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Technical Bulletin #2

TAKING ADVANTAGE OF PURE PTFE'S QUALITIES IN MICROWAVE SUBSTRATES A TECHNICAL DISCUSSION

Since the advent of PTFE, approximately 40 years ago, thousands of engineers and designers have discovered many uses for this amazing material. One is the dielectric material in microwave substrates.

UNIQUE CHARACTERISTICS OF PTFE

Electrical and Physical Properties

PTFE has unique electrical and physical properties: low loss tangent and dissipation factor, low dielectric constant, very high volume and surface resistivity, high temperature resistance, chemical inertness, and zero water absorption. PTFE has been used as insulation in many RF (low to microwave frequencies) applications, including commercial, government and military, that require these special properties. It is the only material currently available where all these desired and diversified characteristics exist together.

Mechanical Properties

PTFE is a semi-rigid material, and due to this characteristic it has two minor drawbacks, namely; cold flow extrusion and a higher coefficient of thermal expansion ratio than rigid materials. Some substrate manufacturers have added various elements to the PTFE to make it more rigid. This has reduced these problems slightly, but has, in turn, created more serious problems, such as raising the loss tangent and creating non-uniformity of the dielectric constant in the substrate. Additionally, the dielectric constant is not consistent over temperature and frequency variations.

POLYFLON'S CUFLON® SUBSTRATE

Polyflon has taken advantage of the PTFE qualities and coupled them with a proprietary plating process to produce a microwave substrate called "CuFlon" whose performance cannot be equaled by any other substrate available at this time.

The pure PTFE material with a dielectric constant of 2.1, and a maximum peak dissipation factor of .00045 (at 1 to 3 GHz), is available in standard and custom dielectric thicknesses, (.001" to .005" and .010"to .125") with double sided copper, in a standard range of copper plated cladding from 1/3 oz. (0.5 mil), to ½ oz. (0.7 mil) and 1 oz. (1.4 mil). More or less copper can be applied in the plating process to meet customer requirements.

Because Polyflon's proprietary plating process, engineers are enjoying the many advantages of PTFE, and have found simple ways to resolve the few minor drawbacks of the PTFE materials.

STEPS TO OFFSET PTFE'S DRAWBACKS

1) Cold Flow

Cold flow is defined as "a change in dimension, or distortion, caused by sustained pressure." In the case of stripline construction, the PTFE dielectric will have its Z dimension compressed. Problems can arise from this type of construction since the b dimension used for calculating stripline impedances and coupling dimensions consists of the total thicknesses of the dielectric materials use (Figure 1). If this dimension changes (decreases) under pressure, the initial calculated values of impedance and coupling no longer apply, and the circuit will not operate as designed. To eliminate this problem, the use of microstrip construction is the recommended alternative medium for PTFE substrates. With this type of construction, there is no pressure applied to the dielectric material. There is only one laminate, and therefore the cold flow problem is eliminated.

When specifications call for stripline construction, make sure the boards fit snugly in the housing so that lateral movement is impossible. In this way, there is nowhere for the PTFE to flow.

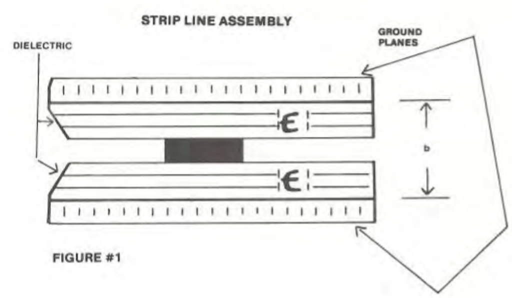

FIGURE #1

2) Coefficient of Thermal Expansion

This is in reference to changes in dimensions of the PTFE dielectric material, primarily in the X and Y directions, when subjected to wide temperature variations (both hot and cold). Excessive dimensional changes can result in thin copper circuit traces being broken due to the copper being stretched beyond the breaking point.

To minimize these dimensional changes, certain precautions should be observed when laying out the circuit traces. The thin narrow trace lines should be made as short as possible. It is also recommended that long thin trace lines be meandered rather than stretched out over the entire length or width of the CuFlon circuit board. Do not keep thin traces close to and/or parallel to the outside edges of the circuit, since the greatest dimensional changes are along the outside edges of the PTFE dielectric material.

When specifications call for the CuFlon circuit board to operate over a wide temperature range, and there is a critical length of line needed for circuit operation (a delay line, for example), it may be advantageous to place this length of trace line on heater coils or a heater blanket. The trace line temperature can then be elevated, closely controlled, calibrated, and operated at this temperature regardless of what the ambient temperature is. These methods, if used, can offset the X-Y dimensional expansion of the pure PTFE dielectric substrate material. Attaching the CuFlon circuit board to a rigid ground plane will also prevent movement in the X-Y plane.

