Table of Contents

Thermal Clad® Overview

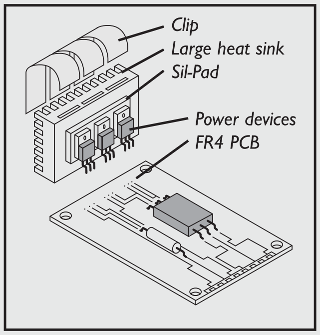
Key Benefits Of Thermal Clad®

The Bergquist Company is the world leader in the development and manufacture of thermally conductive interface materials. Thermal Clad Insulated Metal Substrate (IMS®) was developed by Bergquist as a thermal management solution for today's higher watt-density surface mount applications where heat issues are a major concern.

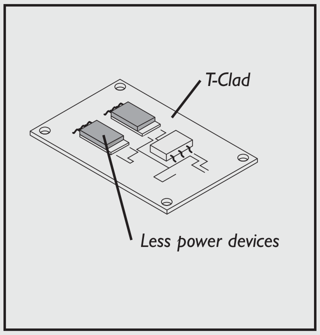
Thermal Clad substrates minimize thermal impedance and conduct heat more effectively and efficiently than standard printed wiring boards (PWB's). These substrates are more mechanically robust than thick-film ceramics and direct bond copper constructions that are often used in these applications.

Thermal Clad is a cost effective solution which can eliminate components, allow for more simplified designs, smaller devices and overall less complicated production processes. Additional benefits of Thermal Clad include lower operating temperatures, longer component life and better durability.

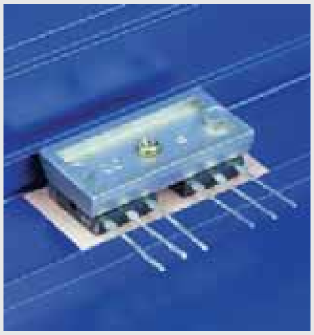
Bergquist Thermal Clad substrates are not limited to use with metal base layers. In one example, power conversion applications can enhance their performance by replacing FR-4 with Thermal Clad dielectrics in multi-layer assemblies. In this application, the thickness of the copper circuit layer can be minimized by the high thermal performance of Thermal Clad. For additional information on this topic, refer to the specialty section on pages 10-11 of this guide.



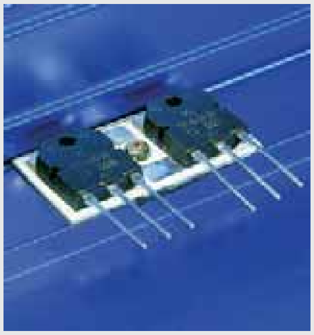
Traditionally, cooling an FR-4 board required the use of a large heat sink, interface material and various hardware (brackets, screws or clamps). This configuration requires manual assembly which is labor intensive.



Cooling with Thermal Clad can eliminate the need for heat sinks, device clips, cooling fans and other hardware. An automated assembly method will reduce long term costs.

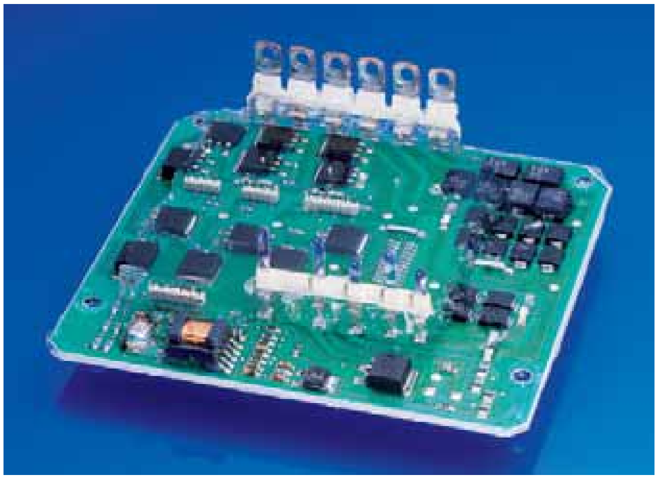


Conventional methods measured junction temperature
5W=Tj 43ºC



Thermal Clad measured junction temperature
5W=Tj 35ºC

Thermal Clad is a versatile substrate. In this motor control application, the dielectric has been selectively removed and the metal has been formed with three-dimensional features.



Motor control Thermal Clad after power and control devices are mounted. The heat spreading capability has optimized the design, eliminating the need for additional heat sinks.

Thermal Clad is a complete thermal management system, unlike the traditional technology which uses heat sinks, clips and other mounting hardware. Thermal Clad enables low-cost production by eliminating the need for costly manual assembly.

Thermal Clad Benefits Include:

- RoHS compliant
- Lower operating temperature
- Reduce printed circuit board size
- Increase power density
- Extend the life of dies
- Reduce the number of interconnects
- Improve product thermal and mechanical performance
- Combine power and control
- Improve product durability
- Enable better use of surface mount technology
- Reduce heat sinks and other mounting hardware, including thermal interface material
- Replace fragile ceramic substrates with greater mechanical durability

Improve Durability and Performance

Thermal Clad improves durability because designs can be kept simple while components are kept cool. The low thermal impedance of the Thermal Clad dielectric out-performs other insulators for power components allowing for cooler operation.

Thermal Clad keeps assemblies cool by eliminating thermal interfaces and using thermally efficient solder joints. Voltage breakdown and thermal performance improve in potted assemblies using SMDs and bare die on Thermal Clad.

Thermal Clad can also reduce production costs by enabling automated pick-and-place equipment for SMDs.

Reduce Board Size and Replace Hardware

Thermal Clad greatly reduces board space while replacing other components including heat sinks. It offers the opportunity to eliminate mica and grease or rubber insulators under power devices by using direct solder mount to Thermal Clad. In eliminating this hardware, heat transfer improves.

Interconnects can be eliminated by using etched traces on the Thermal Clad board. In fact, whole sections of PWB's are often eliminated. It permits using surface mount power and passive devices to reduce real estate. With Thermal Clad, many discrete devices can be replaced at the board level.

The Anatomy Of A Thermal Clad Board

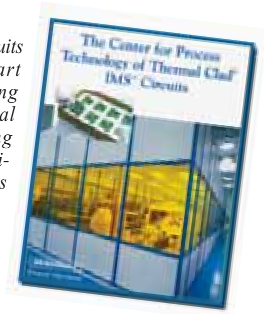
Thermal Clad is a dielectric (ceramic-polymer blend) coated metal base with a bonded copper circuit layer. This unique material offers superior heat transfer to help cool components while eliminating the problems associated with fragile ceramics.

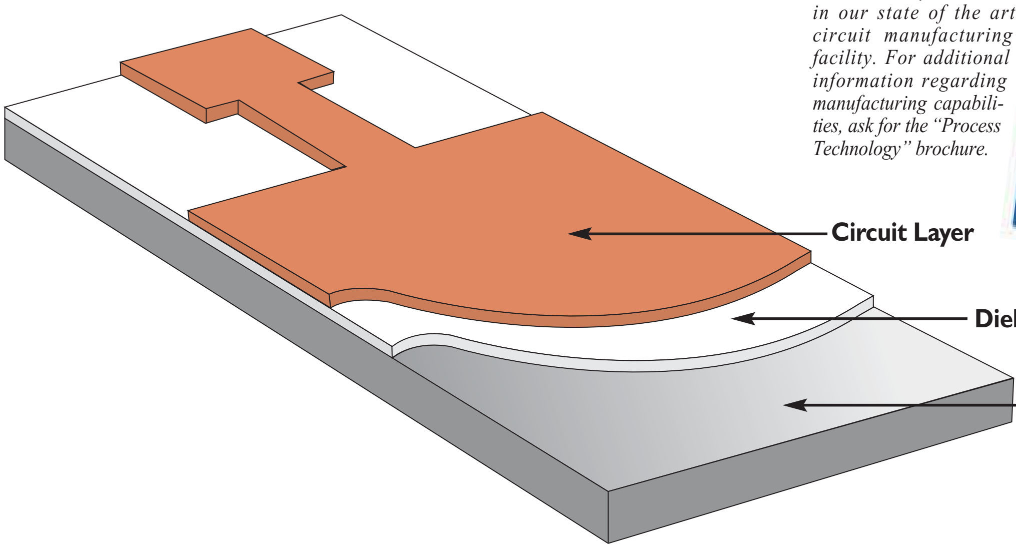
Thermal Clad is a unique, three layered system comprised of the following three layers:

- **Circuit Layer:** This is the printed circuit foil with thickness of 1oz to 10oz (35-350μm) in standard Thermal Clad.
- **Dielectric Layer:** This offers electrical isolation with minimum thermal resistance. The multi-layer dielectric is the key element of Thermal Clad, and bonds the base metal and circuit metal together. The dielectric has UL recognition, simplifying agency acceptance of final assemblies.
- **Base Layer:** This is often aluminum, but other metals such as copper may also be used. The most widely used base material thickness is 0.062" (1.6mm) in aluminum, although many thicknesses are available. In some applications, the base layer of metal may not be needed. See specialty section on page 10.

Bergquist's manufacturing facility located in Prescott, Wisconsin features state-of-the-art process capabilities. Process manufacturing uses the latest in technology for environmental clean room control, surface finishing, coating and lamination.

We can build your circuits in our state of the art circuit manufacturing facility. For additional information regarding manufacturing capabilities, ask for the "Process Technology" brochure.



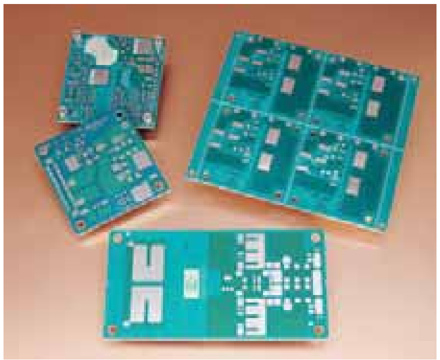


Thermal Clad Applications

Power Conversion

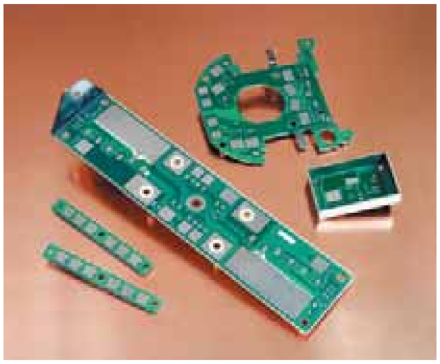
Due to the size constraints and watt-density requirements in DC-DC conversion, Thermal Clad has become the favored choice. Thermal Clad offers a variety of thermal performances, is compatible with mechanical fasteners and is highly reliable. It can be used in almost every form-factor and fabricated in a wide variety of substrate metals, thicknesses and copper foil weights.

Note: In some power conversion applications, the base layer of metal may not be needed. Refer to page 10 of this guide.



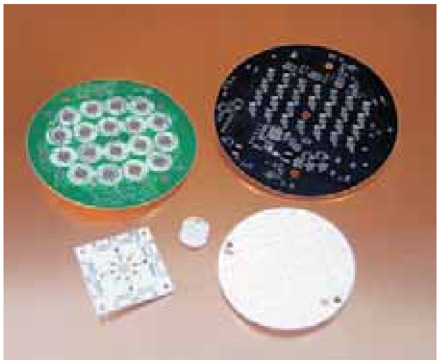
Heat-Rail And Forming

The use of Thermal Clad in heat-rail applications has grown significantly and is currently used in automotive, audio, motor control and power conversion applications. Utilizing the many advantages of surface mount assembly, attachment capabilities and high thermal performance, Thermal Clad offers a cost effective solution for heat management. When using Thermal Clad as the metal base substrate, the assembly process can be fully automated, eliminating the high labor cost of hand assembly.



