



Beyond FR-4:

High Performance PCB Materials for Advanced Designs

THE EVOLUTION OF FR-4

In the past forty-plus years of printed circuit board (PCB) manufacturing, the primary material of choice has overwhelmingly been e-glass supported FR-4 resin laminates. This is due to the excellent dimensional stability and reasonably acceptable thermal performance (based on glass transition temperature T_g and decomposition temperature T_d). In general, these materials exhibit impressive performance and excellent cost for a wide range of applications.

Cheaper and lower performance materials such as the CEM class and earlier G10 and FR-5 formulations have largely disappeared and are no longer used in mainstream products. There are still very low-cost foreign die-cut low-tech laminates used for very inexpensive and simple circuits but again have largely been replaced by the competitive price and superior performance of modern FR-4 materials.

Now, as the circuit board has become an integral part of the signal path with controlled impedance and specific transmission line performance specifications necessary for the design, higher performance materials have emerged in the FR-4 category to meet the need. High speed designs requiring lower dielectric constant (Dk) and lower loss tangent have driven materials R&D to provide advanced FR-4 laminates such as Panasonic Megtron 6, Isola FR408, Nelco N4000-13, and even e-glass engineered to lower the Dk such as Nelco's SI (for signal integrity) cloth. More and more modern designs are moving to these higher speed FR-4 offerings.

But there are applications that demand even greater thermal performance and severe environment reliability that requires materials with specific qualities not present in these modern FR-4 laminates. And some of these materials have been with the industry for decades but never found a wider audience due to limited supply and/or higher cost.

POLYIMIDE

This legacy material has been with us for decades and continues to provide a solution for designs requiring increased thermal performance, higher operating temperatures, and severe environment capability. Compared to FR-4's glass transition temperature typically in the 170C to 180C range (typical FR-4 chosen for medium to advanced designs), Polyimide's T_g is in the 260C area. The decomposition temperature is well over 400C (lead-free assembly requires a typical 340C or greater), and the maximum operating temperature (MOT) as tested/certified by Underwriters Laboratories (UL) is in the 140C to 210C range (short and long term testing qualification). This is much greater than the MOT of FR-4 which is typically 130C.

There are a couple of technical issues to be aware of when selecting Polyimide—the first being which chemistry formulation to use. Most Polyimide laminates and prepregs are available in Brominated and Non-Brominated blends (the flame retardant which is also used in FR-4). Non-MDA (Methylenedianiline) formulations also tend to be less brittle. One issue to watch is the moisture absorption characteristics as Polyimide can exhibit higher leakage as compared to FR-4 resin systems. Overall, it is best to compare your design requirements carefully in all areas to be sure that Polyimide will provide the necessary benefits without undue negative performance issues.

PPO/PPE

For many years Getek has been a choice for designers requiring a material with superior characteristics for higher speed designs. The PPO (Polyphenylene Oxide) epoxy resin is the closest to FR-4, but exhibits a lower Dk (3.60) and Df (0.009) in an affordable material that is supported by most PCB fabrication shops due to standard manufacturing specifications. However, in recent years the supply has been reduced as it remains a material not quite in the mainstream, so suppliers now manufacture it on an as-ordered basis resulting in typically longer lead times.

A newer material to excite the industry in the past few years, and one that is rapidly increasing its market share is Panasonic's Megtron 6, which comes in a PPO (as well as PPE) blend. The superior performance is due to very low Dk and Df so it is a natural candidate for high-speed designs. The tradeoff is that it is a Japanese-manufactured material so domestic USA stocking and local availability can vary accordingly.

HIGH FREQUENCY/RF MATERIALS (Hydrocarbon/Ceramic, PTFE, etc.)

Both Rogers Corporation and Taconic offer several flavors of materials engineered to address the needs of the high frequency, microwave & RF world. These are specific laminates, often requiring different types of b-stage/prepreg or bonding sheets to laminate them for multilayer designs.

By far the most commonly used is the Rogers RO4000 series of high frequency materials. RO4350B laminate is a hydrocarbon/ceramic base, which can be manufactured using standard FR-4 type multilayer processes, making it not only popular but economical to manufacture. Low dielectric loss is the major appealing characteristic of this material. Multilayers can be constructed of a "pure package" using Rogers 4450 prepreg, or by using standard FR-4 prepreg. Popular constructions limit the Rogers material to the "caps" of the stackup thereby managing overall cost by using the material only where it is required, and filling the remainder of the board with standard FR-4 cores/prepreg.

PTFE, commonly known as "Teflon" is another fairly common callout for this genre's material requirements. There are many different formulations and laminates such as Rogers 3000 series ceramic-filled PTFE composites, R/T Duroid 5870 and 5880 glass microfiber reinforced PTFE, etc. They can be very difficult in multilayer configurations however, as some require the use of high temperature bonding films or adhesives. The old saying that "nothing likes to stick to Teflon!" sometimes holds true. But their extremely low loss characteristics make them ideal for exacting stripline and microstrip circuit designs.

In Part 1, we covered basic FR-4 and variants that have been used in the commercial and military market for the past few decades, but in this report we will delve into the newer materials that target a specific application and/or market segment. As printed circuit boards have become less a point-to-point wiring base and more an integral part of the signal path, so have the properties of the material become more important due to their effect on the signal.

In the quest to provide lower loss and dielectric constant there have been continual advancements in the resin formulation, such as high-Tg DICY-cured materials, high Tg unfilled phenolic-cured materials, high Tg filled phenolics, and modified epoxies. With advantages gained in signal integrity there have also been trade-offs in reliability, most commonly high temperature solderability and thermal decomposition. And other considerations such as stiffness, brittleness, moisture absorption, outgassing, etc. all need to be considered. So in short there is no “perfect material” that is best in all circumstances but rather a list of characteristics that should be carefully scrutinized and chosen for the particular end-use of the product.

Questions You Should Ask Yourself

When considering a specific laminate material for the design there is a short list of characteristics that must meet the need before final selection:

- Do I need Lead-free assembly compliance (RoHS)?
- Will I be limited by the manufacturer’s available core and prepreg thicknesses?
- What factor is most important—low (or high) dielectric constant or low loss tangent?
- What is the operating (frequency) range of the product (particularly in RF/microwave designs)?
- Are there published and verified outgassing specifications (typ. aerospace and military apps)?
- Is hardness/brittleness a factor?
- What is the average (or maximum) intended operating temperature?
- Will I require offshore availability (for volume manufacturing)?
- Cost?

And there are many more considerations as well. Let’s take a closer look into some of the modern material selections that address specific needs. In the previous installment we reviewed Polyimide, PPO (ex: Getek) and high frequency materials (ex: Rogers & Taconic). Here are a few slightly more (specifically targeted) materials to add to the mix:

Thermal Laminates

As metal dissipates more thermal energy in the form of heat than thermoplastics, early PCB designs that had heat-generating components or were intended to dissipate heat relied on thicker metal layers or cores—heavy copper cores, brass and aluminum were also commonly used. But they came with manufacturing challenges as heavier metal required special fabrication processes which reduced the availability of qualified suppliers or raised the board price as a result.

Today there are specific formulations of laminates engineered to work with a heavier metal layer to dissipate heat more effectively (if not more economically). Some of these materials are available from Bergquist Corporation, Laird Technologies, Stablcor and Arlon-Med. There are combinations of metal-backed laminates that are engineered for specific purposes (such as the booming LED industry). But they still come with their unique manufacturing requirements so selection should be considered by consulting your PCB fabricator's engineering department.

Some of the newer formulations such as Arlon's 91ML and 92ML offer great promise as the fabrication process is not radically different than building a typical FR-4 board. And the material properties are such that the benefit does not come at as high a premium as previous materials—such is the goal of modern material development.

HDI (High Density Interconnect)

Thin-Laminates When it comes to laser microvia processing perhaps the most important characteristic of the material is that it can be laminated in a very thin layer—in order to keep the aspect ratio of the ablated hole manufacturable, and considering that the microvias are completely copper filled it must be thin enough to maintain a reasonable plating cycle time. Modern microvias are plated with copper from bottom to the top, and the technology must still allow a fairly thin surface thickness to facilitate fine lines and spaces—it would seem that one works against the other! So a fully copper plated/filled microvia must be completely filled, void-free, and post-planarized very flat to provide a planar surface for a robust solder joint. And here's the rub—the smaller the microvia the thinner the associated dielectric thickness has to be.

Around fifteen or so years ago the cell-phone industry required a thin resin-coated foil (RCF)—often referred to as resin-coated copper (RCC) that would enable very small wellformed laser ablated microvias as there was the absence of e-glass support (as in standard PCB materials). But the trade-off for small diameter holes was a serious issue with X/Y dimensional stability (layer registration) due to the lack of reinforcement. If the features were as large as possible and the production panels as small as possible (to minimize registration errors), then it was workable, but as chip packages evolved ever smaller the registration issues increased. So RCF/RCC was gradually phased out, and for many years it was back to thin prepreg (ex: 106) or flat-weave e-glass varieties of the same. Now there are improved materials available that address X/Y registration, small pad adhesion, and all of the other drawbacks while still maintaining the lack of supporting e-glass which is necessary for small diameter hole formation. Products such as ZetaLam introduced by Integral Technologies Corporation meet this current need.

Embedded Capacitance Materials

With the need to considerably reduce the overall form factor of modern PCB designs one of the methods is to eliminate passive surface components, and even though the overall size and pitch of such has been constantly shrinking they can still take up a lot of space. Add to that the need to shorten signal lines and the popularity of capacitance layers has steadily been on the increase.

The most commonly known version of capacitance layer pairs has been the product marketed as BC (ex: Buried Capacitance—which began as "ZBC" when Zycon Corporation originally patented the concept—then bought by Hadco Corporation and finally Sanmina Corporation in its present day

iteration). Basically, as opposing copper planes are placed closer to each other a natural capacitance can be achieved. It has been a technology that was licensed (both in the material manufacturing as well as PCB fabrication) but there are also alternative products that achieve similar results without a license (ex: DuPont HK-4, 3M ECM, etc.). Basically added to the board stackup as a thin plane/plane pair with the proper routing the electrical benefit can be achieved--and also reducing the number of assembled caps as a side benefit makes it attractive if your design warrants it.

Thin-Film Resistors

The same concept of eliminating surface components is the idea behind thin-film resistor layers. As a hybrid layer of Ni/Cr or Ni/P (depending upon the product—Ohmega or Ticer—two of the most commonly used technologies). The etched signal layer will include in-line resistors (the value being determined by surface area) which are then embedded within the board as laminated layers and thus eliminates surface components and possible trace length reduction. It is a mature process but does take additional processing and testing steps so there is a natural cost adder involved.

We have only scratched the surface of what is available in the advanced PCB world and there are new technologies being introduced every year, but you will want to thoroughly investigate each option and discuss the pros and cons with the PCB fabricator as with any advanced technology. Please contact your Advanced Circuits' sales representative for more information about our extensive selection of advanced PCB materials, capabilities, and state-of-the-art equipment.