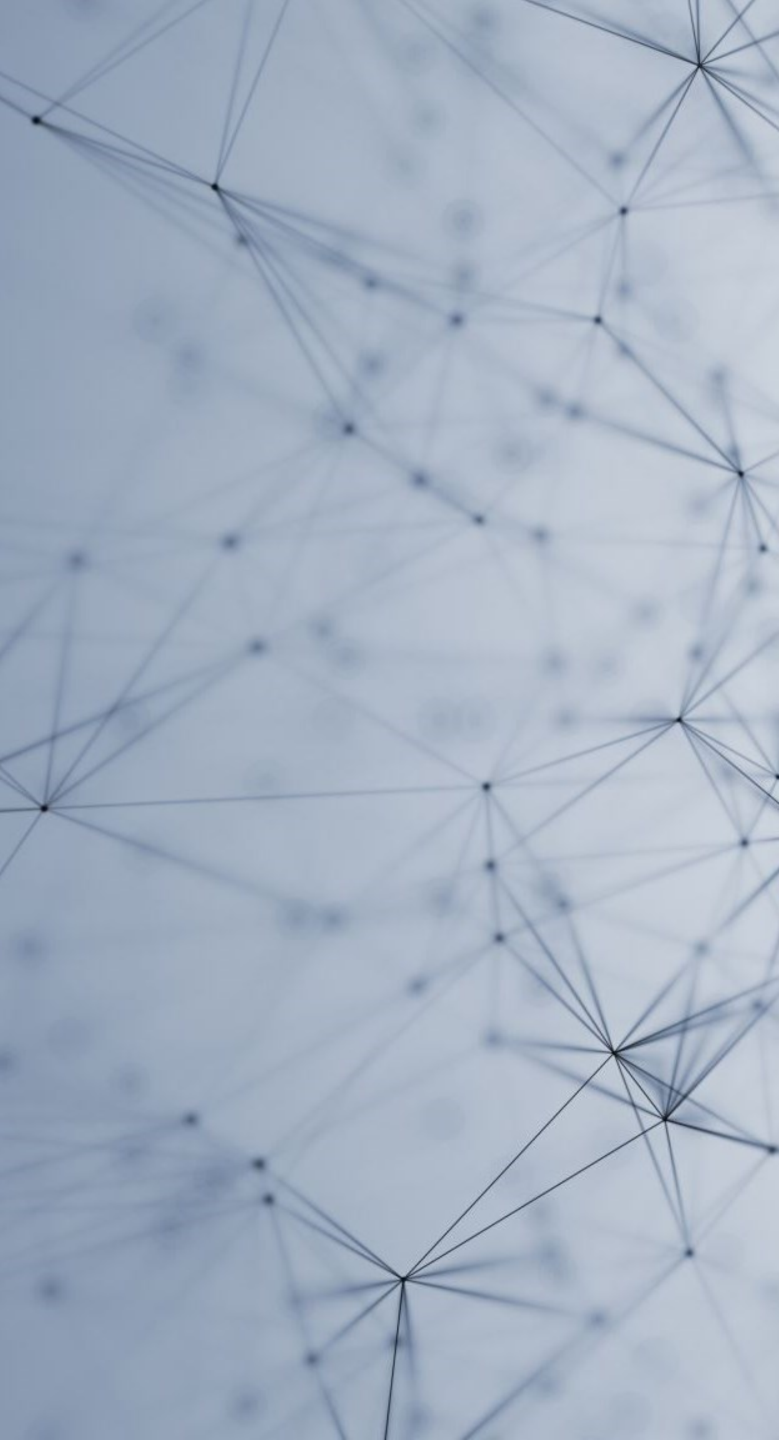


PCB Substrates and Methods for High Temperature Applications

DK-DALEBA
Printed Circuits

Scope Of Presentation

Thermal Management of Electronics:

- Heat dissipation.
- Increases component life, product life, and long-term reliability.
- A consequence of the trend for electronics to operate at higher performance levels.
- In particular, in the field of automotive engineering. With many functions now being solved electronically rather than mechanically.
- Power electronics is another area where thermal management is a critical consideration and substrates with excellent thermal management properties are critical.

Increasing Operating Temperatures:

- High power electronics are generating increased temperatures testing not only thermal management, but also material operating temperatures.
- The latest developments of EV power applications are seeing Silicon Carbide Chips running at approximately 800v+ and 800 amps with resulting operating temperatures of 200°C +
- Alternative chip substrates such Gallium Nitride which can operate at temperatures up to 400°C.

Introduction to DK-Daleba

- DK-Daleba is part of the TCL group of PCB companies founded in 1963
- Over 31 million PCBs to our customers last year
- We have our own UK and Asia manufacturing facilities as well as manufacturing trade partners throughout Asia and Europe
- Strong focus on trends in customer demands and new manufacturing techniques using the latest materials.
- Specifically products for the growing demand of high-temperature resistant materials and PCBs suitable for high power applications. These products, information on each we will be presenting today are:
  - IMS – Insulated Metal Substrates
  - Ceramic
  - Heavy Copper
  - Pedestal technologies

IMS – Insulated Metal Substrates – Most commonly used for LED applications. High performing materials can also be used for products dealing with high power.

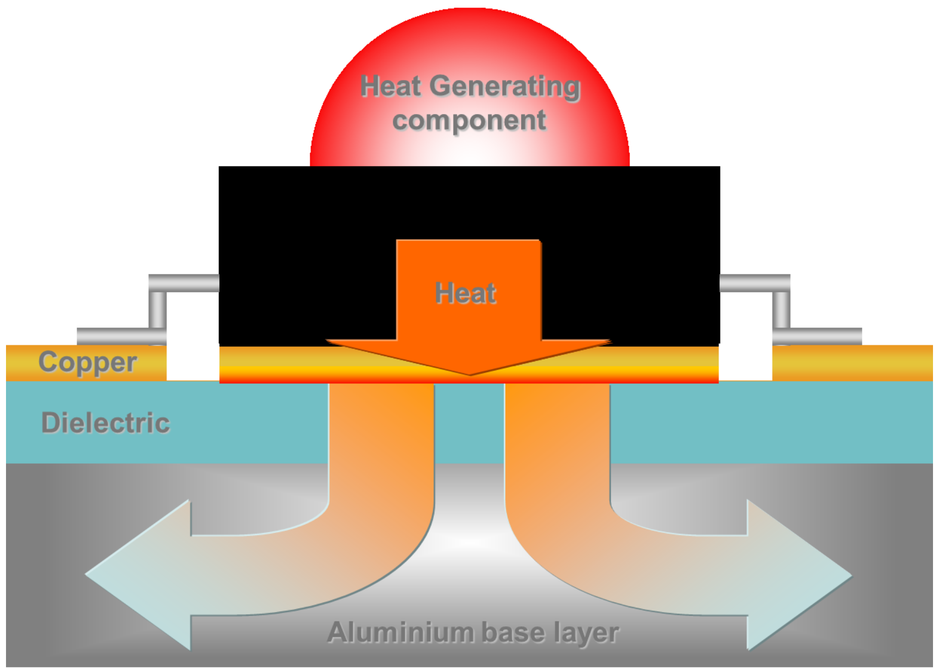
Ceramic Substrates – Very high Thermal Conductivity and MOT.

Heavy Copper – Allows increased current capacity to deal with high power.

Pedestal Technology– Improves Thermal Performance of IMS by linking surface copper to base metal.