LEDs

In high-brightness LED applications, light output and long life are directly attributable to how well the LED's are managed thermally. Thermal Clad is an excellent solution for designers. Because T-Clad is a metal based material, it can be configured for special shapes, bends and thicknesses thus allowing the designer to put high-brightness LED lamps in virtually any application. Mounting high-brightness LED's on T-Clad assures the lowest possible operating temperatures and maximum brightness, color and life.

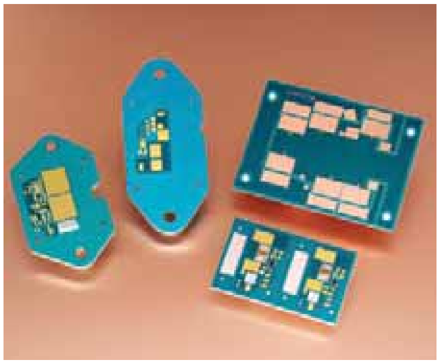


Motor Drives

Compact high reliability motor drives built on Thermal Clad have set the benchmark for watt-density. Dielectric choices provide the electrical isolation needed to meet operating parameters and safety agency test requirements. With the ability to fabricate in a wide variety of form-factors, the implementation into either compact or integrated motors drives is realized. The availability of Thermal Clad HT makes high temperature operation possible.

Solid State Relays/Switches

The implementation of Solid State Relays in many control applications calls for very thermally efficient, and mechanically robust substrates. Thermal Clad offers both. The material construction allows mounting configurations not reasonably possible with ceramic substrates. New dielectrics meet the high thermal performance expectations and can even out-perform existing ceramic based designs.



Got a great new T-Clad application idea?

Give us a call today and our skilled team of engineers, technicians and sales personnel will work with you to create a custom solution!

Thermal Clad Reliability

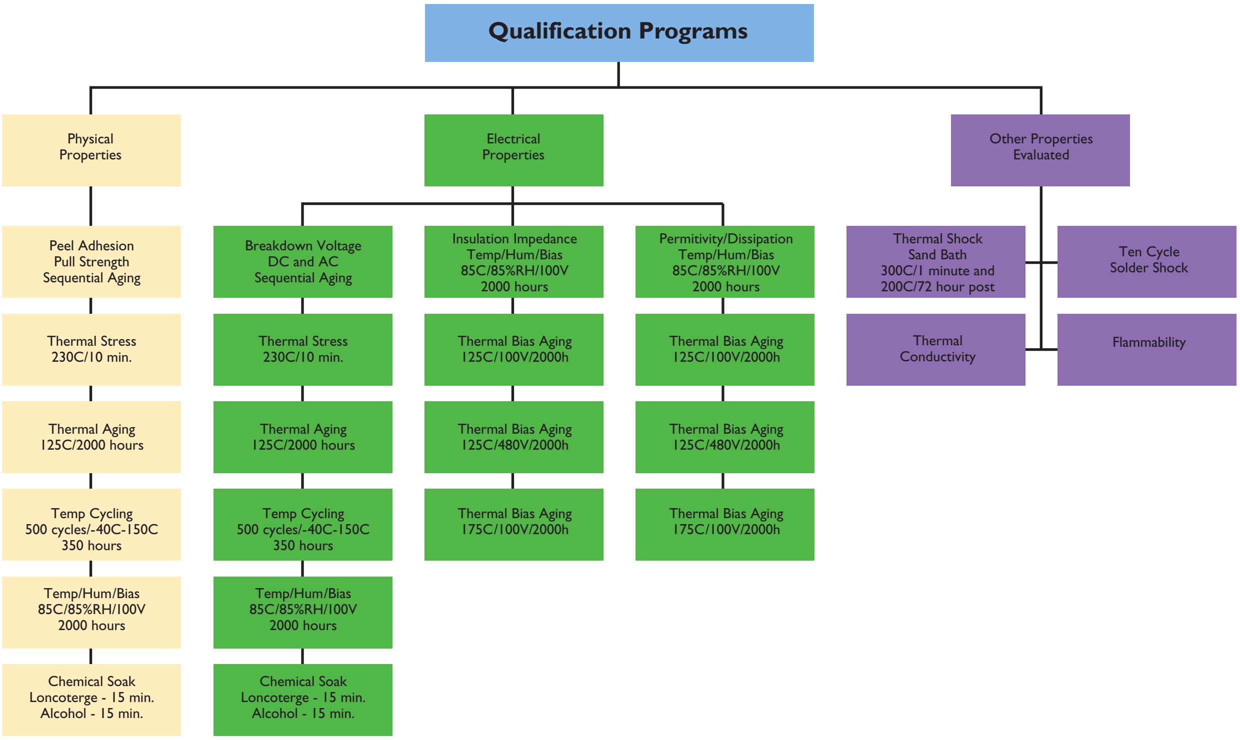
Thermal Clad Long Term Reliability

New materials undergo a rigorous 12 to 18 month qualification program prior to being released to the market.

In state-of-the-art laboratories and test facilities, Bergquist performs extensive testing on all their thermal materials for electrical integrity. Bergquist utilizes stringent development procedures outlined in Bergquist document #Q-6019. The lab facilities at Bergquist are UL certified and manufacturing facilities are ISO 9001:2000 certified.

Extensive qualification testing consists of mechanical property validation, adhesion, temperature cycling, thermal and electrical stress. To validate long term reliability, electrical testing is performed at selected intervals to 2000 hours where final evaluation is completed.

To ensure consistent product performance with materials manufactured, we couple the up-front qualification test with ongoing monthly audits. These audits include physical, electrical and thermal property tests.



Thermo Gravimetric Analyzer (TGA) *– Measures the stability of our dielectrics at high temperatures, baking the materials at prescribed temperatures and measuring weight loss.*

Chamber Ovens *– Over 3000 cubic feet of oven capacity is dedicated to long term thermal bias age testing. The ovens take material to temperatures above Tg. At selected intervals, samples are removed and tested to verify material integrity.*

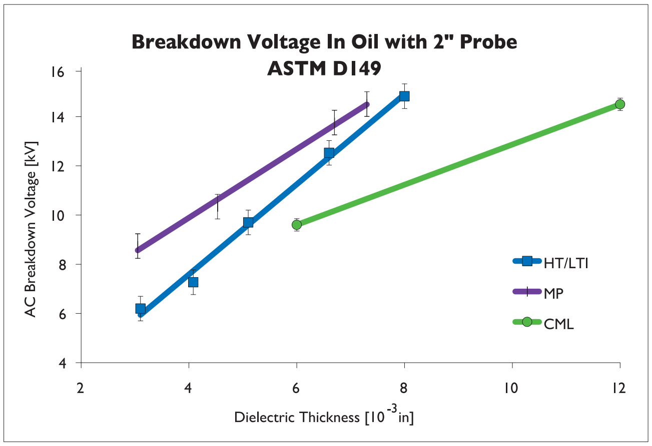
Dynamic Mechanical Analysis (DMA) *– Measures the modulus of materials over a range of temperatures.*

Selecting Dielectric Materials

Dielectric Layer

The technology of Thermal Clad resides in the dielectric layer. It is the key element for optimizing performance in your application. The dielectric is a proprietary polymer/ceramic blend that gives Thermal Clad its excellent electrical isolation properties and low thermal impedance.

The polymer is chosen for its electrical isolation properties, ability to resist thermal aging and high bond strengths. The ceramic filler enhances thermal conductivity and maintains high dielectric strength. The result is a layer of isolation which can maintain these properties even at 0.003" (75μm) thickness. This guide will help you select the best dielectric to suit your needs for watt density, electrical isolation and operating temperature environment.



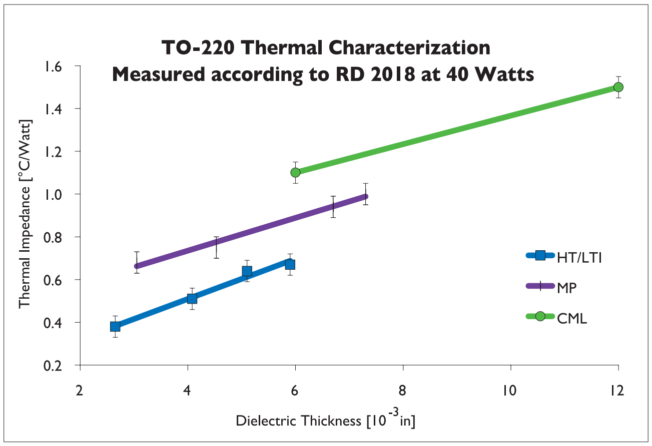
Electrical Isolation

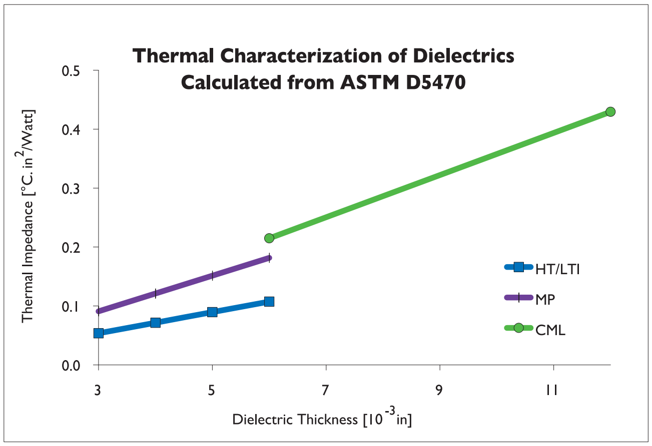
Dielectrics are available in thicknesses from 0.003" (75μm) to 0.006" (150μm), depending on your isolation needs. See electrical design considerations on pages 18-19 to help determine which thickness is appropriate for your application.

Thermal Impedance Determines Watt Density

Thermal impedance is the only measurement that matters in determining the watt density capability of your application because it measures the temperature drop across the stack-up for each watt of heat flow. Lower thermal impedance results in lower junction temperatures. The lower the thermal impedance, the more efficiently heat travels out of the components.

