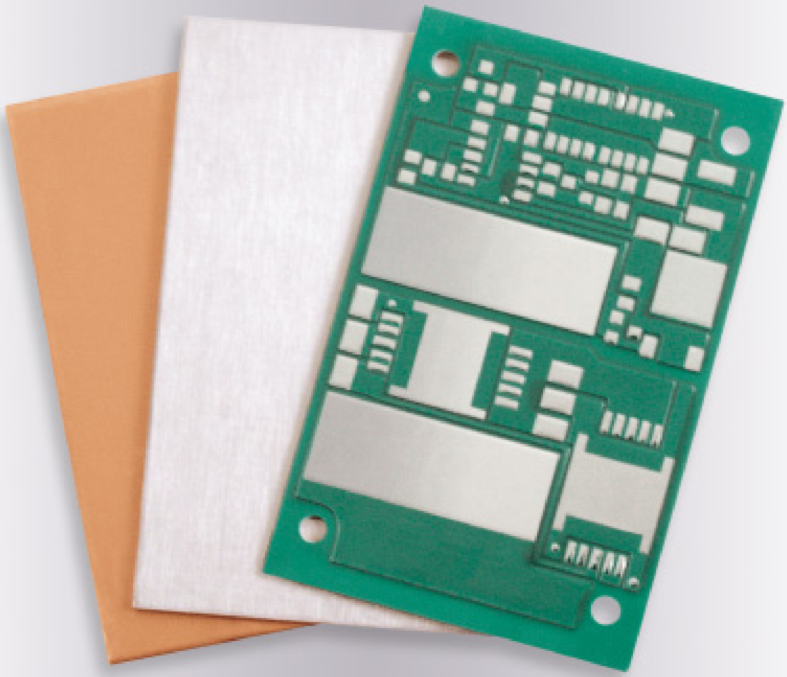
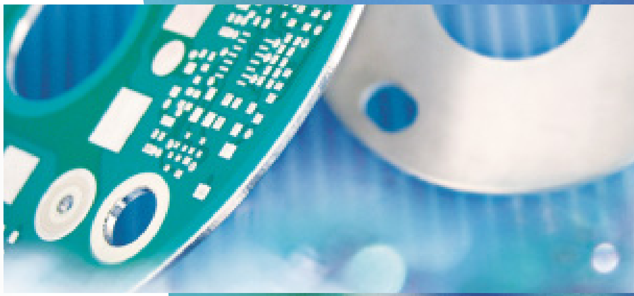
Thermal Solutions
For Surface Mount
Power Applications

ThermalClad®
SELECTION GUIDE





THE BERGQUIST COMPANY

January 2002

Thermal Clad®: U.S. Patent 4,810,563 and others

ACCREDITED
BY THE RvA

ANSI-RAB
QMS
ACCREDITED

Registered Firm
ISO 9001/Q91
Certificate QSR-572

QS-9000
Certificate Number,
QSR-QS-048

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THERMAL CLAD® OVERVIEW

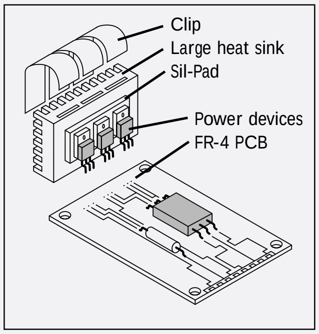
Key Benefits Of Thermal Clad®

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 die size is reduced and heat issues are a major concern.

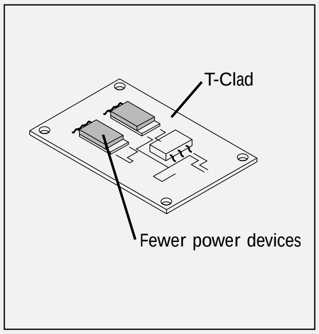
Thermal Clad substrates minimize thermal impedance and conduct heat more effectively and efficiently than standard PWB's. These substrates are more mechanically robust than thick-film ceramics and direct bond copper constructions that are often used in these applications.

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

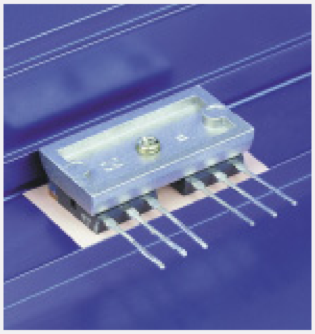
Bergquist Thermal Clad substrates are not limited to use with metal base layers. In one example, power conversion applications can enhance their performance by replacing FR-4 with Thermal Clad dielectrics in multi-layer assemblies. In this application, the thickness of the copper circuit layer can be minimized by the high thermal performance of Thermal Clad. (Note: For additional information on this topic, refer to the "specialty section" on page 12 of this guide).



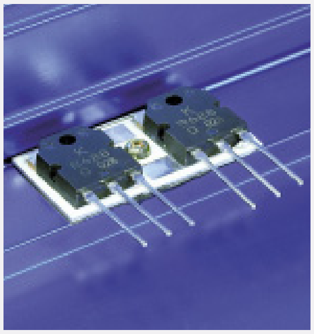
Traditionally, cooling an FR-4 board required the use of a large heat sink interface material and various hardware (brackets, screws or clamps). This configuration requires manual assembly which is labor intensive.



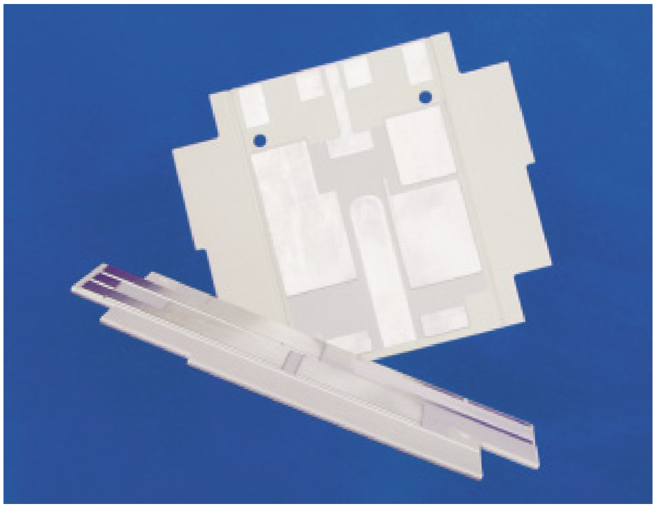
Cooling with Thermal Clad eliminates the need for heat sinks, device clips, cooling fans and other hardware. An automated assembly method will reduce long term costs.



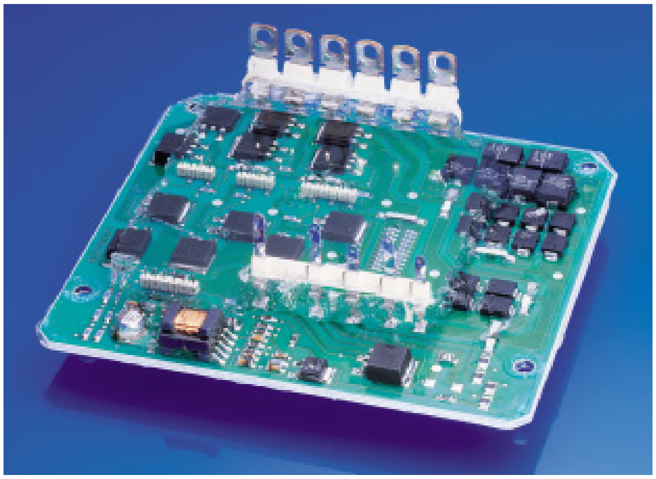
Conventional methods
measured junction temperature
5W=Tj 43ºC



Thermal Clad
measured junction temperature
5W=Tj 35ºC



In this power conversion application, two layers of 10 oz. copper were used. Thermal Clad HT dielectric was utilized as a replacement to FR-4.



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:

- 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 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 older 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

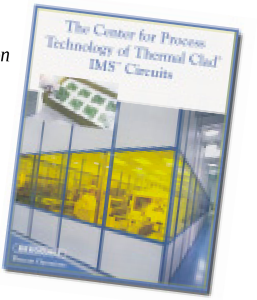
Thermal Clad is a dielectric (ceramic-polymer blend) coated metal base with a bonded copper circuit layer. This unique material offers superior heat transfer to help cool components while eliminating the problems associated with fragile ceramics.

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

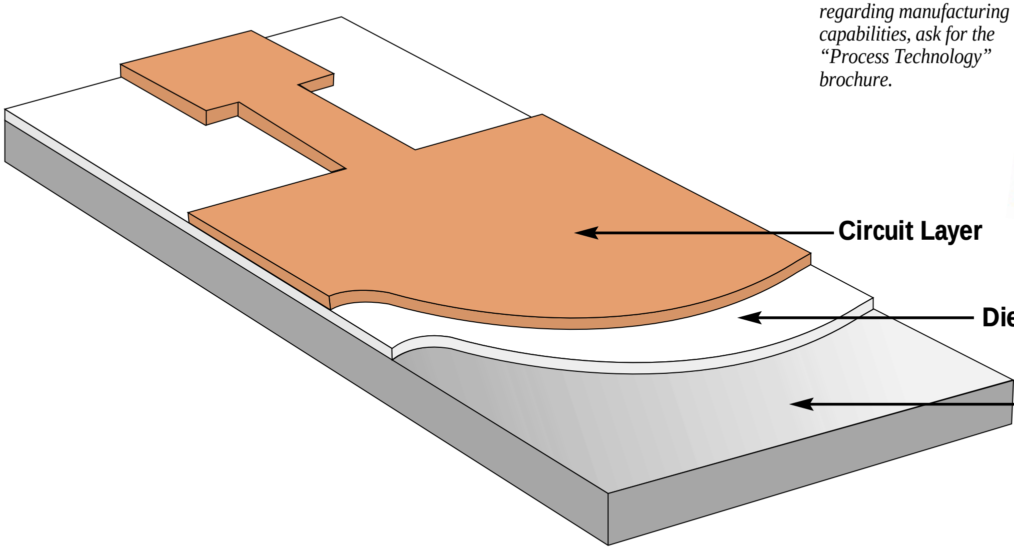
- **Circuit Layer:** This is the printed circuit foil with thickness of 1oz to 10oz (35-350µm) in standard Thermal Clad.
- **Dielectric Layer:** This offers electrical isolation with minimum thermal resistance. The multiple-layer dielectric is the key element of Thermal Clad, and bonds the base metal 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 0.040" (1.0mm) in aluminum, although many thicknesses are available. In some applications, the base layer of metal may not be needed. See specialty section on page 12.

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.

For additional information regarding manufacturing capabilities, ask for the "Process Technology" brochure.



