Integrated metal substrates improve LED thermal management

Compared with standard FR4, integrated metal substrates deliver valuable thermal management improvements for LEDs, enabling higher light output and greater reliability, writes **Nico Bruijnis**.

As with power transistors, the performance and longevity of highbrightness LEDs depends upon effective thermal management. Accordingly, LED manufacturers are adopting similar package design techniques to those now seen in surface-mounted power devices. However, thermal management between the boundaries of the package and the ambient environment is equally important, and systems integrators are also adopting power electronics techniques to achieve cost-effective solutions.

Power LEDs and temperature

Effective thermal management influences both the quality and quantity of light available from a high-brightness (HB) LED. Since the emitted wavelength increases linearly with the temperature of the die, maintaining a stable die temperature for consistent colour output is important in assemblies containing large numbers of LEDs. This is particularly important with the emerging families of white LEDs, as the human eye is able to differentiate very small colour changes in white light.

Also, the intensity of the emitted light is heavily dependent on the forward current supplied, and higher current causes the die temperature to increase. Good thermal management techniques are required to achieve bright light without exceeding the recommended maximum die temperature.

Better thermal management allows a higher forward current to be applied to the LED, resulting in greater light output. This may reduce the number of LEDs required to achieve the desired optical power. Maintaining a cooler assembly at an equivalent power equates to more light per die. It is also possible to pack the die more closely in an assembly that utilises good thermal management techniques, to deliver a physically compact solution capable of high performance. An equally important consideration is that the lifetime of a LED is closely related to the operating junction temperature. With proper thermal management, HB-LED lifetimes can exceed 100,000 hours. As a simple rule of thumb, every 10°C drop in junction temperature will double the lifetime of the LED.

Thermal management

The tendency for LED die temperature to rise is related to the mechanisms by which energy leaves the chip. For example, even though up to ninety percent of the electrical energy supplied to a red AlInGaP LED will be converted into visible light, only part of this light energy can be ejected from the chip. The remaining energy, which cannot leave the chip, will be converted into heat.

Manufacturers of HB-LEDs and system integrators each have a role to play in removing this heat from the die efficiently to ensure a stable operating temperature up to the rated forward current, within the manufacturer's specified maximum. In the brightest devices now available, this can be significantly over 1A.

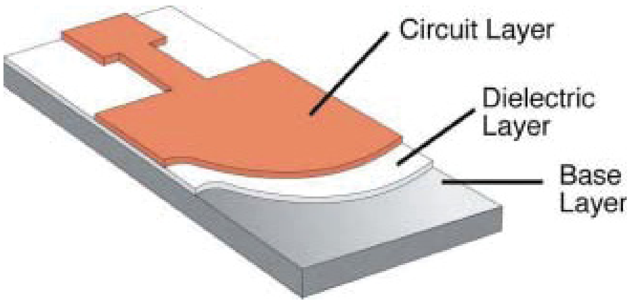

Figure 1. Construction of an insulated metal substrate (IMS) for enhanced thermal management.

Generally, this heat must be conducted away from the die through the package, and into the PCB. Hence, a thermally efficient path from the die to the edge of the package, through the PCB to the heatsink, is essential. LED manufacturers are adopting packaging technologies from surface-mount power transistors, including flip-chip attachment of electrodes, high thermal capacity lead-frame designs, and provision of heat slugs for direct soldering to the PCB.

However, while today's power LED packages are highly efficient at coupling heat energy into the printed circuit board, the standard FR4 PCB substrate material is not designed for high thermal performance. In modern LED arrays for exterior lighting, signage and similar applications, hundreds or even thousands of densely-packed individual power LEDs can thermally saturate the PCB. The result is rapid overheating of the die, which will lead to early failure of the assembly.

From the package to the board

To overcome these limitations of FR4, an insulated metal substrate (IMS) provides a high-performance alternative technology. IMS is a composite construction typically comprising an aluminium or copper baseplate that not only increases the thermal capacity of the PCB but also improves heat dissipation into ambient or, if required, into a larger heatsink. A thin, thermally-conductive dielectric layer insulates the metal baseplate from the circuit layer that provides the interconnection between the LEDs and other components mounted on the circuit board. Figure 1 illustrates the construction of the IMS.