3) Ground Plane Attachment

When a copper circuit is etched on CuFlon substrates, 10 mils thick and below, the board will have a tendency to curl on the edges. The best solution, if this should occur, is to attach the board to a rigid ground plane.

To ensure a flat level circuit board, solder or epoxy (conductive) the CuFlon board to the rigid ground plane with appropriate and uniform weights placed on the circuit board, to ensure its flatness. The term "uniform" is used so that the phenomena of "cold flow" does not come into effect. Too much weight on the entire surface, or use of an uneven distribution of weight, will cause cold flow in only one area.

CuFlon substrates should never be attached to a rigid ground plane by screws alone. If this is done, the PTFE dielectric material will be compressed and forced out from under the screws. The continuity (contact) between the circuit board ground plane and the rigid ground plane will also not be uniform across the circuit board where there are no screws. This will cause a discontinuous ground plane and will result in faulty circuit operation. Transmission of microwave energy in the circuit board assembly relies on a continuous ground plane.

ADVANTAGES OF PURE PTFE SUBSTRATE

- Ultra-Low Loss Tangent & Dissipation Factor
- Low Dielectric Constant – consistency over temperature & frequency range
- Negligible Moisture Absorption
- Isotropic Material
- Excellent Bond Strength

1) Ultra Low Loss Tangent & Dissipation Factor

Since the dielectric in CuFlon is pure PTFE, the losses are lower than those encountered in PTFE/glass materials. This can be further understood by referring below to the discussions on moisture absorption and anisotropy. Figure 2 shows the relationship between the dissipation factor vs. frequency for woven and microfiber PTFE/glass and CuFlon, PTFE-based material. The dissipation factor of the pure PTFE used in CuFlon reaches a maximum peak of .00045 at 1.0 to 3.0 GHz, with the higher frequencies being much lower. This makes CuFlon an excellent choice for low loss, very high frequency applications. This, as seen in Figure 2, is not the case for PTFE/glass laminates, since the losses increase substantially when used above 5 GHz.

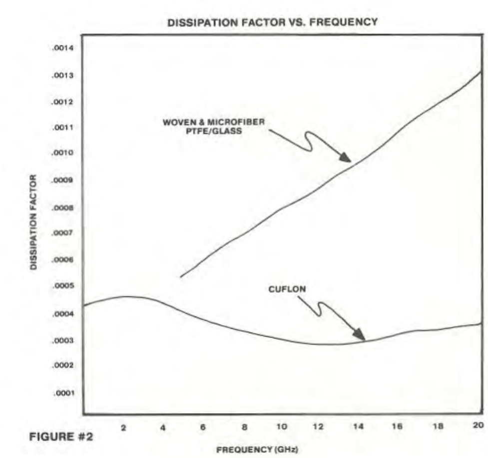

FIGURE #2

2) Dielectric Constant

When designing for higher frequency applications (above 10 GHz), the dielectric constant is a very important parameter to consider. Ideally, you would like to operate with an air dielectric constant of 1.0. This would ensure that any fractional wavelength components would be small enough to eliminate any cross-talk between the lines. Since this is not possible, you must consider the material with the lowest dielectric constant. Figure 3 illustrates two important points of the CuFlon dielectric material. First, the dielectric constant is below 2.1, which is excellent for very high frequency operation. Secondly, the dielectric constant is consistent from 1 to 20 GHz and beyond. This is very essential when broadband components and systems are to be designed.

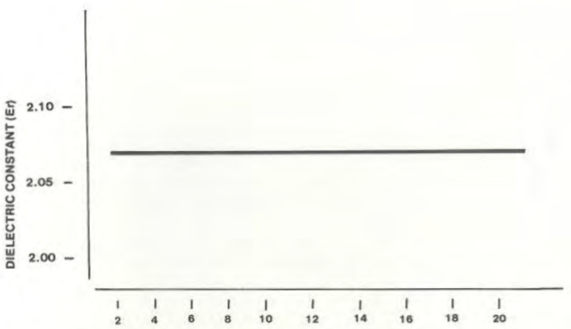

FIGURE #3

3) Moisture Absorption

It is important that a microwave laminate absorb no moisture. In order to ensure that the dielectric constant of the dielectric material remains consistent, it is necessary to prevent any foreign substance from entering and contaminating the material. This is what moisture does when it penetrates a microwave laminate. This contamination changes the dielectric constant and adds to the material losses. Figure 4 shows a comparison of woven glass/PTFE, microfiber glass/PTFE and CuFlon's dielectric in reference to moisture absorption. It can be seen that both the woven glass/PTFE and microfiber glass/PTFE absorb moisture while CuFlon's dielectric has less than .01% absorption. This is because of its uniform, pure PTFE structure.

