Thermal Clad®

Comprehensive Selection Guide

TCLAD Inc (TCLAD), a Polytronics related company, formerly BERGQUIST Thermal Clad Division, located in Prescott, Wisconsin, since 1997. For over 50 years, our products have been the world's most trusted thermal management materials. Multi-award-winning formulations in various mediums provide essential heat dissipation for applications within numerous markets including automotive, lighting, power and industrial automation, defense & Aerospace and many others. As electronic systems integrate more capability into increasingly challenging, complex designs and compact footprints, our products provide efficient thermal management to maximize performance and limit heat-related failures**.**

WHY CHOOSE TCLAD

TCLAD's mission is to build meaningful customer relationships, actively participate with product design, and develop new materials and processes that exceed our customer's expectations. With our history and experience in the electronics industry, our experts can help find ways to improve reliability, control and manage heat, and back it all with exceptional service.

TCLAD, the original Bergquist Thermal Clad®, is the leading global solution provider for thermal management Insulated Metal Substrates. With high quality thermal management dielectric materials, offer an advantage for power electronics systems. Beyond that, we work closely with our customers to understand their thermal challenges and deliver technologically advanced thermal solutions backed by exceptional engineering support.

Prescott Wisconsin—2021

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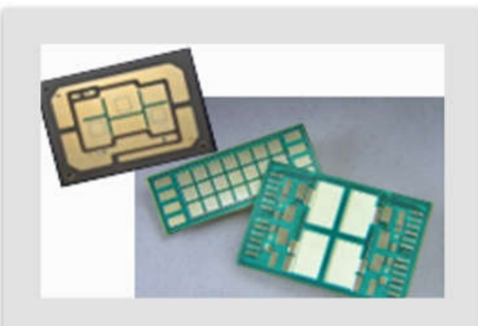


THERMAL CLAD Overview

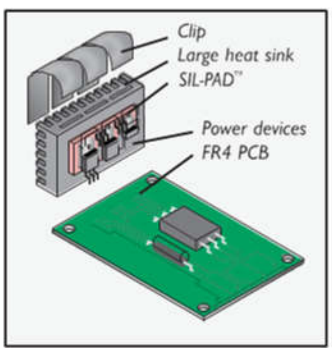
Key Benefits of THERMAL CLAD

TCLAD Inc. is the world leader in the development and manufacture of THERMAL CLAD Insulated Metal Substrate (IMS®) materials and circuits. It was developed by Bergquist as a thermal management solution for higher power surface mount applications where excessive heat issues are a major concern.

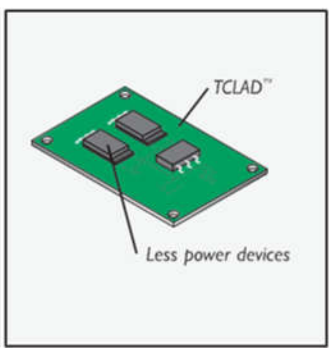
THERMAL CLAD substrates minimize thermal impedance and conduct heat more effectively and efficiently than standard printed wiring boards (PWB's). These substrates are more mechanically robust than DBC (direct bond copper) constructions, which are often used in these type of applications.

THERMAL CLAD is a cost-effective solution which can eliminate components, allow for simplified designs, smaller devices, and an overall less complicated production process. Additional benefits of THERMAL CLAD include lower operating temperatures, longer component life, and increased durability.

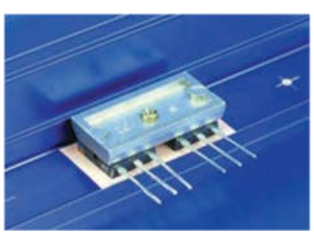
TCLAD Inc's THERMAL CLAD substrates are not limited to use with metal base layers. In one example, power conversion applications can enhance their performance by replacing FR-4 with THERMAL CLAD dielectrics in multi-layer assemblies. In this application, the thickness of the copper circuit layer can be minimized by the high thermal performance of THERMAL CLAD. For additional information on this topic, refer to the "Specialty Applications" section on page 6 of this guide.



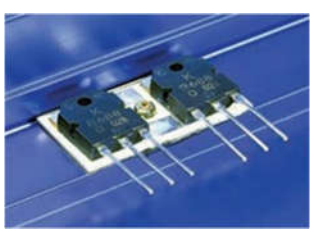
Traditionally, cooling an FR-4 board required use of a large heat sink, thermal interface material and various hardware (brackets, screws, or clamps); a configuration requiring labor intensive manual assembly



Cooling with THERMAL CLAD can eliminate the need for heat sinks, device clips, cooling fans, and other hardware. An automated assembly method will reduce manufacturing costs.



Conventional methods measured junction temperature 5W=Tj 43ºC



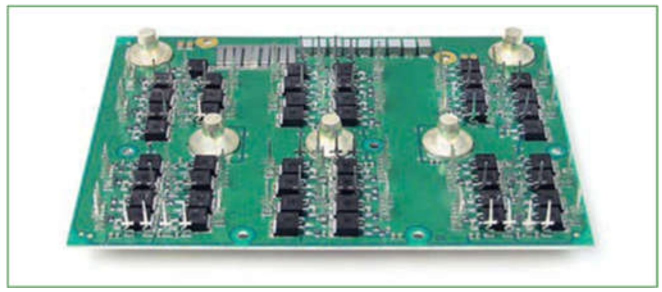
THERMAL CLAD measured unction temperature 5W=Tj 35ºC

Case Study: FR-4 power board conversion to IMS

Original Power Board Assembly (Actual)

(66) Thru-hole FETs (15) High profile capacitors (9) High profile bus bars Total Weight 3.4lbs (1543.6 g)

New Power Board Assembly (Actual)



(48) FETs (9) Low profile capacitors (5) Low profile bus bars Total Weight 0.82lbs (370.6 g)

THERMAL CLAD is a complete thermal management system, unlike 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

- RoHS and REACH compliant and halogen-free
- Lower component operating temperatures
- Reduce printed circuit board size
- Increase power density
- Extend component life
- Reduce the number of interconnects
- Improved 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
- TCLAD Inc. is your one-stop source for IMS laminate materials and finished metal base printed circuit boards.

Improve Durability and Performance

THERMAL CLAD improves durability because designs can be kept simple while components are kept cool. The low thermal impedance of THERMAL CLAD dielectric outperforms 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 when using surface mount components and bare die on THERMAL CLAD.

THERMAL CLAD can also reduce production costs by enabling automated pick-and-place process for SMD's.

Reduce Board Size and Replace Hardware

THERMAL CLAD greatly reduces board space while replacing other components including heat sinks in some cases. It offers the opportunity to eliminate thermal grease or thermal pads under power devices by using direct soldering to THERMAL CLAD circuits. By eliminating this hardware, heat transfer is improved.

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 the use of 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 on a metal base and bonded to a copper circuit layer. This unique material offers excellent electrical isolation and superior heat transfer to help cool components while eliminating the problems associated with fragile ceramics. Different than others, TCLAD Inc's brand does not use fiberglass reinforcement in the dielectric, allowing for better thermal performance and lower CTE.

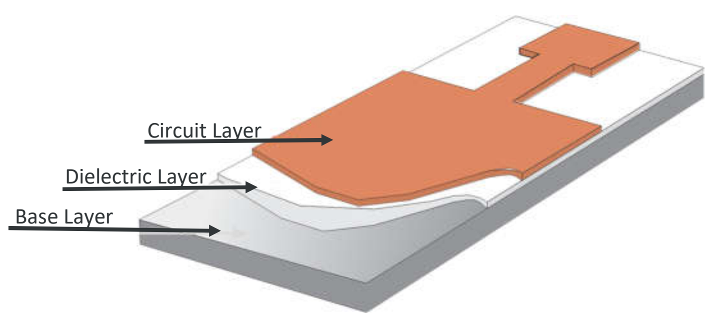
THERMAL CLAD typically has a construction consisting of three layers, circuit layer, dielectric layer, and base layer:

Circuit Layer: This is the etched copper circuit with a thickness range of .5oz. to 10oz. (17-350µm) in standard THERMAL CLAD.

Dielectric Layer: The dielectric offers excellent electrical isolation and minimum thermal resistance. Fiberglass reinforcement layers degrade thermal performance which is why our dielectrics do not contain fiberglass. The dielectric layer is the key element of THERMAL CLAD and bonds the base metal and circuit layer together. The laminated panel using Thermal Clad dielectric and finished circuit have UL recognition, simplifying agency acceptance of final assemblies.

Base Layer: The metal base layer is most often aluminum, but other metals such as copper may also be used. The most widely used base material thicknesses are 0.040" (1.0mm) and 0.062'' (1.57mm) in aluminum, although most gage thicknesses from 0.032" (0.8mm) to 0.125" (3.2mm) are available. In some applications, the base layer of metal may not be needed. See "Advanced Circuit Processing" on page 12.