The dielectric layer is critical in the thermal management of HB-LEDs, since it is potentially one of the highest thermal resistance interfaces in the entire path from die to ambient. However, its specification also has an important bearing on the cost of the chosen IMS.

To consider a practical example of an IMS suitable for use with large arrays of LEDs, The Bergquist Company's Thermal Clad IMS has a 150-micron dielectric with relatively high thermal conductivity. To satisfy a

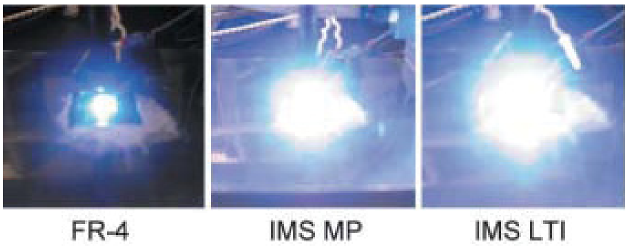

Figure 2. Simulated die temperature for a power chip LED under constant current conditions. The use of an insulated metal substrate results in lower die temperature.

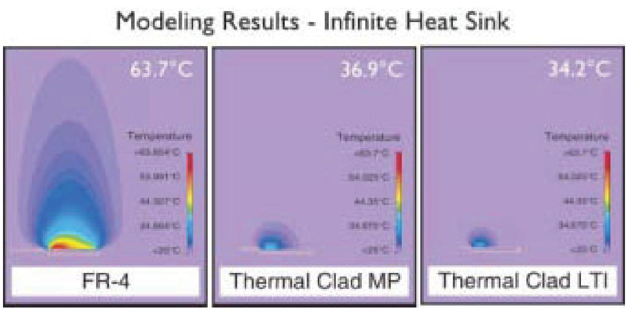

Figure 3. Light output at a constant die temperature of 50°C. Improved thermal management supports higher drive current.

wide range of applications with the optimal costperformance characteristic, Thermal Clad is available in different thermal conductivity ratings. Three product variants are now available, including BondPly TCP-1000 which is specifically designed for use with HB-LEDs, as well as the higher performance Thermal Clad Multi-Purpose (MP) and Thermal Clad Low Thermal Impedance (LTI) material.

To show how different thermal materials affect LED performance, Figure 2 illustrates modelling results for a high-performance power LED chip. An InGaN LED is mounted on either Thermal Clad MP, Thermal Clad LTI or FR4. This thermal model shows the temperature of the die when a constant current is applied to produce a total power dissipation of 1.0 watt.

When the LED is mounted on FR4, the resulting die temperature is 63.7°C. The use of Thermal Clad MP reduces the die temperature to 36.9°C, while Thermal Clad LTI enables a further reduction to 34.2°C, thereby extending the operating lifetime of the LED. From a different perspective, the ability to remove heat efficiently from the die, through the package, into the IMS and out of the assembly allows, for a given die temperature, a higher operating current and therefore higher light output.

Figure 3 illustrates the result of a bench test carried out using the same LED die mounted on the same three substrates, with the forward current adjusted to maintain the die at a constant 50°C in each case. The differences in light output are significant, and clearly show the advantages of using IMS in place of FR4 to achieve the highest light output, reliability and longevity.

Conclusion

Vendors of HB-LEDs, and integrators of lighting systems using these devices, are both finding successful solutions to the challenges of minimising thermal resistance between the LED die and the external heatsink. These include flip-chip package assembly techniques as well as direct die attachment to the PCB in large lighting assemblies. These technologies are able to efficiently couple heat from the die into the PCB, demanding improvement in the thermal capacity and conductivity of the substrate material. IMS delivers valuable improvements that enable higher light output and greater reliability.

In the future, as high-powered LED lighting enters the mainstream, market demands for miniaturisation will demand more effective heat removal from smaller, higher-power LEDs. In this context, the contribution of a high-performance, thermally conductive IMS such as Thermal Clad will become even more valuable.