The Center for Process Technology of Thermal Clad® IMS™ Circuits

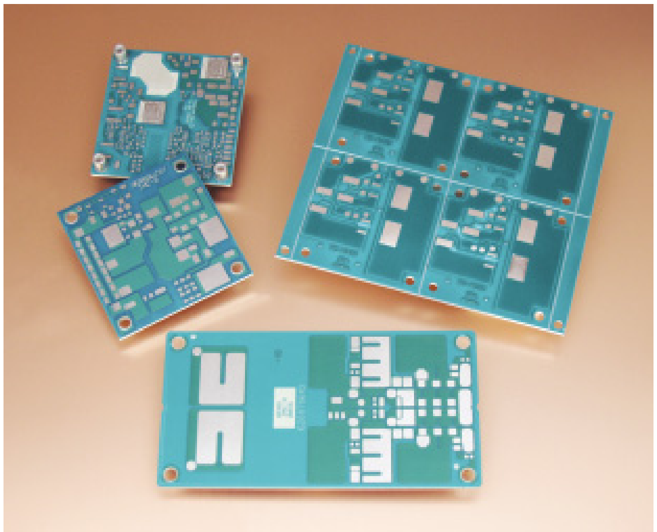


THERMAL CLAD APPLICATIONS

Power Conversion

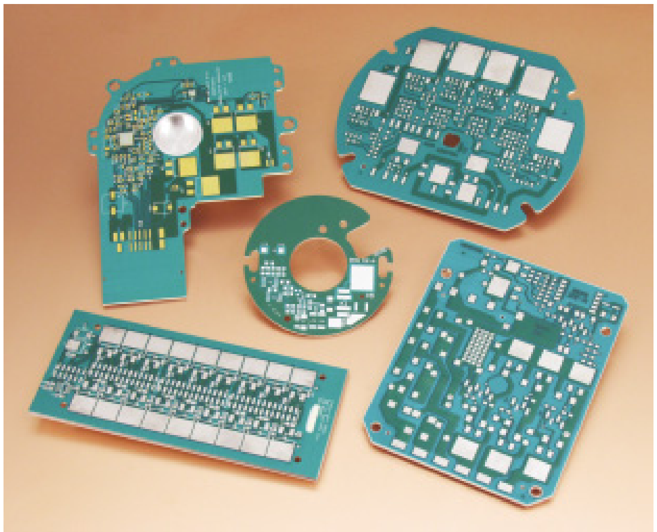
Due to the size constraints and watt-density requirements in DC-DC conversion, Thermal Clad has become the favored choice. Thermal Clad offers a variety of thermal performances, is compatible with mechanical fasteners and is highly reliable. It can be used in almost every form-factor and fabricated in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

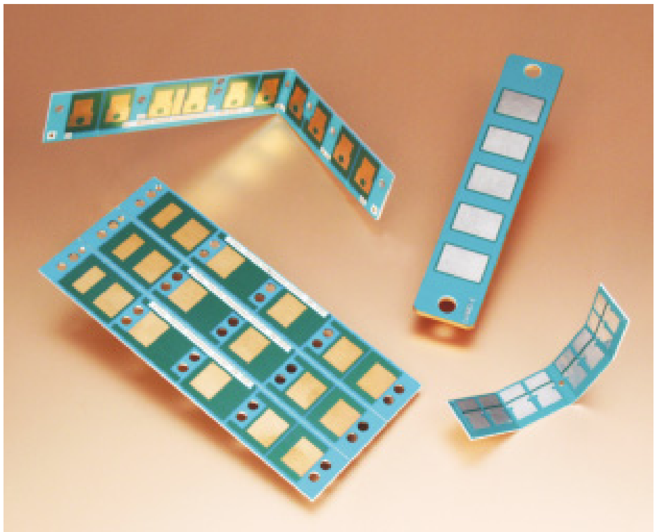
(Note: In some power conversion applications, the base layer of metal may not be needed. Refer to page 12 of this guide).



Motor Drives

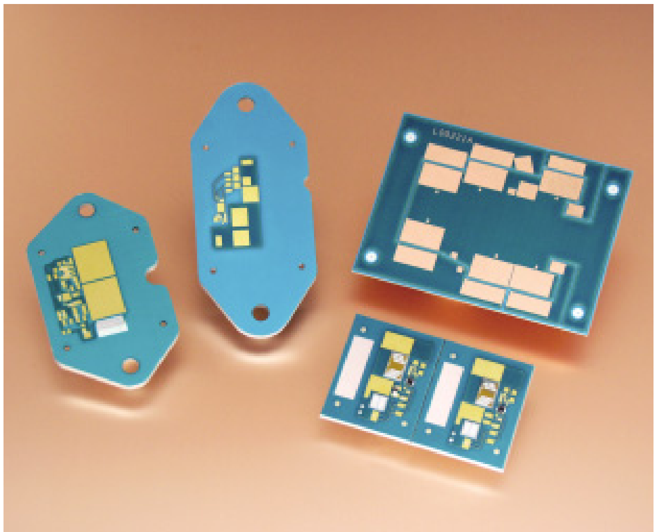
Compact high reliability motor drives built on Thermal Clad have set the benchmark for watt-density. Dielectric choices provide the electrical isolation needed to meet operating parameters and safety agency test requirements. With the ability to fabricate in a wide variety of form-factors, the implementation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





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 simplified and made more efficient.



Solid State Relays

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.

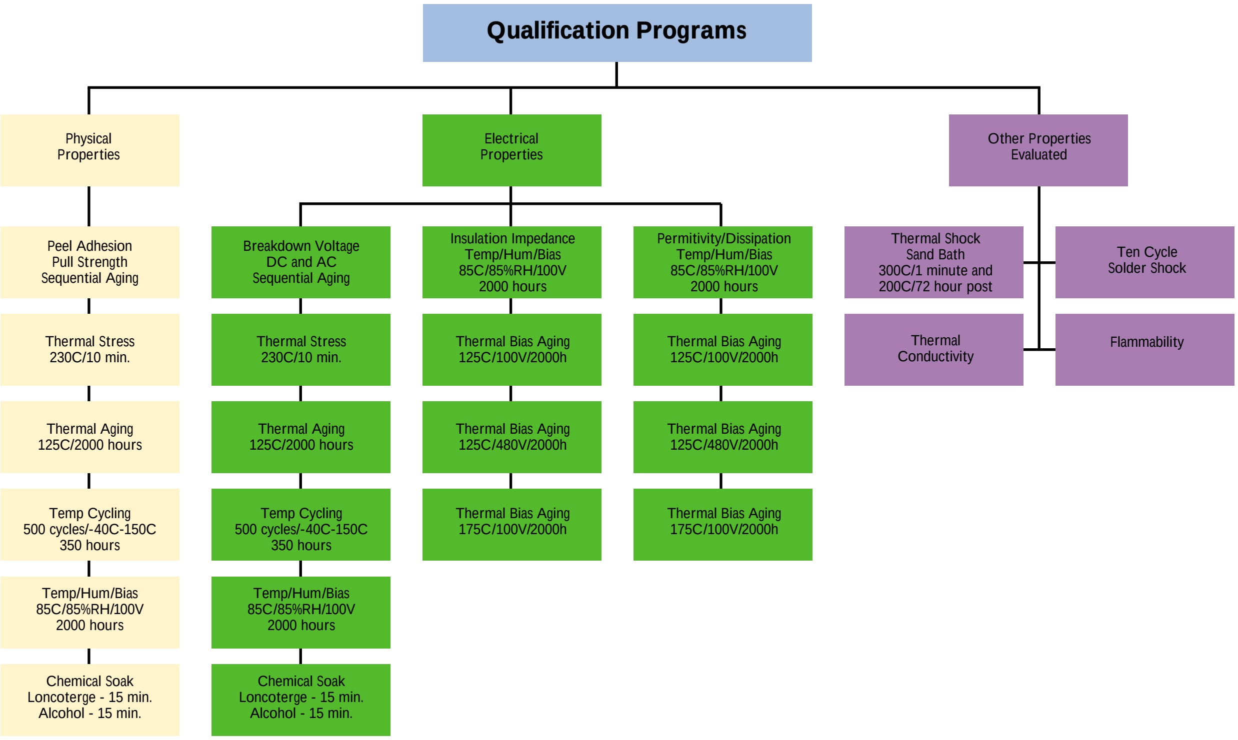
Thermal Clad Long Term Reliability

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 QS 6019. The lab facilities at Bergquist are UL certified and manufacturing facilities are QS 9000 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.



Qualification Programs

- Physical Properties
  - Peel Adhesion Pull Strength Sequential Aging
  - Thermal Stress 230C/10 min.
  - Thermal Aging 125C/2000 hours
  - Temp Cycling 500 cycles/-40C-150C 350 hours
  - Temp/Hum/Bias 85C/85%RH/100V 2000 hours
  - Chemical Soak Loncoterge - 15 min. Alcohol - 15 min.
- Electrical Properties
  - Breakdown Voltage DC and AC Sequential Aging
    - Thermal Stress 230C/10 min.
    - Thermal Aging 125C/2000 hours
    - Temp Cycling 500 cycles/-40C-150C 350 hours
    - Temp/Hum/Bias 85C/85%RH/100V 2000 hours
    - Chemical Soak Loncoterge - 15 min. Alcohol - 15 min.
  - Insulation Impedance Temp/Hum/Bias 85C/85%RH/100V 2000 hours
    - Thermal Bias Aging 125C/100V/2000h
    - Thermal Bias Aging 125C/480V/2000h
    - Thermal Bias Aging 175C/100V/2000h
  - Permitivity/Dissipation Temp/Hum/Bias 85C/85%RH/100V 2000 hours
    - Thermal Bias Aging 125C/100V/2000h
    - Thermal Bias Aging 125C/480V/2000h
    - Thermal Bias Aging 175C/100V/2000h
- Other Properties Evaluated
  - Thermal Shock Sand Bath 300C/1 minute and 200C/72 hour post
  - Ten Cycle Solder Shock
  - Thermal Conductivity
  - Flammability

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.*

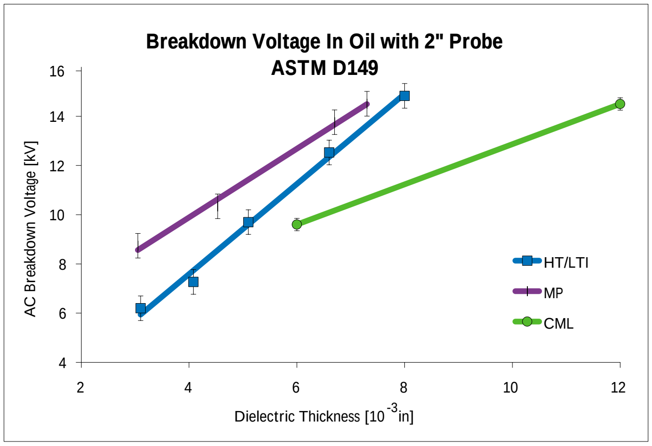
Dynamic Mechanical Analysis (DMA) *– Measures the modulus of materials over a range of temperatures*

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.