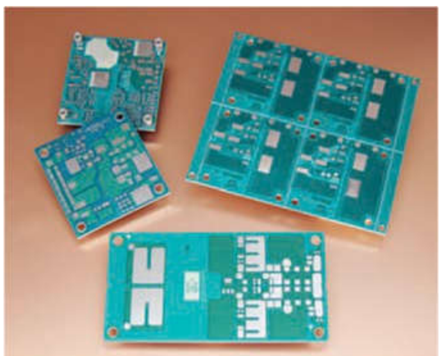
TCLAD INC's manufacturing facility located in Prescott, Wisconsin USA features state-of-the-art process capabilities. Process manufacturing uses the latest in technology including environmental clean room control, surface finishing, coatings, and lamination.



THERMAL CLAD Applications

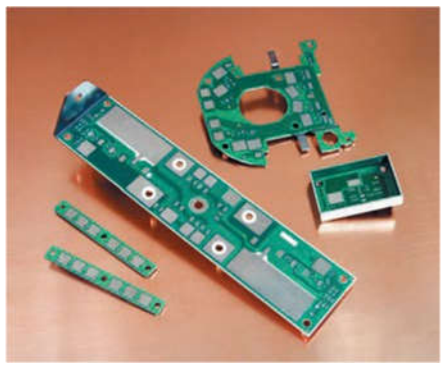
Power Conversion

Due to the size constraints and power density requirements in DC/DC power conversion, THERMAL CLAD has become the favored choice. THERMAL CLAD is available in a variety of thermal performances, is compatible with mechanical fasteners and has a history of high reliability. It can be used in almost every form-factor and fabricated in a wide variety of substrate metals, thicknesses, and copper foil weights.



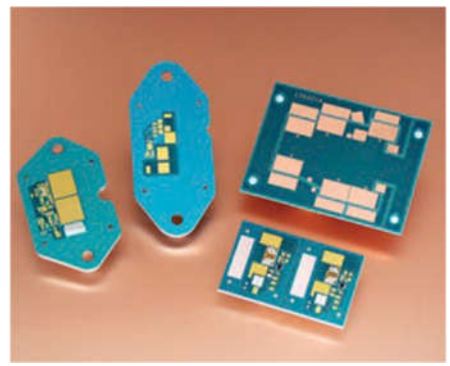
Power-Rail and Forming

The use of THERMAL CLAD in power-rail applications has increased significantly and is currently used in automotive, audio, motor control and power conversion applications. THERMAL CLAD offers many advantages including surface mount assembly and excellent thermal performance. The dielectric can be selectively removed, and the metal base can be formed with 3D features making THERMAL CLAD a very versatile thermal substrate.



Solid State Relays/Switches

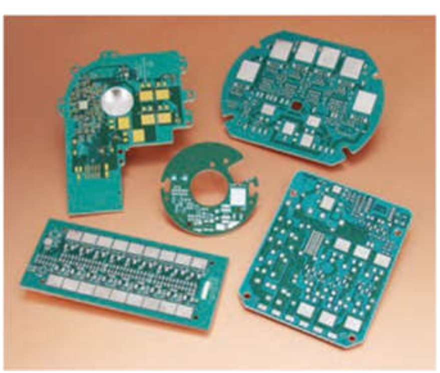
The implementation of solid-state relays in many control applications calls for thermally efficient, & mechanically robust substrates. THERMAL CLAD offers both. The material construction allows mounting configurations not reasonably possible with ceramic substrates. THERMAL CLAD meets the high thermal and mechanical performance expectations and out-performs ceramic-based designs



Motor Drives

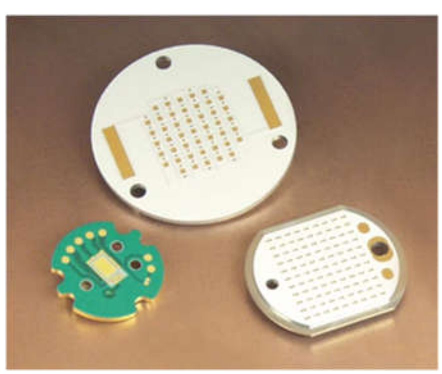
Compact high-reliability motor drives built using THERMAL CLAD have set the benchmark for power-density. Dielectric choices provide the electrical isolation necessary to meet operating parameters and safety agency test requirements.

With the ability to fabricate in a wide variety of form-factors, implementation into either compact or integrated motor drives can be realized. The availability of THERMAL CLAD HT dielectric makes high temperature as well as high breakdown strength and excellent thermal performance possible.



LEDs

In high power LED applications, light output, consistent CRI and long life are directly attributable to how well the LED's are managed thermally. THERMAL CLAD is an excellent solution for designers. Thermal Clad is a metal -based material (often referred to as a MCPCB or IMS) and can be configured for special shapes with bends and a variety of thicknesses thus allowing the designer to use LED light engines in virtually any application. Mounting power LED's or COB on Thermal Clad assures the lowest possible operating temperatures and maximum output, brightness, color rendering and life.



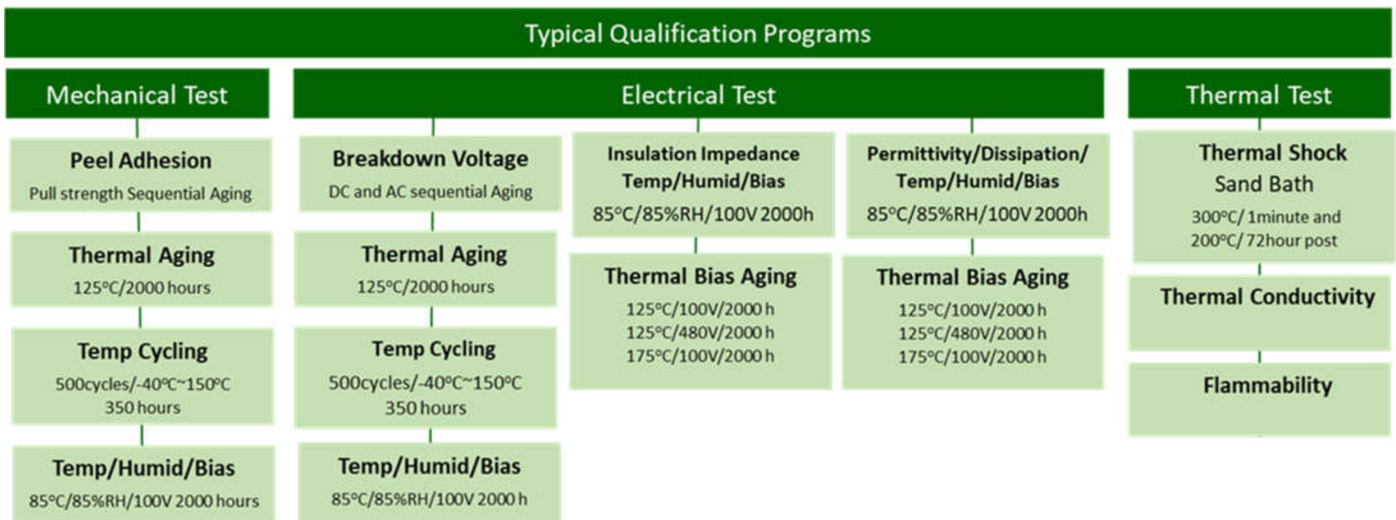
THERMAL CLAD Reliability

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, TCLAD Inc performs extensive testing on all their thermal materials for electrical integrity and thermal performance. TCLAD Inc utilizes stringent development procedures.

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 2,000 hours.

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



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

Chamber Ovens – 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.

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

Selecting Dielectric Materials

Dielectric Layer

The technology of THERMAL CLAD resides in the dielectric layer. It is the key element for optimizing performance in the 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 0.0015'' (38µm) thickness. Contact a TCLAD INC Sales Representative for thin dielectric information. We will help you select the best dielectric to suit your needs based on power-density, electrical isolation, and operating temperature environment.

Standardized Methods for Measuring Thermal Conductivity

There are several different test methods for determining a material's thermal conductivity value. Results can vary depending on the method of analysis, so it is important to use the same test methods in material comparisons, see Standardized Test methods table 1.

Standard test methods include ASTM D5470 and ASTM E1461. ASTM D5470 is a steady state method and is referred to as the guarded hot plate. This method provides an analytically derived value and does not use approximations. ASTM E1461 is a transient method referred to as Laser Flash Diffusivity.
In E1461, thermal diffusivity is the test output and thermal conductivity is calculated.

