A successful LED design needs a balance of form and function to be a desirable luminaire with the right lumen output. Sounds simple enough, but these two requirements are often in conflict. When form trumps function, LEDs that are usually mounted onto a metal-clad PCB (MCPCB) as a module are all too often crammed together, creating a module with high-power density. If the device has not been designed to remove the heat from the LEDs effectively, there is a real risk of the LED overheating. As with any semiconductor, when LEDs overheat efficiency is reduced, light quality deteriorates, lifespan shortens and ultimately the LED can catastrophically fail.

Even with extreme high power density designs, this can be avoided by having a basic understanding of thermal design. However, it can be difficult to unravel the claims made by thermal management suppliers regarding how their materials perform. This can lead poor choices, and in a worst-case scenario overheating or failing, LEDs.

Three critical factors to consider when looking at the thermal performance are conductivity, interface resistance and impedance, which combine to give the total thermal resistance of the design.

**Thermal conductivity**

Thermal conductivity is a simple constant that describes how well a particular material transfers heat by conduction. However, the thermal conductivity figures given by manufacturers cannot always be taken at face value. While there are plenty of known and standardized methods for testing thermal conductivity, based on the number of heterogeneous materials, the result can vary widely depending on the testing method employed. And, as you might expect, manufacturers often pick the test value that returns the most favourable result. Datasheet values describing thermal conductivity should therefore be treated with caution, especially when using them as input for wider thermal models.

**Thermal resistance and the importance of the z-axis**

Thermal resistance (the measurement of the temperature difference by which a given material resists a heat flow) is a highly useful measure as it draws in the z-axis (thickness) of the material in question; a critical real-world consideration.

\[
\text{Layer thickness} + \text{thermal conductivity} = \text{thermal resistance}
\]

Reduction in the thickness of a material can have a dramatic effect on the level of thermal resistance. As a variable, it is easier to reduce the z-axis by an order of magnitude (thus dramatically...
reducing thermal resistance and improving thermal performance) than it is to find an alternative material with dramatically better thermal conductivity within an appropriate price bracket.

**Interface resistance**

Also massively important is interface resistance, how much heat resists moving from one material to another. This is particularly important when you consider that some thermal management products, and all thermal stacks, involve multiple layers of connected materials.

Interface resistance is usually modelled as a *thermal resistance* with a z-axis value of zero (which is practically never true). The degree of interface resistance can also be affected by a bewildering variety of factors, including bow, porosity, temperature, pressure, warp, roughness, etc., and can be highly complex to compute. As such, often the only way to accurately measure interface resistance is with hands-on testing.

**Total thermal impedance and absolute thermal resistance**

By combining the thermal resistance of materials in a stack with their individual interface resistances, we get the total *thermal impedance* of the assembly, measured in °C.cm²/W. Unfortunately, this figure isn’t usually offered by manufacturers, so you’ll have to figure it out yourself through testing.

This gives you what you need to deduce the absolute thermal resistance of your design.

\[
\text{Thickness ÷ thermal conductivity x area} = \text{absolute thermal resistance (units °C/W)}
\]

[Where thermal conductivity is aggregated to include interface resistances]

This measurement of *absolute thermal resistance* will finally allow you to determine whether the temperature of your LED design can be kept within safe limits (though when applying this to the real world bear in mind that the ambient temperature outside the heat sink could be as much as 40°C or more).

Thermal resistance has no dimensions, so it *must* be communicated relative to either a component with known specs (e.g. a heat sink rated at 0.7°C/W), or a material of fixed dimensions (e.g. a 2mm thick round plate measuring 60mm²). If the dimensions are given alone it must also refer to the shape being described, as differing shapes will have very different lateral thermal gradients.

It’s worth bearing in mind that manufacturers sometimes list ‘absolute thermal resistance’ on spec sheets simply as ‘thermal resistance’. Be sure to look at the *specific units* listed on the spec sheet in order to know which one you’re dealing with.

**Leveraging the primacy of the z-axis for a new approach to thermal management**

Bearing in mind the disproportionate impact of the z-axis on reducing thermal resistance, one solution has taken this consideration to its logical conclusion by reducing the z-axis to tens of microns. This process involves the application of a patented electrochemical process to convert the surface of an aluminum sheet to a nanoceramic dielectric layer measuring as little as 10–30 µm (depending on breakdown voltage requirements). The nanoceramic is formed of nanoscale crystals measuring as little as 20nm which form an atomic level bond with the aluminium. This ensures perfect contact between the materials and minimises interface resistance.
Such an approach means that although the nanoceramic has a relatively poor thermal conductivity, its thinness means an absolute thermal resistance of around 0.035°C.cm²/W (compared to aluminum nitride which has an absolute thermal resistance between 0.071 to 0.028°C.cm²/W based on purity). This nanoceramic approach also brings other benefits — as it’s mostly composed of aluminum it’s incredibly robust and can be made in large tiles improving yields and helping to drive economies of scale.

Fundamentally a good understanding of the measurements involved in LED thermal management (and knowing some of the pratfalls involved) is critical. It can make the difference between a differentiated design that saves money and one that will either be uncompetitive or, in some cases, literally burn itself out.

Also see:

- Extend the life of LED lighting systems with thermal management
- Hot tips on thermal management for LED lighting
- Cooling high-power LEDs: The four myths about active vs. passive methods