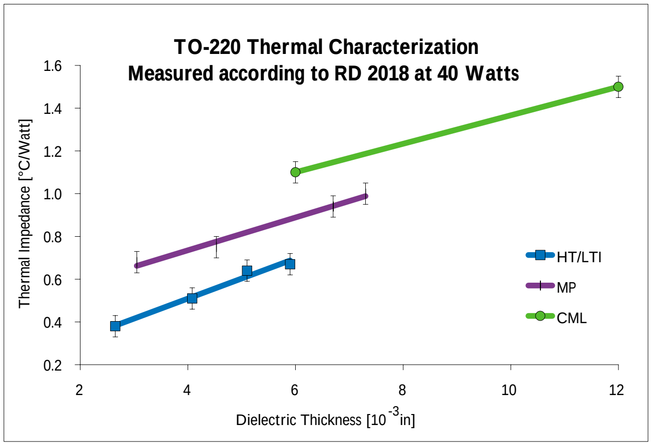
Electrical Isolation

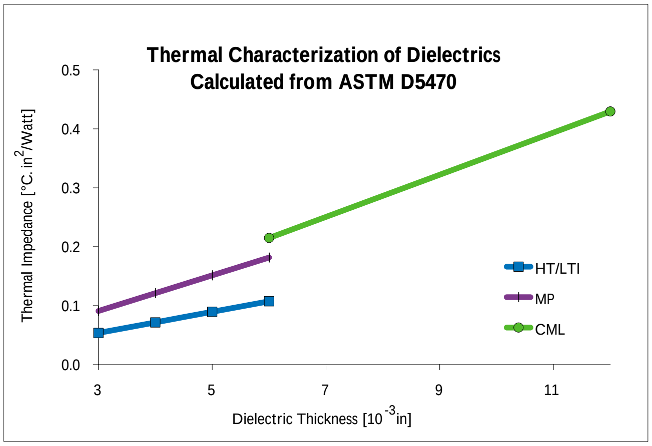
Dielectrics are available in thicknesses from 0.003" (75µm) to 0.012" (300µm), depending on your isolation needs. See electrical design rule checks on pages 20-21 to help determine which thickness is appropriate for your application.

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.

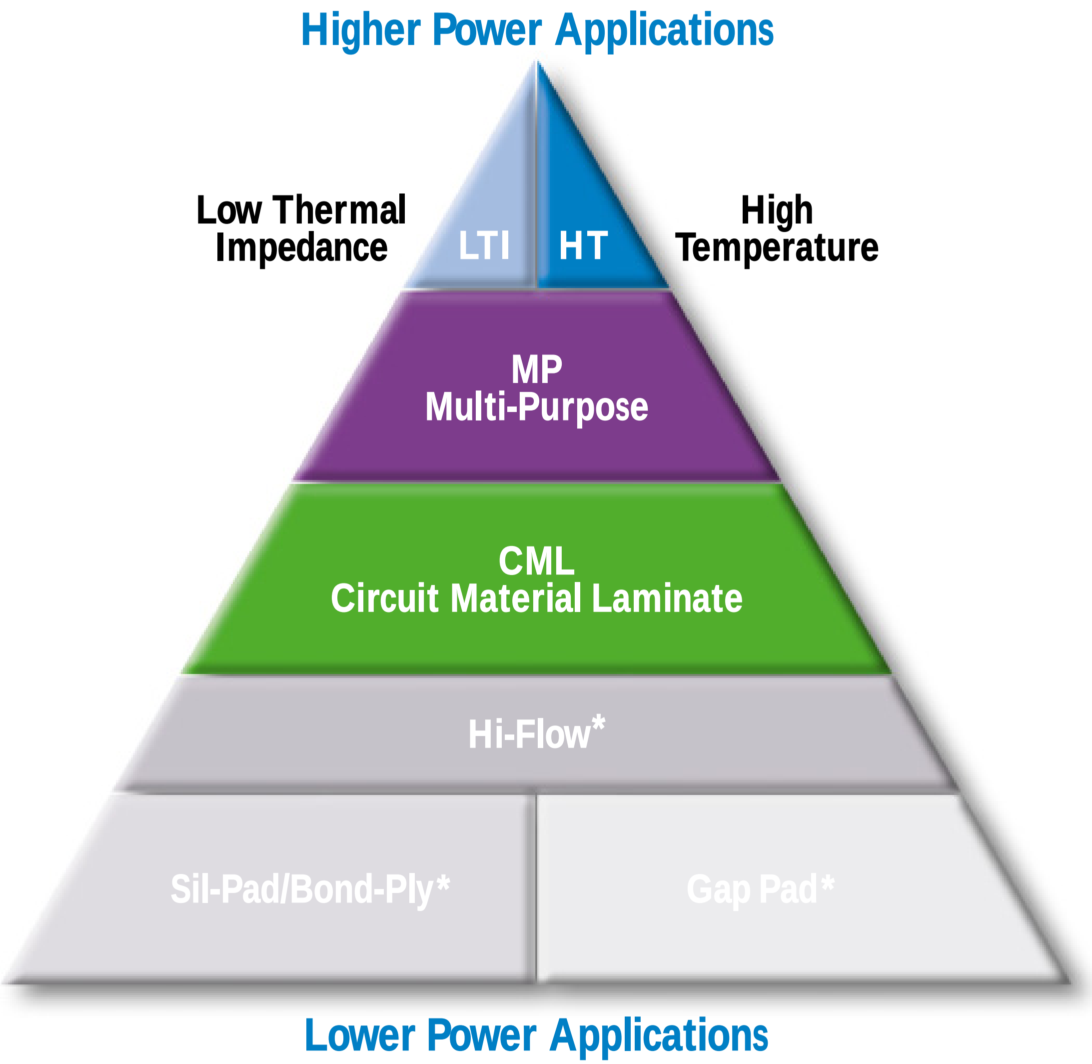
High thermal conductivity is relevant to your application when the thickness of the dielectric material is taken into consideration. Impedance to heat flow is proportional to the ratio of thickness to thermal conductivity.





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

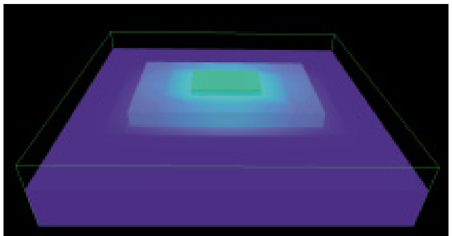
Lower Thermal Impedance = Lower Junction Temperatures

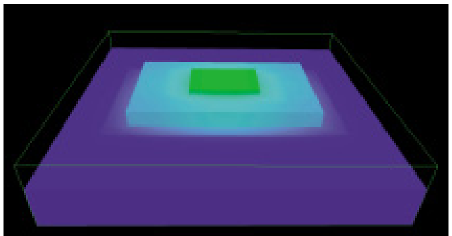


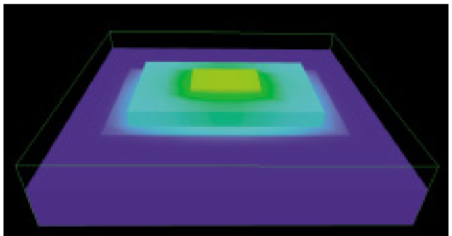
*See page 24 and 25

Thermal Models

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

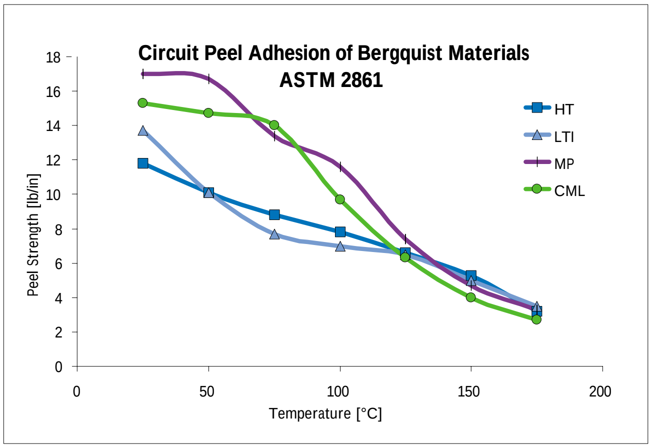

LTI - Low Thermal Impedance
and HT - High Temperature


MP - Multi-Purpose


CML - Circuit Material Laminate

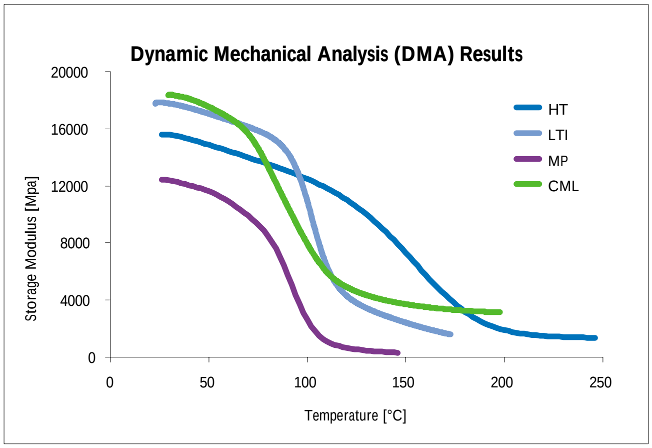
DIELECTRIC PERFORMANCE CHARACTERISTICS

Peel Strength



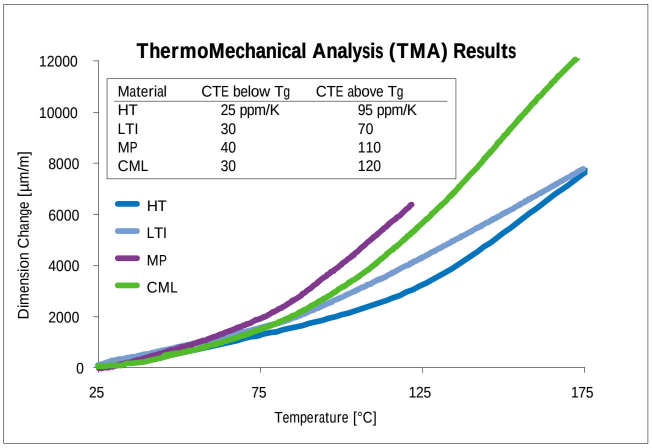
This chart graphs the stability of the bond strength between the dielectric and the circuit layer during temperature rise. Although bond strength goes down at higher temperatures, it maintains at least 3 lbs. even at 175 degree C.

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 22-23 for additional information.

Coefficient of Thermal Expansion

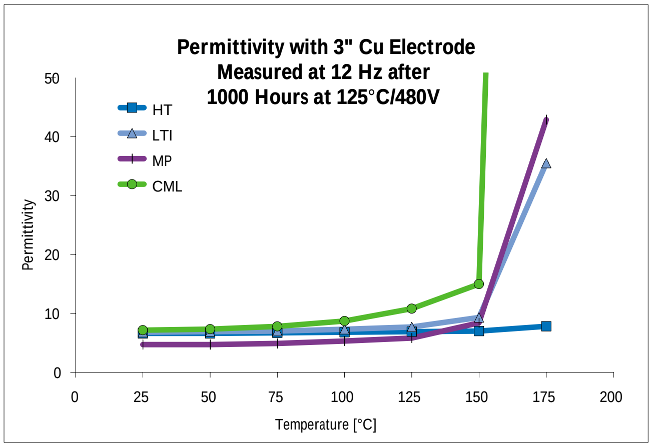


Material	CTE below Tg	CTE above Tg
HT	25 ppm/K	95 ppm/K
LTI	30	70
MP	40	110
CML	30	120

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 14-15 for base layer selection.