Non-Standard In-House Test Methods

Table 2 shows how vastly different thermal conductivity values can be achieved by using "in-house" or non-standard test methods. For example, when the same dielectric is chosen, we can derive a completely different and much higher thermal conductivity value by testing a stack-up or laminate with base metal layer. We can modify the test further by using different materials for the substrate to obtain even higher results. Although thermal conductivity values are still relative to one another, these test methods do not give an accurate depiction of true thermal performance in the application. Included in the chart is a modeled value for thermal conductivity, a respected model for predicting the effective thermal conductivity of anisotropic particulate composites, but not helpful for determining thermal performance in application. We emphasize using standard test methods such as ASTM D5470 and ASTM E1461, which are universally accepted and repeatable.

Note: The hot disk method is not a method we use for comparison because typically this method measures the conductivity of the dielectric alone, which neglects thermal interfacial resistance between layers and carrier holding the dielectric. These values must be understood in order to calculate the actual thermal impedance or thermal performance data. See section regarding thermal impedance on page 9.

Thermal Conductivity

Thermal conductivity is relevant to the application's thermal performance when the thickness of the dielectric material, interfacial resistance and area are taken into consideration. See "Thermal Impedance" section for more information, as this data will be the most relevant to your application.

Table 1

Standardized Test Methods (W/m-K)

PART NUMBER	ASTM D5470[1]	ASTM E1461[2]
HPL-03015	3.0	3.3
SJR-5804	2.7	2.5
HT-04503	2.2	2.0
MP-06503	1.3	1.2

Method Description

1 - ASTM D5470 Guarded Hot Plate

2 - ASTM E1461 Laser Flash Diffusivity

Table 2

Non-Standard Thermal Conductivity Test Methods and Model (W/m-K)

PART NUMBER	MODEL[1]	GUARDED HOT PLATE LAMINATE[2]	GUARDED HOT PLATE LAMINATE[3]	LASER FLASH LAMINATE[2]	LASER FLASH LAMINATE[3]
HT-04503	9.0	32.2	36.4	67.6	115.0
HT-07006	9.0	21.5	23.3	46.0	86.5
MP-06503	4.5	14.0	24.0	34.9	102.0

Method Description

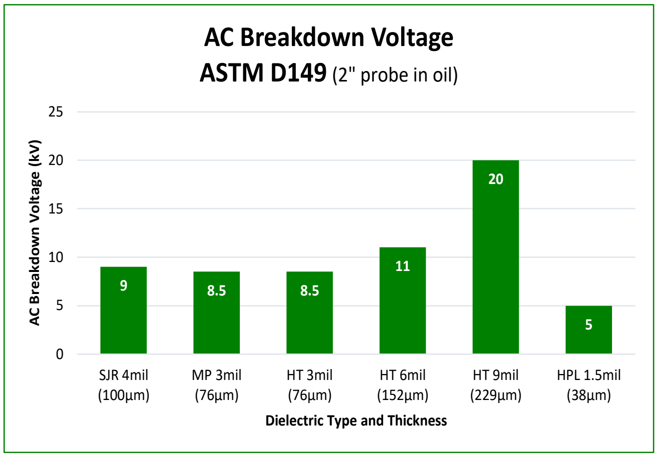
1 - Bruggeman Model

2 - Tested with 0.062" (1.57mm) 5052 aluminum substrate and 2 oz. (70µm) copper foil

3 - Tested with 0.062" (1.57mm) C1100 copper substrate and 2 oz. (70µm) copper foil

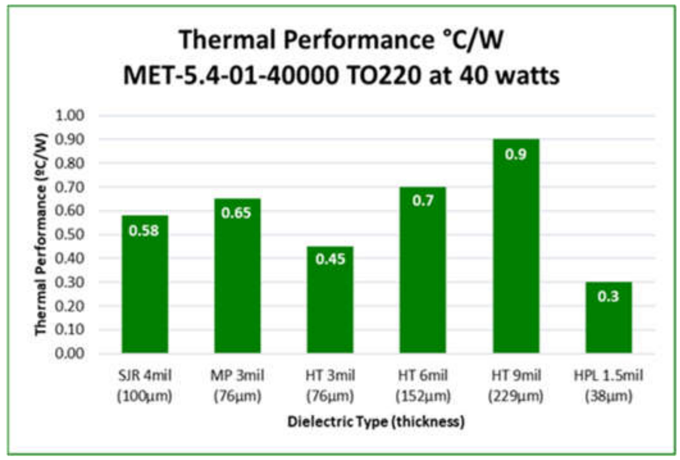
Electrical Isolation - Power Applications

Dielectrics are available in thicknesses ranging from 0.0015” (38µm) to 0.009'' (229µm), depending on your isolation requirements. See “Baseplate Design Considerations” on pages 14-15 to help determine which thickness is appropriate for your application.



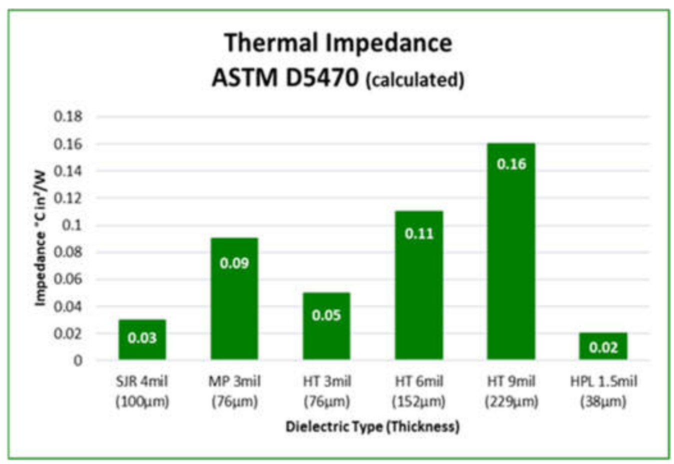
High Power Lighting Applications

HPL is a dielectric specifically formulated for high power lighting LED applications with demanding thermal performance requirements. This is a very thin dielectric at 0.0015”(38µm). It has an ability to withstand high temperatures with a glass transition of 185°C and phenomenal thermal performance of 0.30°C/W. For detailed product characteristic information, call TCLAD Inc’s sales or go online for a Product Data Sheet.



Thermal Impedance Determines Power Density

Thermal impedance is the one performance characteristic that matters most in determining the power density capability of an application because it measures the temperature drop across the entire stack-up. Lower thermal impedance results in lower junction temperatures. The lower the thermal impedance, the more efficiently heat moves from the component to the heatsink.

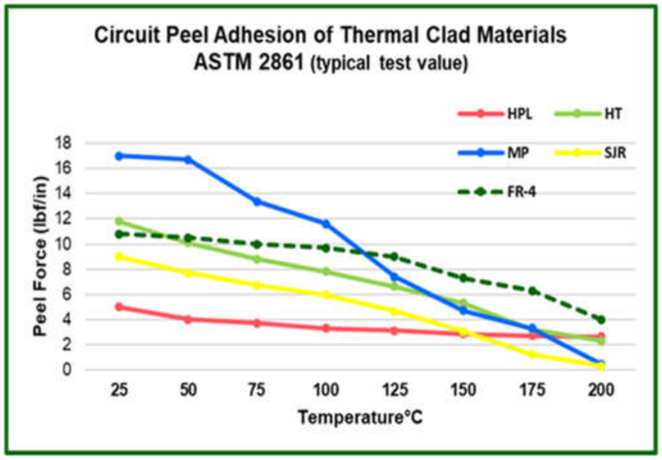


$$\text{TOTAL IMPEDANCE} = \frac{\text{Sample Thickness}}{\text{Thermal Conductivity}} + \text{Interfacial Resistance}$$

Lower Thermal Impedance = Lower Junction Temperatures

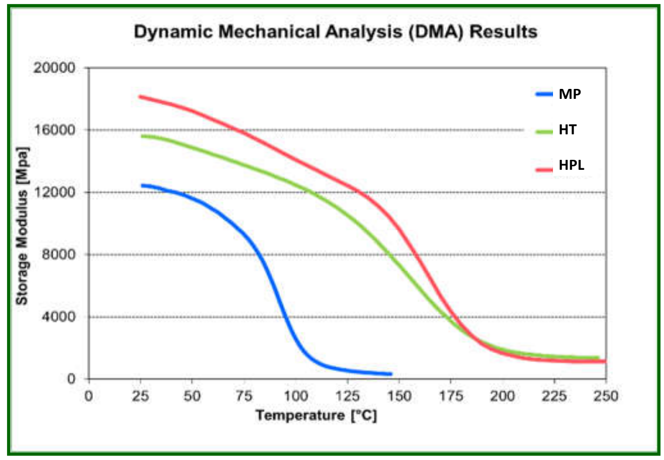
Dielectric Performance Considerations

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 0.53 N/mm (3lbs/inch) even at 175°C.

