# LED Packaging Thermal Performance
## Comparing Heat Sink Materials

With the advent of high power packages for LEDs, the industry is experiencing a variety of approaches. This can be confusing to the manufacturers and their customers. LED packaging is repeating the evolution of packages that accompanied transistors and integrated circuits. They started out with metal and ceramic packages. These were inexpensive to tool up and easy to get into production. As the volumes increased, there was a move to plastic packages [TO-92, TO-220, P-DIPs]. In high volumes, plastic packaging has a price-performance advantage. The materials are less expensive than with metal or ceramic packages. The down side is that the tooling is very expensive. Consequently, it takes high volumes to justify converting to plastic packaging.

In surveying LED power packaging we see ceramic packages, metal core boards, printed circuit boards glued to heat sinks, and some plastic packages. Lets compare their respective performance. Printed circuit boards are excluded.

Table 1

| MATERIAL | THERMAL CONDUCTIVITY* | CTE* |
|---|---|---|
| Alumina | 30 W/m-K | 7.4 um/m |
| Beryllia | 248 W/m-K | 6.4 um/m |
| Aluminum | 210 W/m-K | 24 um/m |
| Copper | 385 W/m-K | 16.4 um/m |

*MatLab.com

The different materials used are: alumina or common ceramics, beryllia, aluminum, and copper. Copper has a significant advantage in thermal conductivity [see Table 1]. This means that for the same thermal transfer, a smaller cross sectional area can be used. This means a smaller package. It can be thinner by a factor of 2 to 3, meaning a further reduction in size. The disadvantage of copper and aluminum is the coefficient of expansion. They have a larger mismatch with the LED chip. That limits the size of the LED chip. Beryllia is best choice among the other materials, but is relatively expensive. There are some other materials, such as nitrides, that we could consider, but they are very expensive.

One might ask “What difference does the materials make?” A good question. Ceramic packages have been .06” thick, aluminum has been .04”, and copper has been between .02” & .11” thick. Using the thermal conductivity and the thickness of each material we can compare these materials [see Table 2].

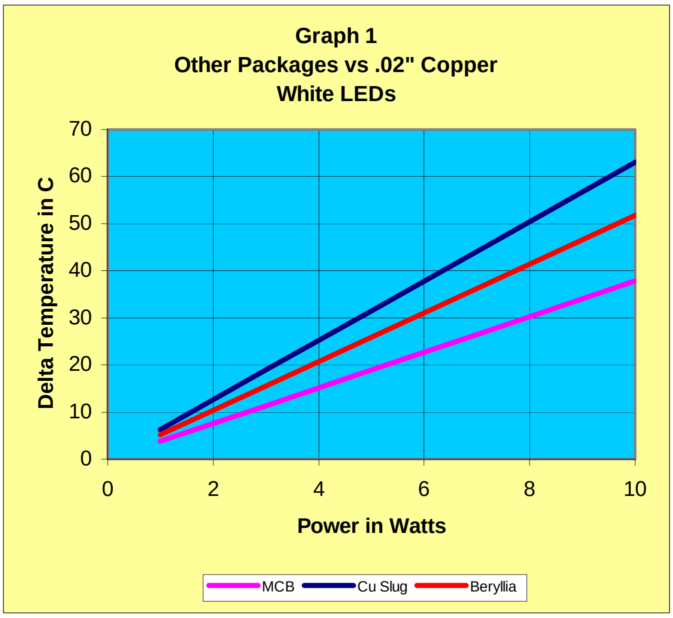
Table 2

| MATERIAL [thickness] | THERMAL CONDUCTIVITY* | THERMAL COMPARISON* |
|---|---|---|
| Alumina- .06” | 30 W/m-K | 38 X |
| Beryllia- .06” | 248 W/m-K | 4.7 X |
| Aluminum- .04” | 210 W/m-K | 3.7 X |
| Copper- .11” | 385 W/m-K | 5.5 X |
| Copper- .02” | 385 W/m-K | 1 X |

For the same chip, .02” copper has a distinct advantage in thermal transfer based on thickness and thermal conductivity. This difference translates into several advantages:

- For the same thermal transfer, .02” copper can have a smaller foot print, or
- For the same foot print, transfer more heat [i.e., a higher power package], and
- For the same foot print, have a lower LED junction temperature and higher light output
- For the same foot print, increase the maximum ambient temperature

Assuming the same footprint, The LED chip junction will be cooler on a .02” copper, package heat sink. The temperature difference is depicted in Graph 1. At higher powers this becomes significant.