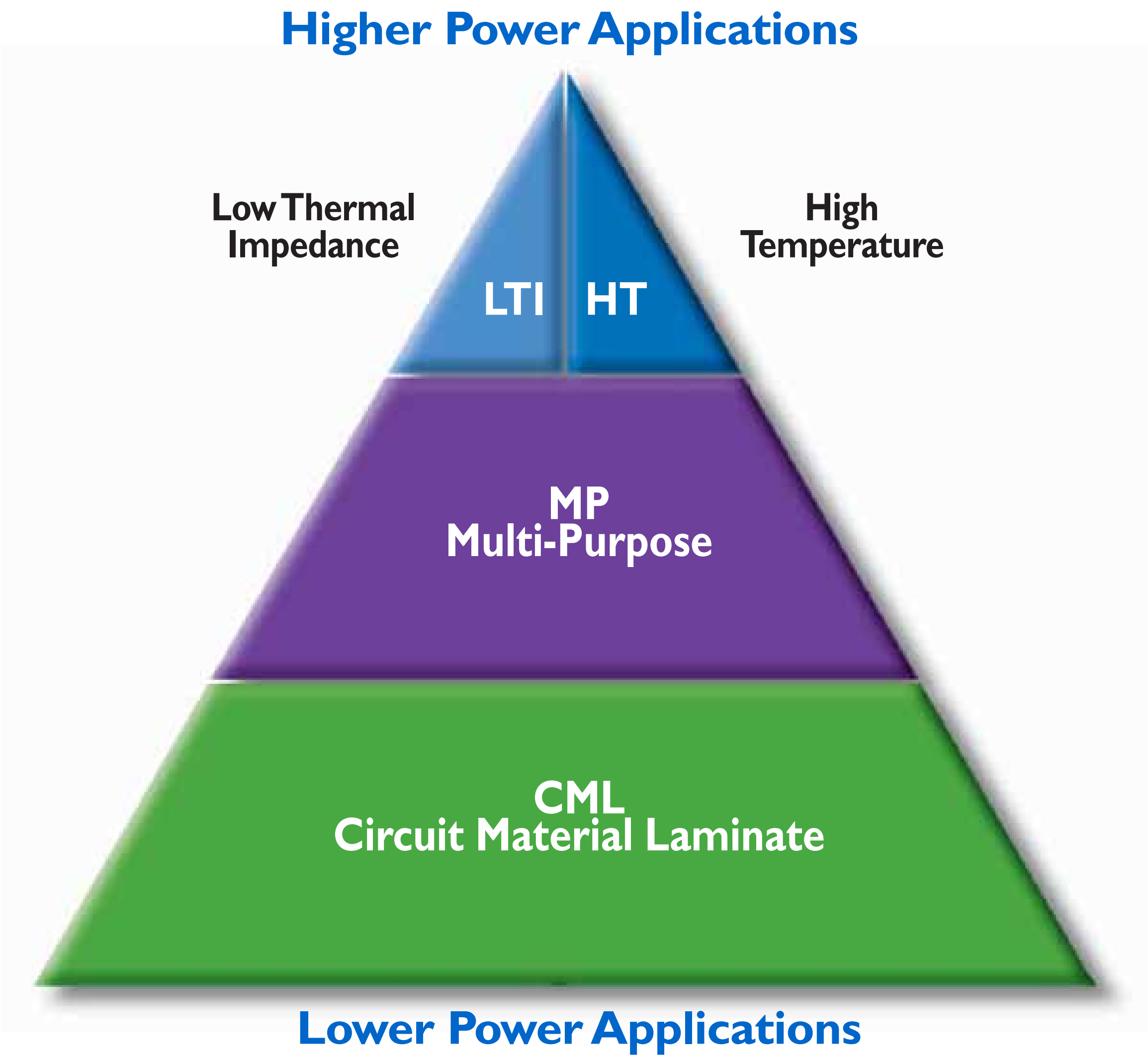
High thermal conductivity is relevant to your application when the thickness of the dielectric material is taken into consideration. Impedance to heat flow is proportional to the ratio of thickness to thermal conductivity.





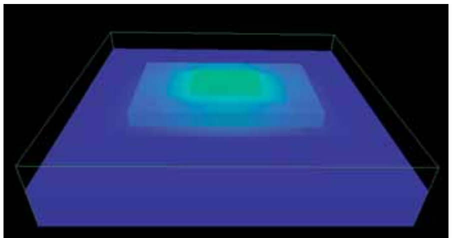
$$\text{TOTAL IMPEDANCE} = \frac{\text{Sample Thickness}}{\text{Thermal Conductivity}} + \text{Interfacial Resistance}$$

Lower Thermal Impedance = Lower Junction Temperatures

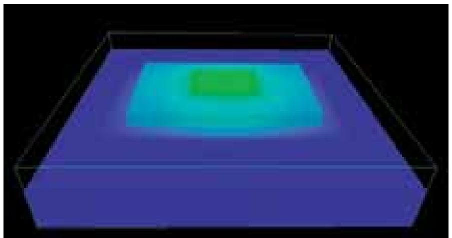


Thermal Models

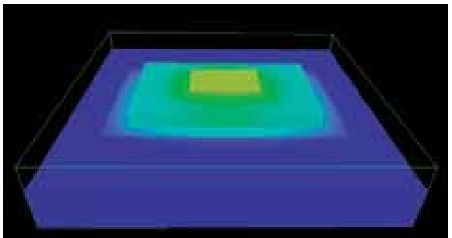
The following photos are thermal models, which depict heat spreading and thermal transfer capability of each dielectric family.



LTI - Low Thermal Impedance and HT - High Temperature



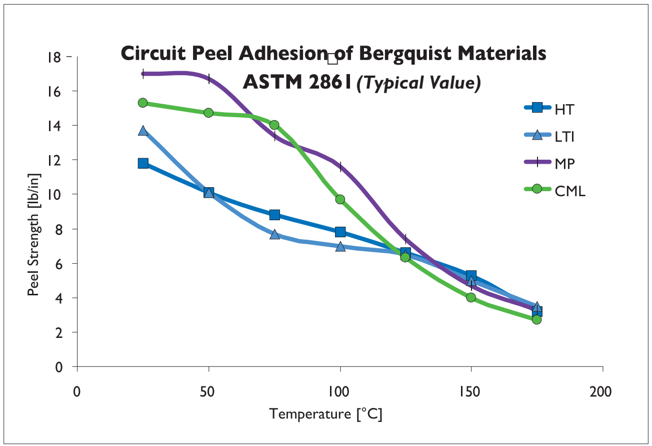
MP - Multi-Purpose



CML - Circuit Material Laminate

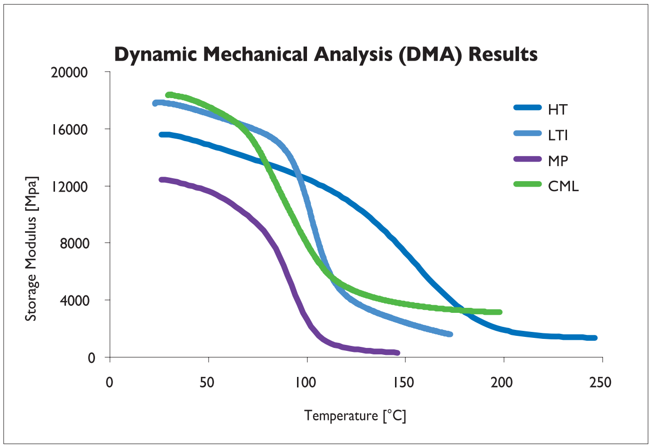
Dielectric Performance Considerations

Peel Strength



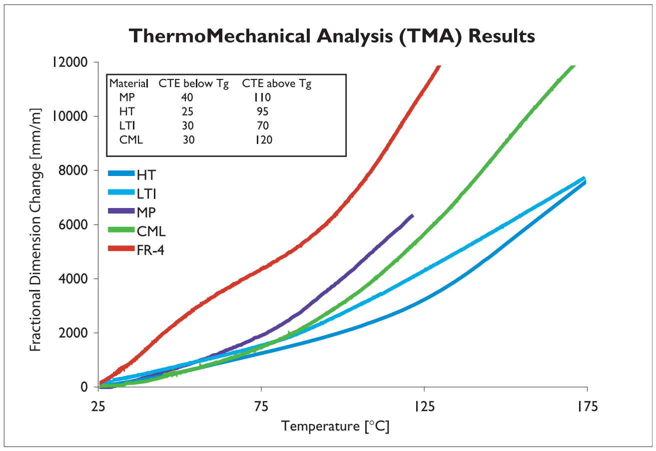
This chart graphs the stability of the bond strength between the dielectric and the circuit layer during temperature rise. Although bond strength goes down at higher temperatures, it maintains at least 3 lbs. even at 175°C.

Storage Modulus



This chart depicts the storage modulus of the material over a temperature range. All of our dielectrics are robust, but you will want to choose the one that best suits your operating temperature environment. See Assembly Recommendations on pages 20-21 for additional information.

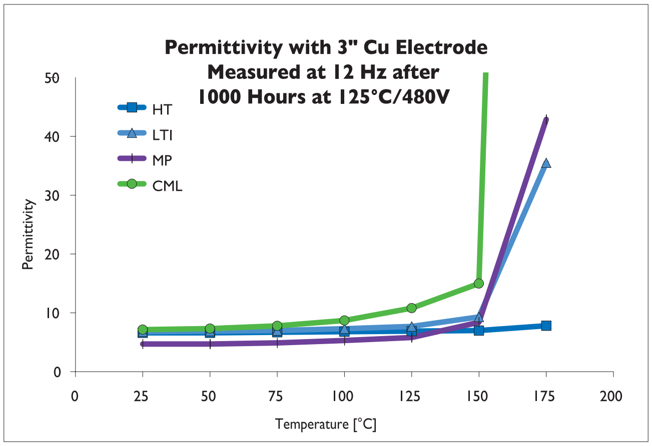
Coefficient of Thermal Expansion



Thermo Mechanical Analysis (TMA) measures the dimensional stability of materials during temperature changes, monitoring the Coefficient of Thermal Expansion (CTE). Note: In the application, the CTE of the base material is a dominant contributor to thermal mechanical stress. See pages 12-13 for base layer selection.

CTE OF IMS BOARDS - The concerns in exceeding Tg in standard FR4 materials from a mechanical standpoint should be tempered when using Thermal Clad. The ceramic filler in the polymer matrix of Thermal Clad dielectrics results in considerably lower Z-axis expansion than in traditional FR-4 materials, while the low thickness of the dielectric means significantly less strain on plated-through-hole (PTH) connections due to expansion.

Dielectric Stability



This charts depicts the stability of the dielectric electrical properties over a range of temperatures. The flatter the line, the more stable. Note the stability of our high temperature dielectric, HT to a temperature of 175°C.

Operating Thermal Clad Materials Above Tg

Above the Tg of the material, mechanical and electrical properties begin to change. Mechanical changes of note are reduction of peel strength of the copper foil, an increase in the CTE, and decreasing storage modulus. ***There is a potential benefit of relieving residual stress on the dielectric interfaces, in solder joints and other interconnects due to CTE mismatches by choosing a dielectric with Tg below the operating temperature***. The dielectric material above T_g is in its elastomeric state (much lower storage modulus), allowing some of the stresses to relax. Changes in electrical properties must also be considered in operation above Tg, although they are typically only important at frequencies above 1 MHz. Effects to consider are changes in the permitivity, dielectric loss and breakdown strength of the material. ***Important Note:*** Many Thermal Clad products have UL rating up to 45% higher than their glass transition temperature and are used extensively in applications above rated T_g.