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 at a temperature of 175 degree C.

SUMMARY OF DIELECTRIC CHARACTERISTICS

		THERMAL PERFORMANCE			DIELECTRIC PERFORMANCE				OTHER		
Part Number	Thickness[1] [10⁻³in/10⁻⁶m]	Impedance[2] [°C/W]	Impedance[3] [°Cin²/W]	Conductivity[4] [W/m-K]	Proof Test[5] [VAC]	Operating [VAC]	Breakdown[6] [kVAC]	Permitivity[7]	Glass Transition[8] [°C]	UL Index[9] [°C]	Peel Strength[10] [lb/in]
HT-04503	3/75	0.45	0.05	2.2	1500	120	6.0	7	150	140/140	8
HT-07006	6/150	0.70	0.11	2.2	5000	480	11.0	7	150		
LTI-04503	3/75	0.45	0.05	2.2	1500	120	6.5	7	90	130/130	6
LTI-05004	4/100	0.50	0.07	2.2	3000	240	7.5	7	90		
LTI-06005	5/125	0.60	0.09	2.2	4000	480	9.5	7	90		
LTI-07006	6/150	0.70	0.11	2.2	5000	960	11.0	7	90		
MP-06503	3/75	0.65	.09	1.3	1500	120	8.5	6	90	130/140	9
MP-07504	4/100	0.75	0.12	1.3	3000	240	10.0	6	90		
MP-08005	5/120	0.80	.015	1.3	4000	480	11.0	6	90		
MP-09006	6/150	0.90	0.18	1.3	5000	960	12.5	6	90		
CML-11006	6/150	1.1	0.21	1.1	5000	960	10.0	7	90	130/130	10
CML-16012	12/300	1.6	0.43	1.1	5000	960	14.0	7	90		

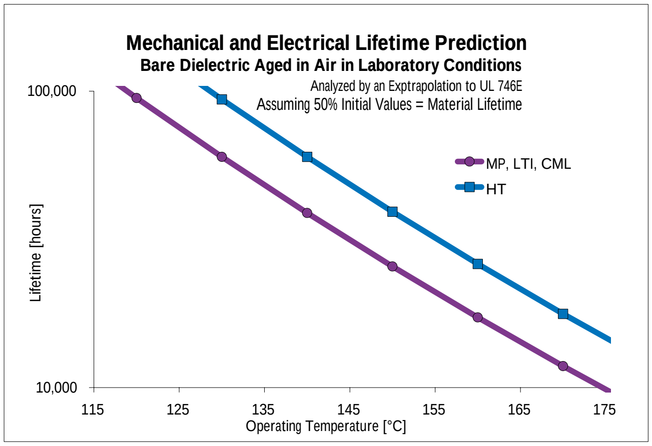
Method Description

1-Optical
2-Internal TO-220 test RD 2018
3-Calculation from ASTM 5470
4-Extended ASTM 5470
5-500 V/sec ramp, 5 sec hold
6-ASTM D149
7-ASTM D150
8-Internal MDSC test RD 2014
9-UL 746 E
10-ASTM D2861

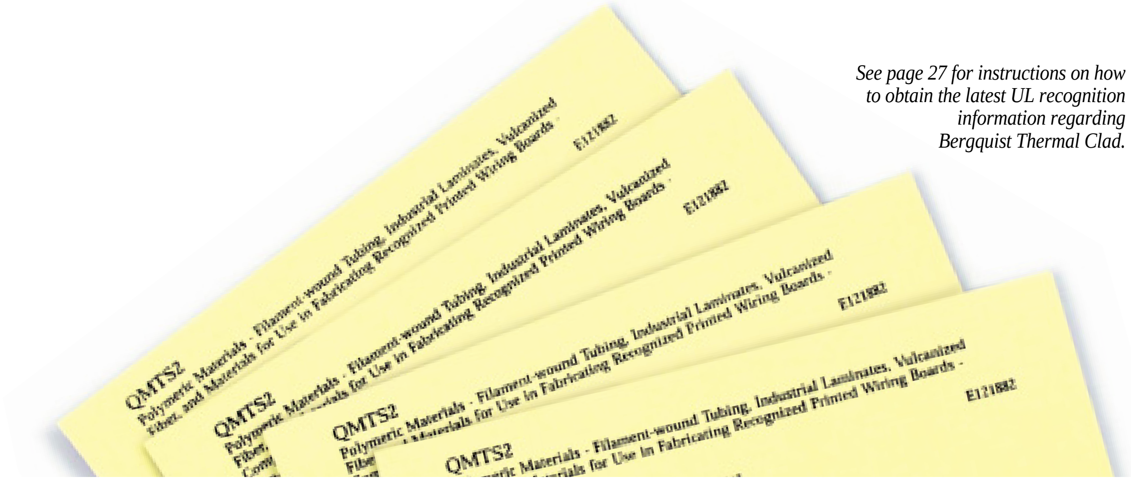
Operating Temperatures

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
HT	**140 / 140° C**
LT	**130 / 130° C**
MP	**130 / 140° C**
CML	**130 / 130° C**



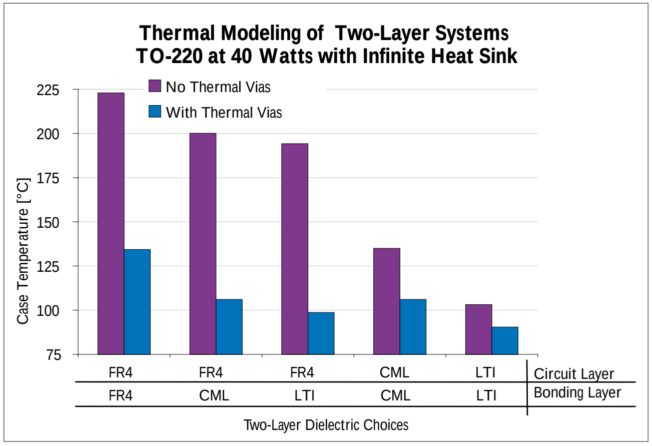
See page 27 for instructions on how to obtain the latest UL recognition information regarding Bergquist Thermal Clad.



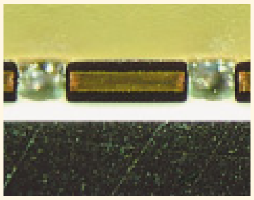
USING THERMAL CLAD DIELECTRIC MATERIAL –

Multi-Layer Systems Using FR-4 Circuits or Thermal Clad Circuits

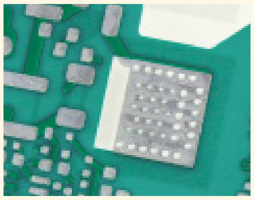
Bergquist dielectrics are ideal for applications requiring a multi-layer solution. Multi-layer constructions can provide shielding protection and additional electrical interconnects for higher component density. Bergquist dielectrics in conjunction with FR-4 type circuits or Thermal Clad circuits provide superior thermal performance over traditional FR-4 constructions. In addition, thermal vias 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.



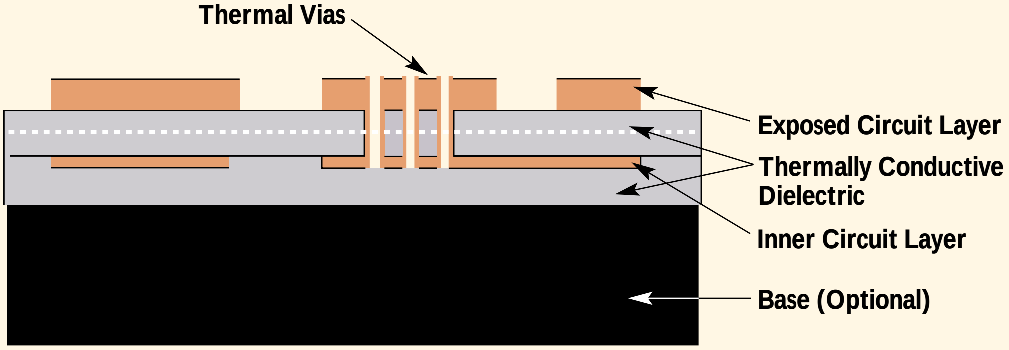
The graph depicts the modeled thermal result of various two-layer constructions as a function of device case temperature. The emphasis is the thermal effect of proper via utilization.



Thermal Vias Cross Section



Thermal Vias Plane View

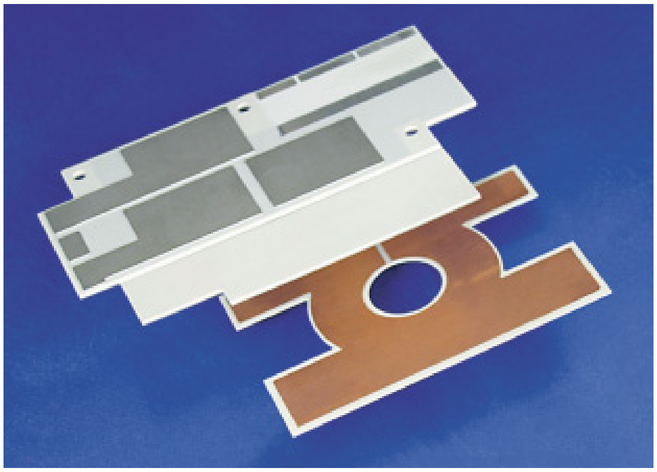


The picture above represents the construction of a two-layer circuit material bonded with Bergquist dielectrics to a metal base. These configurations utilize either Thermal Clad circuit or FR-4 type circuit materials, depending on the thermal requirements and the cost objectives. The configuration pictured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

Single Board Solutions Without The Metal Base

The thermal performance of Thermal Clad dielectrics are often sufficient to handle thermal requirements, thus 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 section on pages 16-17 for additional information.

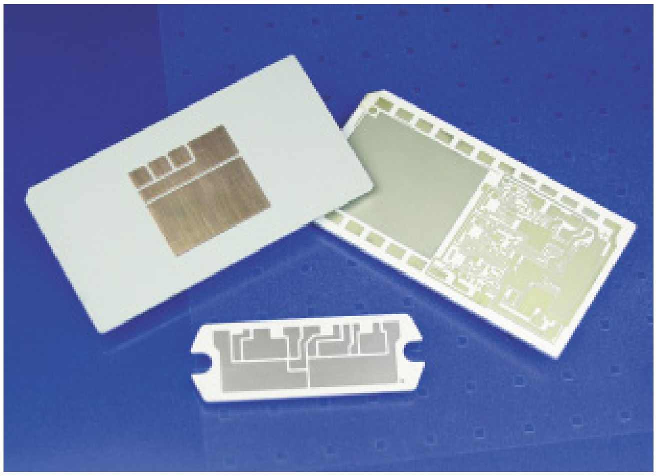
With the elimination of the metal base, components can be mounted on both sides. This can often create a single board solution where the power components are no longer separate from the logic components as is the case in a two-board system. Whether a metal base layer is used or not, magnetics can now be incorporated with Thermal Clad dielectric constructions.