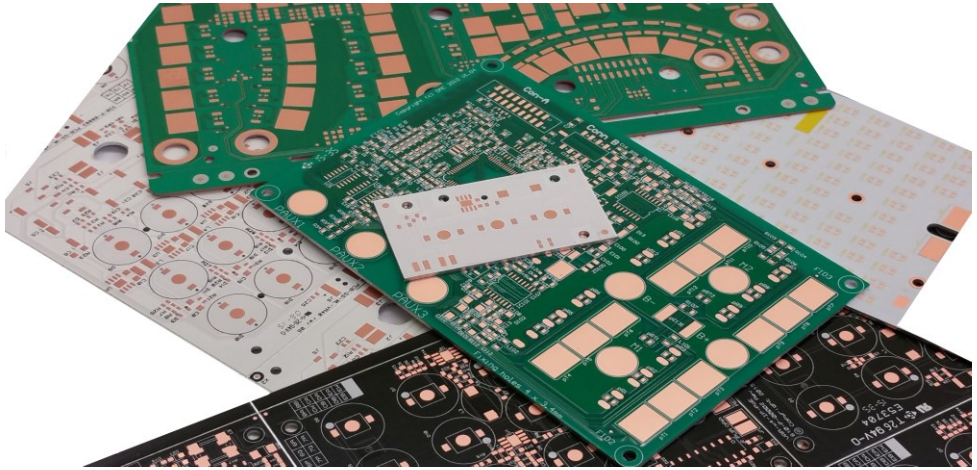
IMS – Insulated Metal Substrate

- IMS materials were introduced to combat rising junction temperatures of surface mount components.
- Consisting of an electrically isolating dielectric layer between copper tracks, and an aluminium/copper base.
- Dielectrics can be constructed from a range of materials—most commonly using one of the following bases-
  - Polymer
  - Ceramic
  - Epoxy
  - Boron Nitride
  - Or a combination of the above
- The most common stack-up for IMS PCBs is a 1-1.5mm Aluminium base with 50-100um Dielectric and 35-70um (1-2oz) Copper



IMS – Insulated Metal Substrate

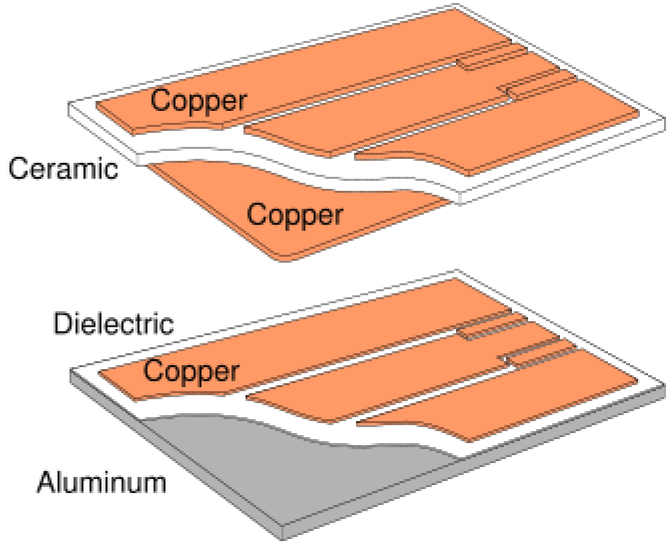
- IMS materials are suited for heat generating applications such as LED and high power.
- However, they have their limitations in both:
  - Thermal Conductivity – up to 8-10W
  - And running temperatures – MOT up to 155/160°C



	Dielectric				
DK Material Code	Thickness (µm)	Conductivity (W/m-K)	Impedance (°C-cm²/W) (Calculate	Max operating Temp (°C)	Breakdown Voltage (kV AC)
DK20-05	76	1.3	0.58	130	8.5
DK20-01	76	2.2	0.35	140	8.5
DK20-03	152	2.2	0.69	140	11
DK20-09	76	1	0.76	130	7.5
DK20-08	38	3	0.13	140	5
DK30-02	95	2	0.48	130	-
DK40-01	80	2	0.40	115	6.3
DK40-01	150	2	0.75	115	9.2
DK40-03	85	4	0.21	105	6.1
DK40-03	170	4	0.43	105	9.8
DK40-05	85	4.5	0.19	155	4.9
DK40-05	150	4.5	0.33	155	4.9
DK50-01	95	2	0.48	110	3.5
DK50-08	95	2	0.48	160	4
DK50-10	95	8	0.12	160	4
DK50-09	95	5	0.19	160	4
DK80-01	102	3	0.34	110	2.6
DK80-02	152	3	0.51	120	4.8
DK115-01	75	1	0.75	90	4.5
DK115-01	100	1	1.00	90	5
DK115-02	75	1.6	0.47	90	6
DK115-02	100	1.6	0.63	90	7.5
DK115-03	75	2.2	0.34	90	6
DK115-03	100	2.2	0.45	90	7.5
DK115-04	75	3	0.25	90	3.5
DK115-04	100	3	0.33	90	4
DK115-05	50	3	0.17	130	4
DK115-05	75	3	0.25	130	7
DK115-06	75	4.2	0.18	130	7
DK115-06	100	4.2	0.24	130	8
DK115-07	75	7	0.11	130	7

Ceramics – Introduction

- The main limitation with IMS PCBs comes from the Thermal transfer through the Dielectric layer.
- Although designed to be Thermally Conductive, it does act as a thermal barrier with limits on it's performance.
- The use of Ceramic substrates as the base for the PCB negates this limitation with the substrate being in direct contact with the copper tracks, and having Thermal Conductivity values ranging from 24-180W/mK – depending on the material chosen.
- Ceramic substrates can be utilised in situations where larger external heat-sinks are not possible and thermal management is critical.



Ceramics - Advantages

High Thermal Conductivity – Effective heat dissipation

High MOT (Maximum Operation Temperature) – Ceramic can withstand large temperature fluctuations

Low CTE (Coefficient of Thermal Expansion) – Ceramics do not expand/contract much with changes in temperature. This is often an issue associated with component cracking on other substrates

Electrical Insulation – High dielectric strength allows for strong electrical isolation.

Ceramic – Substrate Options

Al2O3 (Alumina Oxide) – Most commonly 96%, this is the most standard and cost-effective option, with a Thermal Conductivity of around 24W/mK. A 99.6% option is also available.

AlN (Aluminium Nitride) – Required when Thermal Conductivity is the driver. With a TC of around 170W/mK it is the best option for highly demanding systems.

Si3N4 (Silicon Nitride) – More resistant to shock than other substrate options, with a higher fracture toughness and bending strength. Well suited for automotive applications where structural reliability is key.

Sapphire Ceramics – Transparent substrate suitable for lighting products. More cost effective than Ceramic, however not as efficient Thermally (only 1-2W/mK). Better breakdown voltage and Higher Operation Temperature than standard substrate materials (FR4/Metal).