Summary Of Dielectric Characteristics

		THERMAL PERFORMANCE			DIELECTRIC PERFORMANCE			OTHER		
Part Number	Thickness[1] [10⁻³ in/10⁻⁶m]	Impedance[2] [°C/W]	Impedance[3] [°C in²/W]	Conductivity[4] [°W/m-K]	Typical Proof Test[5] [VDC]	Breakdown[6] [kVAC]	Permitivity[7] [Dielectric Constant]	Glass Transition[8] [°C]	UL Index[9] [°C]	Peel Strength[10] [lb/in]
HT-04503	3/75	0.45	0.05	2.2	1500	6.0	7	150	140/140	6
HT-07006	6/150	0.70	0.07	2.2	2500	11.0	7	150		
LTI-04503	3/75	0.45	0.05	2.2	1500	6.5	7	90	130/130	6
LTI-06005	5/125	0.60	0.09	2.2	2000	9.5	7	90		
LTI-07006	6/150	0.70	0.11	2.2	2500	11.0	7	90		
MP-06503	3/75	0.65	0.09	1.3	1500	8.5	6	90	130/140	9
CML-11006*	6/150	1.1	0.21	1.1	2500	10.0	7	90	130/130	10

Method Description

1 - Optical
2- Internal TO-220 test RD2018
3 - Calculation from ASTM 5470
4 - Extended ASTM 5470
5 - 500V/sec ramp, 5 sec hold
6 - ASTM D149
7 - ASTM D150
8 - Internal MDSC test RD2014
9 - UL 746 E
10 - ASTM D2861

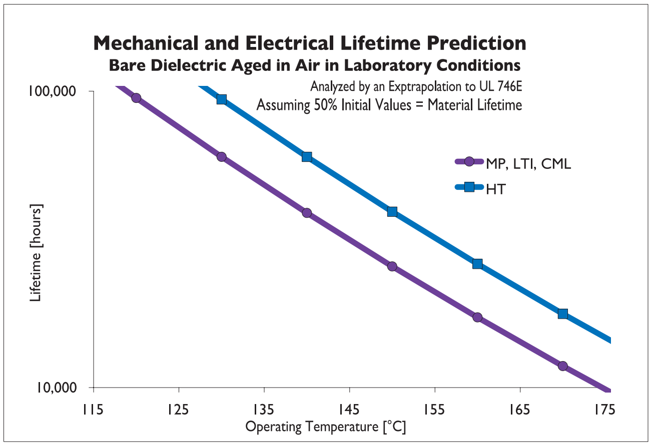
Note: For applications with an expected voltage over 480 Volts AC, Bergquist recommends a dielectric thickness greater than 0.003" (75μm).
Note: Maximum test voltage is a function of material and circuit design. Typical proof test does not represent the maximum.

**CML is available in prepreg form.*

Operating Temperatures

Choose the dielectric that best suits your operating temperature environment. For high temperature applications, such as automotive, HT offers the right solution. All of our dielectrics are UL recognized.

MATERIAL	UL RTI - ELECTRO / MECHANICAL
HT	**140°C / 140°C**
LTI	**130°C / 130°C**
MP	**130°C / 140°C**
CML	**130°C / 130°C**

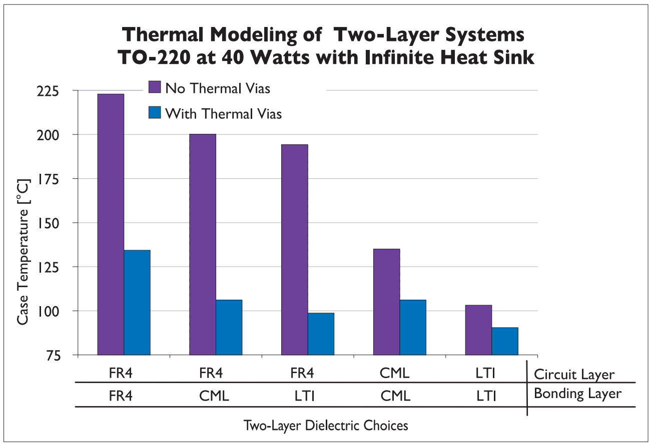


See inside back cover for instructions on how to obtain the latest UL recognition information regarding Bergquist Thermal Clad.

Using Thermal Clad Dielectric Material...

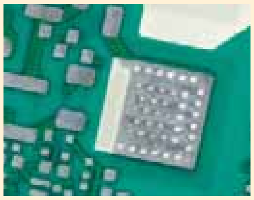
Two-Layer Systems Using FR-4 Circuits Or Thermal Clad Circuits

Bergquist dielectrics are ideal for applications requiring a two-layer solution. Two-layer constructions can provide shielding protection and additional electrical interconnects for higher component density. Bergquist dielectrics will provide superior thermal performance over traditional FR-4 constructions. In addition, thermal vias can maximize thermal capabilities for applications utilizing power components. When vias can not be used, selecting higher performance dielectrics can solve thermal issues independently (see adjacent graph).

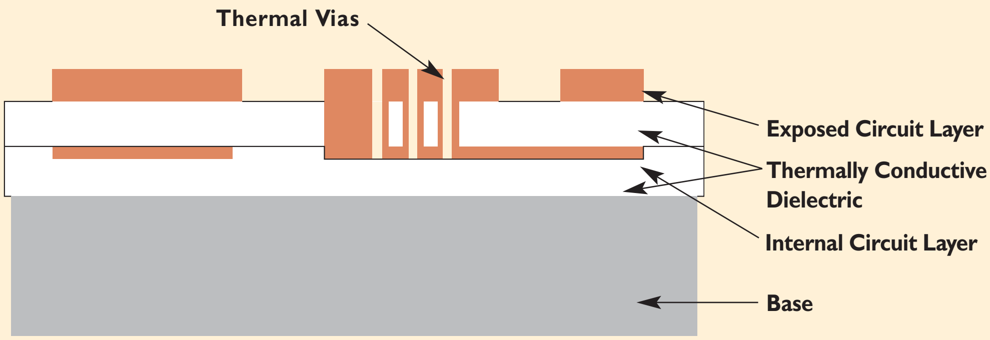


The graph depicts the modeled thermal result of various two-layer constructions as a function of device case temperature. The emphasis is the thermal effect of proper vias utilization.

Thermal Vias Cross Section



Thermal Vias Plane View

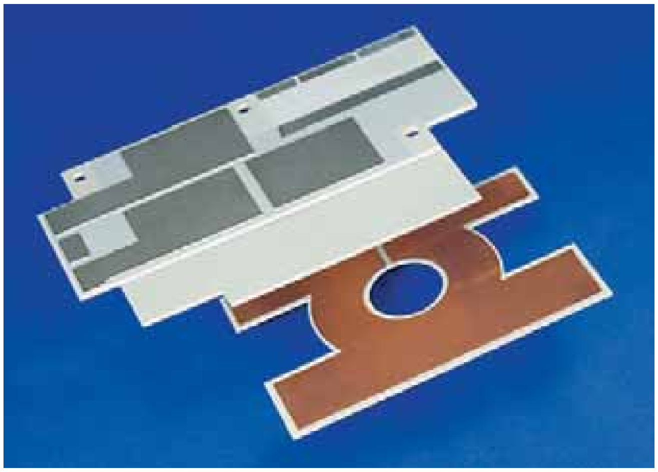


The picture above represents the construction of a two-layer circuit material bonded with Bergquist dielectrics to a metal base. These configurations utilize either Thermal Clad circuit or FR-4 type circuit materials, depending on the thermal requirements and cost objectives. The configuration pictured above is that of a two-layer circuit pair, however, multi-layer constructions are also available on copper base material.

Single Board Solutions Without The Metal Base

The thermal performance of Thermal Clad dielectrics are often sufficient to handle thermal requirements, eliminating the need for a metal base layer. In addition, the current carrying capability is often improved enough to reduce the thickness requirement. See "Selecting a Circuit Layer" on pages 14-15 for additional information.

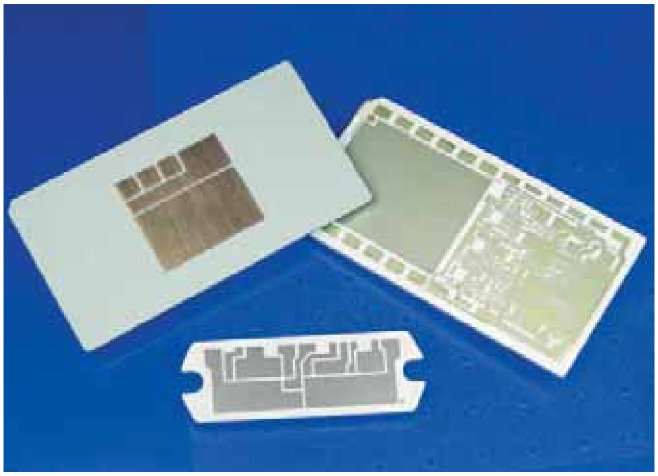
With the elimination of the metal base, components can be mounted on both sides. This can often create a single board solution where the power components are no longer separate from the logic components as is the case in a two-board system.



DBC Replacement

Replace Ceramic Substrates

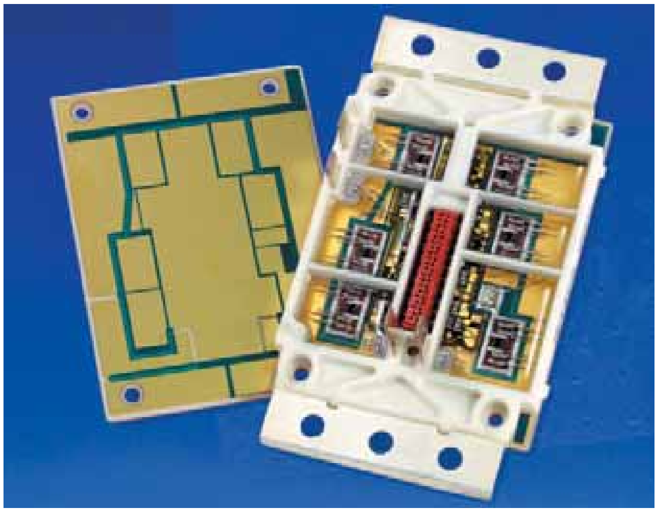
Thermal Clad can replace large-area ceramic substrates. It can also be used as a mechanically durable support for ceramic spacers or direct-bond copper sub assemblies. The copper circuit layer of Thermal Clad has more current carrying capability than thick film ceramic technology.

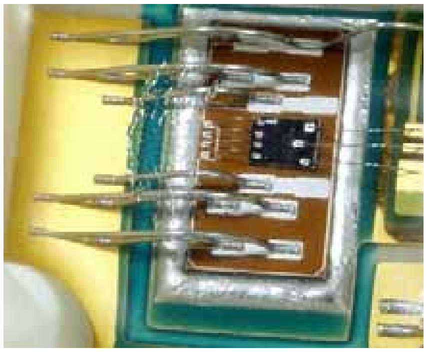


Thermal Clad has replaced ceramics and DBC in applications due to mechanical robustness and ability to be fabricated in a wide variety of form-factors.

Direct Die Application

Thermal Clad is successfully used in applications requiring direct die attachment. Die are reflow-soldered to the substrate and then wire bonded to the power and control circuitry to complete the electrical connections. The proper selection of material configuration, copper foil thickness allows for wide temperature range and high current applications. In some applications the copper circuits are nickel/gold plated to provide good solderability and wire bond integrity. If thermosonic gold wire bonding is to be used, it is important to use HT dielectric because of its high Tg (thus higher modulus) at wire bond temperatures.



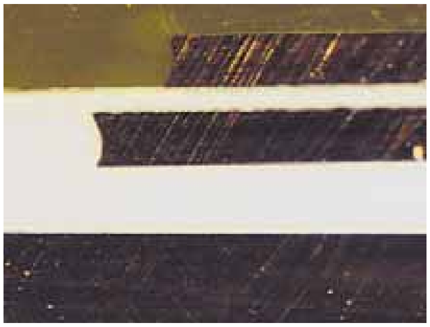


Close-up view of direct die attachment. The Thermal Clad substrate is used to mount the die or module.

Heavy Copper

Applications requiring heavy copper for high current or heat spreading are not limited to single-layer needs. The ability to have internal layers of heavy copper can provide greater application flexibility. Combined with direct access to the internal copper layer to directly attach or mount components provides unique applications capability.

Look for opportunities to reduce the thickness of copper. In many applications, our thermal performance reduces the need for heavy copper.



Cross sectional view of heavy copper - two-layer 10 oz. over 10 oz. utilizes Thermal Clad HT dielectric with a 0.020" (0.5mm) copper base heat spreader.