DBC Replacement

Replace Ceramic Substrates

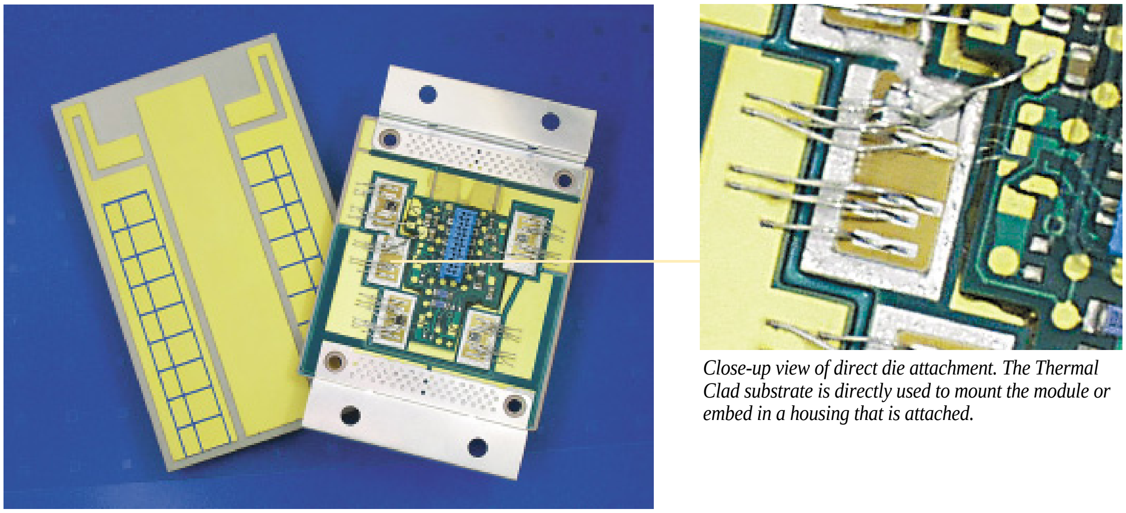
Thermal Clad can replace large area ceramic substrates. It can also be used as a mechanically durable support for ceramic spacers or direct bonded copper sub assemblies. The copper circuit layer of Thermal Clad has more current carrying capability than thick film ceramic technology.



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 all of these applications the copper circuits are Nickel/Gold plated to provide good solderability and wire bond integrity.

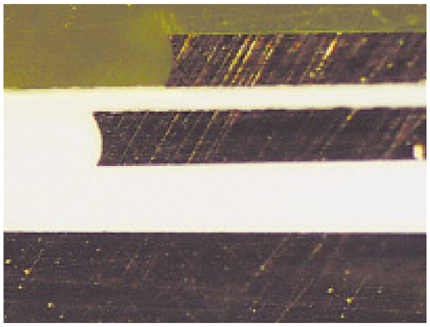


Close-up view of direct die attachment. The Thermal Clad substrate is directly used to mount the module or embed in a housing that is attached.

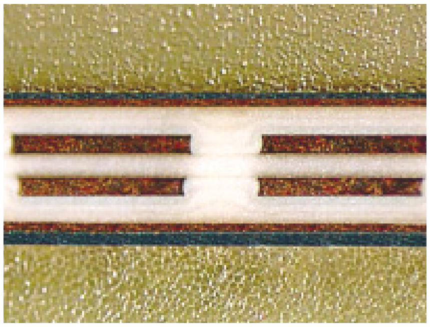
Heavy Copper

Applications requiring heavy copper for high current or heat spreading are just 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.



Cross sectional view of 4 oz. copper on 4 layers utilizes Thermal Clad HT dielectrics with no metal base.

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 Layer
- Surface Finish
- Costs

Coefficient Of Thermal Expansion And Solder Joints

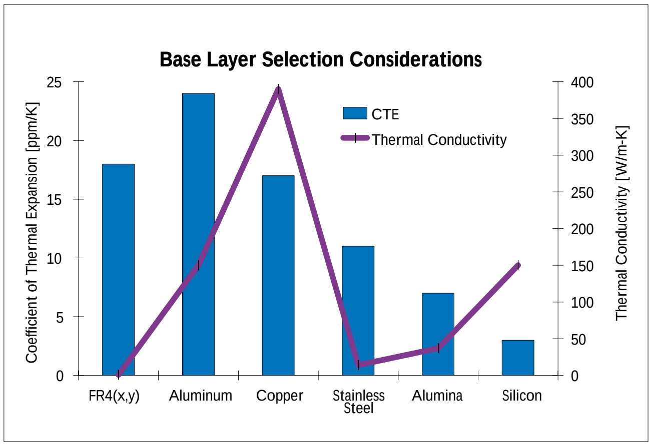
Solder joint fatigue can be minimized by selecting the correct base layer to match component expansion. The major concern with thermal expansion is the stress the solder joint experiences in power (or thermal) cycling. Solder joints are not mechanically rigid. Stress induced by heating and cooling will 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 22 covers these issues in greater detail.

METAL / ALLOY	THERMAL CONDUCTIVITY W/m - K	COEFFICIENT OF THERMAL EXPANSION ppm / K
Copper	400	17
Aluminum	150	25
304 Stainless Steel	16	16.3
Cold Rolled Steel	50	12.5
Iron	80	11.8
CIC Copper - Invar - Copper	20	5.2
CMC Copper - Molly - Copper	200	6.5
20% ALSIC / Aluminum	175	15

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.



SELECTING A BASE LAYER

Strength, Rigidity and Weight

MATERIAL	DENSITY	MODULUS OF RIGIDITY	YIELD STRENGTH
Copper C11000 Full Hard	0.32 lbs/in^3 (8.90 g/cc)	6400 ksi (44.1 GPa)	45 ksi (310 MPa)
Aluminum 5052 H34	0.097 lbs/in^3 (2.68 g/cc)	3757 ksi (25.9 GPa)	31 ksi (215 MPa)
Aluminum 6061 T6	0.098 lbs/in^3 (2.7 g/cc)	3751 ksi (26 GPa)	33 ksi (230 MPa)

BASE LAYERS			
Aluminum	0.020"	0.50 mm	**6061 T6 or 5052 H34**
	0.030"	0.75 mm	
	0.040"	1.00 mm	
	0.062"	1.60 mm	
	0.080"	2.00 mm	
	0.093"	2.36 mm	
	0.125"	3.20 mm	
Copper	0.020"	1.00 mm	**C11000 Alloy**
	0.030"	0.75 mm	
	0.040"	1.00 mm	
	0.062"	1.60 mm	
	0.080"	2.00 mm	
	0.093"	2.36 mm	
	0.125"	2.36 mm	

Anodized, Copper and Aluminum finishes

STANDARD THERMAL CLAD MATERIALS
16" x 19" 18" x 24" Sheets Usable area: subtract one inch

Thickness

Thermal Clad is normally purchased in one of the standard constructions in the table above. Special materials are also available.

Electrical Connections to the Base Plate

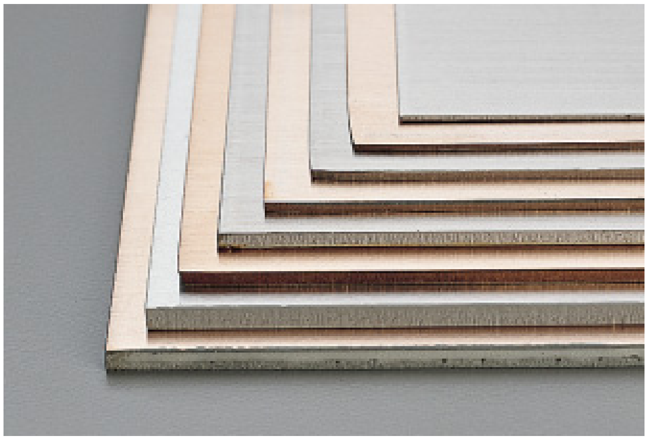
If a connection to the base plate is desired, copper is the most compatible base layer to use. Copper is a solderable alloy thus allowing easy via connection. Other base layers can be used for connection, but will require different attachment schemes.

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" (1.0 mm) Copper is equal to the cost of 0.125" (3.2 mm) 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.



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. On Thermal Clad smaller lines will not overheat, but they will increase the waste thermal heat of the assembly.

The following equation can be used to calculate minimum trace width utilizing both circuit thickness and current requirements. For additional information regarding this equation, ask for *Guidelines For Establishing The Current Carrying Capabilities of a Film Conductor* in the reference section on page 26.

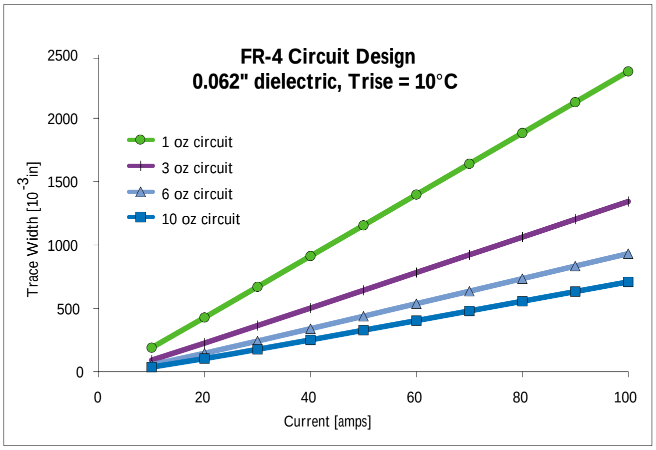
$$\text{MINIMUM TRACE WIDTH} = \left[\frac{T_S I^2 R_S}{K_S T_{RISE}} + T_S^2 \right]^{1/2} - T_S$$

T_S = Dielectric thickness

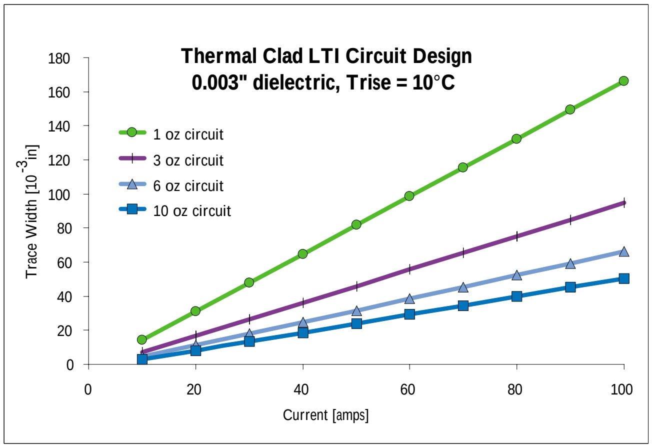
I = Current

R_S = Circuit sheet resistivity (function of thickness)

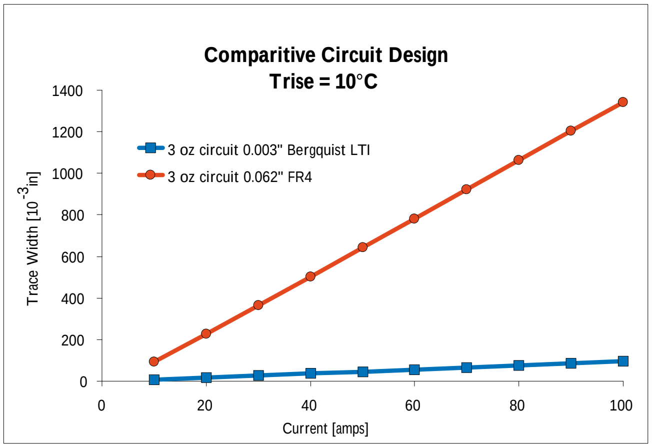
K_S = Dielectric thermal conductivity



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.