Ceramic - Material Specifications

Property	Unit	Al2O3 (96%)	Al2O3 (99.6%)	AIN	Si3N4	Sapphire
Thermal Conductivity	W/mK	24	29	**180**	85	1.2
Maximum Operating Temperature (MOT)	°C	>800	>800	>800	>800	650
Coefficient of Thermal Expansion (CTE)	x 10^{-6}/K	6.7	6.8	4.6	**2.6**	3.3
Dielectric Constant	-	9.8	9.9	9	9	5-10
Signal Loss	x 10^{-3}	0.2	0.2	0.2	0.2	-
Light Reflectivity	%	**70/85**	75	35	-	-
Dielectric Strength	KV/mm	≥15	≥15	≥15	≥15	≥15
Rupture Strength	Mpa	400	550	450	**800**	40-120

Ceramic – Al2O3 (Alumina Oxide)

Property	Unit	Al2O3 (96%)	Al2O3 (99.6%)
Thermal Conductivity	W/mK	24	29
Maximum Operating Temperature (MOT)	°C	>800	>800
Coefficient of Thermal Expansion (CTE)	x 10^{-6}/K	6.7	6.8
Dielectric Constant	-	9.8	9.9
Signal Loss	x 10^{-3}	0.2	0.2
Light Reflectivity	%	**70/85**	75
Breakdown Voltage	KV/mm	15	15
Rupture Strength	Mpa	400	550

- High value of Thermal Conductivity (24-29W/mK)
- High operating temperatures – over 800°C
- Low CTE
- Suitable for high frequency applications due to low signal loss
- High light reflectivity
- Possibility for Hermetic packages with 0% water absorption

Ceramic – AlN (Aluminium Nitride)

Property	Unit	AlN
Thermal Conductivity	W/mK	**180**
Maximum Operating Temperature (MOT)	°C	>800
Coefficient of Thermal Expansion (CTE)	x 10^{-6}/K	4.6
Dielectric Constant	-	9
Signal Loss	x 10^{-3}	0.2
Light Reflectivity	%	35
Breakdown Voltage	KV/mm	15
Rupture Strength	Mpa	450

- Superior values of Thermal Conductivity (Up to 170W/mK)
- High operating temperatures – over 800°C
- Very low CTE
- Suitable for high frequency applications due to low signal loss
- Possibility for Hermetic packages with 0% water absorption

Ceramic – Si3N4 (Silicone Nitride)

Property	Unit	Si3N4
Thermal Conductivity	W/mK	85
Maximum Operating Temperature (MOT)	°C	>800
Coefficient of Thermal Expansion (CTE)	$x\ 10^{-6}$/K	**2.6**
Dielectric Constant	-	9
Signal Loss	$x\ 10^{-3}$	0.2
Light Reflectivity	%	-
Breakdown Voltage	KV/mm	15
Rupture Strength	Mpa	**800**

- Thermal Conductivity value between Al2O3 and AlN at 85-90W/mK run at extremely high temperatures, but in addition it has a
- High operating temperatures – over 800°C
- Very low CTE
- High rupture strength - makes it a more attractive solution to harsher environments or environments with high levels of vibration.
- Suitable for high frequency applications due to low signal loss
- Possibility for Hermetic packages with 0% water absorption

Ceramic - Material Specifications

Property	Unit	Al2O3 (96%)	Al2O3 (99.6%)	AlN	Si3N4	Glass
Thermal Conductivity	W/mK	24	29	**180**	85	1.2
Maximum Operating Temperature (MOT)	°C	>800	>800	>800	>800	650
Coefficient of Thermal Expansion (CTE)	x 10^{-6}/K	6.7	6.8	4.6	**2.6**	3.3
Dielectric Constant	-	9.8	9.9	9	9	5-10
Signal Loss	x 10^{-3}	0.2	0.2	0.2	0.2	-
Light Reflectivity	%	**70/85**	75	35	-	-
Dielectric Strength	KV/mm	≥15	≥15	≥15	≥15	≥15
Rupture Strength	Mpa	400	550	450	**800**	40-120

Highlighted in the table are some of the extreme values that suit each material for different applications –

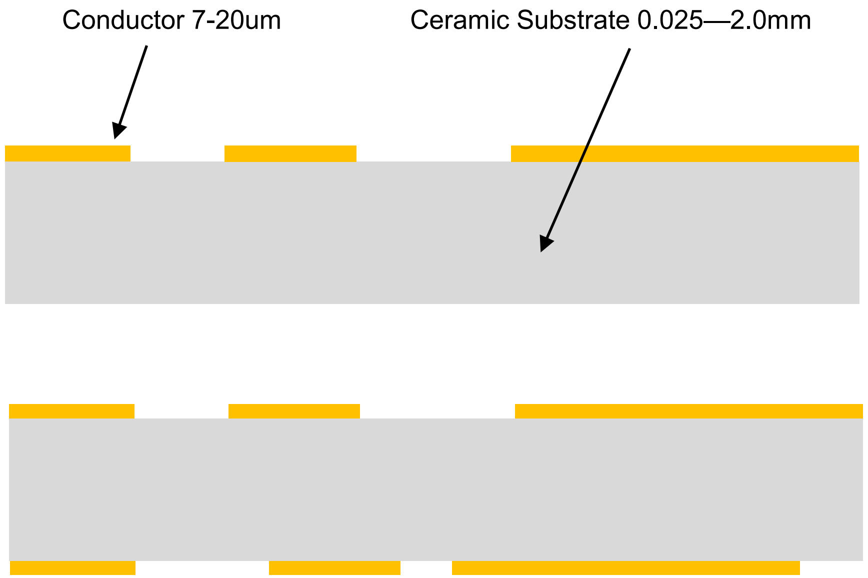
- **Al2O3** has better **light reflectivity** – making it suited for LED products.
- **AlN** has superior **Thermal Conductivity** – making it suitable for very high power applications requiring the best possible thermal substrate.
- **SiN** has a very low **CTE.** Coupled with a high **Rupture Strength** it can withstand stronger thermal shock.

Ceramics – Process Methods

	Thick Film	DPC	DBC
Substrate Type	Al203/AlN/SiN/Sapphire	Al203/AlN/SiN/Sapphire	Al203/AlN/SiN/Sapphire
Conductor	Copper/Silver	Copper	Copper
Conductor Thickness	7-20um	10-140um	140-350um
Max Layers	2	2	2
Circuit Resolution	150um	10-50um	≥150um
Plated Vias Possible	No	Yes – Plated and/or Filled	No
Current Handling	Poor	Good	Excellent
Finish Options	ENIG/Silver	ENIG/ENEPIG/EPIG/Im Silver/ Im Tin/OSP	ENIG/ENEPIG/EPIG/Im Silver/ Im Tin/OSP
Cost	Low	Medium	High

