NANOTHERM®

Application Note

Nanotherm DM

Thin film, thermally-conductive substrate

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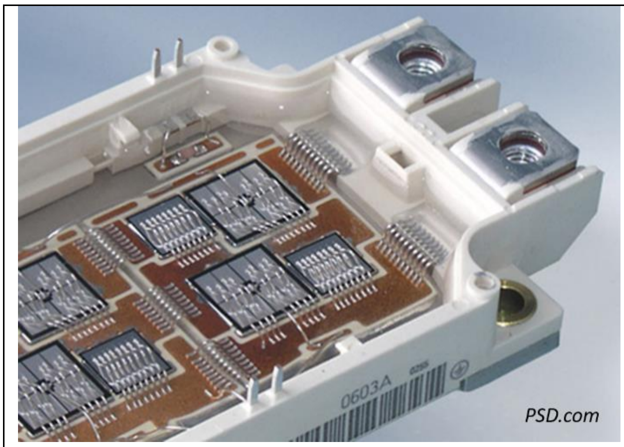
Contents

1. Introduction

Commonly, thin film substrates are either alumina or aluminium nitride (AlN) ceramic. AlN in particular has high thermal conductivity, which explains its widespread use where there is a need to remove heat from electronic components. Two types of electronic component that require careful attention to thermal management are power semiconductors and LEDs.

 PSD.com	 Luxendi.com
Power electronic module with semiconductors mounted on a common thermally conductive substrate	High power LED module attached to a heat sink

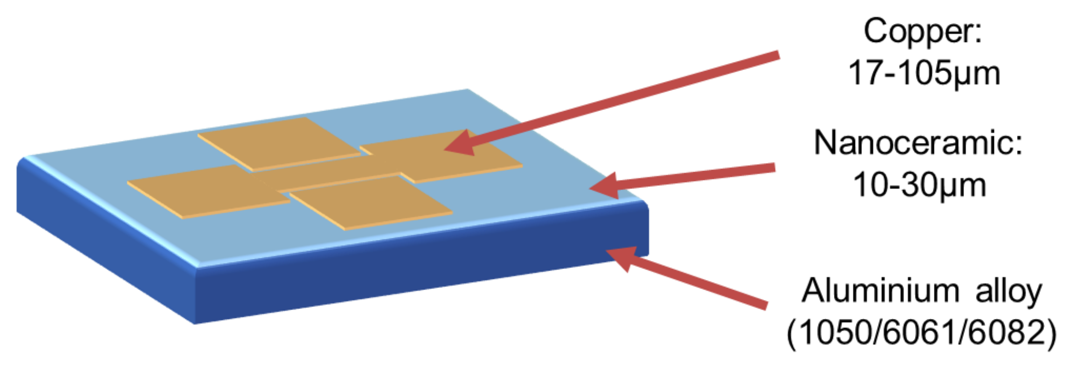
2. Thin film, thermally-conductive substrates

For applications where there is a need to keep electronic components cool, thin film thermally conductive substrates are used. This consists of a plate of alumina or AlN ceramic, around 0.63mm thick. On one or both sides are applied patterned copper layers and then optionally completed with solder mask and a finish applied to the lands, exactly as with a standard FR4 board. Where required, the copper patterns on the two sides can be joined by vias.

Ceramic thin film substrates are expensive to manufacture due to their high energy content. Being ceramic, they have low fracture toughness. This has two consequences. First, the largest substrate commercially available measures 5x7 inches (125x175mm) so the process economics cannot leverage area scaling. Secondly, the substrates must be processed with considerable care to avoid breakage and mounting methods like bolts and clamps must be used with extreme caution.

In place of ceramic, Cambridge Nanotherm uses a tough and flexible aluminium plate as the thermally conductive substrate. An ultra-thin (10-20um) layer of nanograin alumina provides the requisite dielectric isolation of the patterned copper. The dielectric is manufactured in an electrochemical cell, where the surface of the aluminium metal core is converted to nanograin, alpha-phase alumina. Because the dielectric is created by conversion of the surface of the aluminium plate, it is perfectly adhered and presents virtually no thermal impediment to the passage of heat across the interface. Nanograin alumina ceramic is an excellent dielectric (50-75V/um), so the layer can be extremely thin yet permit the copper tracking to be at a high potential relative to the aluminium plate. Keeping the dielectric layer thin also helps the thermal performance since the thermal impedance of a layer is its thickness divided by the thermal conductivity (20-30W/mK for alumina and slightly lower for the material in nanograin form).