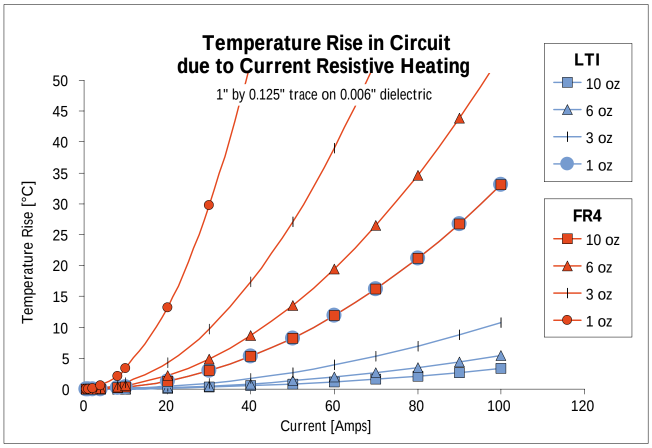


Comparison of Bergquist Dielectric LTI and FR-4 current capability.

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 package. See Heavy Copper Application section on page 13.

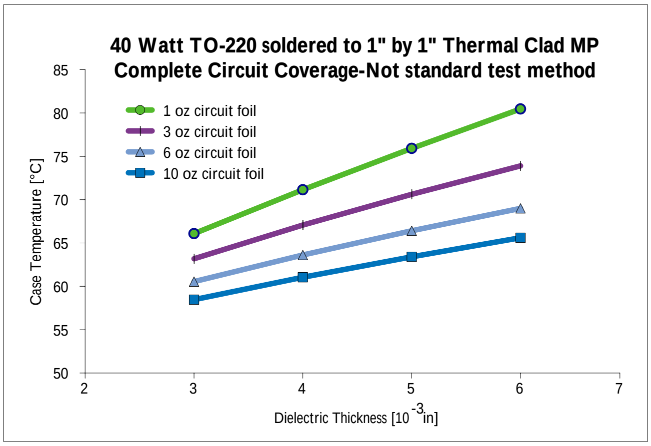
The following graphs depict both the thermal impedance value and case temperature when relating dielectric and foil thickness.

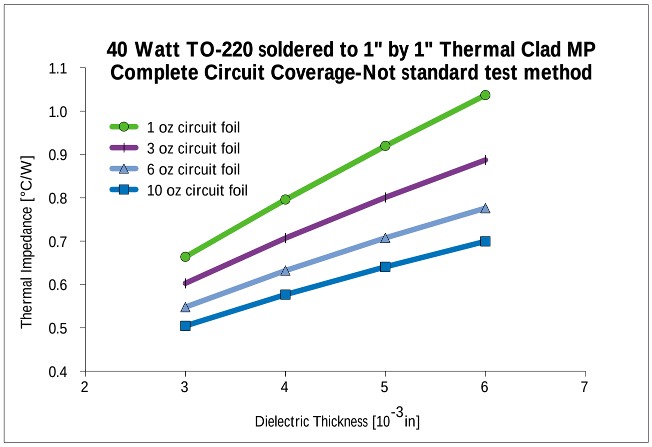


Temperature rise comparison graph depicts the significant difference between Bergquist Dielectric LTI and FR-4. Additional comparison charts regarding all Bergquist Dielectrics are available.

Standard Circuit Layer Thickness

LAYER	MATERIAL	THICKNESS	REMARKS
Circuit Layer	ED Copper	1oz. 0.0014" (35 µm)	Zinc Treatment
		2oz. 0.0028" (70 µm)	
		3oz. 0.0042" (107 µm)	
		4oz. 0.0056" (140 µm)	
		5oz. 0.0070" (178 µm)	
		6oz. 0.0084" (210 µm)	
		8oz. 0.0112" (284 µm)	
		10oz. 0.0140" (356 µm)	





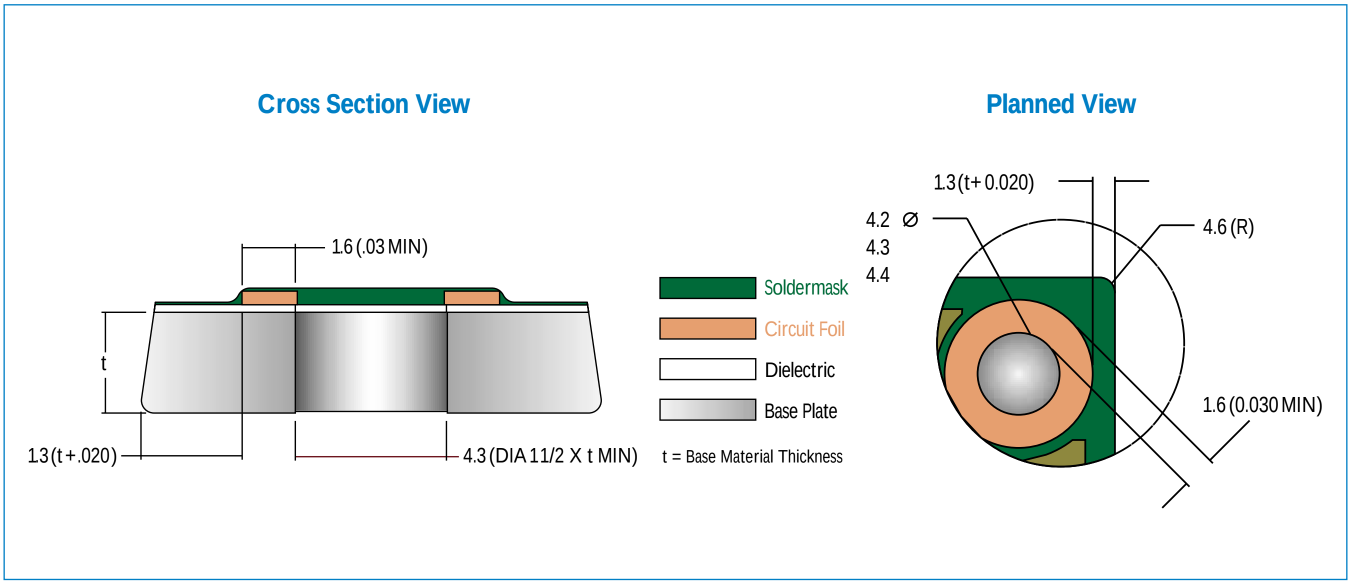
Flatness

Circuit flatness can be a concern when the base layer is Aluminum. To achieve a flat circuit, maintain the proper ratio of circuit layer thickness to base. If the thickness of the copper circuit layer is kept at 10% of the base layer thickness or thinner, the Aluminum base will mechanically dominate, keeping the circuit flat. For additional information see Circuit Design Section, pages 18-19.

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 pages 20-21).



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 low to moderate 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 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 between the circuit and 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 thermal coefficient of expansion 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) percent of the substrate thickness, the aluminum will be mechanically dominant. Constructions with more circuit copper than (10) percent of the substrate thickness will exhibit a bow.

The table below offers recommended 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 SPECIFICATIONS	
1.0 **Circuit Design**	1.1 Minimum Circuit Width	1oz - 0.005" (0.13mm) 2oz - 0.006" (0.15mm) 3oz - 0.007" (0.18mm) 4oz - 0.008" (0.20mm) 6oz - 0.010" (0.25mm) 8oz - 0.015" (0.38mm) 10oz - 0.015" (0.38mm)	
	1.2 Minimum Space/gap	**Single layer (non-plated)** 1oz - 0.007" (0.18mm) 2oz - 0.009" (0.23mm) 3oz - 0.012" (0.30mm) 4oz - 0.014" (0.36mm) 6oz - 0.020" (0.51mm) 8oz - 0.024" (0.61mm) 10oz - 0.030" (0.76mm)	**Multi layer (plated)** 1oz - 0.009" (0.23mm) 2oz - 0.011" (0.28mm) 3oz - 0.014" (0.36mm) 4oz - 0.016" (0.41mm) 6oz - 0.022" (0.56mm) 8oz - 0.026" (0.66mm) 10oz - 0.032" (0.81mm)
	1.3 Minimum Circuit to edge blanking	One material Thickness + 0.020" (0.5mm)	
	1.4 Minimum circuit to edge v-scored/milled/routed	**Material Thickness** 0.040" – (1.02mm) 0.062" – (1.57mm) 0.080" – (2.03mm) 0.125" – (3.18mm)	**Circuit to Edge Distance** 0.026" – (0.66mm) 0.029" – (0.74mm) 0.031" – (0.79mm) 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) min. Drilled/plated via hole is 0.010" (0.25mm) min.	
	1.7 Minimum Character height for etched nomenclature	0.060" (1.52mm)	
2.0 **Soldermask Design**	2.1 Minimum soldermask line width	0.060" (1.52mm)	
	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)	
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 0.015" (0.38mm)	
	3.3 Silk Screen bridging	To maintain legibility, features should not bridge traces on designs using 3oz. (0.11mm) fil or higher.	
	3.4 Minumum 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** 0.040" - (1.02mm) 0.062" - (1.57mm) 0.080" - (2.03mm) 0.125" - (3.18mm)	**Base Plate Thickness** 0.030" - (0.76mm) 0.030" - (0.76mm) 0.040" - (1.02mm) 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 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.

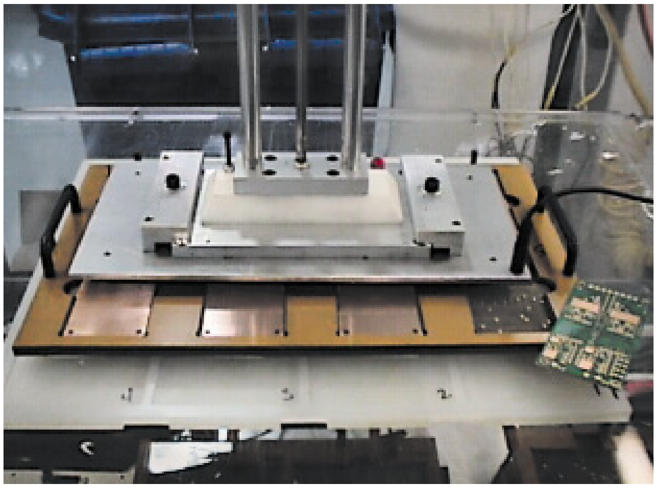
The term "Partial Discharge" is relatively new and includes a broad spectrum of life reducing (i.e., material damaging) phenomena such as:

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 in application note #130.