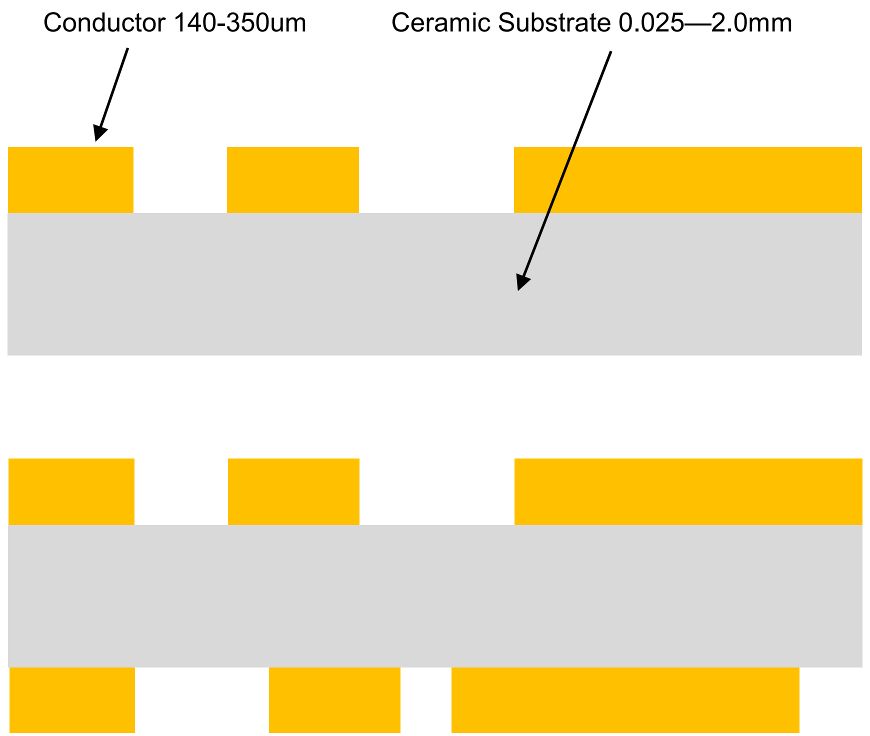
Ceramics – Thick Film

- Thick Film technology involves the addition of layers of conductor (Copper or Silver) onto a Ceramic substrate via screen printing processes.
- Suitable for use with Al203/AlN and Sapphire substrates.
- A cost-effective solution with fewer manufacturing processes than other methods.
- With a conductor thickness between 7-20um it is not well suited to power electronics requiring high current capacity.
- Due to conductor application it is also unsuitable for designs requiring fine tracks and/or plated/filled vias.



Ceramics – DBC

- Direct Bonded Copper (DBC) is used when a high copper thickness is required – 140um (4oz)-350um (10oz). Heavy Copper.
- The copper is bonded to the Ceramic substrate on one or both sides using a high-temperature oxidation process.
- The copper and substrate are heated in an atmosphere of nitrogen containing about 30 ppm of oxygen; under these conditions, a copper-oxygen eutectic forms which bonds successfully both to copper and the oxides used as substrates.
- The copper layers can then be etched using standard PCB technology to form an electrical circuit.
- Laser drilling is then used for any through hole requirements and profile machining.



Disadvantages:

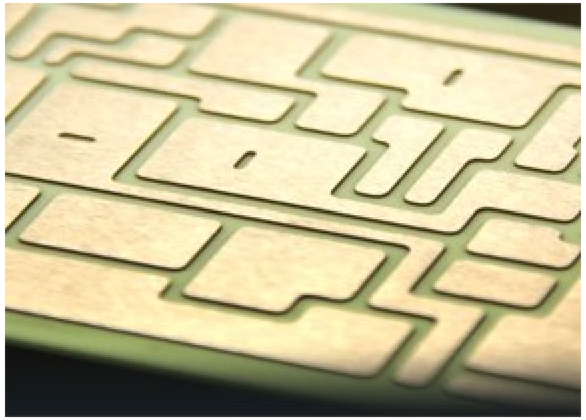
- Not suitable for designs requiring PTH/Vias
- Due to the Oxidisation bonding process there can be a slight reduction in Thermal Conductivity created by a void between the Copper and Ceramic layers.

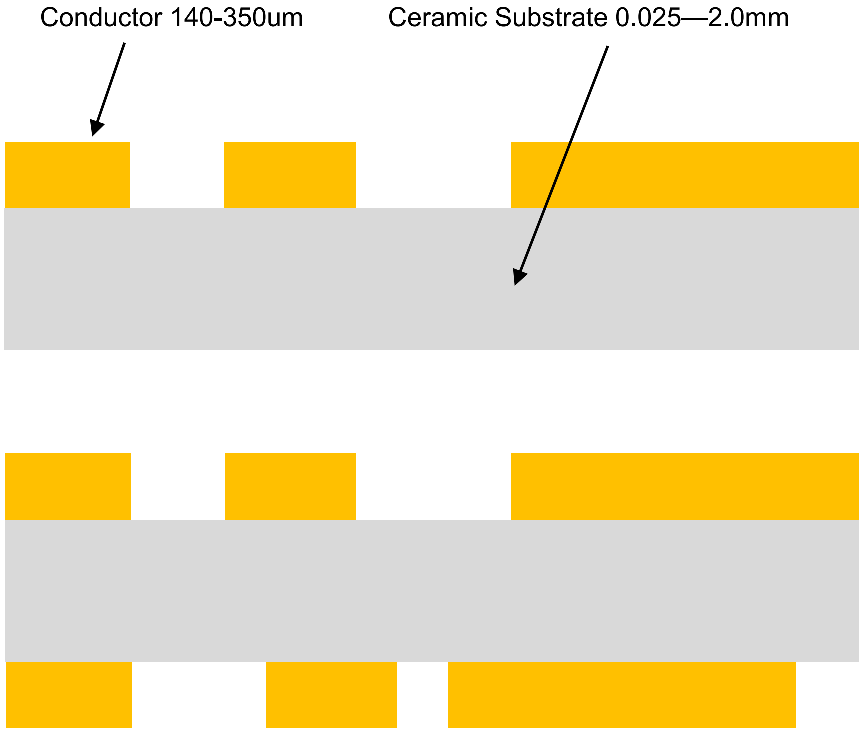
Ceramics – DBC

Applications:

Main applications are high power modules, like IGBT, CPV, or any other wide bandgap device modules.

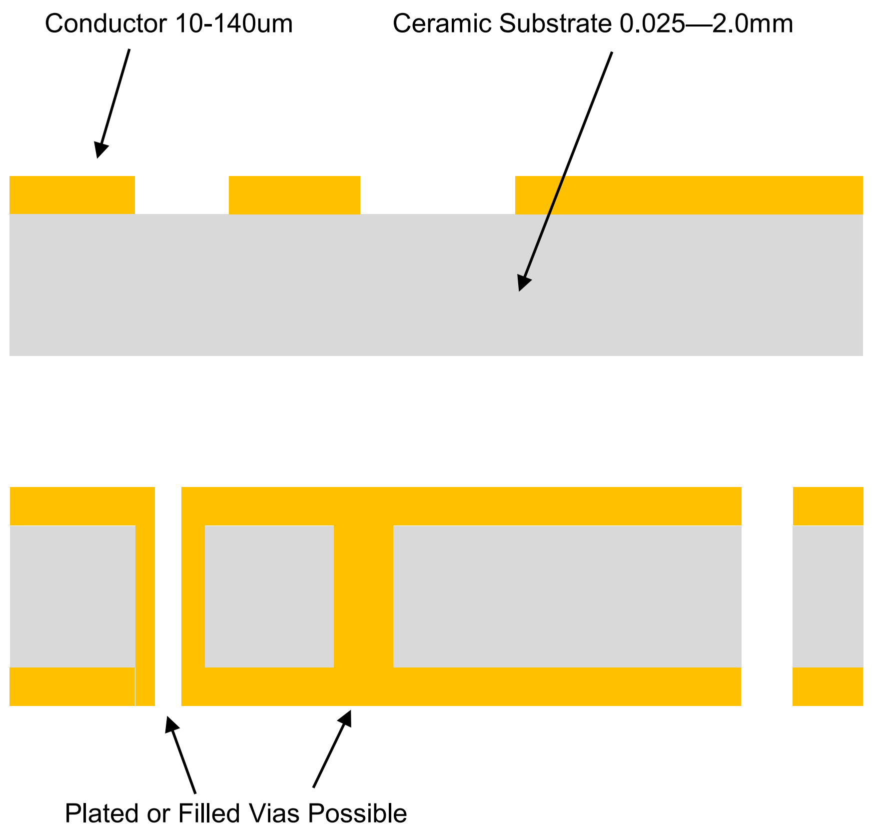
- IGBT
- High-Frequency Switching Power Supply
- Automotive
- Aerospace
- Solar Cell Component
- Power Supply for Telecommunication
- Laser Systems