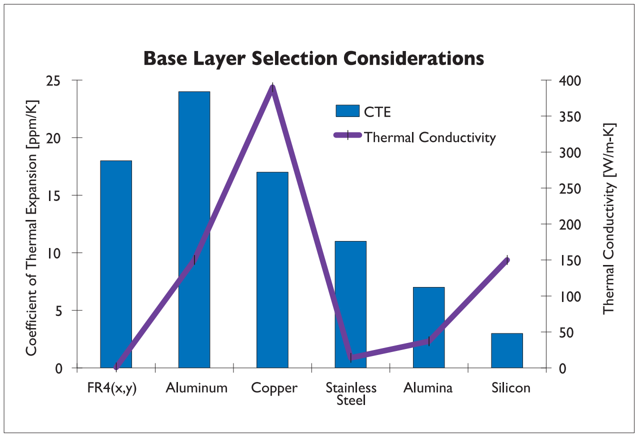
Design Considerations When Selecting The Base Metal Layer

- Coefficient Of Thermal Expansion And Heat Spreading
- Coefficient Of Thermal Expansion And Solder Joints
- Strength, Rigidity And Weight
- Electrical Connections To Base Plate
- Surface Finish
- Costs

METAL / ALLOY	THERMAL CONDUCTIVITY [W/mK]	COEFFICIENT OF THERMAL EXPANSION [ppm/K]	DENSITY [g/cc]	MODULUS OF RIGIDITY [GPa]	YIELD STRENGTH [MPa]
Copper	400	17	8.9	44.1	310
Aluminum 5052	150	25	2.7	25.9	215
Aluminum 6061	150	25	2.7	26	230

Coefficient Of Thermal Expansion And Heat Spreading

The adjacent graph depicts the CTE of the base material in relationship to the heat spreading capability of the metal. Although Aluminum and Copper are the most popular base layers used in Thermal Clad other metals and composites have been used in applications where CTE mismatch is a factor. The adjacent table represents standard and non-standard base layers.



Coefficient Of Thermal Expansion And Solder Joints

Solder joint fatigue can be minimized by selecting the correct base layer to match component expansion. The major concern with thermal expansion is the stress the solder joint experiences in power (or thermal) cycling. Solder joints are not mechanically rigid. Stress induced by heating and cooling will cause the joint to fatigue as it relieves stress. Large devices, extreme temperature differential, badly mismatched materials, or a minimum solder thickness will all place increased cyclic strain on solder joints.

Solder joint fatigue is typically first associated with passive, ceramic components and with the device termination. The assembly section on page 20 covers these issues in greater detail.

Base Thickness

Copper and aluminum Thermal Clad is normally purchased in one of the standard-gauge thicknesses shown in the table below. Non-standard thicknesses are also available.

Aluminum - Standard Thickness

Inches	Millimeters
0.020	0.51
0.040	1.02
0.062	1.57
0.080	2.03
0.125	3.18

Copper - Standard Thickness

Inches	Millimeters
0.032	0.81
0.040	1.02
0.060	1.52
0.080	2.03
0.125	3.18

Electrical Connections To Base Plate

If a connection to the base plate is desired, copper is the most compatible base layer to use. When using electrical or thermal vias, it is important to match the circuit and base coefficients of thermal TCE expansion as closely as possible. Otherwise, excess plated-hole stress will occur during thermal cycles. Other base layer materials can be used for connection, but will require different connection schemes.

Costs

The most cost effective base layers are aluminum and copper because they represent industry standards. Copper is more expensive than aluminum when comparing the like thicknesses, but can be the less expensive option if design considerations allow for a thinner layer. As an example, typically the cost of 0.040" (1.0mm) copper is equal to the cost of 0.125" (3.2mm) aluminum.

Surface Finish

Aluminum and copper base layers come with a uniform commercial quality brushed surface. Aluminum is also available anodized with choices of clear, black, blue and red colors.

Standard Thermal Clad Panels

Available in:

- 18" (457.2mm) x 24" (609.6mm)
  Usable area: 17" (451.8mm) x 23" (584.2mm)
- 20" (508mm) x 24" (609.6mm)
  Usable area: 19" (482.6mm) x 23" (584.2mm)

Selecting A Circuit Layer

- ▼ Current Carrying Capabilities
- ▼ Heat Spreading Capabilities
- ▼ Flatness In Relationship To Thickness

Current Carrying Capabilities

The circuit layer is the component-mounting layer in Thermal Clad. Current carrying capability is a key consideration because this layer typically serves as a printed circuit, interconnecting the components of the assembly. The advantage of Thermal Clad is that the circuit trace interconnecting components can carry higher currents because of its ability to dissipate heat due to I^2R loss in the copper circuitry.

The following equation can be used to calculate minimum trace width utilizing both circuit thickness and current requirements.

Calculating Minimum Trace Width

$$W_C = \left[\frac{T_S I^2 R_S}{K_S T_{RISE}} + T_S^2 \right]^{1/2} - T_S$$

where:

W_C = Conductor Width (meters)

T_S = Dielectric Thickness (meters)

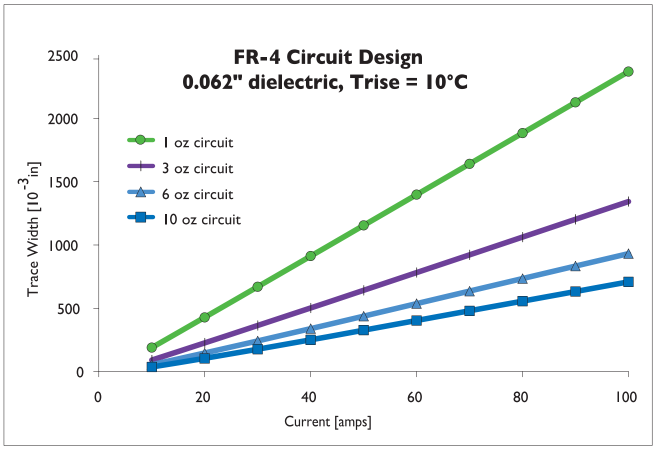
I = Current (Amps)

R_S = Circuit Sheet Resistivity $= \dfrac{1.78 \times 10^{-8}\ \Omega \cdot m}{T_C}$

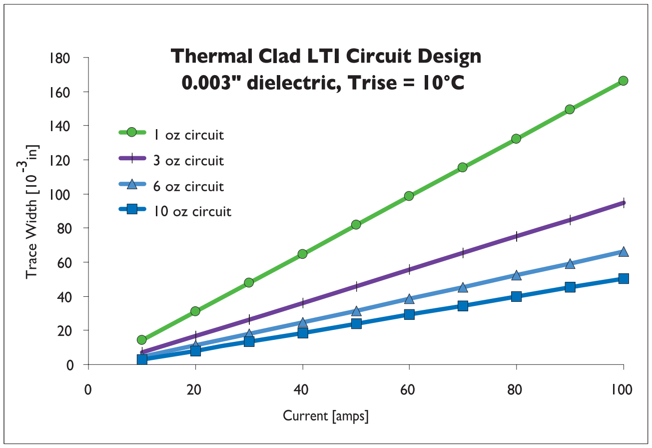
T_C = Foil Thickness (meters)

K_S = Thermal Conductivity of the Dielectric (W/m-K)

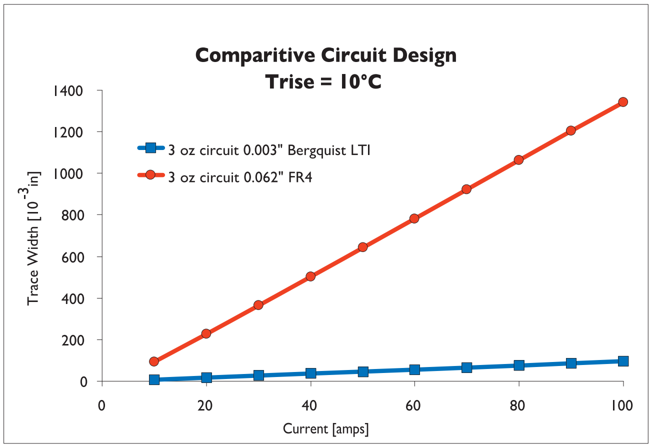
T_{RISE} = Allowable Temperature Rise (K)



Example of FR-4 current capability with known trace width and a series of circuit thicknesses.



Bergquist Dielectric LTI current capability with known trace width and a series of circuit thicknesses. Additional charts regarding our other dielectrics are also available.

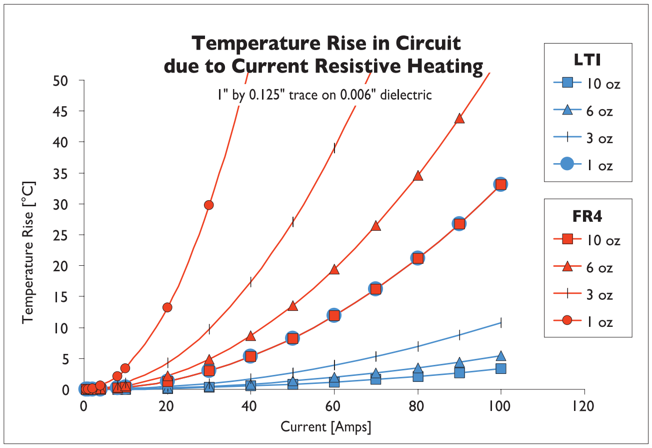


Comparison of Bergquist Dielectric LTI and FR-4 current capability.

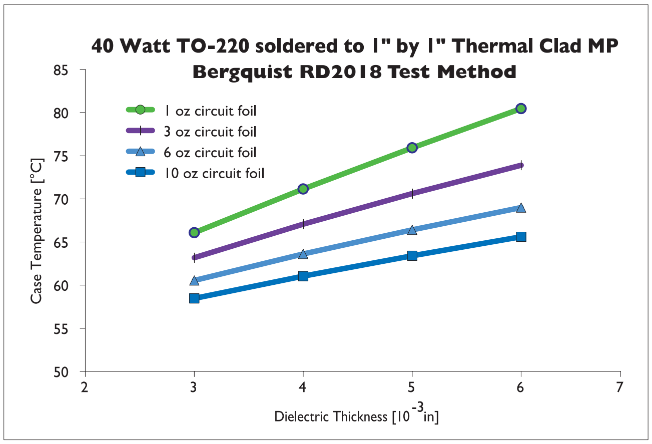
Heat Spreading Capability

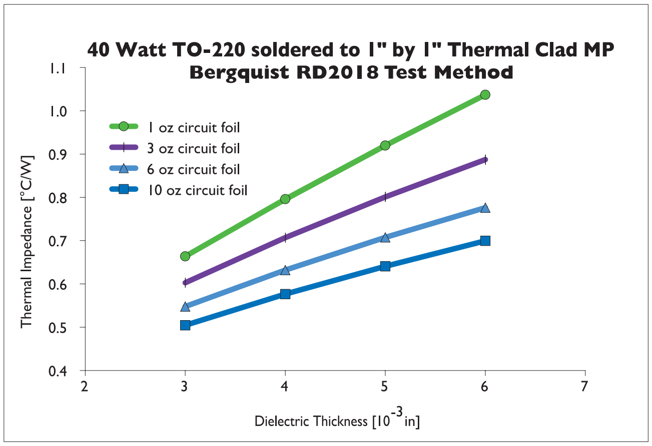
Dielectric thickness and foil thickness both influence heat spreading capability in Thermal Clad. Heat spreading is one of the most powerful advantages derived from IMS. By increasing copper conductor thickness, heat spreading increases and brings junction temperature down. In some cases very heavy copper can be utilized along with bare die to eliminate the need for a standard packaged component. See “Heavy Copper Application” on page 11.