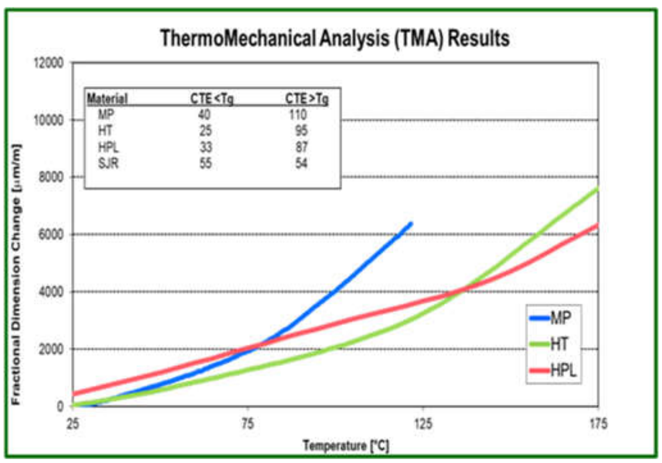
Storage Modulus



This chart depicts the storage modulus of the material over a temperature range. All Thermal Clad 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.

For SJR dielectric, see separate graph

Coefficient of Thermal Expansion



Thermomechanical Analysis (TMA) measures the dimensional stability of materials during temperature changes, monitoring the Coefficient of Thermal Expansion (CTE). In this application, the CTE of the base material is a dominant contributor to thermal mechanical stress. See pages 14-15 for base layer selection.

Note: *CTE OF an IMS BOARD - The concerns in exceeding the T_g in standard FR-4 materials from a mechanical standpoint should be tempered when using THERMAL CLAD. The ceramic filler in the polymer matrix of THERMAL CLAD dielectrics as well as there being no fiberglass results in considerably lower Z-axis expansion than in traditional FR-4 materials, while the thin dielectric means significantly less strain on plated-through- hole (PTH) connections*

Operating Above Tg

Operating above the Tg of the dielectric, mechanical and electrical properties begin to change. Mechanical changes of note are a 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 to the dielectric interfaces, in solder joints and other interconnects due to CTE mismatch by choosing a dielectric with Tg below the operating temperature. The dielectric material above Tg is in its elastomeric state (much lower storage modulus), allowing some of the stress related to CTE mismatch between the base metal and dielectric to relax. Changes in electrical properties must also be considered in operation above Tg, although they are typically only important at frequencies above 1MHz. Effects to consider are changes in permittivity, dielectric loss, and breakdown strength. Important Note: Some THERMAL CLAD products have UL rating up to 45% higher than their glass transition temperature and are used extensively in applications above rated Tg.

Summary of Key Product Characteristics

Thermal Clad™ Performance Characteristics

SINGLE LAYER		PRODUCT PERFORMANCE			DIELECTRIC PERFORMANCE			OTHER	
Part Number	Thickness[1] [µm/mils]	Thermal[2] Performance [°C/W]	Impedance[3] [°C in²/W] [°C cm²/W]	Conductivity[2] [W/m-K]	Breakdown[5] [kVAC]	Permittivity[6] [Dielectric Constant]	Dielectric[4] Conductivity [W/m-K]	Glass[7] Transition [°C]	Peel Strength[8] [lbs/in] / [N/mm]
HPL-03015	38 / 1.5	0.3	0.02 / 0.13	7.5	5	6.6	3	185	5 / 0.9
HPL-03602	50 / 2.0	0.4	0.026 / 0.17	7.5	7.7	6.6	3	185	5 / 0.9
HPL-06706	152 / 6	0.58	0.039 / 0.25	7.5	17.4	6.6	3	185	5 / 0.9
SJR-05804	100 / 4	0.58	0.03 / 0.18	3.7	9.2	6.3	2.7	66	5.7 / 1.0
HT-04503	76 / 3	0.45	0.05 / 0.32	4.1	8.5	7	2.2	150	6 / 1.1
HT-07006	152 / 6	0.7	0.11 / 0.71	4.1	11	7	2.2	150	6 / 1.1
HT-09009	225 / 9	0.9	0.16 / 1.03	4.1	20	7	2.2	150	6 / 1.1
MP-06503	76 / 3	0.65	0.09 / 0.58	2.4	8.5	6	1.3	90	9 / 1.6
MULTI-LAYER									
HPL-06706	152 / 6	0.58	0.039 / 0.25	7.5	17.4	6.6	3	185	5 / 0.9
SJR-05806	152 / 6	0.58	0.03 / 0.18	3.7	9.2	6.3	2.7	66	5.7 / 1.0
HT-07006	152 / 6	0.7	0.11 / 0.71	4.1	11	7	2.2	150	6 / 1.1
HT-09009	225 / 9	0.9	0.16 / 1.03	4.1	20	7	2.2	150	6 / 1.1
Method Description		1 - Optical	2 - MET-5.4-01-40000-Thermal Performance		3 - Calculation from ASTM 5470, Thermal Impedance		4 - Extended ASTM 5470, Thermal Conductivity		
			5 - ASTM D149, Breakdown Strength		6 - ASTM D150, Permittivity		7 - MET-5.4-01-7800, Tg		
* validation in process			8 - ASTM D2861 Substrates (IMS), Peel Strength						

Note: For applications with an expected operating voltage of 480 Volts AC or above, TCLAD Inc recommends a dielectric thickness greater than 76µm / (3mil)

Note: Circuit design is the most important consideration for determining safety agency compliance

Note: Breakdown Voltage does not represent max operating or proof test voltage. For additional information reference page 19

Note: Product Performance "Thermal Conductivity" based on a material stack up of 1.6mm aluminum x dielectric x 2oz

Operating Temperatures

Choose the dielectric that best suits your operating temperature environment. For high temperature applications, such as automotive, HT offers the right solution.

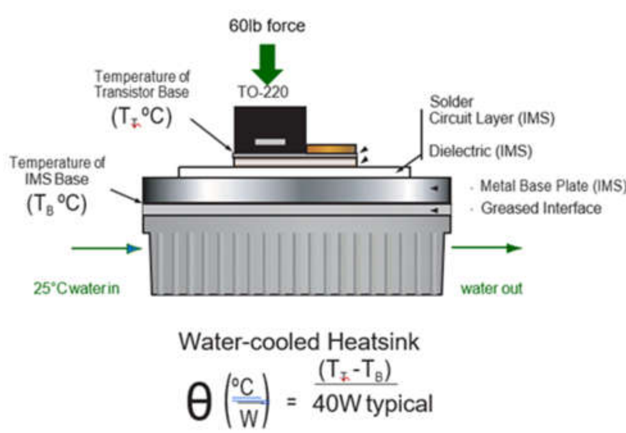
MATERIAL	RTI - ELECTRO / MECHANICAL PER UL 746 E	CTI
HPL	140°C / 140°C	0 / 600
HT	140°C / 140°C	0 / 600
MP	130°C / 140°C	0 / 500 (425)
SJR	90°C / 90°C *	0 / 600
* UL testing ongoing, est RTI 130C		
+CTI=Comparative Tracking Index - ASTM D3638 / IEC 60112		

MATERIAL	U.L. SOLDER LIMIT RATING
HPL*	325°C / 60 seconds
HT *	325°C / 60 seconds
MP	300°C / 60 seconds
SJR *	325°C / 60 seconds
* Covers all soldering options including Eutectic Au/Sn	

All of our dielectrics are UL recognized.

Thermal Performance

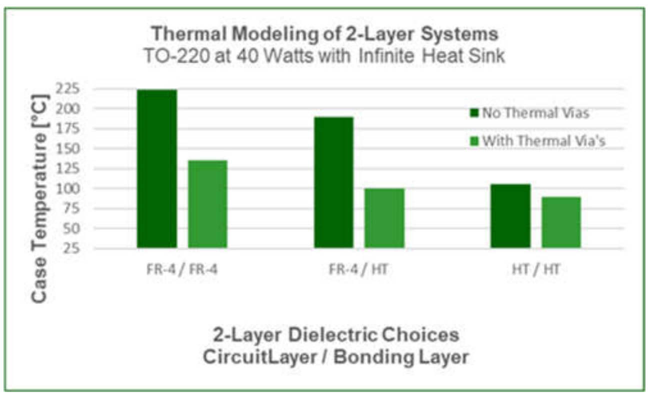
This drawing represents the MET-5.4-01-40000-Test Thermal Performance of Insulated Metal Substrates (IMS) TO-220



Advanced Circuit Processing

Two-Layer Circuits

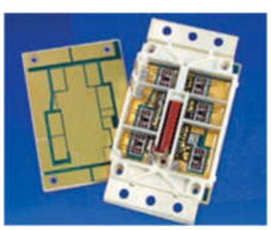
Thermal Clad HT dielectric is ideal for applications requiring a two-layer circuit. Two-layer constructions can provide shielding protection, additional heat spreading and electrical interconnects for higher component density. TCLAD Inc's brand dielectrics will provide superior thermal performance over traditional FR-4 constructions. In addition, thermal vias can maximize thermal transfer for applications utilizing power components. When vias cannot be used, selecting higher performance dielectrics can solve thermal issues independently (see graph, below).