Ceramics – DPC

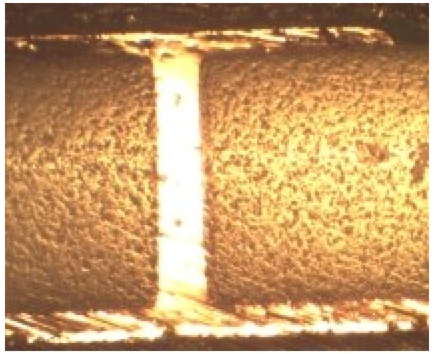
- Direct Plated Copper (DPC) is the newest development in the field of Ceramic Substrate PCBs.
- It involves plating the copper conductor layer to the copper substrate under high temperature and pressure conditions.
- The addition of a thin titanium layer acts as a bonding interface between the copper and Ceramic layers.
- A very thin layer of Copper is deposited at this stage coating the Ceramic substrate and any pre-drilled holes.
- Track printing and etching is then performed with the thin Copper allowing for very fine tracks and reduced undercutting.
- The panels are then plated up to the required end copper thickness.
- Using this method can result in copper thickness' ranging from 10um (≈ 1/3oz) to 140um (4oz).
- It also allows for the possibility of plated or filled vias. Something not possible with Thick Film or DBC technology.

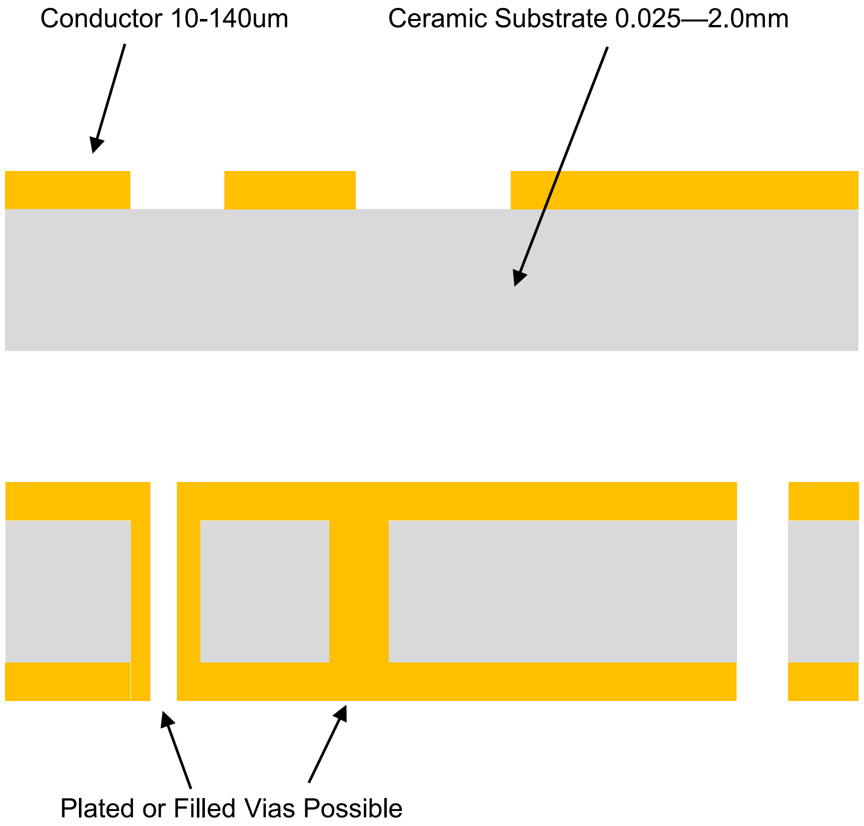


Ceramics – DPC

Applications:

- HBLED
- Substrates for solar concentrator cells
- Power semiconductor packaging including automotive motor control
- Hybrid and electric automobile power management electronics
- Packages for RF
- Microwave devices





Ceramics – DPC vs DBC

Both DBC and DPC have the same advantages for high power applications, due to the use of a direct bond between Copper and the Ceramic substrate, therefore, the same key attributes for both of them are:

- Outstanding Thermal Conductivity
- High operating temperatures
- Good mechanical strength; mechanically stable shape, good adhesion.
- Excellent electrical insulation
- Very good thermal conductivity
- Superb thermal cycling stability
- Good heat spreading

The differences come when looking at the design considerations and applications. DBC being suited to high current capacity, however limited on circuit design. DPC allowing for finer tracks and through hole connection.

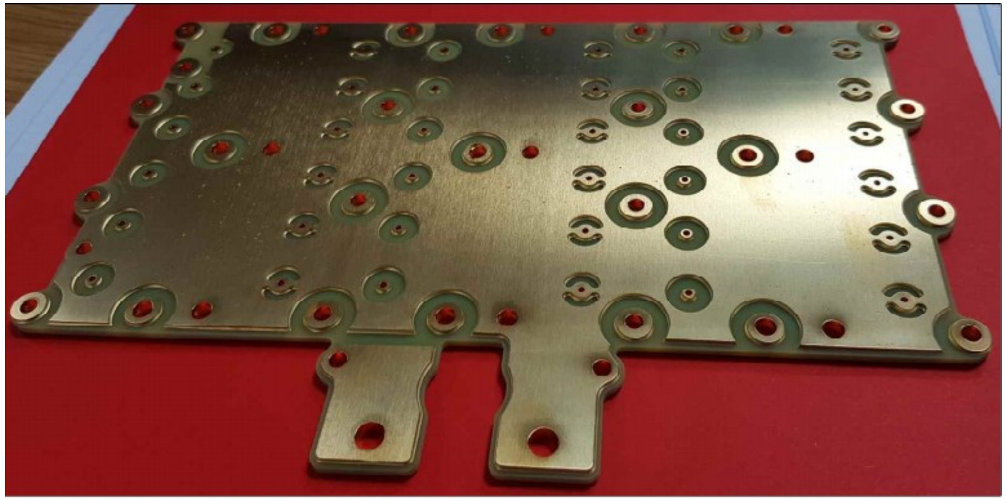
Ceramic - Capabilities

DK-DALEBA
Printed Circuits

Property	DPC	DBC
Compatible Substrates	Al2O3 / AIN / Si3N4	
Substrate Thickness (mm)	0.25/0.38/0.5/0.635.1.0/1.5/2.0	
Copper Weight (oz)	1/3 – 4	4 – 10
Panel Sizes (mm x mm)	Standard: 115 x 115mm Special: Up to 170 x 250mm	
Finish Options	ENIG/ENEPIG/EPIG/Immersion Silver/Immersion Tin/OSP	
Min Track Width (mm)	0.1	Dependant on Cu Weight
Minimum Hole Dia (mm)	0.08	
Plated Via Aspect Ratio	5:1	N/A

Heavy Copper – Introduction

	Weight (oz)	Thickness (mm)
Standard Copper	½ - 4	0.018 – 0.14
Heavy Copper	5 - 15	0.175 – 0.525
Extreme Heavy Copper	15 - 70	0.525 – 2.45
Mixed Copper Weights	1 ½ oz and 30 oz on the same layer (Double Sided)	



1.00mm thick (30oz) extreme heavy copper PCB.

