Extending the life of LEDs – Part 1:

Improving the efficiency and lifetime of LEDs via effective thermal management

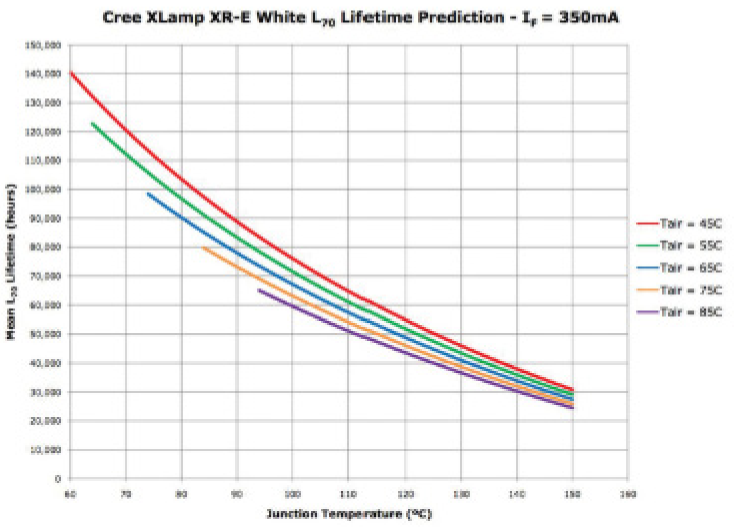
The LED industry is one of the fastest growing markets; despite LEDs being present in many electronic devices for a number of years, more recent developments in this industry have lead to their vast array of use in all types of lighting, signage and domestic appliance products, to name but a few. In offering alternatives to halogen, incandescent and fluorescent lighting systems for both interior and exterior applications, the growth of the LED lighting market alone is expected to grow into a $70 billion industry by 2020; a growth from 18% market share to 70% market share in just over 5 years. (Forbes) The growth is attributed to the advantages LEDs offer over traditional lighting forms in terms of adaptability, lifetime and efficiency; they allow more design freedom, offer an exceptionally long life time and they are also considerably more efficient, converting the majority of energy to light and thus minimising the heat given off.

Although LEDs are considerably more efficient than traditional lighting forms, they do still produce some heat. This heat can have an adverse effect on the LED and therefore must be managed to ensure the true benefits of this technology are realised. Typically categorised by colour temperature, LEDs are available in a huge number of colour variants. With a change in operating temperature of the LED, a change will also occur to the colour temperature; for example, with white light an increase in temperature could lead to a 'warmer' colour being emitted from the LED. In addition, if a variance in die temperatures is present across LEDs in the same array, a range of colour temperatures may be emitted, thus affecting the quality and cosmetic appearance of the device.

Temperature	Luminous Flux (lm)	Voltage (V)	Efficacy (lm/V)
25°C	196.1	3.237	86.5
60°C	182.2	3.149	82.7
85°C	172.3	3.087	79.7

Comparison of LED Performance at Various Temperatures
Source: CREE- Thermal Management of Cree®XLamp®LEDs

As shown in the table above, maintaining the correct die temperature of the LED can not only extend the life but also lead to more light being produced and therefore, fewer LEDs may be required to achieve the desired effect. Therefore, an increase in operating temperature can have a recoverable effect on the properties of the LED, however if excessive junction temperatures are reached, particularly above the maximum operating temperature of the LED (~120-150˚C), a non-recoverable effect could occur, leading to complete failure. Operating temperature is a directly related to the lifetime of the LED; the higher the temperature, the shorter the LED life as shown here in the Cree XLamp lifetime graph. This is also true for the LED drivers where the lifetime of the driver can be derived from the lifetime of the electrolytic capacitor and by calculation it can be determined that for every 10º C drop in the operating temperature the lifetime of the capacitor is doubled. (Philips)Ensuring efficient thermal management is employed will therefore provide consistent quality, appearance and lifetime of LED arrays and in turn, opens up the opportunity for further applications for this ever evolving industry.