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.

DBC Replacement

Replace Ceramic Substrates



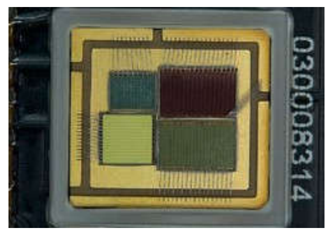
THERMAL CLAD can replace large-area ceramic substrates. It can also be used as a mechanically durable support for ceramic circuits or direct-bond copper (DBC) subassemblies.

THERMAL CLAD has replaced DBC in applications due to mechanical robustness and its ability to be fabricated in a wide variety of form-factors.

Direct Die Application

Direct die attach and wire bonding are increasingly popular methods of component mounting to THERMAL CLAD substrates. A key benefit to this structure is lower thermal resistance as compared to conventional surface mount component packages soldered to an IMS substrate using SAC alloys.

When designing circuits using Chip-On-Board (COB) technology, it is important to use the appropriate surface finish to achieve excellent die mounting and wire bond connections. The die attachment is accomplished using SnPb, Pb-free solders, eutectic Au/Sn (gold/tin) solder, or an electrical/thermal conductive adhesive, depending on the application requirements to adhere the die to the circuit pad. The wire bond typically used to make circuit connections is either gold or aluminum. ENEPIG (Electroless Nickel/Electroless Palladium/Immersion Gold) is recommended for gold wire and ENIG (Electroless Nickel/Immersion Gold) for aluminum wire applications. HT, SJR and HPL dielectrics are UL recognized to 325°C/60 seconds, enabling Eutectic Gold/Tin die attach solders to be used.

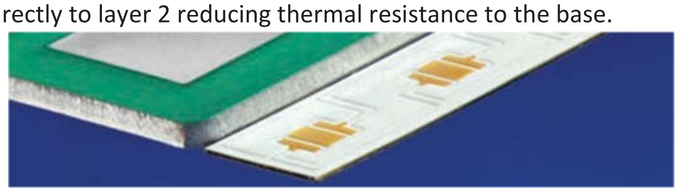


Close-up view of direct die attachment in an LED application. The THERMAL CLAD substrate is used to mount the die or module.

Laminated thick copper up to 5 oz. (175µm) finished on the internal layer using HT dielectric

Heavy Copper

Applications requiring thick copper for high current carrying or for heat spreading applications are not limited to single-layer circuits. TCLAD offers 2-layer constructions with thick copper available on layer 1 up to 10oz (350µ) and up to 5oz (175µm) on layer 2. Internal layers with thick copper can provide greater design flexibility. Access to the internal copper layer by selective dielectric removal can enable die attach or component mounting directly to layer 2 reducing thermal resistance to the base.



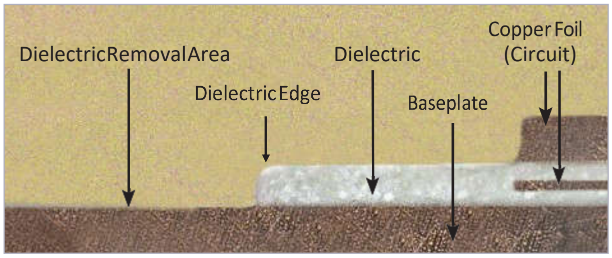
Photographic example of UTC versus a standard 0.062'' (1.57mm) aluminum substrate.

Ultra-Thin Circuits

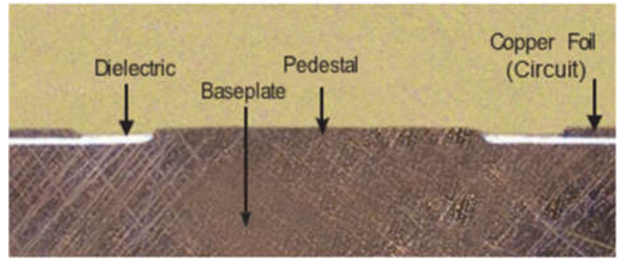
Ultra-Thin Circuits (UTC) utilize THERMAL CLAD dielectrics without the typical thick base layer. These circuits are often used for semiconductor packaging where the thick aluminum or copper base is not required for mechanical strength or thermal mass. UTC is a "stand-alone" ceramic submount replacement where the heat spreading, and heat sinking is done in a different location. In addition, UTC can often be used for standard component package mounting. In some cases, the thermal performance and heat dissipation of the UTC is adequate to eliminate the need for heat sinking altogether. The total profile of a UTC can be as thin as 0.009'' (229µm) and can be built up into multilayer structures.

Advanced Circuit Processing

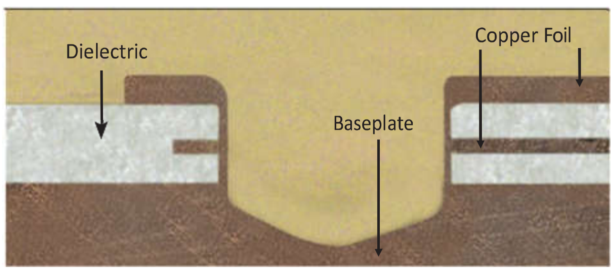
Custom Process Capabilities



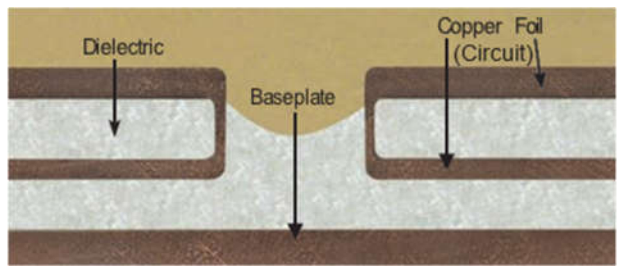
Precision laser removal of dielectric, to expose base for direct component mounting



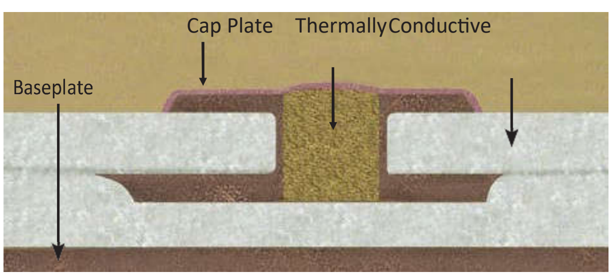
Copper pedestal, coplanar to adjacent circuits for component mounting



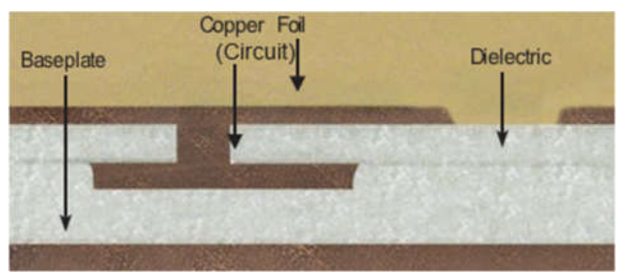
Blind Plated Via to Baseplate, thermal/electrical connection to base



Electrical/Thermal Via, reduces thermal impedance from circuit to base



IPC type 7 Polymer Filled Via, conductive or non-conductive, with cap plating for void free component mounting



Full Copper Plated Micro Via. Can be used as thermal via for void free component mounting

For more detail regarding design and tolerance recommendations for active baseplates, please contact your TCLAD Inc. representative for technical paper "Tools for an Optimal Design".

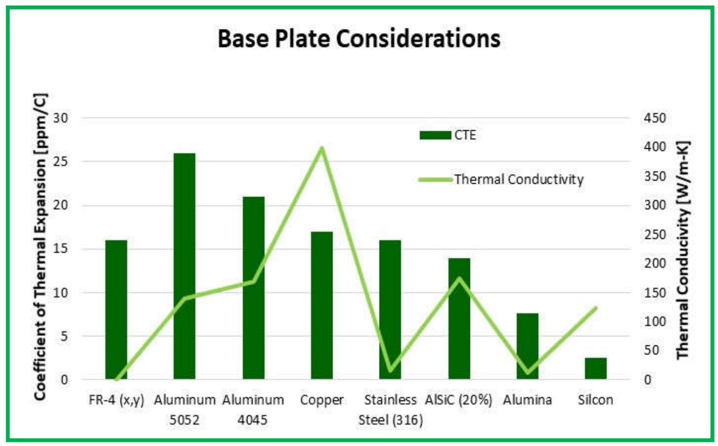
Baseplate Design Considerations

METAL / ALLOY	THERMAL CONDUCTIVITY W/m-K	CTE (COEFFICIENT OF THERMAL EXPANSION) ppm/K	DENSITY g/cc	MODULUS OF RIGIDITY Gpa	YIELD STRENGTH MPa
Copper C1100	400	17	8.9	44.1	310
Aluminum 5052	140	25	2.7	25.9	215
Aluminum 6061	170	25	2.7	26	230
Aluminum 4045 *	171	21	2.67	27	120

* 1.5mm stocked, other thicknesses may be available upon request

CTE and Heat Spreading

The adjacent graph depicts the CTE of the baseplate material in relationship to the thermal conductivity of the metal. Although Aluminum and Copper are the most popular baseplates used in THERMAL CLAD, other metals and composites have been used in applications where CTE mismatch is a factor. The table above represents standard baseplate materials.