Applications:

- High Power Distribution
- Planar Transformers
- Power Converters
- Amplification Systems
- Solar Panel Manufactures
- Power Controllers
- Welding Equipment
- Inverters
- Bus bars – Lower Copper Weight – Lower Cost

Heavy Copper - Benefits

Increased Current Carrying Capacity – In addition to this – heavy copper plated vias carry higher current through the board and help to transfer heat to an external heatsink

Increased Endurance to Thermal Strain – And effective heat dissipation

Increased Mechanical Strength at Connector Sites and in PTH holes

Reduced Product Size – By incorporating multiple copper weights on the same layer of circuitry

Heavy Copper – Fabrication Techniques

Additive (Plating)

Pros –

- Well defined track edge
- Tighter tracks/gaps

Cons –

- More expensive
- May require additional machining

Subtractive (Etching)

Pros –

- Etching has lower cost

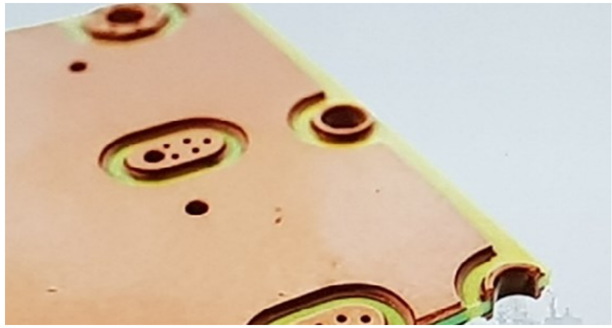
Cons –

- Tracks less well defined
- Cross section – Trapezoid shape
- Requires larger track gaps

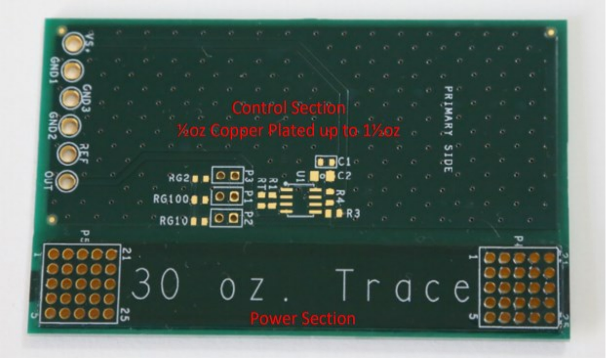
Plated Up **Etched Down**

Heavy Copper – Examples

1.00mm Thick (30oz) Extreme Heavy Copper PCB – Benefits from mechanical durability where the heavy copper planes add to the overall mechanical strength of the board



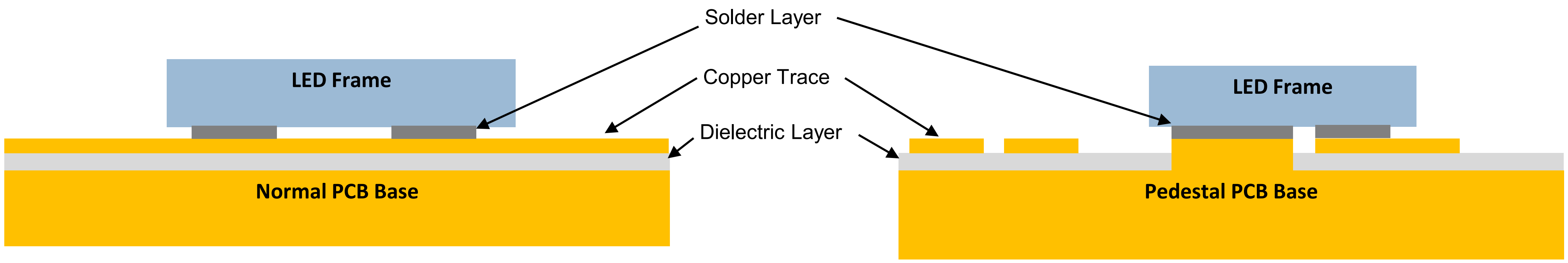
Mechanical Vias – With extra plating used to reinforce the Z axis



Dual Copper Weights – By using different copper weight's on the same layer you can have a control section, and a power section

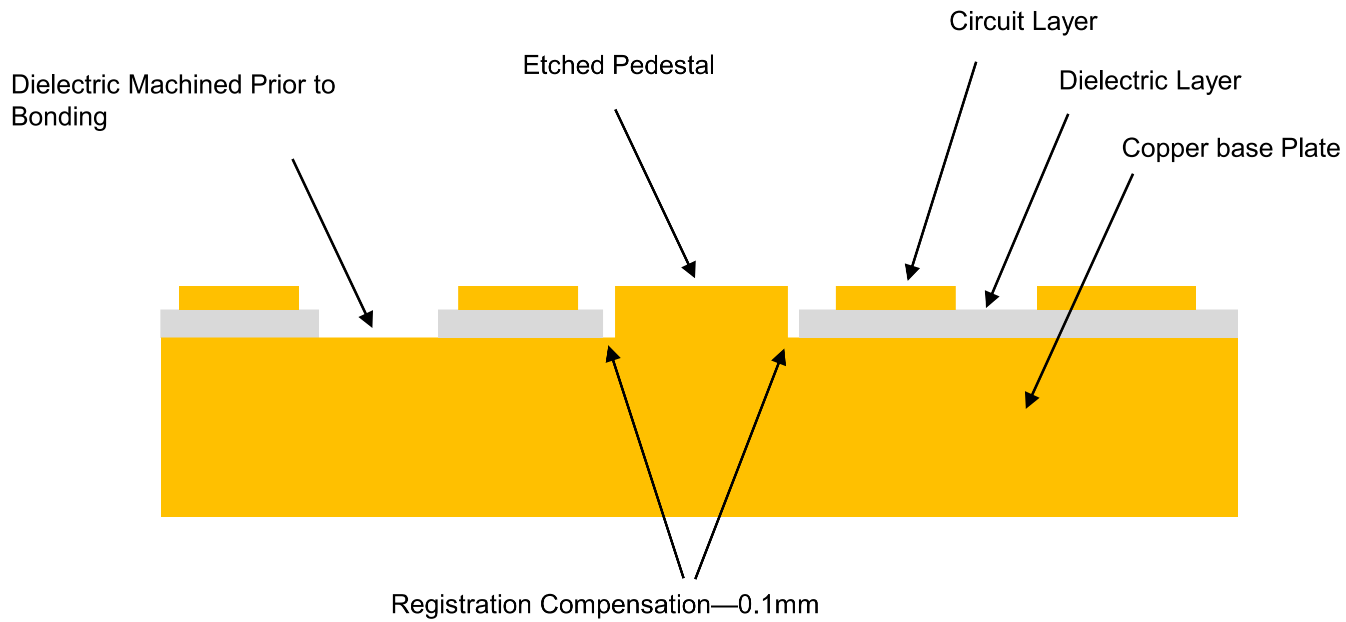
Pedestal Technology - Introduction

- Electronics today are becoming more and more powerful and denser. Therefore, more heat needs to be transported away from components often using conduction through the circuit board towards the heatsink or cold plate.
- PCBs with Pedestal technology are another way to increase thermal transfer. In this case, the biggest thermal bottleneck of a metal core, the dielectric layer between the core metal and the copper circuit is bypassed by a pedestal that makes a direct connection between the (electrically isolated) thermal pad of a component.
- Thanks to this bypass, the heat can be transported with less thermal resistance, keeping the temperature of the component under control and extending its lifetime and operating performance. Building pedestals will be more reliable compared to thermal via's and ensure a better spreading of the heat which allows for a better transfer to the heatsink.



