Materials Engineering Key to Heat Transfer in LED Assembly

Figure 1. Clustering of LEDs mandates efficient transfer of heat to prevent possible failure of the LED assembly.

While LED modules can offer significant benefits over filament and fluorescent lighting, decreased brightness, changes in color, and shortened life can result, unless careful consideration is given to the selection and use of materials in dissipating the heat produced by the LEDs.

LEDs (light-emitting diodes) may seem “cool” – at least to the touch – but they all produce heat. This is a particular design concern for high-brightness diodes, especially in LED clusters (See Figure 1.), and when they are contained within an airtight enclosure. Design challenges also occur in mounting LEDs on circuit boards along with other heat-generating devices. In such a case, insufficient thermal transfer with regard to one or more devices can impact the performance of LEDs and other components on the board.

For most applications, the answer in terms of dissipating heat within an LED assembly involves the selection and use of thermally conductive and (usually) electrically insulating materials. The process is known as thermal management, which simply means sufficient transfer of the heat generated by the LEDs to ensure optimum performance over time. Typical end-use products include automotive headlights, street lights, traffic signals, etc., all of which have a critical purpose and mandate both maximum brightness and longest possible life.

As this white paper will demonstrate, a key contributor in the selection, configuration, and application of materials is the materials converter.

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What is an LED?

LED diodes consist of a die of semiconductor material impregnated, or doped, with impurities to form a p-n junction. (See Figure 2.) When the LED is switched on – in other words, when a forward bias is applied to the LED – current flows from the anode (“p” side) to the cathode (“n” side). At the junction, higher-energy electrons fill lower-energy “holes” in the atomic structure of the cathode material, due to the voltage difference across the electrodes.

The energy released by the electrons in filling the holes produces both light and heat. The light, in turn, is reflected upward by a cavity created for that purpose, while heat is transferred downward into the base of the LED and ultimately through a torturous path to where it can be dissipated into the atmosphere by convection, usually with use of a heat sink. (See Figure 3.)

The process of light emission is called electroluminescence, and the color of the light produced is determined by the energy gap of the semiconductor. Since a small change in voltage can cause a large change in the current, care must be taken to ensure both are within spec and are as constant as possible. Otherwise, the performance of the LED can become degraded over time, even to the point of failure.

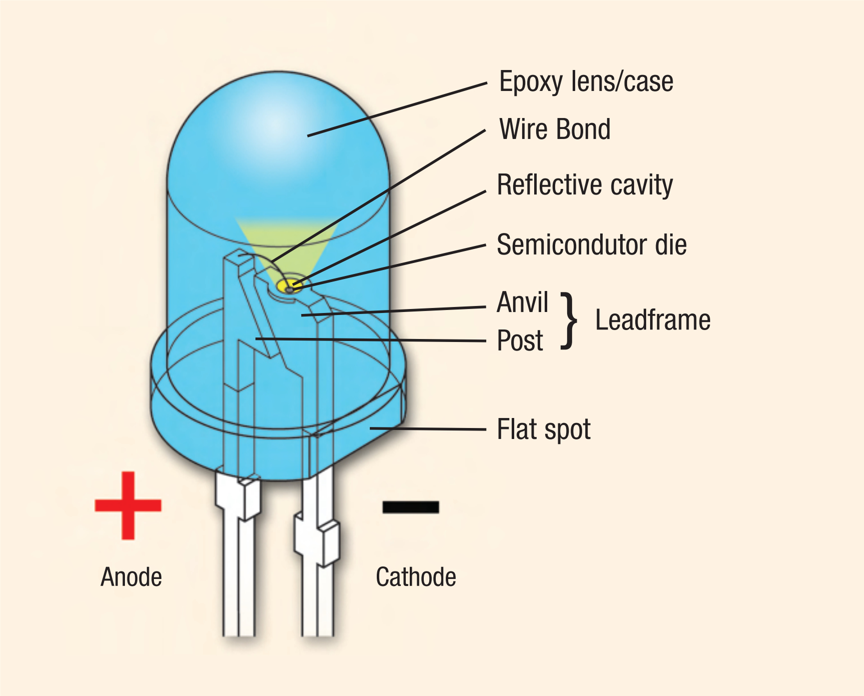

Figure 2. While the light produced by high-energy electrons is reflected upward from the cavity, the heat is conducted downward, the epoxy lens being a poor conductor.

Why use an LED?

LEDs provide distinct advantages over other sources of lighting such as incandescent lights. They offer exceptionally long life, lower energy consumption, smaller size, faster switching, greater durability, and increased reliability. LEDs are ideal for applications where it might be difficult to change an incandescent light.

They deliver a lot of light for a little power, with power levels increasing to 10 watts and up.

LEDs still cost more than incandescent lights, but are rapidly being deployed in applications in aerospace, military/defense, automotive, display technology, sensors, and communications, to name a few.