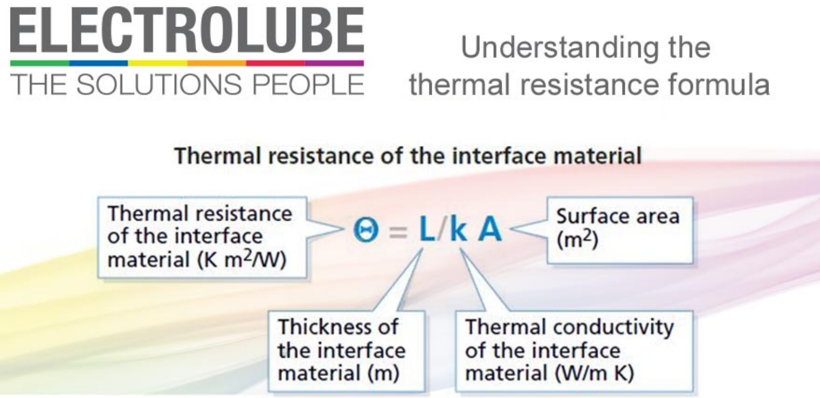
Source: CREE- Thermal Management of Cree®XLamp®LEDs

There are many ways to improve upon the thermal management of LED products and therefore, the correct type of thermally conductive material must be chosen in order to ensure the desired results for heat dissipation are achieved. Products range from thermally conductive encapsulation resins, offering both heat dissipation and environmental protection, to thermal interface materials used to improve the efficiency of heat conduction at the LED junction. Such compounds are designed to fill the gap between the device and the heat sink and thus reduce the thermal resistance at the boundary between the two. This leads to faster heat loss and a lower operating temperature for the device. Curing products can also be used as bonding materials; examples include silicone RTVs or epoxy compounds – the choice will often depend on the bond strength or operating temperature range required.

Another option for managing the transfer of heat away from electronic devices is to utilise a thermally conductive encapsulation resin. These products are designed to offer protection of the unit from environmental attack whilst also allowing heat generated within the device to be dissipated to its surroundings. In this case, the encapsulation resin becomes the heat sink and conducts thermal energy away from the device. Such products can be used to encapsulate the technology behind and attached to the LED device and can also assist with the reflection of light back from within the unit, depending on the colour chosen. Encapsulation resins also incorporate the use of thermally conductive fillers however the base resin, hardener and other additives used can be altered to provide a wide range of options, including epoxy, polyurethane and silicone chemistries.

The different chemistry options will provide a range of properties and each should be considered depending on the end application requirements. For example, a polyurethane material offers excellent flexibility, particularly at low temperatures, a major advantage over an epoxy system. A silicone resin can also match this flexibility at low temperatures as well as offering superior high temperature performance, well in excess of the other chemistries available. The silicone products are also typically more expensive. Epoxy systems are very tough and offer excellent protection in a variety of harsh environments. They are rigid materials with low coefficients of thermal expansion and in some cases, a degree of flexibility can be formulated into the product. The formulation of encapsulation resins can lead to a vast array of products with tailored properties for individual applications and therefore it is advised that applications are discussed in detail with a relevant material supplier.

Regardless of the type of thermal management product chosen, there are a number of key properties that must also be considered. These can be quite simple parameters, such as the operating temperatures of the device, the electrical requirements or any processing constraints - viscosity, cure time, etc. Other parameters are more critical to the device and a value alone may not be sufficient to specify the correct product. Thermal conductivity is a primary example of this. Measured in W/m K, thermal conductivity represents a materials' ability to conduct heat. Bulk thermal conductivity values, found on most product datasheets, give a good indication of the level of heat transfer expected, allowing for comparison between different materials. Relying on bulk thermal conductivity values alone will not necessarily result in the most efficient heat transfer, however.



Thermal resistance, measured in K m^2/W, is the reciprocal of thermal conductivity. It takes into account the interfacial thickness and although it is dependent on the contact surfaces and pressures applied, some general rules can be followed to ensure thermal resistance values are kept to a minimum and thus maximising the efficiency of heat transfer. For example, a metal heat sink will have a significantly higher thermal conductivity than a heat transfer compound used at the interface and therefore it is important that only a thin layer of this compound is used; increasing thickness will only increase the thermal resistance in this case. Using the formula given above, some basic calculations can provide some examples of the differences in thermal resistance likely to be seen between a thermal paste applied at 50μm and a thermal pad that is 0.5mm thick. Therefore, lower interfacial thicknesses and higher thermal conductivities give the greatest improvement in heat transfer.

