

TECHNICAL ARTICLE

Everything You Ever Needed to Know to Process PTFE Microwave and RF Printed Circuit Boards (Without Local Anesthesia)

by Mark Hodgson and Chet Guiles

Processing of PTFE need not be a matter of “Shock and Awe” for a board fabricator if a few simple but critical process parameters are defined and controlled. In this article, the various critical process steps are discussed and starting point recommendation made. Critical areas include drilling, surface and PTH treatment, and lamination, and are covered in detail along with the starting point suggestions for most other process steps. These process recommendations should help the fabricator to design and optimize his process for PTFE fabrication.

The production of Teflon® (PTFE) printed circuits for wireless assemblies, such as antennas and base stations, is on the increase. PTFE laminates, as double sided printed circuits (PCB's) or as composite subassemblies on an FR-4 multilayer base board, have become commonplace. PCB shops specializing in PTFE, have typically supplied this market segment, but as the demand for wireless integration continues, the increase in PTFE

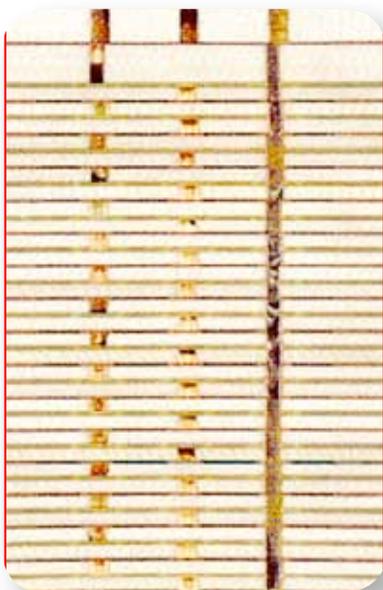
circuits and mixed dielectric printed circuits will increasingly penetrate the traditional FR4 board shops. That being said, PTFE laminates pose challenges to the conventional FR4 printed circuit shop.

There is a widespread belief, especially among PWB shops who do not presently work with microwave and RF circuits, that there is something “magic” associated with processing PTFE materials and that of necessity making PTFE boards is going to cause unendurable pain and result in unacceptable process yields. That translates into reluctance to take on PTFE jobs or into “fear-based” pricing that drives away perfectly good customers. And these days, how many of us want to frighten away paying customers?

The photograph at left (courtesy of Tyco Printed Circuit Group and Space Systems Loral) is a section of a 64 layer ceramic-filled PTFE board that is part of the beam forming antenna array for the space-based Globalstar system.

This sequentially laminated board was made using Arlon's thermally stable CLTE laminate and a variety of bonding media. No doubt this is an exceptional instance, and it is likely that every shop does not have the technical resources to undertake such a complex project, but is simply shown as a dramatic example of what can be done.

This article is a simplified attempt to look at the steps involved in making a PWB, with special emphasis on those areas where PTFE differs from traditional materials due to its unique properties and chemistry. As much as possible, without disclosing any proprietary information, this information derives from actual hands-on experience with making PTFE boards at numerous locations. While dedicated or specific equipment and conditions have been noted to provide as much detail regarding technique as possible, there is endless variation in technologies and procedures employed by the various printed circuit shops, and so there are no hard and fast rules for fabrication.



Where applicable, advantages of one approach over another are identified, but these are starting point guidelines and each fabricator should fine-tune their own process.

The Bottom Line

There are three specific areas that the PWB shop needs to master to successfully process PTFE boards and if we can get these three right, everything else will be essentially like processing rigid double sided FR-4.

1. Copper Surface Preparation
2. Drilling PTFE Materials
3. Plated Through Hole and PTFE Surface Preparation

All of these will be discussed in detail below, and we believe that with some up-front engineering and a little experience, PTFE should be no “harder” to process than any other material.

Storage and Handling

Store materials in a cool dry environment away from direct sunlight, avoiding surface oxidation and contaminants. PTFE laminates are softer than, and laminate surfaces will dent, wrinkle, and bend significantly more readily than their FR4 counterparts. Surface imperfections that might prove insignificant in consumer electronic circuits can affect functional performance in RF circuitry. Lesser defects such as nicks, pinholes and etch outs may contribute to passive intermodulation (PIM) distortion. Higher dielectric constants mean smaller packages and finer lines, demanding tighter controls and superior handling practices. Once etched, ceramic-filled high Dk laminates can be susceptible to moisture uptake and hold times

or storage conditions should be managed to minimize this.