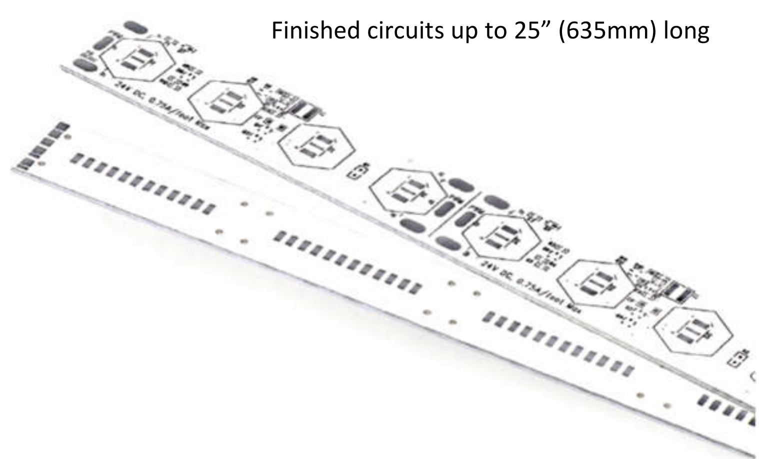
CTE and Solder Joints

Solder joint fatigue can be minimized by selecting the correct base layer to match closer to the component CTE. The major concern with thermal expansion is excessive stress to the solder joint experiences in power (or thermal) cycling. Stress induced by heating and cooling may cause the joint to fatigue. Large devices, extreme temperature differential, badly mismatched materials, or lead-free minimum solder thickness may all place increased cyclic strain on solder joints.

Solder joint fatigue is typically first associated with ceramic based components and with device termination. The section on "Assembly Recommendations" (page 20-21) covers these issues in more detail.

Extra-Long Circuits

Finished circuits up to 25" (635mm) long



Base Plate Design Considerations

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 may also be available. Please check with your TCLAD sales representative on availability.

Electrical Connections to the Baseplate

If an electrical connection to the base plate is desired, copper is the most compatible base material to use. When using electrical or thermal vias, it is important to match the circuit and base CTE as closely as possible. Otherwise, excessive stress to the plated hole can occur during thermal cycle. Other base layer metals can be used for connection but will require different electrical connections other than a plated hole.

Costs

The most cost-effective base layer materials are aluminum and copper because they have high thermal conductivity and represent industry standards. Copper is more expensive than aluminum when comparing like thicknesses but can be a competitive option if design considerations allow for a thinner copper base. As an example, typically the cost of 0.040'' (1.0mm) copper is close to the cost of 0.125'' (3.2mm) aluminum.

ALUMINUM - THICKNESSES	
Inches	**Millimeters**
0.032	0.81
0.040*	1.02*
0.062*	1.57*
0.080	2.03
0.125	3.18
0.160	4.06
0.190	4.83

* Most common thicknesses

COPPER - THICKNESSES	
Inches	**Millimeters**
0.032	0.79
0.040*	1.02*
0.060	1.52
0.080	2.03
0.125	3.18

Surface Finish

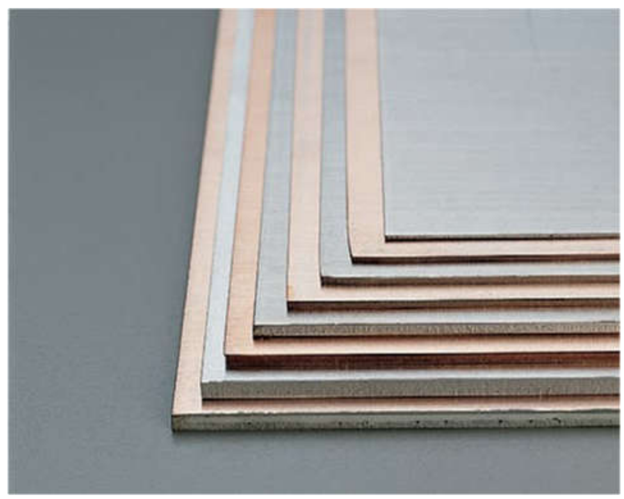
Aluminum and copper base layers come with a uniform commercial quality brushed surface. Aluminum is also available anodized or with other conversion coatings.

Standard THERMAL CLAD Panels

Available in:

- 18'' x 24" (457mm x 610mm)
  - Usable area: 17'' x 23" (432mm x 584mm)
- 18'' x 25" (457mm x 635mm)
  - Usable area: 17'' x 24" (432mm x 610mm)
- 20'' x 24" (508mm x 610mm)
  - Usable area: 19'' x 23" (483mm x 584mm)

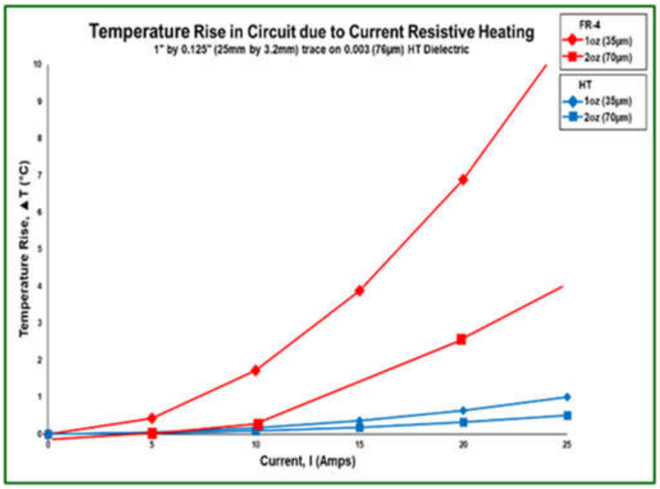
Other panel configurations may be available to allow for more efficient circuit layouts, please contact your local TCLAD sales representative with your requirements.



Selecting a Circuit Layer

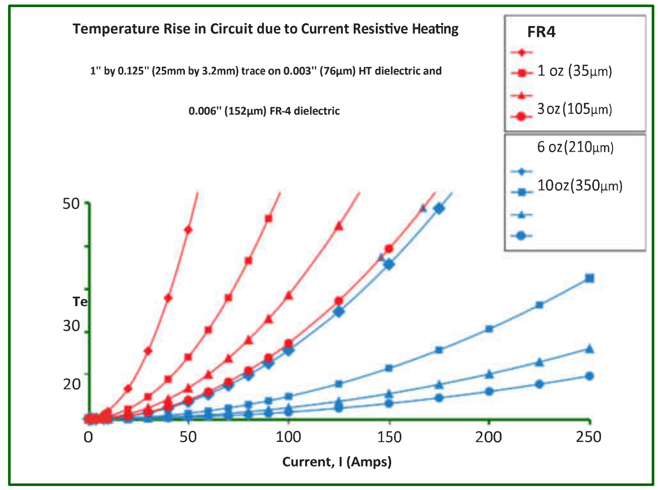
Current Carrying Capabilities

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 than FR-4 because of its ability to dissipate heat due to I^2R losses in the copper circuitry.



Relative temperature rise comparison graph depicts the significant difference between TCLAD INC's Dielectric HT and FR-4. Additional comparison charts regarding all Thermal Clad dielectrics are available.

Note: No base metal used in calculation.



Temperature rise comparison graph depicts the significant difference between TCLAD INC's Dielectric HT and FR-4. Additional comparison charts regarding all Thermal Clad dielectrics are available.

Note: No base metal used in calculation.

Want a cost effective, optimized circuit design?

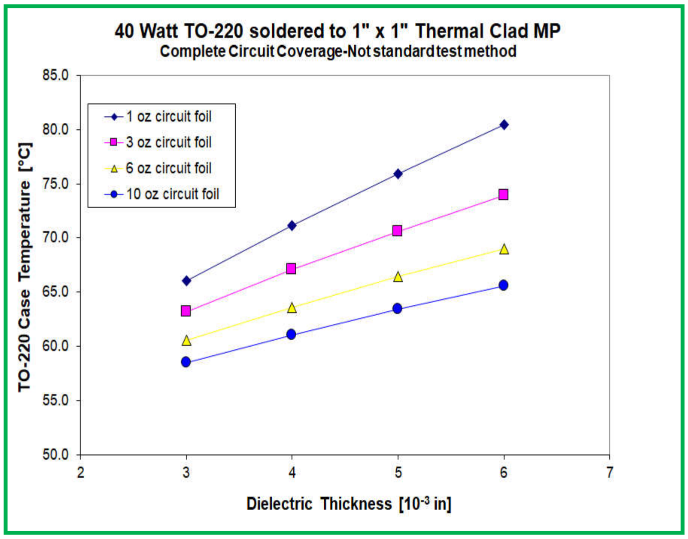
This THERMAL CLAD White Paper addresses specific design recommendations including mechanical, circuit, soldermask, fabrication and test options to help optimize your design.