The following graphs depict both the thermal impedance value and case temperature when relating dielectric and foil thickness.



Temperature rise comparison graph depicts the significant difference between Bergquist Dielectric LTI and FR-4. Additional comparison charts regarding all Bergquist Dielectrics are available. Note: No base metal used in calculation.





Standard Circuit Layer Thickness

MATERIAL	WEIGHT (oz/ft²)	REFERENCE THICKNESS inches	REFERENCE THICKNESS µm
Copper (Zinc Treatment)	1	0.0014	35
	2	0.0028	70
	3	0.0042	105
	4	0.0056	140
	5	0.0070	178
	6	0.0084	210
	8	0.0112	280
	10	0.0140	350

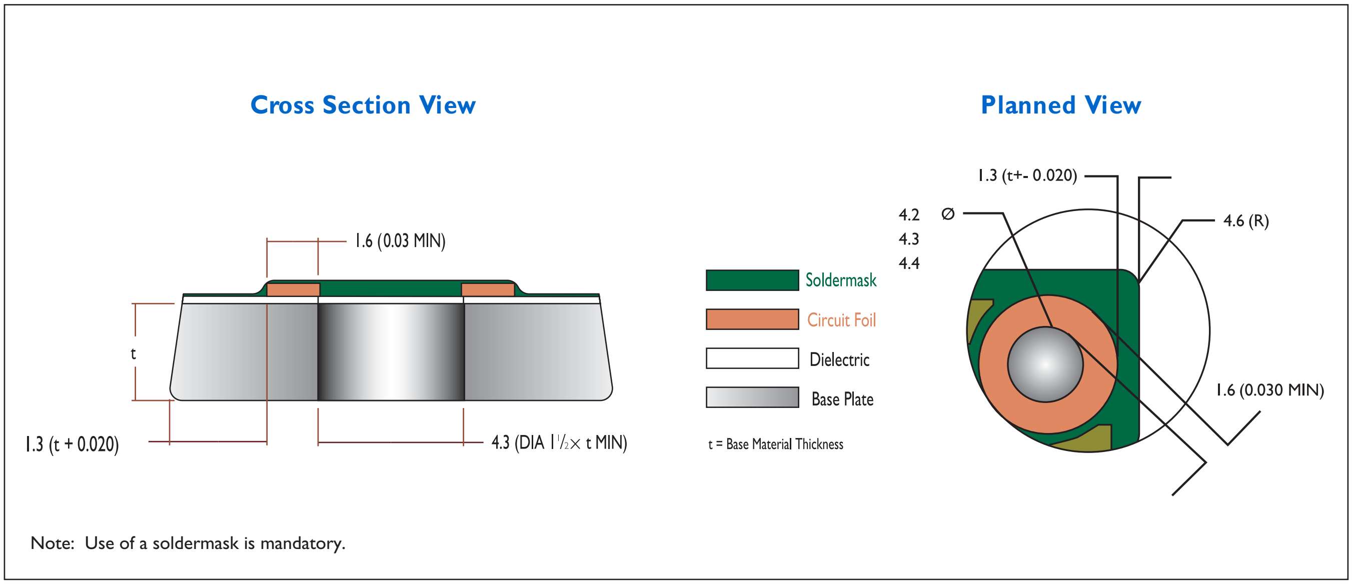
NOTE: Copper foil is NOT measured for thickness as a control method. Instead, it is certified to an area weight requirement per IPC-4562. The nominal thickness given on 1 oz. copper is 1.35 mils/25.7µm.

CAUTION! Values in IPC-4562 (Table 1.1) are not representative of mechanical thickness.

Circuit Design Recommendations

This section will address circuit design with respect to etching, surface finishing and mechanical fabrication processes; such as holes, flatness, singulation and tolerances.

Fabrication of Thermal Clad is similar to traditional FR-4 circuit boards with regard to wet processing operations. However, secondary mechanical operations are unique, therefore consideration to specific design recommendations are critical to insure manufacture of reliable cost effective Thermal Clad circuits. This section will address design recommendations for circuit image, soldermask, legend screen and mechanical fabrication. Additional consideration for trace widths, spacing and clearances may be required for electrical integrity based in application voltage. See "Electrical Design Considerations" on pages 18-19.



Bold numbers within these drawings reference the adjacent table.

Part Singulation Methods

Milling/Routing/Drilling

Processes typically selected for prototype or low volume production with complex geometries. Unique designs with selective areas of removed dielectric may require milling/routing processes. Milling operations require fixturing. Milling/routing is typically not cost effective for moderate to high volume applications.

V-Scoring

V-scoring is a viable process selection for both low and high volume production by taking advantage of material utilization. V-scoring is also a preferred process for prototypes with rectangular geometries with the benefit of no tooling costs. Holes can be drilled or punched prior to scoring.

Blanking

Blanking is one of the most cost effective process for moderate to high volume applications. Blank tooling can accommodate complex part geometries, as well as pierce internal holes.

Flatness

Part design as well as the manufacturing process affects flatness of a Thermal Clad board. There is also an effect from the differential thermal coefficient of expansion (TCE) between the circuit and the base layer. That effect is determined by the base plate material selection, ratio of copper foil to base plate thickness and copper circuit pattern design.

For Thermal Clad, panel or part, there is always some bow caused by the difference in CTE between the circuit layer and the substrate. Flatness is most evident when the substrate metal is aluminum and the circuit layer is copper. Generally, if the thickness of the copper layer is less than 10% of the substrate thickness, the aluminum will be mechanically dominant. Constructions with more circuit copper than 10% of the substrate thickness can exhibit a bow.

Circuit Design Guidelines

The table below offers recommended circuit design guidelines. These recommendations are taken from general metal fabrication guidelines. Safety Agency rules are used to design dielectric creepage distances and clearances.

DESIGN CATEGORY	DESIGN PARAMETER	STANDARD DESIGN RECOMMENDATION AND SPECIFICATION	
1.0 Circuit Design	1.1 Minimum circuit width	**Circuit Thickness**	
		1oz (35µm) - 0.005" (0.13mm)	
		2oz (70µm) - 0.006" (0.15mm)	
		3oz (105µm) - 0.007" (0.18mm)	
		4oz (140µm) - 0.008" (0.20mm)	
		6oz (210µm) - 0.010" (0.25mm)	
		8oz (280µm) - 0.015" (0.38mm)	
		10oz (350µm) - 0.015" (0.38mm)	
	1.2 Minimum space and gap single layer	**Single Layer (non-plated)**	**Multi Layer (plated)**
		1oz (35µm) - 0.007" (0.18mm)	1oz (35µm) - 0.009" (0.23mm)
		2oz (70µm) - 0.009" (0.23mm)	2oz (70µm) - 0.011" (0.28mm)
		3oz (105µm) - 0.012" (0.30mm)	3oz (105µm) - 0.014" (0.36mm)
		4oz (140µm) - 0.014" (0.36mm)	4oz (140µm) - 0.016" (0.41mm)
		6oz (210µm) - 0.020" (0.51mm)	6oz (210µm) - 0.022" (0.56mm)
		8oz (280µm) - 0.024" (0.61mm)	8oz (280µm) - 0.026" (0.66mm)
		10oz (350µm) - 0.030" (0.76mm)	10oz (350µm) - 0.032" (0.81mm)
	1.3 Minimum circuit to edge blanking	One material thickness + 0.020" (0.50mm)	
	1.4 Minimum circuit to edge v - scored/milled/routed	**Material Thickness**	**Circuit to Edge Distance**
		0.040" – (1.02mm)	0.026" – (0.66mm)
		0.062" – (1.57mm)	0.029" – (0.74mm)
		0.080" – (2.03mm)	0.031" – (0.79mm)
		0.125" – (3.18mm)	0.037" – (0.94mm)
	1.5 Minimum conductor to hole edge	One material thickness	
	1.6 Minimum annular ring	Punched non-plated through hole is 0.030" (0.76mm) minimum Drilled/plated via hole is 0.010" (0.25mm) minimum	
	1.7 Minimum character height for etched nomenclature	0.060" (1.52mm)	
2.0 Soldermask Design	2.1 Minimum soldermask line width	0.008" (0.2mm)	
	2.2 Soldermask pad apertures	Bergquist recommends that whenever possible, design the soldermask overlap on top of 0.010" (0.25mm) copper foil	
	2.3 Minimum soldermask aperture size	0.008" x 0.008" (0.20mm x 0.20mm)	
	2.4 Minimum character height and line width for nomenclature	0.008" x 0.008" (0.20mm x 0.20mm)	
	2.5 Soldermask setback	Suggested setback from part edge = one material thickness + 0.025" (0.635mm)	
3.0 Silk Screen Design	3.1 Character height/width	Minimum character height 0.060" (1.52mm) Minimum line width 0.010" (0.38mm)	
	3.2 Silk Screen to pad	Recommend minimum distance from silk-screen feature to nearest pad is 0.010" (0.254mm)	
	3.4 Minimum distance to board edge	One material thickness	
4.0 Mechanical Design	4.1 Hole to board edge	Minimum distance from edge of the hole to edge of board is one material thickness	
	4.2 Punched hole size	Minimum punched hole size is 1.5x material thickness	
	4.3 Minimum drilled hole diameter– copper base plate	One material thickness	
	4.4 Minimum drilled hole diameter– Aluminum base plate	**Base Plate Thickness**	**Drilled Hole Diameter**
		0.040" - (1.02mm)	0.030" - (0.76mm)
		0.062" - (1.57mm)	0.030" - (0.76mm)
		0.080" - (2.03mm)	0.040" - (1.02mm)
		0.125" - (3.18mm)	0.062" - (1.57mm)
	4.5 Minimum drilled via diameter for circuit layer	0.014" - (0.36mm)	
	4.6 Minimum edge radius	One material thickness for blanking no radius for V-scoring	
	4.7 Minimum circuit to edge for blanking	One material thickness + 0.020" (0.51mm)	

The shaded blue areas represent Bergquist circuit processing capabilities. If your application requires different specifications, please contact Bergquist Sales.

Electrical Design Considerations

- ▼ Proof Testing
- ▼ Breakdown Voltage
- ▼ Creepage Distance And Discharge

Proof Test

The purpose of "Proof Testing" Thermal Clad substrates is to verify that no defects reside in the dielectric material. Because testing requires that voltages be above the onset of partial discharge, we recommend the number of "Proof Tests" be kept at a minimum.

In proof testing, partial discharge can look like leakage current. Agency acceptance tests differentiate between discharge current and leakage current. Using soldermask can raise the test voltage where partial discharge is detected. Potting the completed assembly can eliminate partial discharge. A much more complete discussion of discharge and spacing is available in Application Note #130.

Partial Discharges (PD) are localized releases of internal energy stored in electrical insulation systems in regions of defects in the media and/or at interfaces of different materials. These discharges of energy are within the insulation system, being restricted to only a part of the dielectric material, hence not necessarily forming electrically conducting paths amongst system conductors. The series resistance limits partial discharge current in the insulation system.

"Proof Test" fixture to test multiple number of finished circuit boards at one time.

The term "Partial Discharge" is relatively new and includes a broad spectrum of life reducing (i.e., material damaging) phenomena such as:

1. Corona discharge in gases.
2. Treeing and surface contamination.
3. Surface discharges at interfaces, particularly during fault induced voltage reversals.
4. Internal discharges in voids or cavities within the dielectric.

