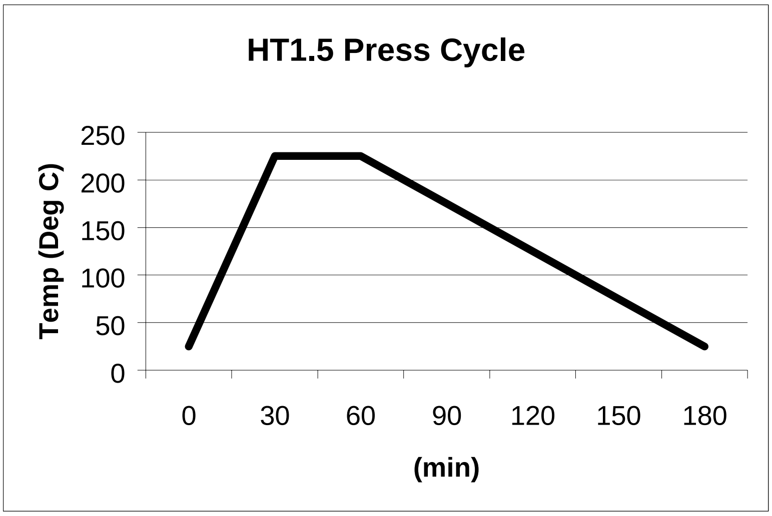

Fig. 6: HT1.5 press cycle

As mentioned in Base Material Selection already, the high lamination temperatures of thermoplastic bonding films limit their use with FR4. In case of an all-RF multilayer as part of a complex multilayer structure this RF multilayer should be laminated first in order to prevent a decomposition of FR4.

Drilling

Since PTFE base materials recommended for hybrid multilayer can be drilled almost identical to FR4, (tables 4, 5), standard FR4 drilling parameter and standard drill bits can be used as base points.

Drill bit diameter (mm)	Chip Load (µm/1)	revs/min	feed (m/min)	Cutting speed (m/min)
0.4	29	110.000	3.2	150
0.8	65	60.000	3.9	150
1.0	85	48.000	4.0	150
1.5	100	32.000	3.2	150

Table 4: Typical drilling parameter for FR4 (source: Hawera)

Drill bit diameter (mm)	Chip Load (µm/1)	revs/min	feed (m/min)	Cutting speed (m/min)
0.4	36	100.000	3,6	
0.8	65	56.000	3,6	140
1.0	76	45.000	3,4	140
1.5	90	30.000	2,7	140

Table 5: Typical drilling parameter for PTFE base material TLC-30 (source: Hawera)

Desmearing

Drill smear is only caused by FR4, not by PTFE, because PTFE has no glass transition temperature. For this reason only epoxy resin has to be removed. Plasma etching is used for this desmearing process, because the PTFE surface in the hole wall has to be treated by means of plasma.

A typical plasma etch cycle uses a 50:50 mixture of oxygen and helium in phase 1, at 4300 W/15 bar/10 min, followed by phase 2 using 100 % Helium at 2575 W/15 bar/15 min and a final temperature of approximately 80 ºC.

Through-hole plating

Experience has proven that both conventional through-hole plating using electroless copper and also direct metallisation can be used for hybrid multilayers. Of utmost importance is an optimal surface preparation of the drilled holes in the process step before, and also optimal conditioning of the holes.

There is one through-hole plating process on the market, which doesn’t require a special hole wall preparation anymore (source: Dexter). This means that PTFE base material can be processed with exactly the same processes as FR4.

Outer layer generation, final finishing

Standard processing steps and chemicals are used.

Routing

Following routing parameter for PTFE base materials are suitable for a standard router bit (table 6)

	PTFE base material TLC-30	**FR4**
revs/min	20.000	29.000
Feed (m/min)	0,9	1,0
Z-Axis feed (m/min)	5	2,5

Table 6: Routing parameter for 2.4 mm router bit (source: Hawera)

Using FR4 parameter as base line, optimal parameter for hybrid multilayers have to be determined.

Summary

This overview for the manufacture of hybrid multilayers demonstrates that exotic material of yesterday can be processed today as easy – or as difficult – as FR4.

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