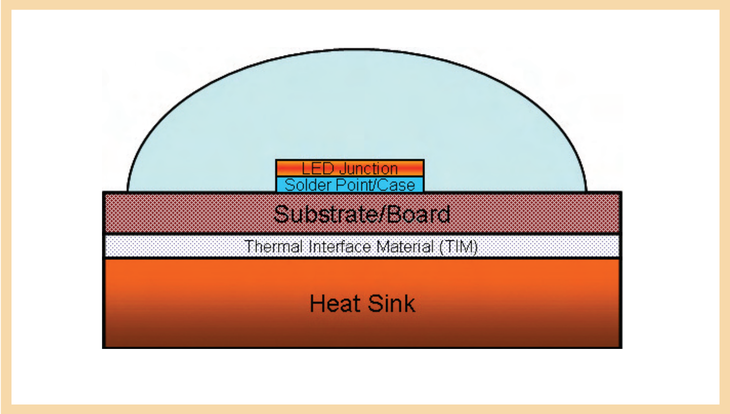

Figure 3. Heat is generated on the underside of the chip and travels through a metal block, known as a “slug”(not shown), to solder points on the circuit board, and eventually to a heat sink where it is dissipated.

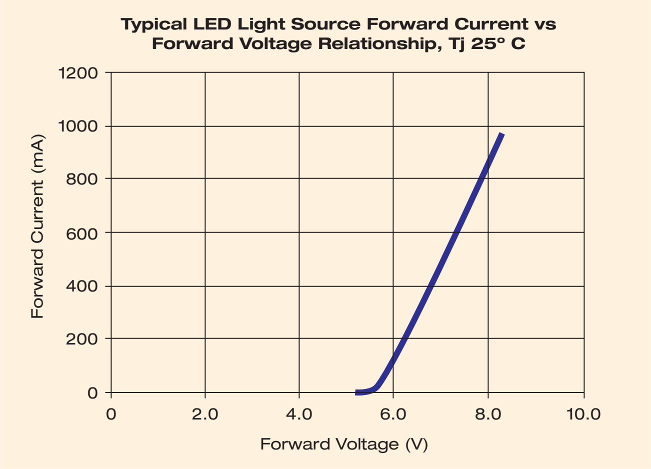

Figure 4. As can be seen in the chart, a small change in the forward voltage can result in a significant increase in the current passing through the diode. In the example shown, an increase of about 3.5 volts causes the current to rise by almost 1,000 mA. The net effect would be a rise in temperature at the p-n junction, adding to heat dissipation problems. Note that in determining the data points, an initial junction temperature of 25°C is assumed.

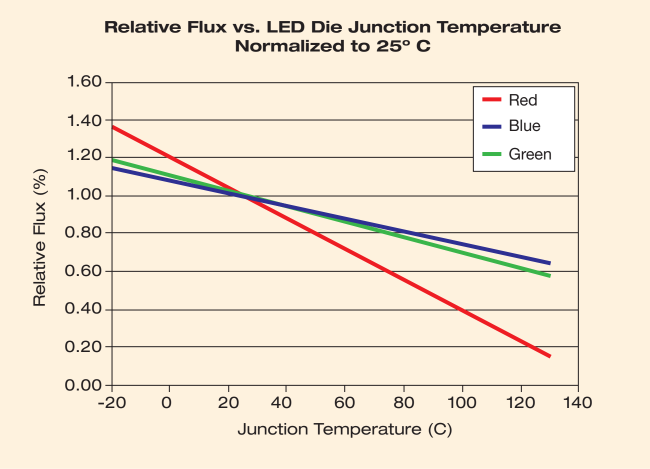

Figure 5. LED light output, as shown, can diminish over time with rises in temperature. The example provided for R (red), G (green), and B (blue) LEDs indicates that red lamps tend to lose brightness the most, and the fastest, as the junction temperature increases. The graph also suggests why white light created from RGB LEDs can appear to have a blue tinge as the junction temperature rises above its intended value. As the chart depicts, blue light falls off slightly less than green and much more so than red.

Is heat really a problem with an LED?

Heat can definitely be a problem, sometimes a difficult problem. As the temperature rises within the LED, the forward voltage drops and the current passing through the diode increases exponentially, thereby leading to even higher junction temperatures. (Figure 4 shows how a small change in voltage can cause a significant change in current.) While catastrophic failures are probably rare, the light output of an LED module will diminish over time (See Figure 5.), efficiency will drop, and the color of the light emitted may even change, due to shifts in wavelength brought on by the temperature rise. Wavelengths typically rise from 0.3 nm to 0.13 nm per °C, depending on the die type. As a result, orange LEDs, for example, may appear to be red, and LEDs producing white light – such as automobile headlights and street lamps – may have a bluish tinge. Other affects include yellowing of the lens, breaking of the wire, and damage to the die-bond adhesive.

Proper thermal management in designing circuitry and modules containing LEDs is thus essential; and while various approaches are available, involving heat sinks, base plates, constant-current power supplies, and fans, the solution almost always encompasses the selection and use of materials for attachment, from thermally conductive adhesives to die cut pads that are electrically isolating, as well as thermally conductive. (See Figure 6.)