“Proof Test” fixture to test etched panels during fabrication process



“Proof Test” fixture to test multiple number of finished circuit boards

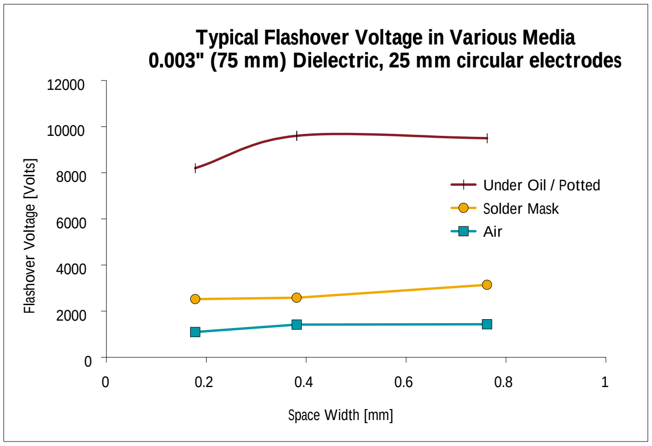
Breakdown Voltage

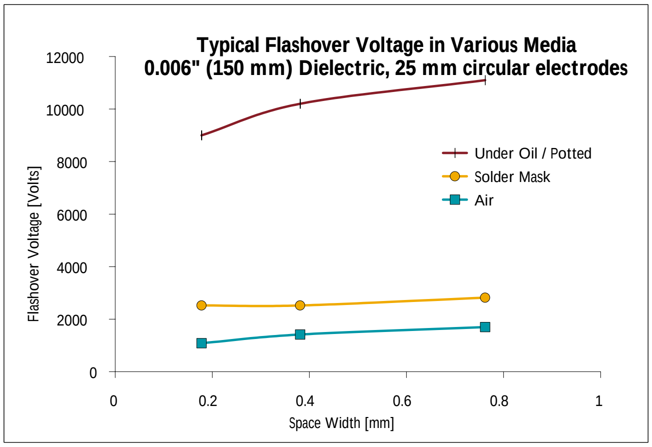
Breakdown voltage is the stress at failure when AC at power frequency is applied. The usual rate of rise is 500 Volts/second. The dielectric in Thermal Clad is prepared in separate layers to insure a void free coating. Breakdown voltage testing does not relate to proof stress "Proof Testing".

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.

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.





ASSEMBLY RECOMMENDATIONS

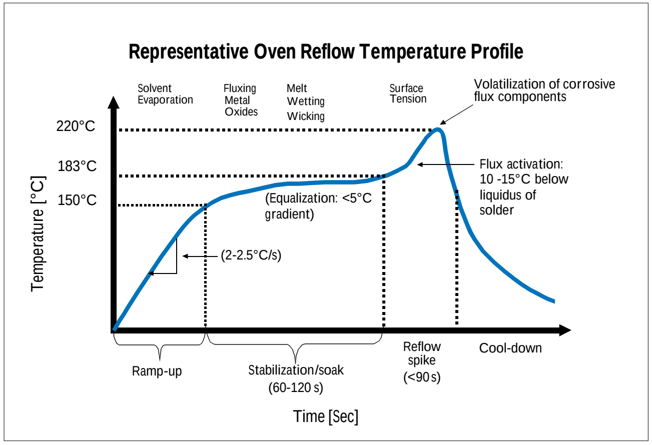
Solder Assembly

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

The typical surface finishes available for Thermal Clad circuits are HASL, OSP and FST. HASL (Hot Air Solder Leveling) is a 63/37 Pb/Sn coating with excellent shelf life and solderability. OSP (Organic Solderability Protectant) is a thin coating to protect the copper and has a shelf life of 3-6 months. FST (Flow Solderable Tin) is a relatively new planar coating. FST has a long shelf life, can be used for a planar solderability circuit and protects the copper baseplate.

Note: For copper base Thermal Clad the soldering process should not exceed 260^0 *C and for Aluminum base Thermal Clad should not exceed* 300^0 *C. See graph below which depicts oven reflow temperature profiles.*



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.

Alloy

In Thermal Clad assemblies, we look to the solder alloy to serve two important functions beyond the obvious mounting needs.

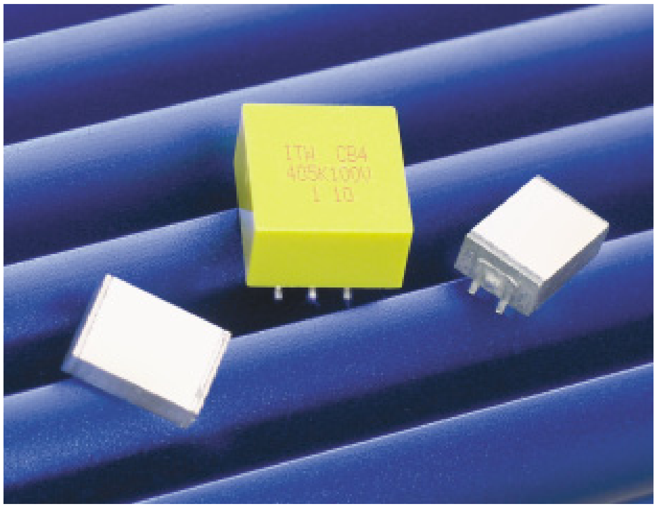
1. The solder alloy must be a good heat transfer medium. This means we need good wetting (no voids) as well as good thermal conductivity.
2. The solder alloy must withstand thermal cycling.

The addition of silver (Ag) to the solder alloy is helpful to both needs. We can recommend a 2% Ag alloy (62 tin, 36 lead, 2 silver). The silver serves to increase the tensile strength of the alloy. In its molten state, the surface tension of this composition is helpful in aligning surface mount components.

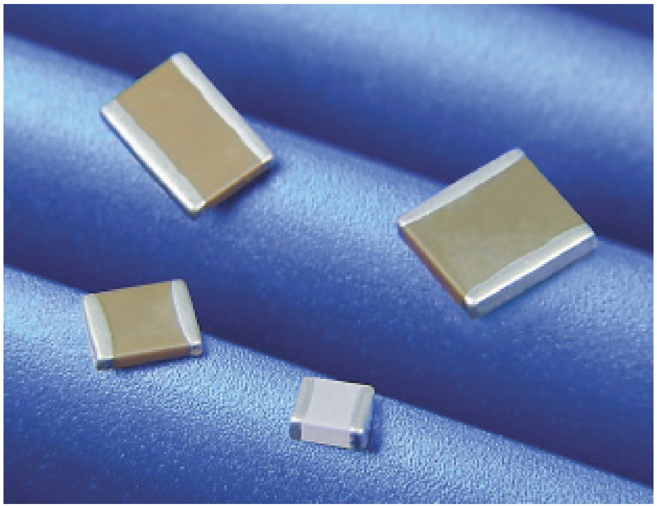
Flux

Consideration should also be given to the flux. An RMA flux (mildly activated rosin) is suggested since it can easily be cleaned. Cleaning will not damage the dielectric under normal process conditions. *Long term service durability is dependent on complete removal of flux residuals.*

"No clean" fluxes are used in many successful Thermal Clad applications. It is important to follow the process temperature recommendation when using these materials. Solder processes below minimum temperatures do not allow conversion or volatilization of corrosive flux components. It is particularly difficult to assure adequate process temperature exposure in rework processes.



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.

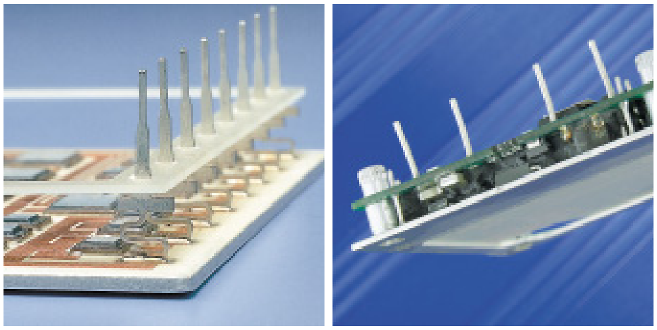
Surfilm® Capacitors and Capstick® Capacitors, trademarks of ITW Paktron.

Connection Techniques

Connections 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. The plastic molding compounds however, 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 epoxy glass control panel is pinned 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.



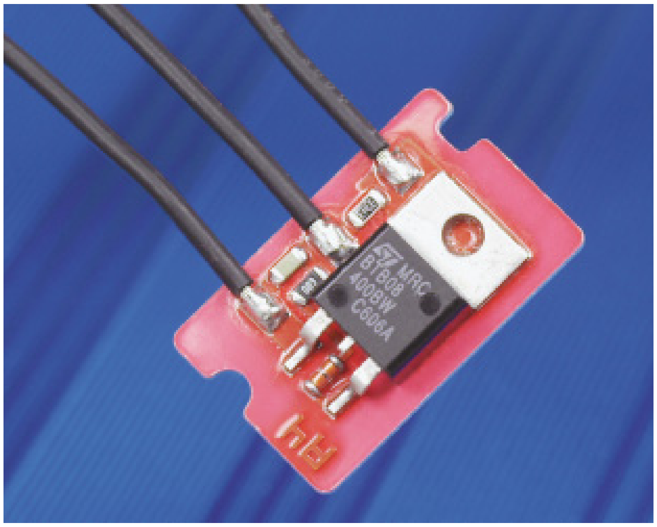
Manufacturers such as AutoSplice and Zierick have off the shelf pins ideal for IMS applications.

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.



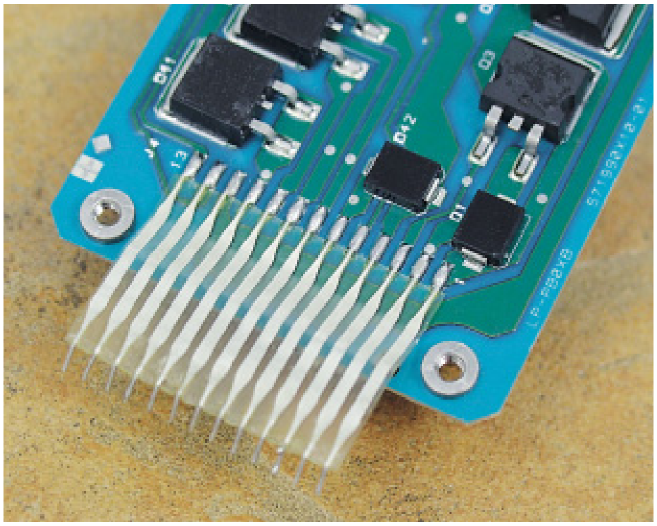
Wire soldering on Thermal Clad

Wire Bonding - Direct Die Attach

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

To use this technique with Thermal Clad, it is important to prepare interconnection sites of the circuit layer for wire bond. For aluminum wedge bonding to the circuit layer, it is recommended that a medium phosphorus content electroless nickel be used in the electroless nickel-immersion gold plating. The electroless nickel should be over 100 microinches, and the gold thickness should range between 3 and 8 microinches. The gold layer will protect the nickel layer from passivation and extend the shelf life of the product. Gold layers should be kept at less then 3% of the total solder joint thickness to keep the joint malleable.

These finishes are compatible with solder wetting requirements for solder die mounting processes. See page 13 for additional information regarding direct die attach.