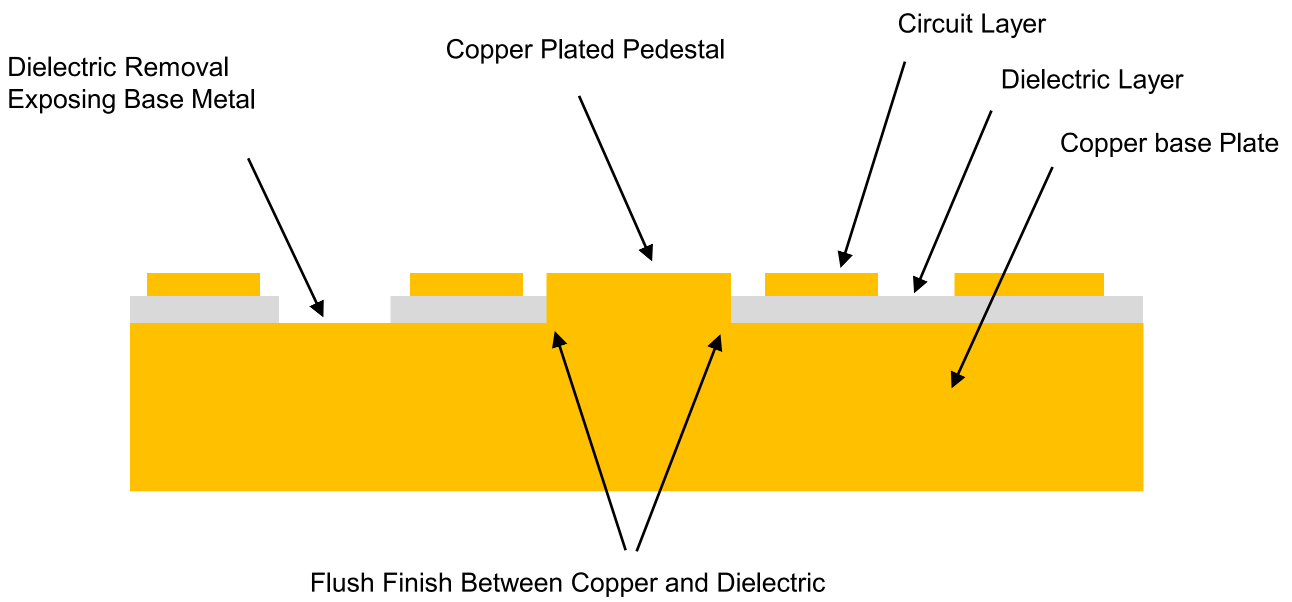
Pedestal Technology – Etch Method

- The ‘Etch Method’ for Pedestal technology involves machining the Dielectric layer prior to bonding.
- The base copper is etched away leaving only the pedestal required.
- Once these two processes have been completed the 2 layers can be bonded together.
- This process must allow for some registration tolerence between the machined dielectric and Pedestal size – generally leaving a minimum void of 0.1mm either side of the pedestal feature.
- The resultant void can however leave the design open to potential Hi-Pot test failures – especially with humidity and/or thermal cycles.



Pedestal Technology – Plating Method

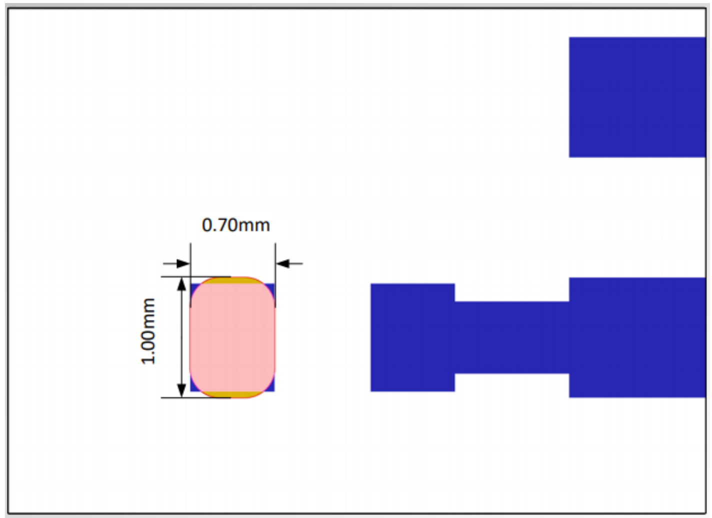
- The ‘Plating Method’ for Pedestal technology involves starting with the bonded substrate and achieves the pedestal by first machining away the dielectric to expose the metal base.
- Copper is then plated up in these areas directly from the base to form the pedestal.
- This is a more expensive method due to the higher cost of plating, and time required. However it does result in perfect registration between the dielectric and copper.
- This neutralises the risk of the Hi-Pot test issues associated with voids.



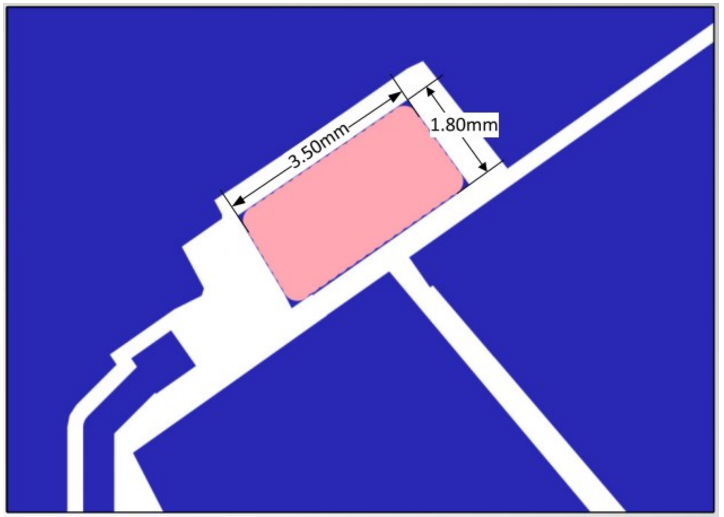
Pedestal Technology – Capabilities

	Base Copper Weight (Thickness)	Standard	Special
Minimum Track Width	0.5oz (18um)	0.10	<0.10
	1oz (35um)	0.10	<0.10
	2oz (70um)	0.20	<0.20
	3oz (105um)	0.25	<0.25
Minimum Track Gap	0.5oz (18um)	0.10	<0.10
	1oz (35um)	0.15	<0.15
	2oz (70um)	0.20	<0.20
	3oz (105um)	0.25	<0.25
Copper base plate can be 1.0mm / 1.6mm or 2.0mm			