The purpose of the "Proof Test" is to verify that there has been no degradation of the dielectric insulation due to the fabrication process or any material defects. Continued testing at these voltage levels will only take away from the life of the dielectric on the circuit board. It has been repeatedly verified that "Proof Testing" above the inception of partial discharge (700 Vac or 1200 Vac with proper use of Soldermask) will detect any and all defects in the dielectric isolation in the Thermal Clad circuit board. Any micro-fractures, delaminations or micro-voids in the dielectric will breakdown or respond as a short during the test.

The use of a DC "Proof Test" is recommended, from an operator safety standpoint. The voltage levels typically used are 1500 to 2250 VDC. Due to the capacitive nature of the circuit board construction, it is necessary to control the ramp up of the voltage to avoid nuisance tripping of the failure detect circuits in the tester and to maintain effective control of the test. This is to avoid premature surface arcing or voltage overshoot. There is safety consideration when DC testing, in that the operator must verify the board tested is fully discharged, prior to removing from the test fixture. A more detailed discussion of "Proof Test" is available upon request.

Breakdown Voltage

The ASTM definition of dielectric breakdown voltage is: the potential difference at which dielectric failure occurs under prescribed conditions in an electrical insulating material located between two electrodes. This is permanent breakdown and is not recoverable. ASTM goes on to state that the results obtained by this test can seldom be used directly to determine the dielectric behavior of a material in an actual application. This is not a test for "fit for use" in the application, as is the "Proof Test", which is used for detection of fabrication and material defects to the dielectric insulation.

Leakage Current HiPot Testing

Due to the variety of dielectric types, thicknesses and board layouts, not all boards test alike. All insulated metal substrates closely resemble a parallel plate capacitor during HiPot testing. The capacitance is equal to:

$$C = \in A/d$$

where:

$\in$ = Permittivity (Dielectric Constant)

A = Surface Area

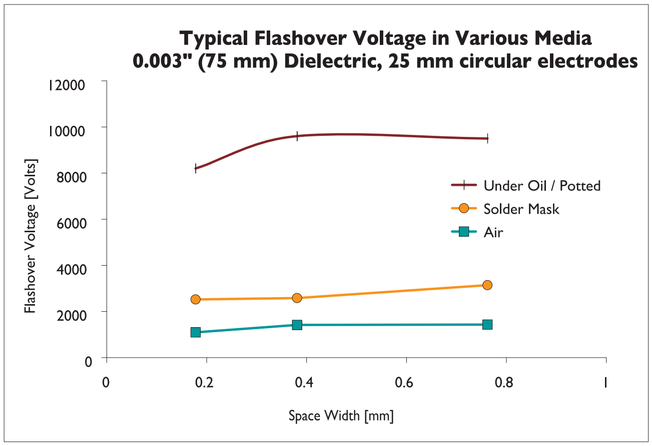
d = Distance (Dielectric Thickness)

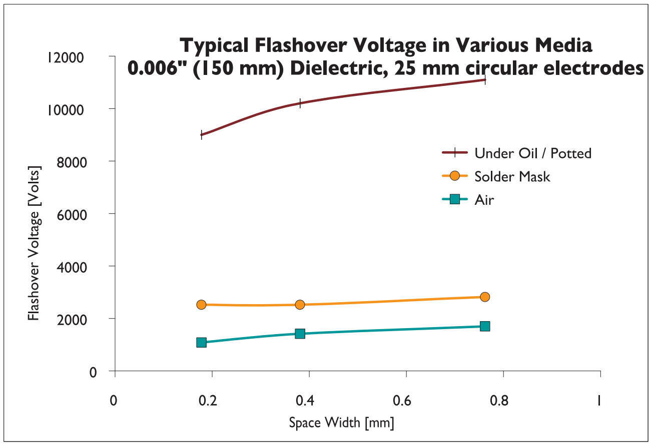
The capacitance value changes with different configurations of materials and board layouts. This can be demonstrated where one board fails the test and another passes, but when both are actually tested for dielectric strength and leakage current in a controlled environment, both pass. Therefore, it is very important to properly design the testing and test parameters with the material characteristics in mind. Test set-up and parameters that over-stress or do not consider reactance of the material and its capacitive and resistive components, can lead to false failures and/or test damage of the board.

Another test characteristic that is generally misunderstood with insulated metal substrates is the leakage and charge current that take place during the test. In most cases, the leakage current value on insulated metal substrates is much smaller than the measurement capability of a typical HiPot tester. What is most misunderstood is the charge current that takes place during the test. Leakage current measurements can only be realized once the board has been brought to the full test voltage (DC voltage) and is held at that voltage during the test. This current value and rate dI/dT is directly related to the capacitance of the board. Therefore, a board that has an effective capacitance higher than another board will have a higher charge current rate than the one with a lower effective capacitance. This does not reflect the leakage current or the voltage withstand of the dielectric insulation instead, it represents the characteristic transient response of the dielectric. Therefore, one is not able to determine comparable leakage current based on the instantaneous charge current. For accurate leakage test data, bring the board up to full test voltage and hold.

Creepage Distance And Discharge

Creepage distance and discharge has to be taken into account because Thermal Clad dielectrics often incorporate a metal base layer. Circuit board designers should consider "Proof Testing" requirements for: conductor-to-conductor and conductor-to-circuit board edge or through holes. The graph adjacent depicts flashover: without soldermask, with soldermask and under oil.





MEASURED CURRENT - CHARGE CURRENT = LEAKAGE CURRENT

Assembly Recommendations

Solder Assembly

Solder joints deserve additional consideration in the design of Thermal Clad assemblies. This section covers solder surface finishes, application and thickness, alloy and flux.

Surface Finishes

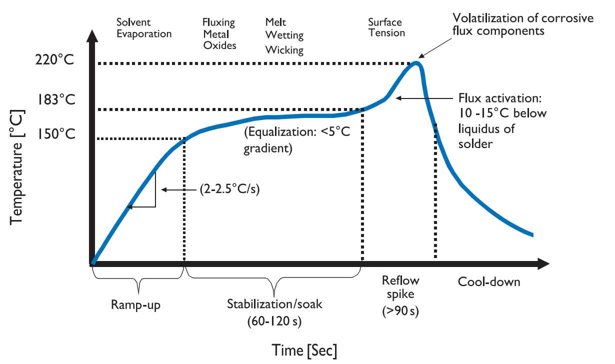
Standard circuit board finishes are available for Thermal Clad circuit boards. These finishes are RoHS compliant – ENIG (Electroless Nickel/Immersion Gold), OSP (Organic Solderability Protectant), immersion silver or tin and lead-free HASL. The standard tin/lead HASL is also available. Shelf life of Thermal Clad circuit board finishes varies from 3 to 6 months for OSP and up to 1 year for ENIG or HASL. The plated finishes and OSP provide a thin planar coating to protect copper base layers from oxidation. The ENIG finish supports aluminum wire bonding. A thicker gold is required for gold wire, so electroless gold or palladium finish can be added to the ENIG process.

Note: For copper-based Thermal Clad, the soldering process should not exceed 260°C for one minute and for aluminum base Thermal Clad should not exceed 300°C for one minute. See graph below which references a typical oven reflow temperature profile.

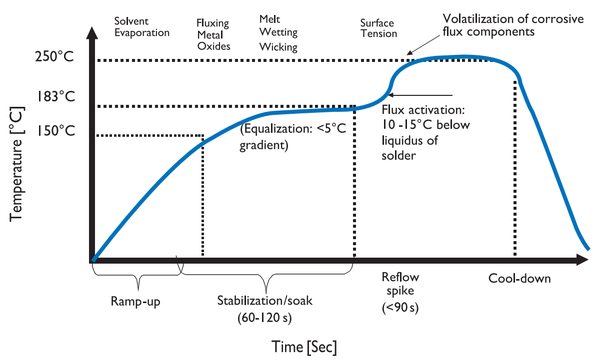
Application and Thickness

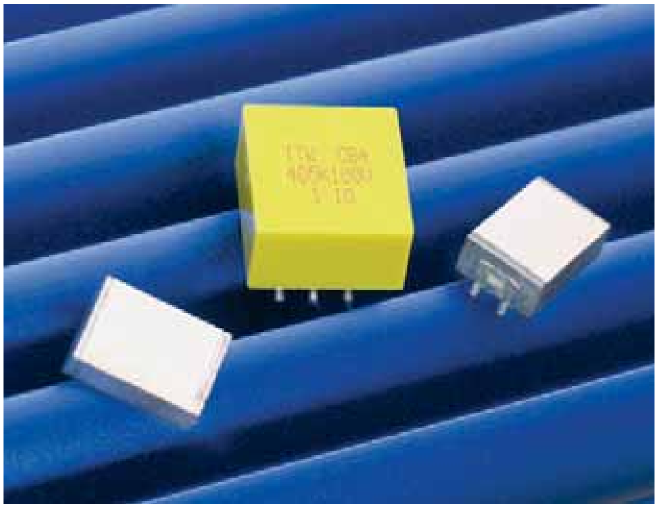
The typical application technique is metal stencil. Dispensing of solder to specific locations is used for secondary operations or special attachment requirements. No other decision will effect the reliability of the solder joint as much as the thickness of the solder to be used. A minimum of 0.004" (100μm) is recommended (after reflow). This thickness dissipates stress build up in the joint. Additional information regarding solder joint reliability is offered in the appendix.

Representative SnPb Reflow Temperature Profile

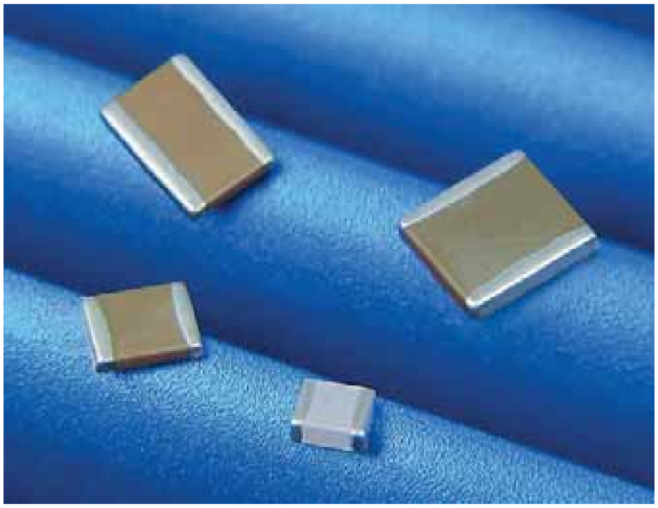


Representative Pb free Reflow Temperature Profile





ITW Paktron Multilayer Polymer (MLP) Capacitors are well suited for IMS. The MLP attributes include stability under AC/DC voltages, ultra low ESR, coefficient of expansion tolerant and robust/non-cracking construction.



Kemet capacitors are well known for their consistent product characteristics. Kemet's high level of manufacturing control and material selection are the key drivers that have made these capacitors a proven solution for IMS applications.

Surfilm® Capacitors and Capstick® Capacitors, trademarks of ITW Paktron.

Connection Techniques

Connection techniques common throughout the industry are being used successfully on Thermal Clad IMS substrates. Surface mount connectors are manufactured using plastic molding materials with thermal coefficients of expansion that roughly match the characteristics of the baseplate metal. However, the plastic molding compounds do have a different thermal capacity and thermal conductivity that can cause stress in the assembly as it cools after soldering and during any significant temperature excursion. Process-caused thermal mechanical stress is specific to the solder reflow process used. For this reason, designs that capture the metal pin without rigidity are preferred, particularly if the major dimension of the connector is large.