PTFE laminates need to be stored flat with support. If they are stored in such a way that they can sag or droop, they will almost certainly take a “set” over time that will result in their being much more difficult to handle.

Surface Preparation/Preclean

All copper foils are treated to reduce the likelihood of oxidation of the copper surface. This anti-tarnish must be chemically removed to ensure adequate adhesion for photo resist. Several good proprietary chemistries exist on the market today, and if you are a home-made chemistry junkie, sodium persulfate, nitric and/or sulfuric acid mixtures with warm deionized rinses will adequately remove the protective treatment. Removal of 40 millionths of an inch is typical and adequate to remove the surface treatment while promoting photoresist adhesion.

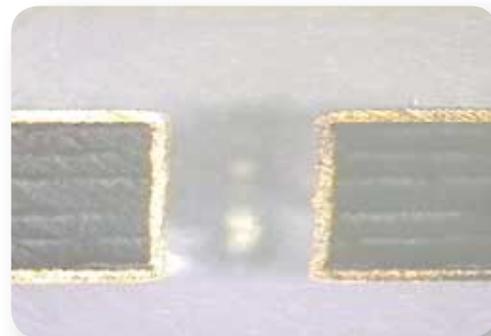
NOTE: The copper surface of PTFE laminates should not be mechanically prepared. Composite brushes, pumice scrubbers or bristle style surface preparation equipment suitable for rigid materials should be avoided as soft substrates will stretch and absorb stresses that will lead to unpredictable dimensional results post etch. This should extend as well to grit blast sanding, even with finely divided aluminum oxide abrasive. Layer to layer registration of multilayers or post-etch registration of soldermask, secondary drill (NPTH) and/or legend applications will be problematic if this simple precaution is not adhered to.

Horizontal or vertical multi-sump equipment is in use in nearly all

printed circuit shops. The primary sump is typically utilized as a soap/ degreasing bath to remove the potential organics while a second sump will microetch the copper followed by a warm deionized water rinse. Chemical cleaning and surface prep will save untold problems with registration after etch.

Drill

A few hard fast rules apply here. Employ new tools at all times when hole plating will be required. As a general guide, start at 2.5 to 3 mil chipload and use a spindle speed that will give 350-450 sfm (surface feet per minute) for your particular drill diameter. PTFE tailing, or spurious laminate fibers can be eliminated with slower infeed and higher chiploads. Ceramic-filled laminates, chosen by PCB designers because of their modified dielectric constant, coefficient of thermal expansion and other properties, offer an additional benefit to the fabricator – easier drilling and cleaner holes. However, ceramics in the laminate can increase drill wear by 25% to 50%, and 350-500 hits is typical compared with 1000 hits for non-filled PTFE products. Secondary tooling holes and/or NPTH (non plated through holes) can be drilled with resharpened tools as long as they are inspected and



.020 1/1 DiClad 880 .024 +/- .002 FINISHED

copper plating will not be required. Hole quality will suffer with use of resharpened tools.

The entry material most often used is .007-.010" aluminum so you need to watch for aluminum debris in the flutes and adjust feed rate if buildup occurs. Ensure that pressure feet are of high quality and operating properly and inspect the bottoms of pressure feet for debris, as PTFE is extremely soft and crud under the pressure feet will dent or scratch the laminate. Backup material is less critical when drilling PTFE. It should be 0.062- 0.093" (2.3mm) thick rigid phenolic or tech board to accommodate the angle of the drill point and should be sufficiently rigid so that it does not deflect (as sometimes happens with vented material) due to pressure of the pressure foot. PTFE will tear leaving tails or streamers if the backup material flexes. Retraction rate should never exceed 500 ipm as excessive retraction speed may also smear PTFE vertically in the hole.

Combinations of drill type, tool supplier, entry/backup materials and drill room conditions are endless. Adjust a single variable at a time or employ well-designed DOE techniques when maximizing the drill operation and evaluate results via cross section and quality of hole metallization.

Deburr

If deburr is required use light orbital hand sanding, wet, with 600 grit wet/dry paper. Use compressed air to remove debris from holes. Do not utilize mechanical scrubbing equipment. Stresses introduced will, as mentioned earlier, result in unpredictable material movement.