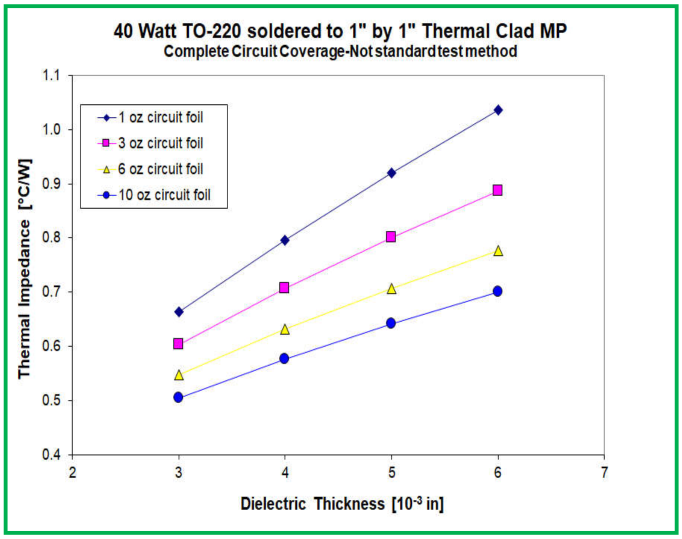
Download available at www.tclad.com

Heat Spreading Capability

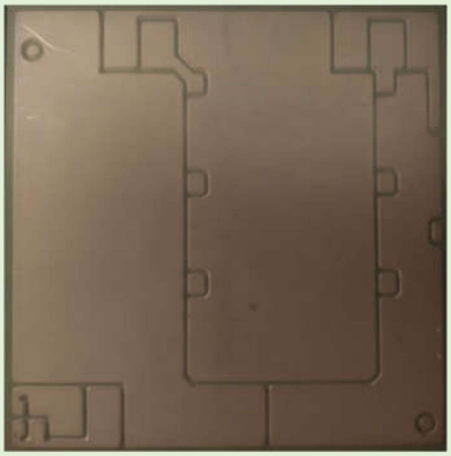
Dielectric thickness and foil thickness both influence heat spreading capability in THERMAL CLAD. Heat spreading is one of the most powerful advantages derived from IMS. By increasing copper conductor thickness, heat spreading increases and brings junction temperature down. In some cases, very heavy copper can be utilized along with direct die attach to eliminate the need for a standard packaged component.

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





Power Module with 17oz (595µm) Circuit Copper and Copper Base



Standard Circuit Layer Thickness

Material	Weight oz / ft^2	Reference inches	Thickness µm
ED copper (zinc treatment)	0.5	0.007	18
	1	0.014	35
	2	0.028	70
	3	0.041	105
	4	0.055	140
	6	0.083	210
RA Copper	8	0.110	280
	10	0.138	350

Note: ED copper foil is not measured for thickness as a control method. Instead, it is certified to an aera weight requirement per IPC-4562 e.g. 1oz/ft^2. The nominal thickness is given on 1oz copper is 0.0014" (35µm).

Caution: Values in IPC-4562 (table 1.1) are not representative of mechanical thicknesses.

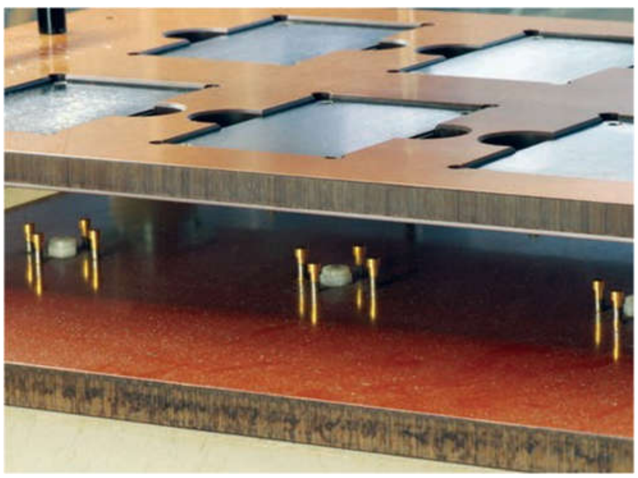
Electrical Design Considerations

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.

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

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



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

The "Proof Test" will 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, delamination 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

ASTM D149 definition of dielectric breakdown voltage: the potential difference at which dielectric failure occurs under prescribed conditions in an electrical insulating material located between two electrodes. This is a 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.

Due to circuit board construction and layout, it is always recommended to "Proof Test" at a value which is less than 50% of the specified ASTM D149 dielectric breakdown voltage. This should include provisions for creepage distance to avoid surface arcing to the metal base.

Leakage Current HiPot Testing

Due to the variety of dielectric types, thicknesses, and board layouts, not all boards test alike. IMS (insulated metal substrates) closely resemble a parallel plate capacitor during Hi-Pot testing. Capacitance is equal to:

C = € A/d

where:

€ = Permittivity (Dielectric Constant)

A = Surface Area

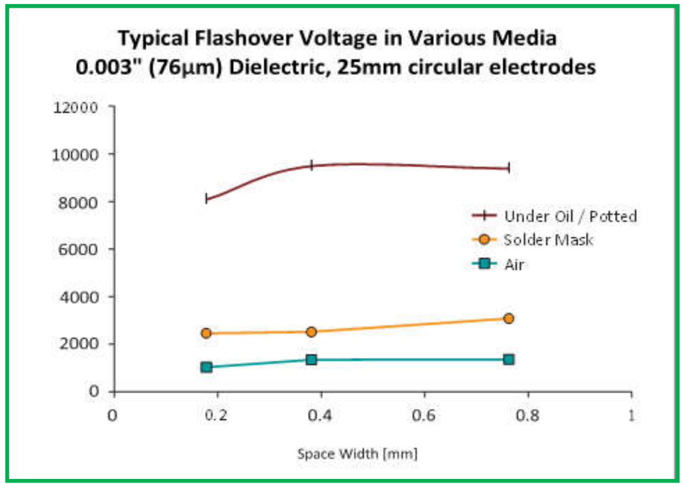
d = Distance (Dielectric Thickness)

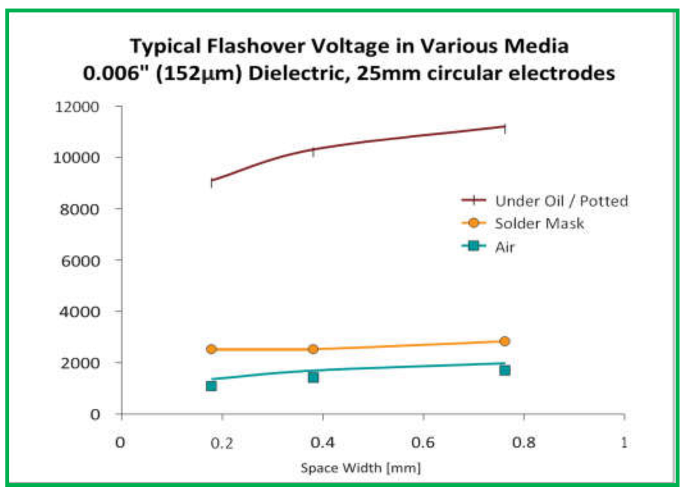
The capacitance value changes with different configurations of materials and board layouts. This can be demonstrated where one board fails the test and another passes, but when both are actually tested for dielectric strength and leakage current in a controlled environment, both pass. Therefore, it is 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 IMS is the leakage and charge current that take place during the test. In most cases, the leakage current value on IMS is much smaller than the measurement capability of a typical Hi-Pot 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 DC test voltage and hold.

Creepage Distance and Discharge

Creepage distance and discharge must 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 graphs below depict flashover: without soldermask, with soldermask and under oil.