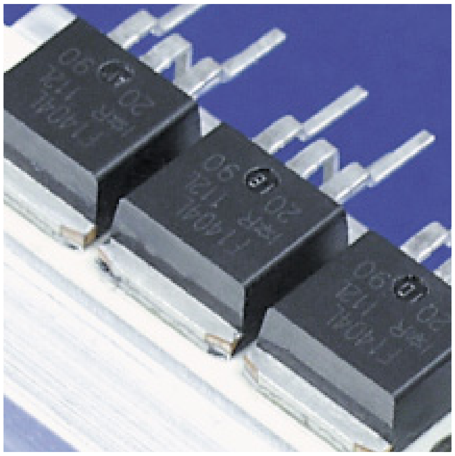


Flex attachment on Thermal Clad

BERGQUIST SOLUTIONS FOR SURFACE MOUNT APPLICATIONS

This guide covers Thermal Clad specifically, but Bergquist offers a wide array of thermal solutions for any surface mount application. Reasons for selecting one material over another are varied, but typically the decision is power density driven.

Maximum Power	100 Watts plus per square inch	Hi-Flow and Heat Spreader with or without Thermal Clad
High Power	40 to 100 Watts per square inch	Bergquist Thermal Clad (CML, MP, LTI and HT)
Medium Power	10 to 50 Watts per square inch	Bergquist Sil-Pad or Bond-Ply with Heat Spreader
Low Power	1 to 15 Watts per square inch	Bergquist Gap Pad with or without Heat Spreader

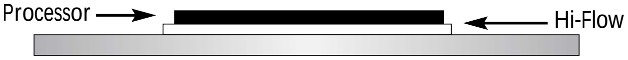


Hi-Flow®

The Hi-Flow family of Phase Change Materials (PCM) materials offer 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 PCM's are specially compounded to prevent pump out of the interface area, which is often associated with thermal grease.

High Power Application
Hi-Flow with Thermal Clad



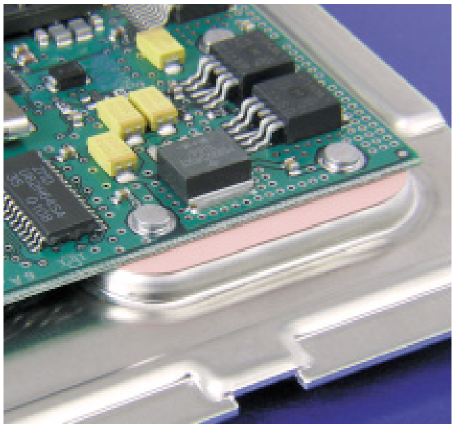
High Power Application
Hi-Flow without Thermal Clad

Typical applications 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.

WHERE THERMAL SOLUTIONS ALL COME TOGETHER

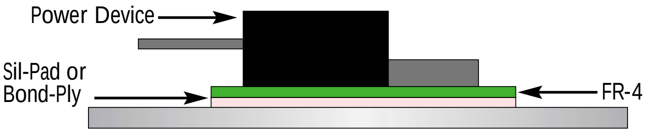


Sil-Pad®

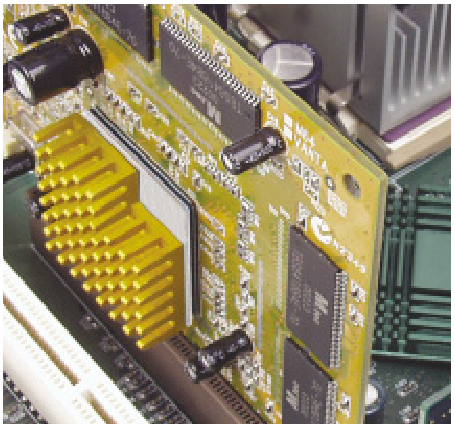
Sil-Pad is the benchmark in thermal interface materials. The Sil-Pad family of materials are thermally conductive and electrically insulating. Sil-Pad materials come in a variety of different thicknesses and are frequently used in SMT applications such as:

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

Sil-Pad is available in custom shapes, sheets, and rolls.



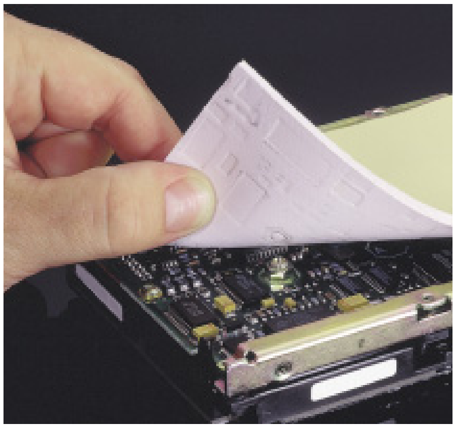
Mid Power Application with Bond-Ply



Bond-Ply®

The Bond-Ply family of materials are thermally conductive and electrically isolating. Bond-Ply is available in a PSA or laminating format, is reinforced with fiberglass or film and comes in a variety of different thicknesses. 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 heatsink
- 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

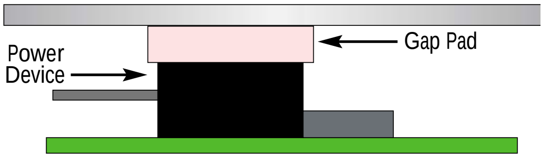


Gap Pad®

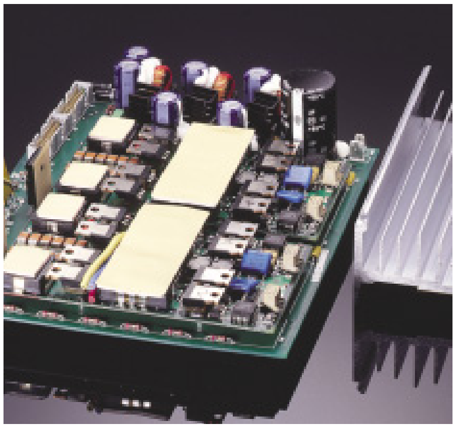
The Gap Pad product family offers a line of thermally conductive materials, which are highly conformable. Varying degrees of thermal conductivities and compression deflection characteristics are available. Typical applications include:

- 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

Gap Pads are available in thickness of 0.010" to 0.200", and in custom shapes, with or without adhesive.

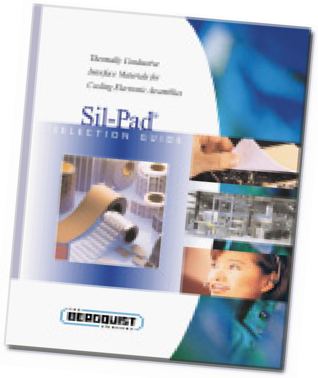


Lower Power Application with Gap Pad



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.



Additional Support Information

Agency Acceptance and Insulation Materials
(Bergquist Literature #76)
Herbert J. Fick

An Evaluation of the Blind Lap Joint for the Surface Mount Attachment of Chip Components
(Bergquist Literature #47)
Paul Vianco/Joseph Dal Porto

Cleanliness Testing for the ‘90s
(Bergquist Literature #72)
Terry Munson

Companion Technologies for Successful Applications of Copper Clad Insulated Metal Substrates
(Bergquist Literature #89)
Herbert J. Fick

Design Constraints for the Use of Insulated Metal Substrates® - Hybrid Circuits
(Bergquist Literature #86)
Herbert J. Fick

Design for Reliability of Surface Mount Solder Attachments
(Bergquist Literature #58)
InterConnection Technology
Werner Englemaier

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Volume 1 Packaging
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Engineering Dielectrics, Volume I
Corona Measurement and Interpretation
(Barnitkas/McMahon, Eds.)
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Electrical Properties of Solid Insulating
Materials: Molecular Structure and
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(Bergquist Literature #54)
Brian N. Ellis

IPC Standards and Specifications Volumes 1, 2 & 3
Institute for Interconnection and Packaging Electronic Circuits

Metals Handbook
Volumes 1 and 2, Tenth Addition, ASM International

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Herbert J. Fick

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Herbert J. Fick

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Surface Mounting of Large Size Ceramic Capacitors on Insulated Metal Substrates
(Bergquist Literature #105)
C. Zardini, P. Solomalala, E. Woirgard, Herbert J. Fick

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SME - Society of Manufacturing Engineers

Thermal Computations for Electronic Equipment
Gordon N. Ellison
Van Nostrand Reinhold (1984)

Using Plastic Pim Chip Capacitors in IR Reflow Soldering Systems
Ian W. Clelland, Rick Price
ITW Paktron (1996)

When Will The Solder Joint Fail?
(Bergquist Literature #53)
Dr. John H. Lau

Wire Bonding in Microelectronics
George G. Harman Second Edition 1997
ISHM ISBN 0-07-032619-3

THERMAL CLAD CONFIGURATIONS



Custom Circuit

Bergquist Thermal Clad substrates are custom configured to your design parameters at our Prescott, Wisconsin facility. Our field application force, mechanical and process engineers are available to assist you in taking your design from paper to finished product. Engineering is available for the following construction parameters and options.

- Artwork layout recommendations
- Base metal requirements and mechanical configuration
- Dielectric thickness
- Copper weights (1-10 oz.)
- Solder mask layouts
- Organic protective coatings
- Hot air solder level
- Special plating options
- Tooling/singulation options

Panel Form

- 16" x 19" (41 cm x 48 cm) and 18" x 24" (46 cm x 61 cm)
- Base plate metals
- Aluminum 6061-T6, 5052-H34, standards from 0.020" to 0.125" (0.5mm to 3.2mm)
- Copper 110 Half-Hard and Full-Hard, standards from 0.020" to 0.125" (0.5mm to 3.2mm)
- Foil Thickness: 1-10oz.

Sheet And Roll Format

CML (Circuit Material Laminate) is a B-Staged ceramic filled polymer that forms a strong, thermally conductive bond to metal heat spreaders and is an excellent alternative to pre-preg.

- 24" (61 cm) Roll Standard (custom sizes are available)
- Maximum roll length of 2000' (609.6 meters)
- Sheets 16"x19" (41 cm x 48 cm) and 18" x 24" (46 cm x 61 cm)

UL Certifications Directory

For information regarding the UL recognition status of Bergquist Thermal Clad materials and “Prescott Operations” circuit fabrication, the UL website provides the latest information.

Using the address: http//www.ul.com select; Online Certifications Directory. Enter one of the following file numbers: UL File Number, to the applicable Bergquist file.

QMTS2.E121882

Polymeric Materials - Filament-wound tubing, Industrial Laminates, Vulcanized Fiber, and Materials for Use in Fabricating Recognized Printed Wiring Boards - Components.

ZPMV2.E122713

Wiring, Printed - Component

In each group there is Guide Information which will give a further description of the categories listed.

In each group the recognized materials or fabricated circuit board types will be listed.

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	IPC-2221	Generic Standard on Printed Board Design
	IPC-MC-324	Performance Specification for Metal Core Boards
	IPC-D-325	End Product Documentation for PWBs
	IPC-TM-650	Cleanliness (2.3.35 & 2.3.26)
	IPC-TM-650-2.4.22	Bow and Twist
	IPC-TM-650-2.4.8B	Peel
	IPC-SM-840B	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

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