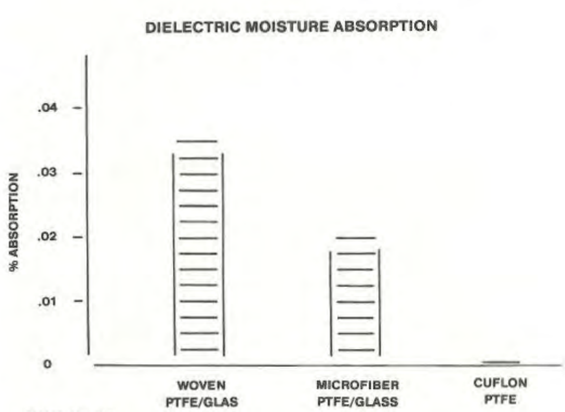

FIGURE #4

4) Anisotropy

Anisotropy is a term used to describe the difference in dielectric constant, in a microwave dielectric, in the X-Y plane of the material, compared to that in the Z direction. This difference comes, about when fill materials (ceramic, glass, etc.) are added to a pure material (PTFE) to try to obtain dimensional stability. The dielectric constant is no longer consistent in all directions when these fill materials are added. The difference in consistency (XY/Z) is measured as anisotropy. Figure 5 shows anisotropy for woven glass/PTFE, microfiber glass/PTFE, and CuFlon. The woven glass/PTFE and microfiber glass/ materials have anisotropy greater than 1.00 (from 1.02 to 1.20). CuFlon is completely uniform and shows anisotropy of 1.00. This is a very important parameter when working in the higher RF frequency ranges (above 10 GHz).

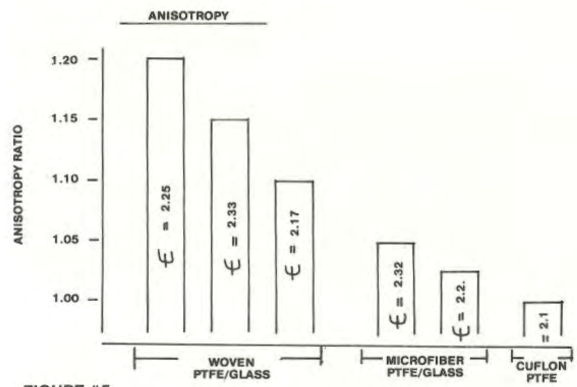

FIGURE #5

5) Copper to PTFE Bond Strength

Bond strength of the copper – PTFE laminate is defined as the amount of pull force, measured in lbs. per inch, on a 1 inch wide laminate, applied at 90 degrees, that will break the bond and separate the copper from the PTFE dielectric. A major problem encountered when using PTFE substrates for microwave circuits has been the lifting of copper circuit traces from the dielectric when soldering components to the circuit traces.

This problem can be minimized by improving the copper to PTFE bond strength. Polyflon has accomplished this by electroplating the copper to the PTFE rather than by using conventional bonding techniques. This plating process produces an intimate bond between the copper and dielectric, particularly at elevated temperatures. To illustrate this point, the following test was run on Polyflon's CuFlon substrate.

1. A series of .010" and .015" wide copper trace lines were etched on 2" squares of CuFlon measuring .031 in dielectric thickness, with ½ ounce copper on two sides.
2. A 35 watt soldering iron was used to heat and apply 60-40 solder to the lines. (60/40 tin/lead solder melts at 370º F, 187º C). The solder was applied along the entire length of the lines. There was no copper separation from the dielectric.
3. The soldering iron was then run back and forth over the lines to keep the entire length of the lines cov-

ered with liquid solder for a period of 1 to 2 minutes. There was no separation of the circuit traces from the dielectric.

The test outlined above shows how well the CuFlon substrate is fabricated and ensures the etched copper traces will remain intact, before, during, and after any necessary assembly construction operations.

COMPARISON OF CUFLON TO TYPICAL PTFE/GLASS LAMINATES

PARAMETER	CUFLON	PTFE/GLASS
Dielectric Constant	2.10	2.17
Dissipation Factor (10 GHz)	.00035	.0013
Peel Strength	8 lbs. /in.	8 lbs. /in.
Water Absorption	0.01%	.035%

It can be seen from the above that CuFlon has some very desirable properties for microwave applications and specifically for higher frequency applications. A combination of the pure PTFE material and electroplated copper make CuFlon an outstanding material for microwave usage.

SUMMARY OF CUFLON'S ADVANTAGES

CuFlon when used properly, will perform better than any other PTFE/glass laminate now available for microwave usage. It offers the designer the following advantages:

- Very Low Losses
- Low Dielectric Constant
- Consistent Dielectric Constant Over Frequency and Temperature
- Negligible Moisture Absorption
- A Fully Isotropic Material
- Very High Volume and Surface Resistivity
- Excellent Line Definitions When Etched
- No Bonding or Adhesives Built Up at the PTFE/Copper Interface
- Excellent Solderability