Role of the Converter in Thermal Management

Designing an LED assembly – whether on a circuit board with other components or within an enclosure – first requires an assessment of the methods available for dissipating the heat to be generated by the assembly. Will the LEDs be through-hole or surface-mounted? Should a dielectric substrate be employed with thermal vias and a copper plate on the underside for absorbing and distributing the heat, or will the LEDs be mounted on a coated metal-core board that acts as a heat spreader? In other words, the initial effort is to determine how the heat is to be dissipated and the most efficient and effective heat path for transferring the heat.

The upfront design work for an LED assembly can be performed either in-house by the manufacturer, or with the assistance of an outside service, namely, a converter with demonstrated experience in thedissipation of heat generated by electronic and optoelectronic components.

In some cases, determining how best to dissipate the heat may benefit from in-depth thermal analyses using temperature modeling software for LED-based module designs. Where the manufacturer does not have the capability, thermal analyses can be performed by companies specializing in such a service.

Once the thermal path has been determined, the next step in designing an LED assembly is the selection and configuration of the thermal interface materials. In this regard, the materials converter should have particular expertise in terms of recommending materials (liquid adhesives, die-cut pads, etc.) that provide the required thermal conductivity and electrical insulation. Such parameters as surface flatness of the substrate and heat sink, shape and metal used for the heat sink, applied mounting pressure, thickness of the interface, contact area, etc., may also be spec'd by the converter.

Today, the manufacturer – and, in particular, the converter – has access to various families of materials developed for thermal management in electronic and optoelectronic assemblies. Options include both off-the-shelf or custom formulations in specified thicknesses and configurations, as well as a variety of choices in types of material: conductive adhesives and greases, tapes, ceramic and metal-filled elastomers (also called "gap fillers"), coated fabrics, and phase-change materials.

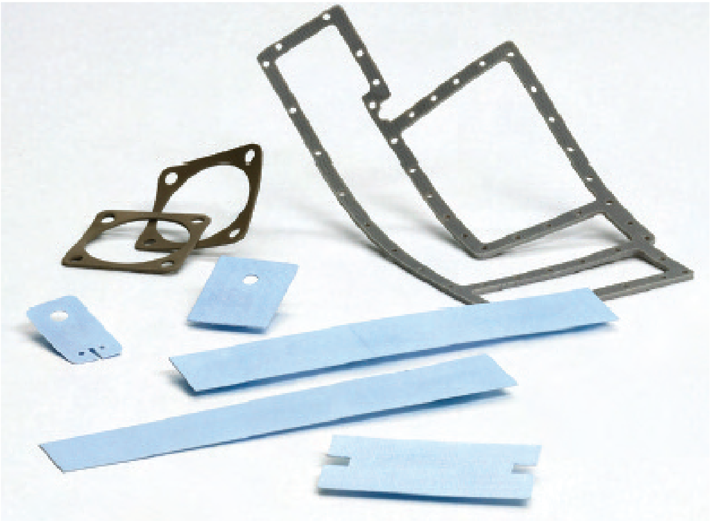

Figure 6. The items shown represent the various types of thermal management products available for dissipating heat generated within an LED assembly. The choice of one over the other will depend on the amount of heat to be transferred and the configuration of the assembly. In most instances, a thermally-conductive/electrically-insulating pad will be the choice in transferring heat to either a heat spreader or a heat sink.

Adhesives and greases have historically been the means of attaching a heat-generating device to a heat sink, and are relatively inexpensive. Pressure-sensitive tapes are also used for mounting components to heat sinks, as are elastomer gaskets, which can be coated with an adhesive on one or both sides and can be die-cut into almost any shape. Thermal fabrics are typically fiberglass-reinforced, ceramic-filled polymer sheets that can provide both thermal conductivity and electrical isolation. Tapes, elastomer pads, and coated fabrics can be formulated to achieve specified performance values in terms of dielectric strength, thermal conductivity, and thermal impedance.

Phase-change materials change from a solid to a liquid during the process of absorbing heat at specified temperatures. The net result is the transfer of heat from a heat-generating device, such as a microprocessor, which is thermally coupled through the material to a heat sink.

Note that the role of a converter involves more than recommending the use of certain materials. For most requirements, the converter provides the finished part – for example, a die-cut gasket. Depending on the needs of the manufacturer, the converter should be able to do the actual assembly work. While the requirement may typically involve thermal transfer – binder, filler material, size and shape of the pad, type of adhesive, method of application, etc. – as essential, are considerations of electrical insulation, as well as EMI/RFI shielding, where needed. Then, too – again depending on the product – environmental sealing may also be required, since LED applications often entail operation under environmental extremes of temperature and weather, and even vibration. (Consider, for example, the vibration requirements for a sealed LED headlight.)

The Bottom Line…

While LEDs seem cool to the touch, heat can be a significant problem, and could cause a product failure. Though excessive heat is not going to cause a color shift that results in a red stop light changing to green, the traffic signal could go out, or more likely, it could dim to the point of not being easily visible.

In designing LED-based products – architectural lighting, street lamps, signs, automobile headlights (and taillights), traffic lights, or any of the many other products in which LEDs are now the technology of choice for brilliance, efficiency, and long life – the heat generated both by the LEDs and surrounding components, if any, requires serious consideration by the product designer, the materials engineer, and the converter contracted to provide a viable, cost-effective solution.

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