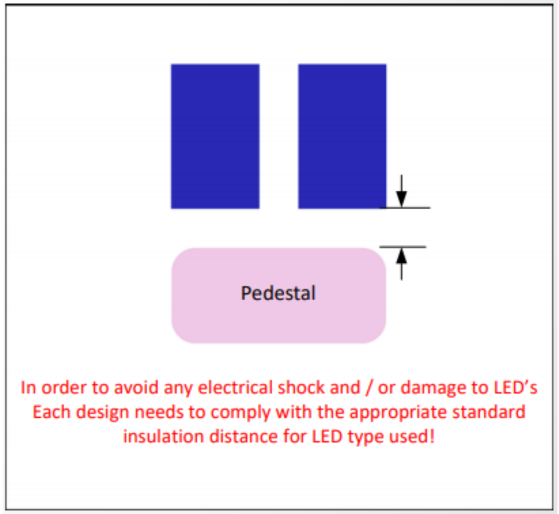
Pedestal Technology – Capabilities



Minimum Pedestal Size

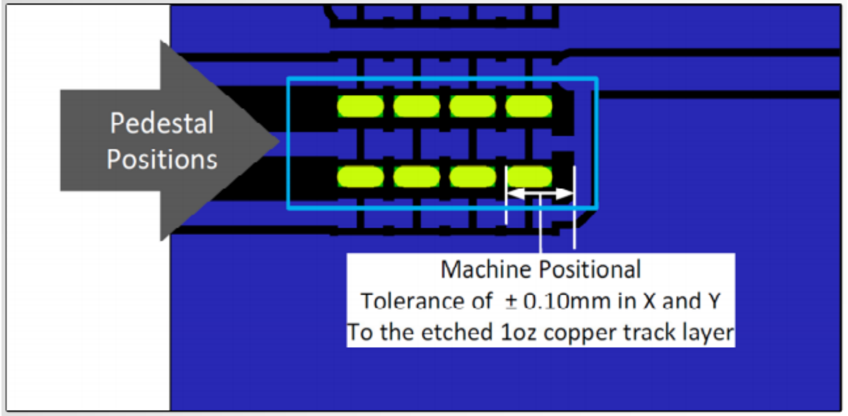


Maximum Pedestal Size

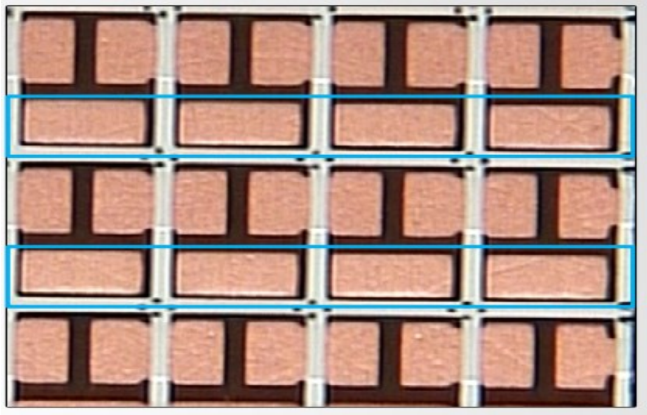


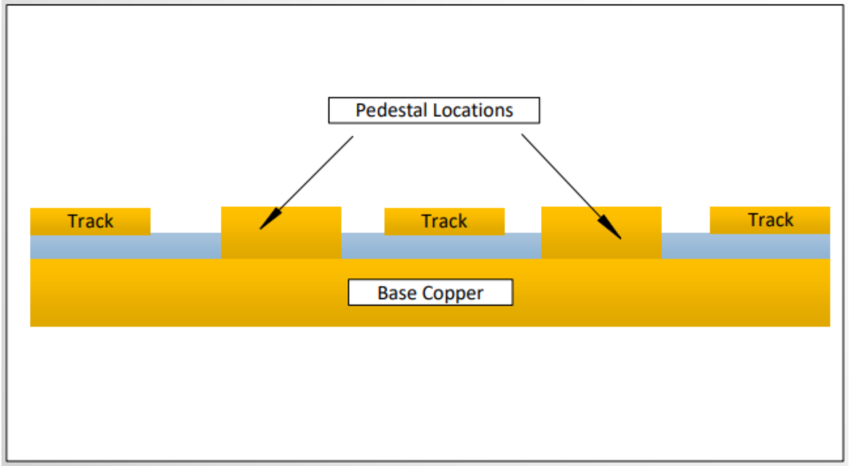
Pedestal Gap

Pedestal Technology – Examples

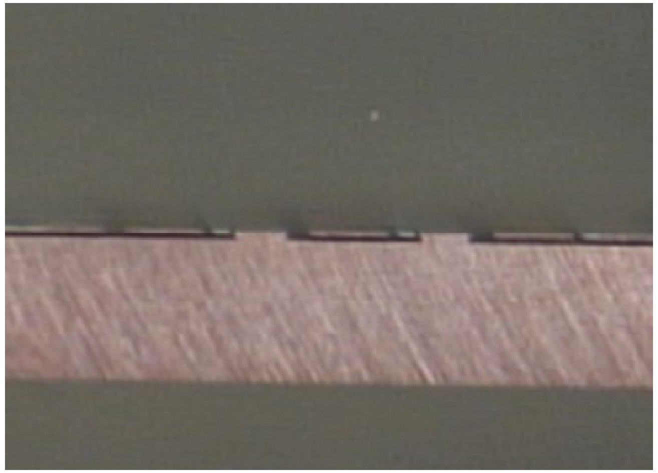


Actual Board



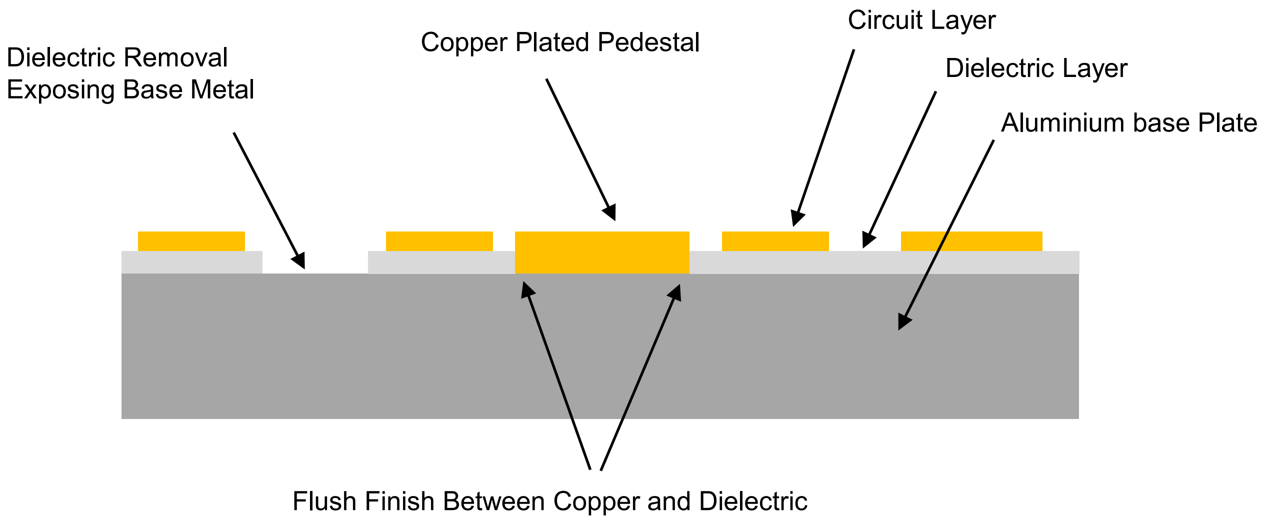


Actual Board



Pedestal Technology – Aluminium Base

- The majority of IMS materials used for Thermal Management consist of an Aluminium base metal as opposed to Copper.
- This is beneficial in terms of both cost and weight.
- Pedestal technology was only previously possible using Copper as the base metal due to the difficulty in creating a reliable bond between Copper and Aluminium.
- We have however developed a reliable method to overcome this issue and fabricate Pedestal technology on an Aluminium base metal.



Thank You

Thank you for listening – if you have any questions, or need further information on any of the content discussed please contact us using the details below:

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