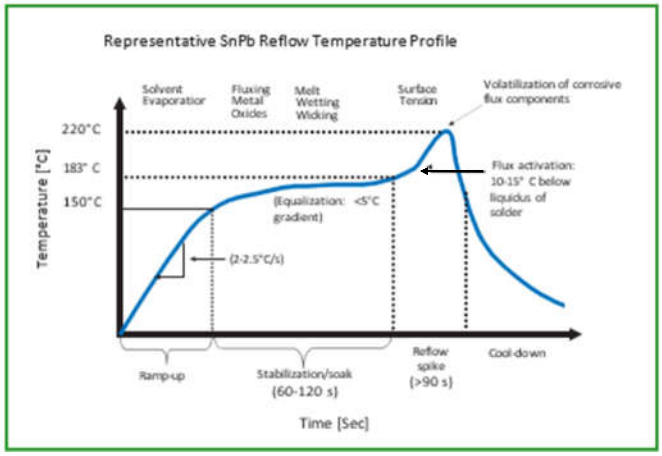




Assembly Recommendations

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.



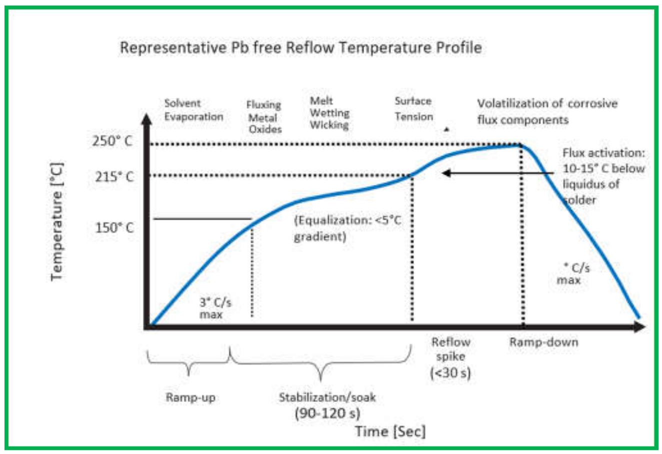
Surface Finishes

Standard circuit board finishes are available for THERMAL CLAD circuit boards.

- ENIG (Electroless Nickel/Immersion Gold)
- ENEPIG (Electroless Nickel/Electroless Palladium/ Immersion Gold)
- OSP (Organic Solderability Protectant)
- Immersion Silver or Immersion Tin
- Lead-Free HASL or Standard Tin/Lead HASL
- Electrolytic Gold - for edge connectors

Application and Thickness - Solder Paste

With the majority of applications now requiring lead-free solder, there are still some specialized applications using the Tin-Lead solder paste. In either case, the final solder joint is key to long-term reliability. The solder joint thickness, component alignment and solder fillet requirements should comply with the industry standard: IPC-A-610 "Acceptability of Electronic Assemblies". The section on solder joints for surface mount assemblies provides the information on acceptance criteria for solder joints. It also describes defects that will require rework to meet acceptance levels.



Note: Additional thickness and/or larger stencil opening may need to be utilized for RoHS compliance applications. Use profile recommended by the component or solder manufacturer.

Hand Soldering

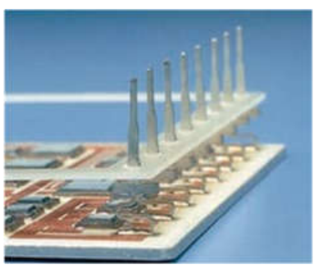
IMS circuits can be hand soldered but care should be taken to not overheat the solder pads. Overheating can cause damage and break the adhesion of the copper to the dielectric. Hand soldering can best be accomplished by heating the base metal to a temperature slightly under the solder melting point (20-30°). Then do the final heating by normal process of soldering iron, hot bar laser or hot air.

Connection Techniques

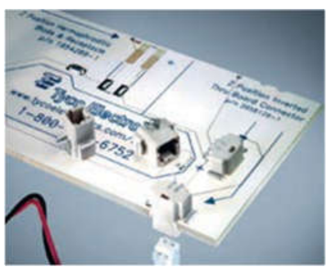
Connection techniques common throughout the industry are being used successfully on THERMAL CLAD IMS substrates. Surface mount connectors are manufactured using plastic molding materials with thermal coefficients of expansion that roughly match the characteristics of the baseplate metal. However, the 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 Milmax and Zierick have off the shelf pins ideal for IMS applications. Custom made pins and connectors are also available.



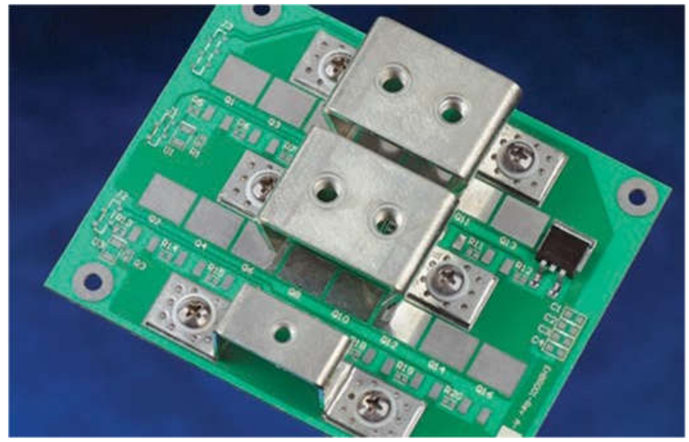
This TE Connectivity SMT thru-board connector provides a way to bring power from the underside of a THERMAL CLAD IMS board, eliminating issues of attaching wires on the top side of LED boards.

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. Thru-board connectors will require adherence to fabrication design rules for IMS PWB's.

Edge Connectors

When using card edge connectors as part of the THERMAL CLAD printed wiring pattern, it is suggested that interfacing conductors be finished with an electrolytic 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.

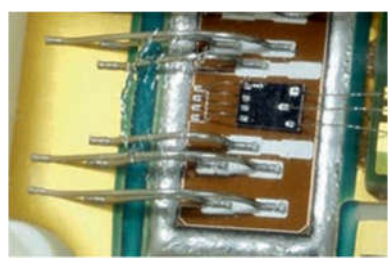


Custom Connectors

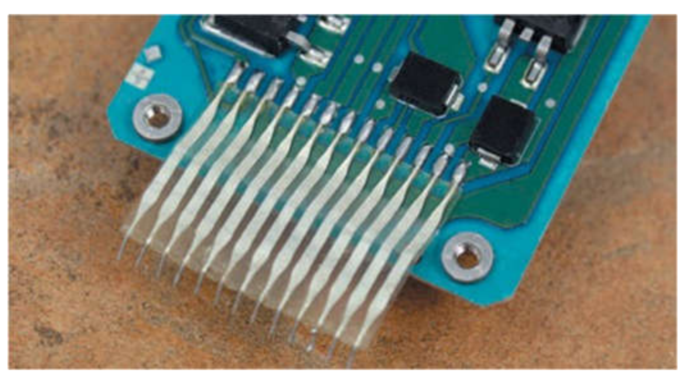
In the example above, the application required a large cable connection to the TCLAD IMS board. Precautions were taken for the best electrical connection with minimized mechanical strain on the etched circuit. This solution addresses both electrical and mechanical fastening. The small holes allow for complete void-free soldering. Also, the insulated shoulder washer prevents shorting to the base plate. These types of connectors are usually custom made and are not commercially available.

Wire Bonding Direct Die Attach

Wire bonding is particularly useful in the design of packages with Chip-On-Board (COB) architecture. This technique uses the surface mount and interconnect capability of THERMAL CLAD in a highly efficient thermal design. See page 12 for additional information.



Close up view of a direct die attachment in a power application.



Flex tail hot bar soldered to THERMAL CLAD.

Thermal Clad Configurations

Custom Circuit

TCLAD Inc.'s brand THERMAL CLAD substrates are custom configured to your design parameters at our Prescott, Wisconsin facility. Our field application support personnel in conjunction with our 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
- Solder mask layouts
- All common circuit finishes
- Tooling/singulation options

Laminates

Additional base metal sizes and thickness options are available.

Standard Sizes:

- 18" x 24" (457mm x 610mm)
- 18" x 25" (457mm x 635mm)
- 20" x 24" (508mm x 610mm)

Standard Base Plate Metals:

- Aluminum 6061 T-6, 5052 H34, 4045 H24
    - 0.032" to 0.190" (0.8mm to 4.8mm)
- Copper 110 Full-Hard
    - 0.032" to 0.125" (0.8mm to 3.2mm)

UL Certifications Directory

The U.L. website provides the latest information regarding the UL recognition status of TCLAD Inc. THERMAL CLAD materials and "Prescott Operations" circuit fabrication.

Using the address: https://iq2.ulprospector.com/, select Online Certifications Directory. Enter "TCLAD Inc." into the "Company Name" field and press the search button. Click on the link of one of the two U.L. File Numbers to view it: QMTS2.E121882 and ZPMV2.E122713.

- 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.

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

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 Permittivity (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 Methods 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 permittivity 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-840	Soldermask
	IPC-A610	Acceptability of Electronic Assemblies
Surface Mount	IPC-7351	Generic requirements for Surface Mount Design and Land Pattern Standards
ISO 4587	Adhesives	Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies

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