The patterned copper and other optional layers are applied directly to the nanograin surface of the aluminium plate using the same process lines for ceramic substrates. Hence the product name "Nanotherm DM", where DM stands for direct metal.



Concept drawing of a Cambridge Nanotherm LC MCPCB. In practice all four layers are equal in area.

Nanotherm DM is engineered to have thermal performance closely similar to AlN, without the limitations of dimensions or fragility. For a typical 1mm thick substrate with a 35um thick copper pattern, the thermal resistance from the top side of the copper to the underside of the aluminium will be less than 0.06°C.cm^2/W. It must be stressed that thermal engineering is a relatively complex subject and there are many good reasons why thermal conductivity (units W/mK) is an inappropriate thermal metric to use when comparing the thermal performance. The correct units are thermal resistance (°C.cm^2/W) for a product and thermal impedance (°C/W) for each unique design of substrate.

3. Construction of Nanotherm DM

Nanotherm DM, thin film thermally-conductive substrates are available in single-sided, dual sided and double-sided permutations. Single-sided substrates have up to five layers, with various options for each layer. Dual- and double-sided substrates can accommodate components on both sides. With double-sided substrates the circuits on each side can be joined electrically by vias that pass through the metal core of the substrate. A brief description of each layer follows:

- Aluminium core. The thickness of the aluminium alloy core can range 0.3-1.5mm. The aluminium alloy can be either 1050HH, 6061-T6, or 6082-T6 depending on the balance of thermal and mechanical properties required. Standard circuit dimensions are 97.2x97.2mm, but can be up to 115.0 x 165.8mm.

- Copper tracking. The standard copper thickness is 35um (1 oz). For a very limited number of circuit designs there may be a need to either decrease or increase the copper thickness to 17 and 150um (1/2-4 oz respectively), due to the need to define fine features or the passage of exceptionally high currents. Cambridge Nanotherm has the capability to run electrical and thermal simulations and can advise on the copper necessary for the application.
- Copper pad finish. All standard pad finishes can also be applied to a Nanotherm DM thin film, thermally-conductive substrates. For reasons of cost and to shorten product delivery lead time it is recommended consideration is given to electroless/immersion silver (IAG) and electrolytic nickel – immersion gold (ENIG).
- Solder mask. There exist many different types of solder mask and each of Cambridge Nanotherm's manufacturing partners have their own preferences and supply chain. Typically, the solder mask will be 20um thick, but some variation is possible. Unfortunately, solder masks that exhibit high reflectivity at short wavelengths (UV-A to UV-C) are not yet commercially available.
- Ident / Legend / Silk screen marking. This layer, which has multiple names, is essentially any "writing" on the board. On white solder mask the legend is usually black, but yellow is also available.

Each of these five layers is subject to a set of design guidelines, an explanation of which is set out in the following section.

Double-sided circuits are linked by vias. These pass vertically through the aluminium core and are insulated from it by a sleeve of nanograin alumina. The via diameter is linked to the substrate thickness, copper thickness and hence the minimum gap in the tracking. Typically, it will be around 70-100um diameter in a 0.5mm thick substrate, having 60um copper applied with 100um minimum gap.

4. Nanotherm DM design guidelines

Manufacture of a thermally conductive thin-film substrate is subject to design rules. Owing to the interdependencies between the various layers and manufacturing processes the complete design rule documentation is substantial and complex. To aid customers, a simplified version is set out below. If the proposed design meets all guidelines, generally there will not be a problem with manufacture. The guidelines are specifically called guidelines rather than rules because infringement does not necessarily mean the design is not manufacturable. Cambridge Nanotherm uses a network of worldwide manufacturing partners, each of whom has different capabilities. The table below is an amalgamation of the worst case for every parameter from all partners, so is very conservative. In instance that a proposed design does not meet the guidelines, Cambridge Nanotherm can review and can comment on aspects like selection of manufacturing partner, product volume, lead time, cost, yield risk etc. that may permit production without undue changes.

Ref.	Property / Material	Parameter	Guidelines
1	Sidedness	Circuit layout	Single-sided Dual sided Double-sided (electrical connection between circuits by vias)
2	Electrical	Withstand	100V DC*
3	Aluminium alloy	Area	97.2 x 97.2 mm (standard) 115.0 x 165.8 mm
		Thickness	0.3-2.0mm, 0.5 mm (standard), 1.0 mm and 1.5 mm
		Alloy	1050, 6061 (standard), 6082
		Warp (bow and twist)	0.50% L
		Underside finish	Brushed (single-sided substrates)
4	**Copper tracking**	Thickness	17-150 um (1/2-4 oz) 35 um +/-10% (1 oz), standard
		Track width and gap (space between tracks)	ENEPIG finish, larger of 150 um and 2.2x copper thickness All other finishes, larger of 75 um and 1.6x copper thickness **ADVANCED:** **100 um for ENEPIG finish,** **50 um for all others**
		Track aperture (e.g. Swiss flag)	125 um (1 oz copper) 150 um (2 oz copper) 175 um (4 oz copper)
		Annular ring	Larger of track width and 75 um
		Finish	E-NiAg (electrolytic nickel-silver), typ. 5+/- 2.5 um Ni, 3 +/- 1 um Ag E-NiAu (electrolytic nickel-gold), typ. 5 +/- 2.5 um Ni, 0.5 +/-0.125 um Au E-NiPDAu (electrolytic nickel-palladium-gold), typ. 5 +/-2.5 um Ni, 0.1 +/-0.05 um Pd, 0.1 +/- 0.05 um Au ENIG (electroless nickel-gold), typ. 5 +/- 2.5 um Ni, 0.5 +/- 0.0125 um Au ENEPIG (electroless nickel-palladium-gold), typ. 5 +/- 2.5 um Ni, 0.1 +/- 0.05 um Pd, 0.1 +/- 0.05 um Au) IAG (immersion/electroless silver), typ. > 0.3um Ag
		Surface roughness	Burnished Ra 0.7 um, Rz 10 um Polished Ra 0.5 um, Rz 4.5 um (compatible with most wire bonding processes) Fine polished Ra 0.4 um, Rz 4 um
		Cut-back from routed/v-score edge or mechanical feature	250 um plus tolerance of edge/feature formation process

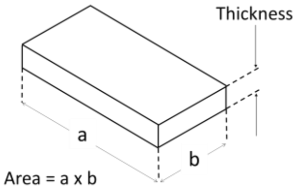
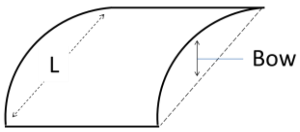
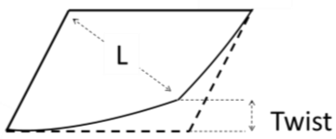
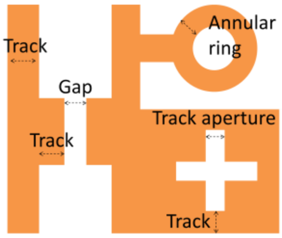
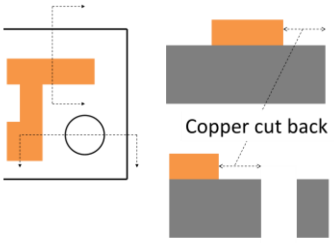
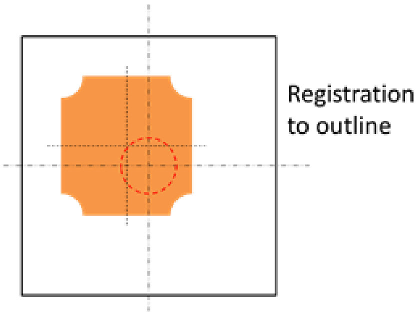
		Mechanical registration to outline	+/- 25 um
		Minimum character height for etched nomenclature	1 mm
5	Solder mask	Type	LEW-3
		Colour	White
		Thickness	20 um +/- 5 um permissible range 10-50 um
		Line width	100 um
		Cut back from routed/v-score edge or mechanical feature	100 um plus tolerance of edge/feature formation process
		Relief to copper	50 um
		Solder mask overlap on copper pad	100 um
		Aperture opening	200 um
		Character height / line width in solder mask	500/200 um
6	Ident / legend / silkscreen	Colour	Black, yellow
		Line width	150 um
		Alphanumeric character	Width 150 um Kerning 150 um Height 1.5 mm
		Cut back from pad, edge or mechanical feature	200 um
		Ident on pad	Not permitted
7	Laser marking	Alphanumeric character on dielectric	Height 80-90 umm Width 22-25 um mm Kerning 135-140 um
		Alphanumeric character on copper	Height 84-121 um Width 38-77 um Kerning 140-210 um
		2D bar code, on dielectric or copper	50um dot, 0.5 x 0.5 mm to 0.6 x 1.3 mm, alphanumeric capacity 3 – 32 characters
		Cut back from pad, edge or mechanical feature	200 um
		Date / lot	To circuit level
8	Holes: Mechanically drilled	Diameter	200 um in <0.5 mm aluminium 400 um in 1 mm aluminium
		Tolerance	+/- 100 um
		Registration to copper	+/- 100 um
		Tenting	<2.5 mm 750 um copper cut-back required for tents
9	Holes/slots: Laser drilled	Diameter	70 um entry, 60 um exit
		Tolerance	+/- 15um
		Registration to copper	+/- 20um
		Spacing	200 um

10	Slots: Routed	Substrate thickness	>1.0 mm
		Trench width	2.0 mm
		Internal radius	0.8 mm
		Registration to copper	+/- 150um
		Tenting	<2.5 mm 750 um copper cut-back required for tents
11	V-score	Substrate thickness	>1.0 mm
		Substrate dimension	> 150 x 200 mm
		V-cut angle	30°
		Web thickness	200 um +/- 100 um (1.0 mm aluminium) 300 um +/- 100 um (1.5 mm aluminium)
		Copper cut back from centre line	500 um
		Solder mask cut back from centre line	300 um
		Registration to circuit	+/- 250 um
		Registration score-to-score	+/- 150 um
12	Dicing	Substrate thickness	< 1.0 mm
		Substrate dimensions	105 x 105 mm
		Copper cut-back	300 um
		Solder mask cut back	250 um
		Street width	200 um
		Street spacing	600 um
		U-channel web 150 um in 0.5 mm aluminium	200 um in 1.0 mm aluminium
13	Inspection	Visual	IPC-A-600H Class2 and/or AABUS criteria
		Electrical	Open / short, withstand. Minimum pad dimension for probing 250x250um
		Mechanical precision	ISO 2768 fine, med (standard), coarse
		Burrs	ISO 13715
		Cross-out rate	% or number required
14	Quality control	First article inspection report	Provided with first sample of each part number
		Customer IQC	Product specification (necessary to fix Nanotherm OQC criteria)
		8D investigation report	Provided where non-conformance to customer IQC or field returns are received
15	Drawings	File format	DXF or DWG. Drawings must include model reference and layered structure for each material (outline, copper, solder mask, vias, drill locations etc). Use 0.00 line widths for all features. Flatten drawings to remove historical layers.

** Substrate insulation capability is higher, but OQC test is limited by voltage of end-of line open/short electrical equipment. Result reported as equivalent resistance for 100V applied.*

** Gerber drawings are required to manufacture. They should be inside a .rar or.zip archive with standard file extensions:

Extension	Layer
pcbname.GTL	Top copper
pcbname.GTS	Top solder mask
pcbname.GTO	Top silkscreen / ident
pcbname.GBL	Bottom copper
pcbname.GBS	Bottom solder mask
pcbname.GBO	Bottom silkscreen / ident
pcbname.TXT	Hole and slot location and dimensions
pcbname.GML/GKO	Board outline

Ref.	Design guideline
3	  
4	 
	 

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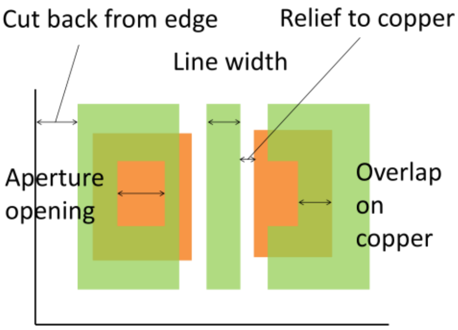
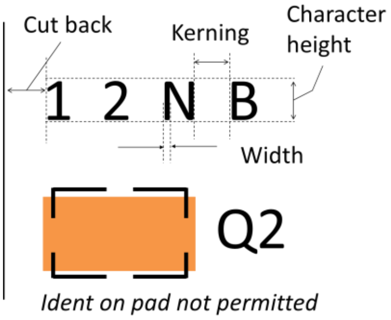
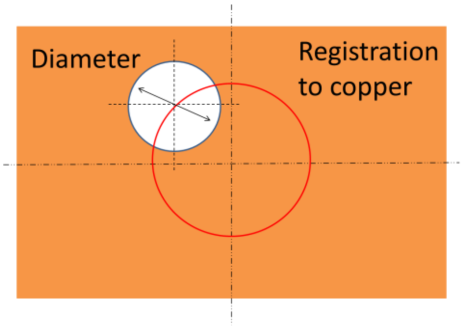
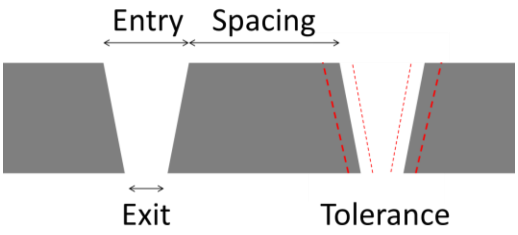
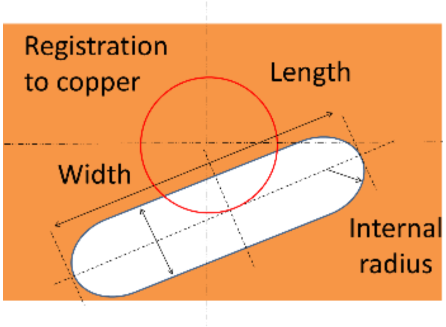
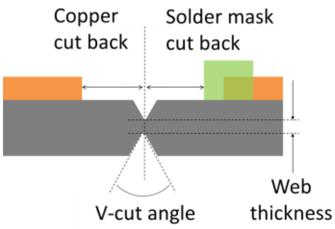
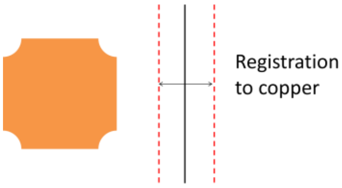
<tr><td>5</td><td colspan="3">Cut back from edge
Relief to copper
Line width
Aperture opening
Overlap on copper</td></tr>
<tr><td>6,7</td><td colspan="3">Cut back
Kerning
Character height
1 2 N B
Width
Q2
Ident on pad not permitted</td></tr>
<tr><td>8,9</td><td>Diameter
Registration to copper</td><td colspan="2">Entry
Spacing
Exit
Tolerance</td></tr>
<tr><td>10</td><td colspan="3">Registration to copper
Length
Width
Internal radius</td></tr>
<tr><td>11</td><td>Copper cut back
Solder mask cut back
Web thickness
V-cut angle</td><td>Registration to copper</td><td>Registration score-to-score</td></tr>
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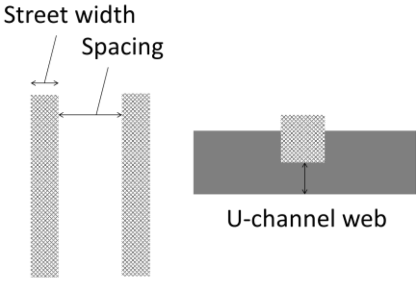
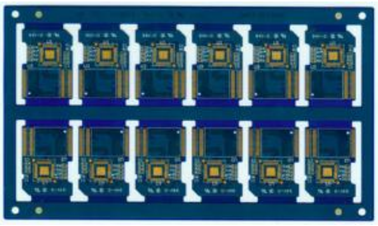
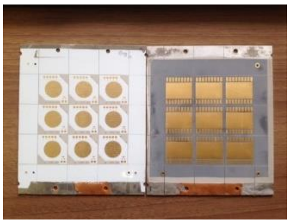
12	

5. Circuits, customer units and panels

The industry uses specific nomenclature to differentiate how the product is delivered to the customer:

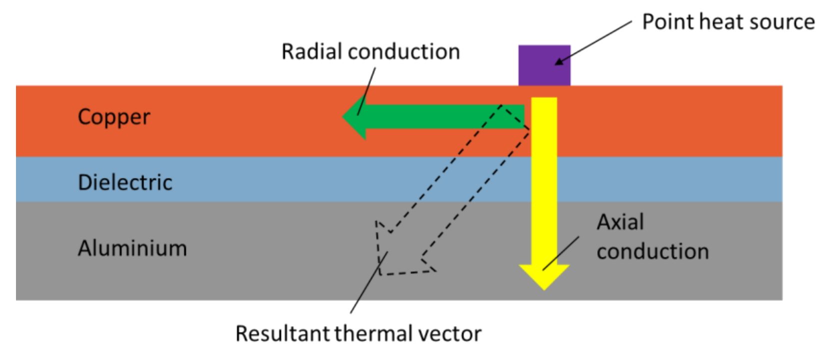
- Circuit. A collection of tracks with a defined boarder, i.e. one functional unit. No further sub-division is undertaken for incorporation in a product.
- Customer unit. This is the form the circuit is delivered to the customer. It may be a single circuit or array of circuits or an entire panel. Where the customer unit is an array of circuits these are often provided with a frame that has tooling holes and fiducials to aid placement of the components.
- Tile or panel. Full-area substrate processed by Cambridge Nanotherm and it’s MCPCB manufacturing partners. For efficiency and economy, the challenge is always to fit as many customer units as possible on a panel.

		
Circuit – can vary in dimensions from a few mm per side to over 400mm.	Customer unit, containing 12 circuits within a frame that has tooling holes and alignment fiducials.	Processed tile, carrying one customer units, each of which contains nine circuits.

6. Principles of thermal design

The purpose of using a thin film, thermally-conductive substrate in place of a conventional PCB is to remove heat efficiently from electronic components. This means the board layout not only has to provide an electrical function but a thermal one.

Heat transport though a thin film, thermally-conductive substrate is a combination of radial spreading in the copper tracking and axial conduction through the copper, dielectric and aluminium to the heat sink. The resultant thermal vector is a combination of these two pathways.



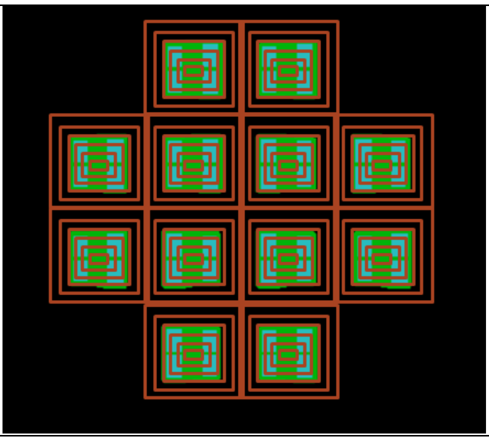
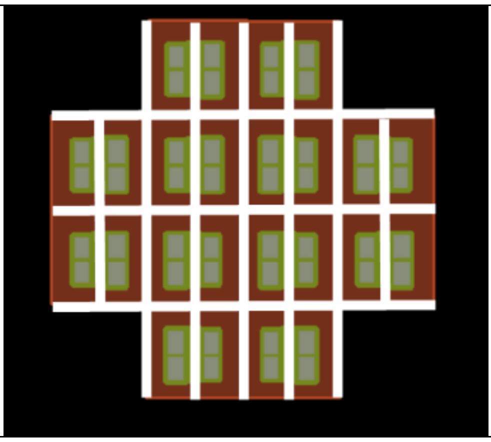
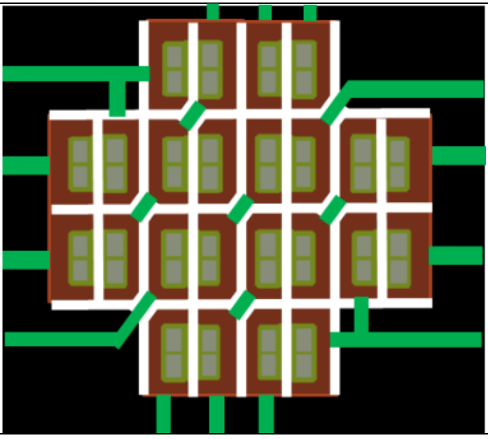
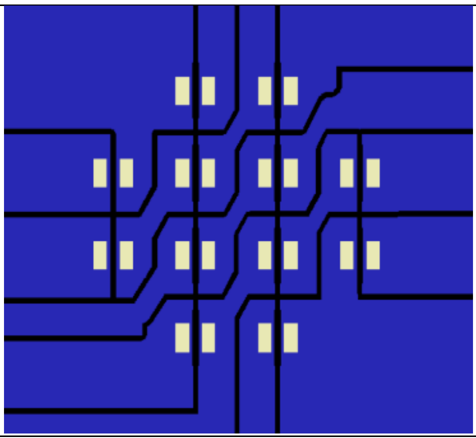
Heat transport pathways in a thin film, thermally-conductive substrate

As can be seen from the above diagram, a large area of thick copper will be beneficial in extracting heat. But there are good technical and commercial reasons why thick copper is should be avoided. In particular, thick copper:

- Cannot be patterned into fine tracks and narrow gaps, necessary for many components (see Design Guidelines, above)
- Increases cost and weight of the MCPCB
- Provides only marginal benefit to the thermal performance and can actually increase the thermal resistance if the area is too small since the heat has to travel through the copper to reach the heat sink
- Often increases the delivery lead time and can hurt yield due to the extra handling and processing involved.
- Is harmful to the environment due to increased chemical and electricity consumption

There are very occasional instances where thick copper is necessary due to the electrical current the tracking must carry. Due to the superior thermal performance of MCPCBs this is seldom a consideration, as explained in the next section. For the vast majority of applications that use Nanotherm DM, 35um (1oz) copper is a good choice.

A common requirement is for a thin film, thermally-conductive substrate to provide cooling to an array of components. In this instance there is a conflict between the layout for electrical function and the copper area required to remove heat effectively. A simple thermal design methodology is to proceed as follows:

	
1) From the centre of each component draw concentric rectangles until adjacent rectangles adjoin	2) Divide copper into islands having the narrowest possible gap, as per Design Guidelines
	
3) Join islands with narrowest possible tracks to form wiring trace and trim corners of copper islands to fit diagonal connections	4) Example design

7. Current carrying ability

The high thermal conductivity of Nanotherm Nanotherm DM thin film, thermall-conductive subatrates means the copper wiring trace can safely carry high currents without fusing. A convenient means of determining the minimum track dimensions for a given current is to use a calculator for FR4 (following specification IPC-2221), based on a 20°C temperature rise and multiply the result x50.

For the track width of 100um in 35um thick copper on Nanotherm DM, the safe current carrying ability is 325A.

8. Conclusions

Nanotherm DM is a robust metal-based thin film, thermally conductive substrate. It possesses exceptional through-thickness thermal conductivity on account of the unique Nanoceramic material used for the dielectric and the thinness of that layer. The thin film copper pattern, other layers and process steps are near-identical to those applied to AlN and alumina substrates, resulting in the design guidelines being closely similar to any other volume manufacturer for this type of product. Cambridge Nanotherm can provide electrical and thermal evaluation of a proposed design and, where appropriate, suggest modifications for optimum performance.