There is however, a concern with using bulk thermal conductivity values alone or comparing thermal resistance values given on the product datasheets. Significant variations in thermal conductivity and thermal resistance values for the same product can be achieved by utilising different test methods or parameters. This can result in bulk thermal conductivity values that appear very high when quoted but in use have a dramatically reduced efficiency of heat dissipation. Some techniques only measure the sum of the materials' thermal resistance and the material/instrument contact resistance. Electrolube use a version of the heat-flow method that measures both of these values separately, giving a much more accurate bulk thermal conductivity measurement. The test for thermal resistance should ideally be carried out on the actual unit using the normal application, spacing and weight/pressure parameters or alternatively using a comparable method where the pressure is defined. However these tests may be conducted, it is essential that products are compared using the same method to obtain bulk conductivity and thermal resistance values and in all cases, the products should be tested in the final application for a true reflection of effective heat dissipation.

This leads us to another important factor in product selection, the application of thermal management materials. Whether it is an encapsulation compound or an interface material, any gaps in the thermally conductive medium will result in a reduction in the rate of heat dissipation. For thermally conductive encapsulation resins, the key to success is to ensure the resin can flow all around the unit, including into any small gaps. This helps to remove any air gaps and ensure there are no pockets of heat created throughout the unit. In order to achieve this, the resin will have to have the correct combination of thermal conductivity and viscosity; typically, as the thermal conductivity increases, the viscosity also increases. Electrolube offer specialist resins to help reduce viscosity for ease of application, whilst maintaining a high level of thermal conductivity for efficient heat dissipation.

For interface materials, the viscosity of a product or the minimum thickness possible for application will have a great effect on the thermal resistance and thus, a highly thermally conductive, high viscosity compound that cannot be evenly spread onto the surface, may have a higher thermal resistance and lower efficiency of heat dissipation when compared to a lower viscosity product with a lower bulk thermal conductivity value. It is essential that users address bulk thermal conductivity values, contact resistance, application thicknesses and processes in order to successfully achieve the optimum in heat transfer efficiency.

A practical example highlighting the requirement for such considerations is provided in the table below. It shows the potential differences in heat dissipation by measuring the temperature of a heat generating device in use. These results have been based on work completed by an end user, where all products were thermal interface materials, applied using the same method, at the same thickness.

PRODUCT#	BULK THERMAL CONDUCTIVITY (W/m K)	DEVICE TEMPERATURE (°C)	REDUCTION IN TEMPERATURE (°C)
No Interface	N/A	30	N/A
1	12.5	22	27%
2	1.0	24	20%
3	1.4	21	30%
4	4.0	23	23%

Comparison of effective heat dissipation using different thermal interface materials

It is clearly evident that a higher bulk thermal conductivity value, in this case 12.5 W/m K, does not necessarily result in more effective heat dissipation when compared to products with lower values, such as the above at 1.4 W/m K. The reason for this could be due to the processing method not being suitable for the product, for the product not being easy to apply or possibly the product was not designed for this particular application and thus is exhibiting a high thermal resistance when compared to the other products tested. Whatever the reason, it highlights the importance of product application as well as product selection and by finding the correct balance of both of these parameters the maximum efficiency of heat transfer can be achieved.

Looking back at the original data for LED performance vs. lifetime and using the above results as an example, a conclusion on the importance of the use and correct selection of thermal management materials can be drawn. Take product #2, this reduces the operating temperature by 20% in this application. If a similar percentage reduction was achieved for the LEDs discussed above it would result in increased efficacy through the reduction in operating temperature from 85ºC to 68ºC and similarly, an increased lifetime from 95,000 hours to 120,000 hours; a great improvement. However, when you compare this to product #4 a greater operating temperature reduction is achieved, resulting in an increase in efficacy >3% and an increased lifetime from 95,000 hours to 140, 000 hours. Therefore, by selecting the correct product and using the best process lifetime can be improved by a further 15-20% when using product #4 in place of product #2.

With such rapid advances in the electronics industry and more specifically, LED applications, it is imperative that materials technology is also addressed to meet the ever demanding requirements for heat dissipation. Electrolube have developed specific technologies to improve the ability to process thermal management compounds, easily and effectively. This has resulted in reduced viscosity compounds with higher bulk thermal conductivities and with these two properties combined these products provide maximum efficiency in heat dissipation by minimising thermal resistance. This technology has now also been transferred to encapsulation compounds, providing products with higher filler loadings and thus improved thermal conductivity combined with improved flow. In addition and discussed in Part 2 of this paper, Electrolube also manufacture a range of products other than thermal management materials. Such products include conformal coatings and encapsulation resins in optically clear formats for applications where protection of the entire LED is required, once again re-confirming the importance of continually developing formulated chemical products to meet the rapid and demanding requirements of this popular technology.

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Extending the life of leds part 2