Hole Preparation prior to

Metalization

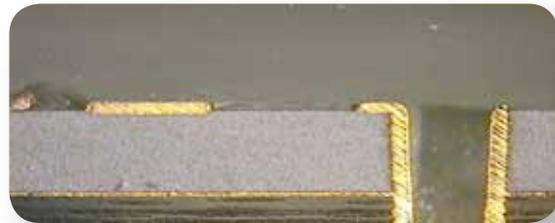
Sodium etchants or Plasma gas cycling are the standards within the PCB industry. Stripping /removal of the fluorine from the Teflon surface is critical to the metallization, marking and multilayering of PTFE laminates.

Plasma: Plasma gasses and cycles vary within the PWB industry. The ideal plasma gas for PTFE is probably hydrogen because of its small atomic radius and the fact that it can react with fluorine and remove some of it from the PTFE surface as HF gas. It is well understood that the hydrogen plasma treatment lasts longer than other plasma treatments. Other fabricators prefer not to handle hydrogen, and prefer the use of an inert gas plasma such as a 30 minute nitrogen treatment, although at least one of our major customers has had unfailingly good success with a conventional 30 minute treatment with an 80/10/10 mixture of Oxygen, CF4 and Nitrogen.

Note: Plasma is a surface micromechanical treatment (you can think of it as atomic level sand blasting) and does not remove fluorine atoms entirely from the PTFE, which can "heal" itself over time. As a result hold times post plasma should be restricted to less 12 hours unless you are using hydrogen, in which case it may be stretched longer..

Sodium Etchants: provide increased post processing hold times, reduced cycle time and complete stripping of the fluorine atoms from the PTFE surface. As a result of this stripping action the bond lap shear values increase over those achieved by Plasma. W.L.Gore, thru distributors, and Acton Technologies Inc. are the

present sodium etch providers. Acton Technologies designs inline processing equipment and higher flashpoint chemistry to allow for safe processing of PTFE laminates in standard dip chemistry processing tanks, with minor modification, and they offer treatment of spent chemistry. Processing guidelines for sodium etchants are provided by suppliers, and should be studied carefully prior to application. Shelf life of Sodium etched products, if protected from excessive temperature, humidity and ultra-violet light can be several months. Studies have shown bond strengths continue to increase for the first 24 hours after etching.



Ceramic-Filled PTFE Board over FR-4 Core with PTH

Metalization

Electroless copper and direct metallization requires no additional considerations provided an adequate surface has been achieved in thru hole preparation. Several PCB shops double Dep thru electroless copper and more than half of the PTFE processors that utilize plasma as hole preparation elect to double Dep. Glass etch is not required if drill quality is acceptable. Sodium etchants and Plasma gasses only affect the surface of the PTFE and do not result in a positive etchback, as is the case with thermoset resins.

Copper Plating

Copper plating of PTFE and ceramic loaded high Dk laminates requires some special considerations. The higher Z-axis CTE's of "pure" PTFE laminates necessitates use of high tensile and elongation of plated copper. A 12-15% minimum elongation copper plate at a minimum plating thickness of 0.0015" will minimize the tendency to crack in high aspect ratio holes. CTE's of FR-4 start near 50 ppm in the Z-axis when tested at 180 degrees F, while PTFE laminates vary widely, from 40 ppm for CLTE (a ceramic filled Arlon PTFE laminate) to over 250 ppm for some pure PTFE-glass laminates such as DiClad 880. While PTFE has an inherently low modulus and does not create the force generated by more rigid materials such as epoxies during expansion, barrel cracks, pad lift, and blistering will nonetheless be minimized and/or eliminated by using high ductility copper.

Note: If tin-lead plating is required with high resin content materials (very low dielectric constant for instance) it will be necessary to plate at least 2 mils of copper in the holes or they will to enable them to survive thermal stress at reflow!