Pin Connectors

Pin connectors and pin headers are often used in Thermal Clad assembly when an FR-4 panel is attached to a Thermal Clad assembly. The differential coefficient of expansion between the control panel and the base metal will cause stress in the solder joint and dielectric. The most advanced designs incorporate stress relief in the fabrication of the pin. Redundant header pins are often used to achieve high current carrying capacity.

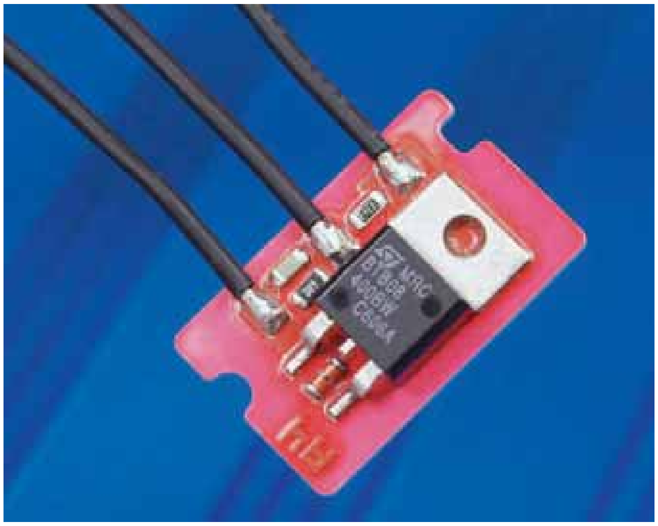
Manufacturers such as AutoSplice and Zierick have off the shelf pins ideal for IMS applications. Custom pins and connectors are also available.

Power Connections

Only a few companies supply spade or threaded fastener connectors for surface mount power connections. In many cases these are lead frame assemblies soldered to the printed circuit pads and bent to accommodate the shell used for encapsulation. Designs incorporating stress relief and a plastic retainer suitable for high amperage are also available.

Edge Connectors

When using edge connectors as part of the Thermal Clad printed wiring pattern, it is suggested that interfacing conductors be finished with a hard gold plating over sulfamate nickel plating. A 45° chamfer is recommended when using an edge connector. Remember to maintain the minimum edge to conductor distance to prevent shorting.

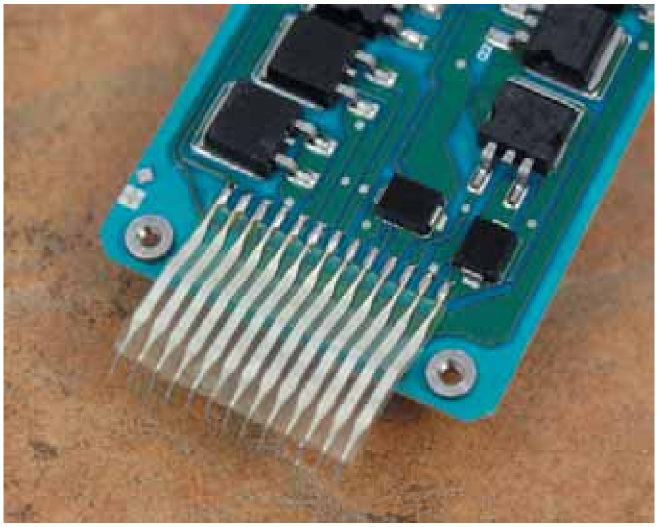


Wire soldering on Thermal Clad.

Wire Bonding – Direct Die

Wire bonding is particularly useful in design of packages with chip on board (COB) architecture. The technique uses surface mount and interconnect capability of Thermal Clad in a highly efficient thermal design.

To use this technique with Thermal Clad, it is important to prepare interconnection sites of the circuit layer for wire bonding. For aluminum wire bonding to the circuit layer, a electroless nickel-immersion gold plating is required. For applications requiring gold wire bonding a electroless nickel – wire bondable gold or a palladium – immersion gold is required. The specific requirements for the plating are typically customer supplied within standard plating capabilities. These surface finishes are very solder compatible and meet wetting requirements for solder die mounting processes.



Flex attachment on Thermal Clad.

Solutions For Surface Mount Applications

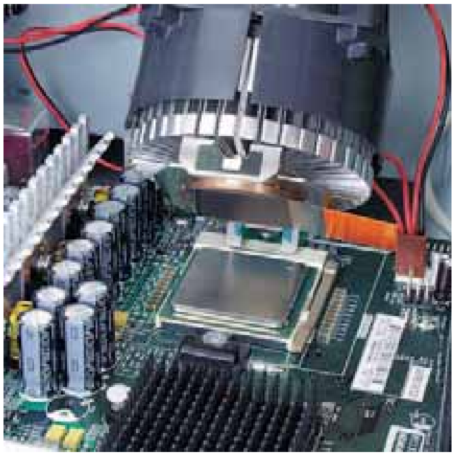
Hi-Flow®

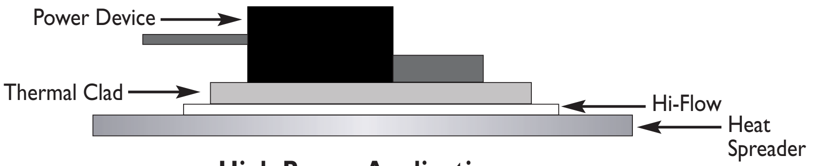
The Hi-Flow family of phase change materials offers an easy-to-apply thermal interface for many surface mount packages. At the phase change temperature, Hi-Flow materials change from a solid and flow with minimal applied pressure. This characteristic optimizes heat transfer by maximizing wet-out of the interface. Hi-Flow is commonly used to replace messy thermal grease.

Bergquist phase change materials are specially compounded to prevent pump-out of the interface area, which is often associated with thermal grease. Typical applications for Hi-Flow materials include:

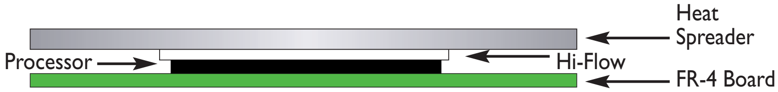
- Pentium®, Athlon®, and other high performance CPUs
- DC/DC converters
- Power modules

Hi-Flow materials are manufactured with or without film or foil carriers. Custom shapes and sizes for non-standard applications are also available.

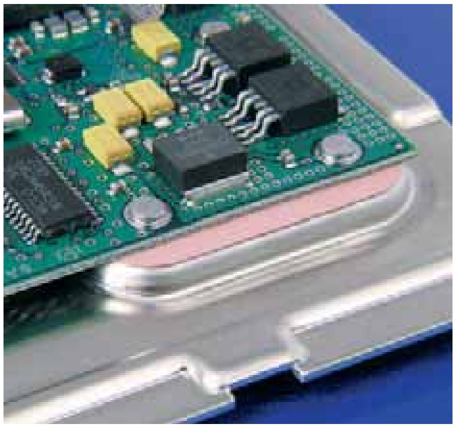




High Power Application
Hi-Flow with Thermal Clad



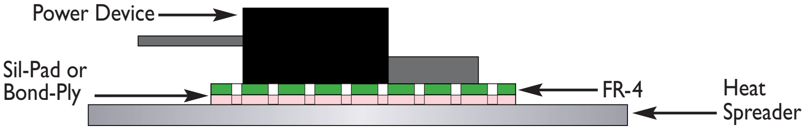
High Power Application
Hi-Flow without Thermal Clad



Sil-Pad®

Sil-Pad is the benchmark in thermal interface materials. The Sil-Pad family of materials are thermally conductive and electrically insulating. Available in custom shapes, sheets, and rolls, Sil-Pad materials come in a variety of thicknesses and are frequently used in SMT applications such as:

- Interface between thermal vias in a PCB, and a heat sink or casting
- Heat sink interface to many surface mount packages



Mid Power Application with Bond-Ply or Sil-Pad

Pentium® is a registered trademark of Intel Corporation.
Athlon® is a registered trademark of Advanced Micro Devices, Inc.

Where Thermal Solutions Come Together

Bond-Ply® & Liqui-Bond®

The Bond-Ply family of materials are thermally conductive and electrically isolating. Bond-Ply is available in a pressure sensitive adhesive or laminating format. Liqui-Bond is a high thermal performance liquid silicone adhesive that cures to a solid bonding elastomer. Bond-Ply provides for the mechanical decoupling of bonded materials with mismatched thermal coefficients of expansion. Typical applications include:

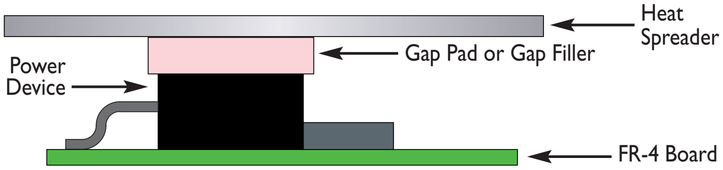
- Bonding bus bars in a variety of electronic modules and sub assemblies
- Attaching a metal-based component to a heat sink
- Bonding a heat sink to a variety of ASIC, graphic chip, and CPU packages
- Bonding flexible circuits to a rigid heat spreader or thermal plane
- Assembly tapes for BGA heat spreader
- Attaching PCB assemblies to housings

Gap Pad® & Gap Filler

The Gap Pad product family offers a line of thermally conductive materials which are highly conformable. Varying degrees of thermal conductivity and compression deflection characteristics are available. Typical applications include:

- On top of a semiconductor package such as a QFP or BGA. Often times, several packages with varying heights can use a common heat sink when utilizing Gap Pad.
- Between a PCB or substrate and a chassis, frame, or other heat spreader
- Areas where heat needs to be transferred to any type of heat spreader
- For interfacing pressure sensitive devices
- Filling various gaps between heat-generating devices and heat sinks or housings

Gap Pads are available in thickness of 0.010" to 0.250", and in custom shapes, with or without adhesive. Gap Fillers are available in cartridge or kit form.



Lower Power Application with Gap Pad

Top Efficiency In Thermal Materials For Today's Changing Technology.

Contact Bergquist for additional information regarding our Thermal Solutions. We are constantly innovating to offer you the greatest selection of options and flexibility to meet today's changing technology.

Appendix

ASTM	D 149	Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
	D 150	Test Methods for AC Loss Characteristics and Permitivity (Dielectric Constant) of Solid Electrical Insulating Materials
	D 257	Test Methods for DC Conductance or Impedance of Insulating Materials
	D 374	Test Methods for Thickness of Solid Electrical Insulation
	D 3165	Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies
	D 5470	Test Methods for Thermal Transmission Properties of Thin Thermally Conductive Solid Electrical Insulating Materials
IEC	60093	Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials
	60243-1	Methods of test for electric strength of solid insulating materials - Part 1: Tests at power frequencies
	60250	Recommended methods for the determination of the permitivity and dielectric dissipation factor of electrical insulating materials at power, audio, and radio frequencies including metre wavelengths
	60626-2	Combined flexible materials for electrical insulation- Part 2: Methods of test
IPC	2221	Generic Standard on Printed Board Design
	6012	Qualifications and Performance Specification of Rigid Printed Boards
	600	Acceptance of Printed Boards
	TM-650	Cleanliness (2.3.35 & 2.3.26)
	TM-650-2.4.22	Bow and Twist
	TM-650-2.4.8	Peel
	SM-840C	Soldermask
Surface Mount	ANSI/IPC-SM-782	Surface Mount Land Patterns (configurations and design rules)
ISO 4587	Adhesives	Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies