NANOTHERM®

Application Note

Nanotherm FL

Formable, thermally conductive dielectric substrates

Available only as R&D / engineering samples

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Contents

1. Introduction

The formability of materials depends on the inherent plasticity of the material and the nature of the forming process. For many materials, elevated temperature greatly increases the plasticity so is a key component of any forming process. Iron and steel are strong and stiff at room temperature, but soft and malleable when red hot. Wood does not change plasticity with temperature, but the addition of steam makes it sufficiently pliable to forced into a new permanent shape. Ceramics, like rock, have no plasticity when solid outside of geological timescales, so must be fabricated in net shape form.

The entire manufacturing infrastructure of the electronics industry is predicated on processing of flat substrates. Printed circuits are made as flat panels, the components are attached to the planar surfaces and the resulting boards are installed in box-like housings with perpendicular surfaces. While this works well for many applications there are instances where it is desirable for the electronics to adopt a more convoluted shape. A prime example is LED lights, where a non-planar substrate can enhance the optical efficiency by directing the light from individual LED die in the direction where it is most needed.

	
Conventional, planar, circuit board of an LED light	3D circuit board of an LED light, manufactured as a planar part then formed into shape

Thermo-electric devices and in particular thermo-electric generators (TEG) used in energy scavenging applications, provide another example of electronic components where non-planar substrates can provide significant benefits. Small TEGs are of great interest as the primary energy source for many Internet of Things (IOT) devices. The heat source is seldom a convenient flat surface, it might even be human skin. While it remains convenient to manufacture TEGs as planar components they must be deformable to a shape that is unpredictable and can vary widely with the end disposition of the device.

Formability is not the only attribute required of an electronic component substrate. In addition, it must provide the original functions of an electrically conductive track network, a dielectric underlay so the tracks doe not short to the substrate and, in the case of TEGs and LEDs, good through-thickness thermal conductivity so heat can easily get into or be removed from the semiconductor.

2. Formable electronic substrates

Commercially available, formable, electronic component substrates are based on polymeric materials and in particular polyimide. Known colloquially as “flexible circuits” they possess all the desired attributes except for thermal conductivity. Polyimide has extremely low thermal conductivity, around 0.1W/mK, so that even when used in thin layers it presents a very significant barrier to the transport of heat. This makes it untenable as a substrate for applications that entail thermal management, exemplified by components such as TEGs and LEDs.

Flexible circuit board having a polyimide substrate

3. Thermally conductive dielectrics

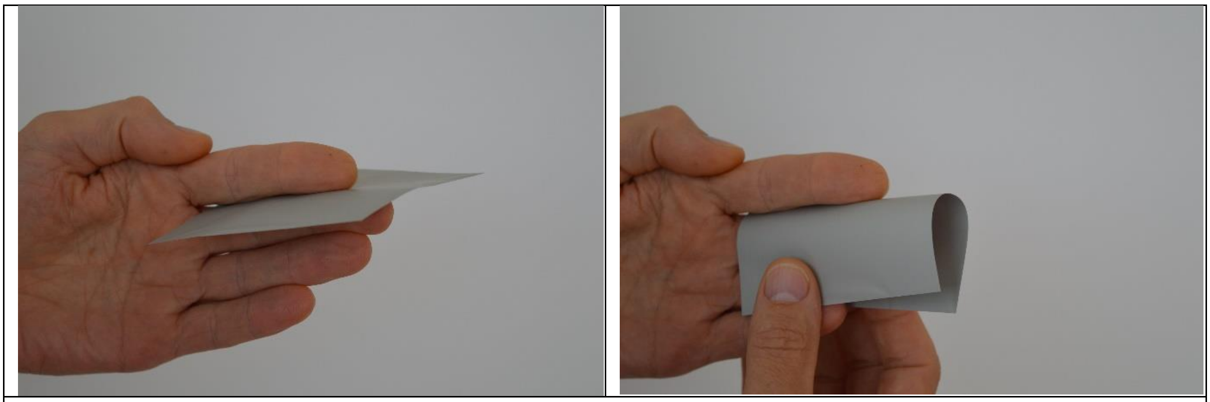
Aluminium is a metal and therefore an excellent thermal conductor. As a thin foil it is also extremely formable, as attested by its widespread use in cooking as a temporary cover over awkwardly shaped foods and containers. Because aluminium is an electrical conductor deployment as an electronic component substrate requires a dielectric between it and the copper tracks to prevent shorts. As the purpose of using a formable metal substrate is efficacy of heat transfer, it beholds the dielectric needs to be as thermally conductive as possible.

Polymers are electrical insulators but possess poor thermal conductivity. This may be rectified to some extent by incorporating thermally conductive particles or fibres. Unfortunately, there is a limit to the loading of second phase material that can be achieved without compromising other properties like adhesive strength and formability.

Certain technical ceramics, such as alumina and aluminium nitride are excellent dielectrics and thermal conductors. But they are expensive due to the high energy content associated with manufacture. Furthermore, they have essentially zero plasticity, made worse by the low fracture toughness (i.e. brittleness) of such materials. This means they have no formability so cannot be considered for any application where this is a requirement.

4. Nanoceramic-coated aluminium foil

Cambridge Nanotherm has developed a process to provide aluminium foil with a tough, flexible, electrically insulative and thermally conductive skin of nano grain size alumina. The layer is ultra-thin (typically 5-25um) because the dielectric strength is circa 20-40V/um. Keeping the dielectric layer thin confers excellent thermal performance since the thermal impedance of a layer is its thickness divided by the thermal conductivity (7W/mK for alumina in nanograin form). The nanograin size (30-60nm) also bestows the ceramic with some plasticity. Modulus measured by nanoindentation is 210GPa, but with 20-25% elastic recovery. This characteristic, when combined with the layer thinness means the dielectric is formable. Nanoceramic-coated aluminium foil can be bent around an 8mm diameter former without fracture.

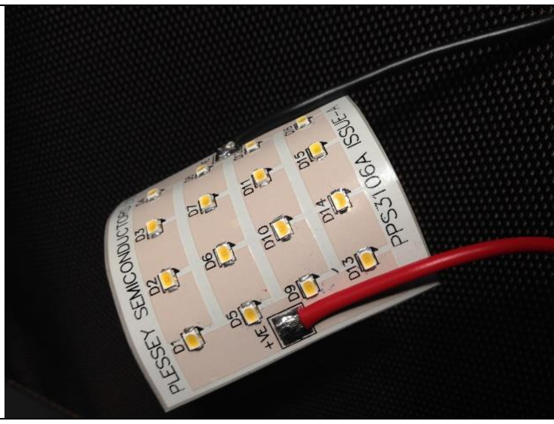


Nanoceramic-coated aluminium foil, demonstrating the mechanical formability of the dielectric

Nanograin alumina is manufactured in an electrochemical cell, where the surface of the aluminium foil is converted to alumina. Because the dielectric is created by conversion of the surface of the aluminium component, it is perfectly adhered to it and this interface presents virtually no thermal impediment to the passage of heat.

The thermal resistance of a nanoceramic dielectric of typical thickness will be less than 0.003°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.

A copper foil can be adhered to the surface of the nanoceramic. Using conventional additive and subtractive processing a thin, formable, thermally conductive substrate for electronic components is manufactured.



Thermally conductive substrate for LEDs, manufactured in planar form then formed into the final functional shape

5. Nanotherm FL design guidelines

Nanotherm FL is currently only available as R&D / engineering samples. These are manufactured by hand, without benefit of an established supply chain. Cambridge Nanotherm is interested in discussing making product commercially available, including roll-to-roll manufacture.

Production of formable electronic component substrates is subject to design rules. Because Nanotherm FL is not yet released as a product neither have the limits of the technology been rigorously investigated nor the interdependencies between the materials and the manufacturing processes. Thus, the simplified design guidelines set out below may not be achievable in their entirety. Likewise, while Cambridge Nanotherm has some reliability and performance date available, the dataset is incomplete and further work is required before any guarantees of performance or lifetime can be provided. To-date the Nanotherm FL has passed lead-free solder reflow (UL746), thermal cycle (-20°C / +150°C) and HAST (JESD22-A110) conducted by an independent organisation.

Formable, thermally conductive dielectric foil:

Property / Material	**Parameter**	**Guidelines**
Aluminium alloy	Alloy type	1XXX series e.g. 1050
Component dimension	Length	300 mm
	Width	300 mm
	Thickness	50 - 300 um
Dielectric thickness	Planar exterior surfaces	5 - 25 um
Masked areas	Uncoated	Requires jig with water-tight mechanical seals
Surface sealing (optional)	Epoxy, polyimide	Enhances electric insulation and decouples properties from influence of ambient humidity

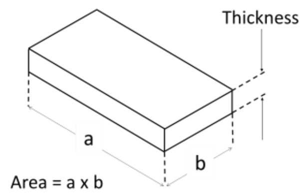
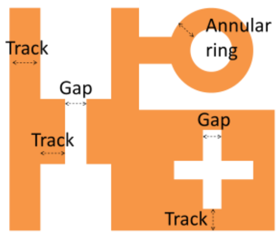
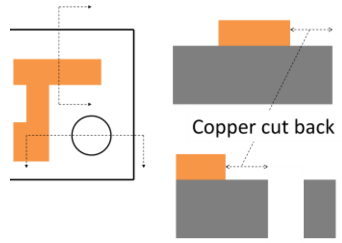
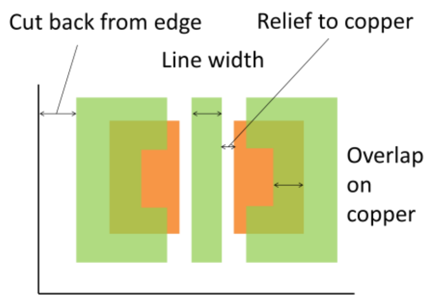
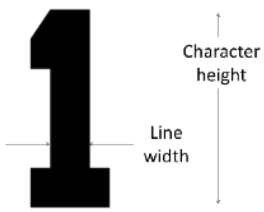
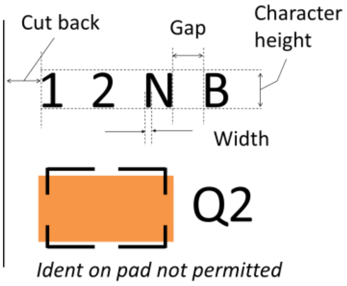
Formable, thermally conductive, dielectric substrates:

Ref.	**Property / Material**	**Parameter**	**Guideline**
1	Sidedness	Circuit layout	Single-sided & dual-sided
2	Electrical	Withstand	25-100V (depends on base alloy and dielectric thickness)
4	Copper tracking	Thickness	35 um (1 oz)
		Track width	150 um
		Gap (space) between tracks	150 um
		Annular ring diameter	300 um
		Finish	Organic solderability preservative OSP, ENIG (typ. 3 um Ni, 0.1 um Au) Immersion silver IAG (typ. 0.15 um)
		Cut-back from edge	500 um
5	Solder mask	Type	EMP110
		Colour	White, green
		Thickness	10-20 um
		Line width	100 um
		Relief to copper	150 um
		Solder mask overlap on copper pad (optional)	250 um
		Cut back from edge	500 um
		Character height / line width in solder mask	500/200 um
6	Ident / legend / silkscreen	Colour	Black, yellow, white
		Width	150 um
		Gap	150 um
		Character height	1.5 mm
		Cut back from pad or, edge	500 um
		Ident on pad	Not permitted
7	Marking	Makers	Yes
		Date / lot	To panel level
8	Singulation	Tool choice	Scissors, guillotine, knife
9	Inspection	Visual	IPC-A-600H Class3
		Electrical	Open / short, withstand
		Mechanical precision	ISO 2768 coarse
10	Drawings	File format	Gerber* of circuit and customer unit where panel perimeter contains features defined by the customer.

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

Ref.	Design guideline	
3		
4		
5		
6		

6. Conclusions

Nanotherm FL is a thin, formable, thermally conductive substrate for electronic components. The dielectric is nanograin alumina, formed by conversion of aluminium foil in an electrochemical cell. The formability arises from a combination of the thinness of the aluminium and the unique nature of the nanoceramic material. By adhering a copper foil to the surface and using standard PCB fabrication processes, a formable yet thermally conductive substrate for electronic components can be realised.