Lamination

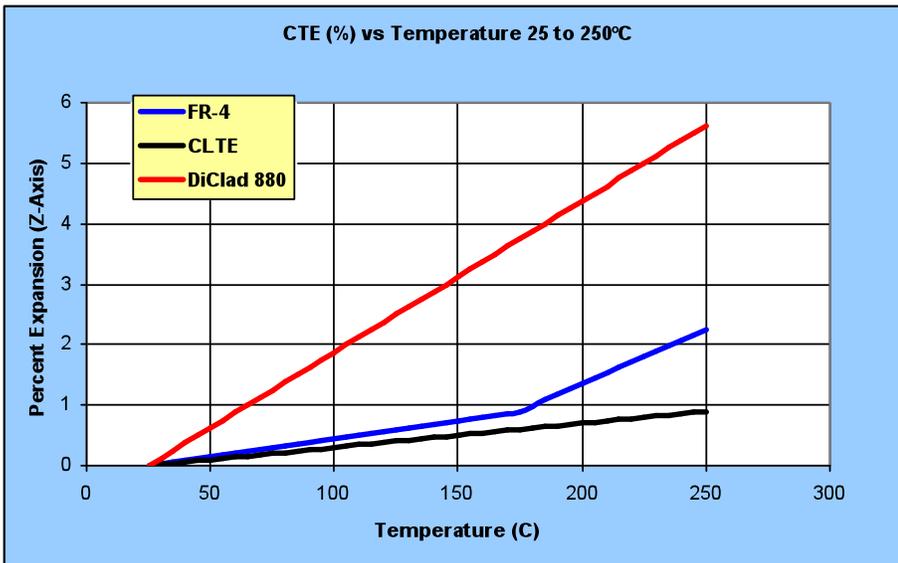
Other than for FR-4 hybrids, oxide pretreatment is not recommended or necessary for multilayering of PTFE laminates. Press temperatures of 700+°F (fusion bonding) exceed oxide limitations. Adequate prep can be achieved by microetching copper circuitry 30 seconds in ambient 5% sodium persulfate followed by warm deionized water rinse prior to lamination. Bake all ceramic loaded laminates a minimum of 1 hour @ 225–250°F prior to lamination to drive off moisture as ceramic loaded laminates tend to have increased moisture uptake during chemical processing. Uncontrolled laminate storage after etch may also require baking to remove absorbed water when thermal excursions in operations such as HASL are employed.

a. Fusion bonding of PTFE laminates, lamination without the use of bonding films and/or prepregs, is achieved utilizing 710 degrees F minimum press temperature with a minimum at-temperature time of 50 minutes. Pure PTFE has a high melt viscosity and flows slowly, so do not shortcut the at temperature dwell without careful experimentation. Because of the high viscosity and resistance to flow of PTFE, lamination pressure of 450-475 psi is required and should be used as a starting guideline for any development.

Note: Use caution during lamination as the temperatures required are above the flashpoint of many commonly used thermal lagging materials.

- b. Bonding films of lower melting range fluoropolymers may be used for reduced temperature processing (250°F or 425°F temperatures are currently available) while still maintaining low dielectric constant and loss properties for minimal interference with the electrical design of the board.
- c. FR4/PTFE hybrids: typically employ FR-4 prepregs and lamination cycles. Oxide treatment of the PTFE layer to be bonded to FR-4 is required. Plasma cycle the PTFE layer prior to oxide treatment. Laminate within 12 hours of circuit etch if plasma/sodium etch is not employed or unavailable.
- d. Ceramic Filled Bonding Plies – ceramic-filled fluoropolymer woven glass reinforced prepreg, such as Arlon's CLTE-P, may also be used as bonding plies for MLB lamination. This is a higher temperature bonding material that requires temperatures over 550°F but closely matches the mechanical and electrical properties of ceramic-filled CLTE laminates.

Ceramic loaded laminates usually need to be baked prior to the lamination process. Bake racked or interleaved panels @225-250 degrees F, (110-120°C) for 60 minutes minimum. Longer cycles are required if panels are stacked. A thermocouple at the center of stack will ensure that the package sees a proper drying cycle when stacking is deemed necessary.



Designer's Note: When designing multilayer PTFE boards, a major consideration should be total thickness vs. Z-direction CTE. As you can see in the attached chart, a pure PTFE product such as DiClad 880 (pictured) can have a Z-expansion of as much as 5% (room temperature to 250°C) compared with a little over 2% for multifunctional epoxy. One of the benefits of certain ceramic filled products is low Z direction CTE -- and since there is no Tg in the range, there is no CTE rate increase above the Tg as is seen with epoxy.

Soldermask

It is recommended that soldermask be applied within 12 hours of circuit etching. To enhance SMOBC (soldermask over bare copper) adhesion to large surface board areas it is recommended to process thru a standard PTFE plasma cycle or sodium etch process prior to soldermask application. You can microetch copper circuitry, to promote adhesion prior to soldermask application.

If required, bake ceramic loaded PTFE laminates prior to application of mask @ 225-250°F (110-120°C) for one hour to drive off residual moisture.

Note: Sodium etchants will discolor PTFE laminate surfaces (they will turn light to medium brown) due to the removal of surface fluorine. This should be considered normal and is not cause for concern. In some cases it will be necessary to explain this to an OEM source inspector if he/she is not certain what is causing the color to occur.

In our experience a large percentage of soldermask applied over PTFE products is used to change the electrical characteristics, such as impedance of copper traces, or to isolate or protect circuits, especially during hand soldering. This means that adhesion to the copper (which has already been prepped) is critical and additional surface preparation is not normally desirable as it may interfere with bond to the copper.

If solder mask needs to cover a broad area of the PTFE surface, then surface preparation is definitely necessary and can be done either with sodium etch or with plasma.

HASL

Prior to HASL all laminates require a bake cycle. This cycle minimum is 1 hour @ 225-250°F. Repeating for emphasis -- This is a minimum cycle. Interleaf or rack laminates, and do not stack, since stacking laminates will require longer bake cycles that can in turn degrade copper bonds (i.e. reduce peel strength values) in reduced oxides on circuit patterns.

Route and Final Fabrication

As in drilling, a few hard fast rules will optimize successful fabrication. Rigid entry and backup materials are required and intimate contact between pressure foot and entry will minimize tailing of the PTFE. It is important to exert sufficient clamping pressure to the material stack. As in the case of drilling, inspect the bottom of the pressure foot for debris, burrs etc. prior to use to eliminate potential damage to soft substrates. Use commercially available two flute, slow spiral, up-cut end mills to depanelize finished circuits. For an .062 cutting tool, a spindle speed of 15,000 rpm and a table speed of 15 linear inches per minute are considered standard.

Water jet routing has also proven extremely successful. This methodology eliminates the need for entry material and cutting tools and eliminates tailing of the PTFE. Several companies offer small orifice high pressure cutting of PTFE laminates. Small orifice (0.010") is available and stack heights to 1" make this alternative very attractive in the case of small part fabrication. The limitation is the single cutting head. Mechanical routing equipment employs 4 -6 cutting spindles while water jet employs only 1.

Passive Intermodulation (PIM) Distortion

Intermodulation affects products in finished assemblies. PIM values of finished antennas have been evaluated by construction methodology. Panel plated circuitry coated with immersion tin have performed 10-20 dBc greater than those with electro-plated tin. The "top hat" effect of etching beneath the plated tin can result in the rounding over of the tin edges that become in effect resonant cavities that aggravate intermodulation. Immersion tin/panel plated products totally encapsulate the etched features and the resulting trapezoidal cross-section minimizes this potential effect.

Conclusion: Processing of PTFE/PTFE Ceramic loaded Laminates require only a few changes or modifications to the standard FR-4 techniques. Drill, hole preparation, copper plate and final route require only slight changes from those of standard FR-4 processing. Entry and back-up materials, new drills, higher spindle speeds matched to slower entry feeds will resolve all drill considerations. Bake cycles prior to thermal excursions will eliminate blistering and pad lift as a result of

moisture uptake. Higher tensile and elongation of plated acid copper eliminate pad lift and barrel cracking associated with higher Z-axis CTE's of high PTFE to glass ratio products, typical of the lower Dk laminates. Ceramic loaded products require the most consideration. Drill and rout, moisture uptake, and sodium or plasma gas hole preparation are the areas that will require consideration.

(This is the "fine print": materials and processes should be evaluated in detail to ensure their suitability for the manufacture of in-specification production parts from individual designs. The information in this article is presented in good faith and based on extensive experience, however its applicability to any specific product or process is entirely the responsibility of the user.)

Teflon® is a tradename of E. I. DuPont de Nemours Company, Wilmington, DE

DiClad® and CLTE® are registered tradenames of Arlon.

Mark Hodgson was Arlon's Sales Engineer for the Southeast Region for many years and had extensive experience in fabrication and front-end design of both conventional and PTFE PWB's. Mark passed away early in 2012. He will be missed.

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Additional information about Arlon, including the text of "Everything You Ever Wanted to Know..." can be found at www.arlon-med.com

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