Since the LED junction is cooler, it is more efficient and increases the light output. Graphs 2 and 3 show this effect for white and red LEDs. For red, this is significant, and less so for white.

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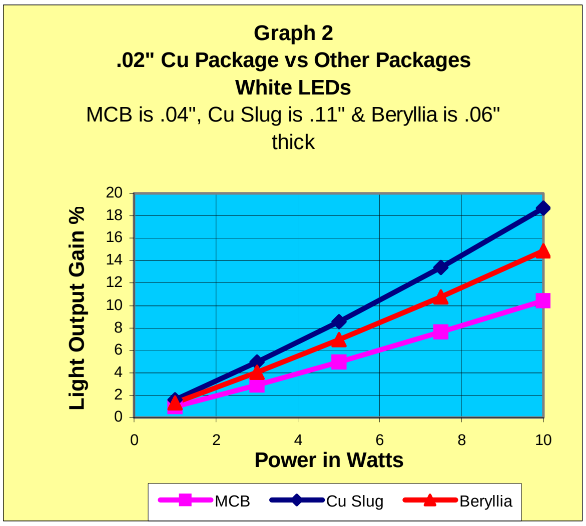
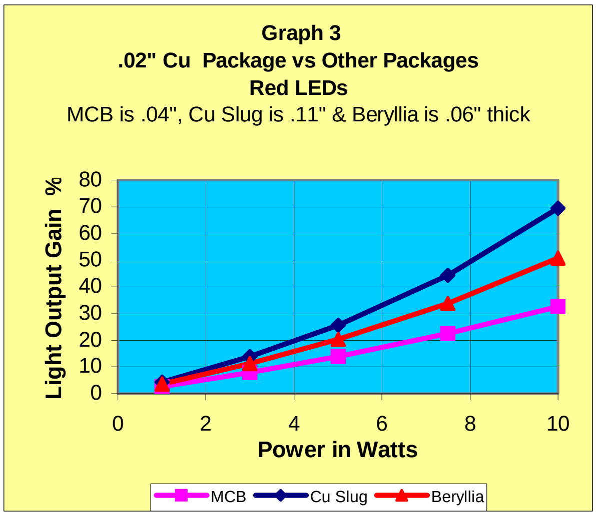
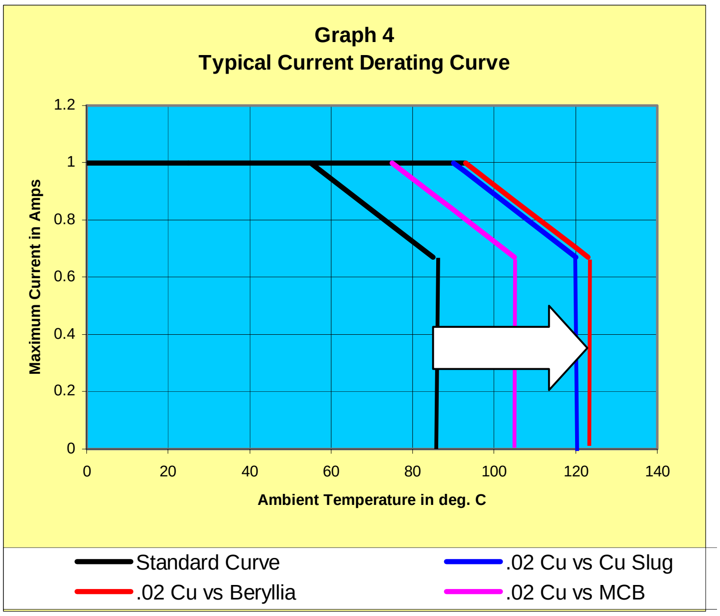



Another advantage of the .02" copper heat sink is that the effective operating region for the LED can be expanded. Graph 4 shows a typical Current Derating Curve for one of the other package types. By converting to .02" copper, the maximum ambient temperature can be increased.

Are these differences significant? At higher powers, the answer is yes. The material presented above provides a strong case for plastic packages using copper as the heat sink material. After amortizing the tooling, they are the lowest cost packages, providing the highest light output, the highest operating region, and the smallest package footprint.

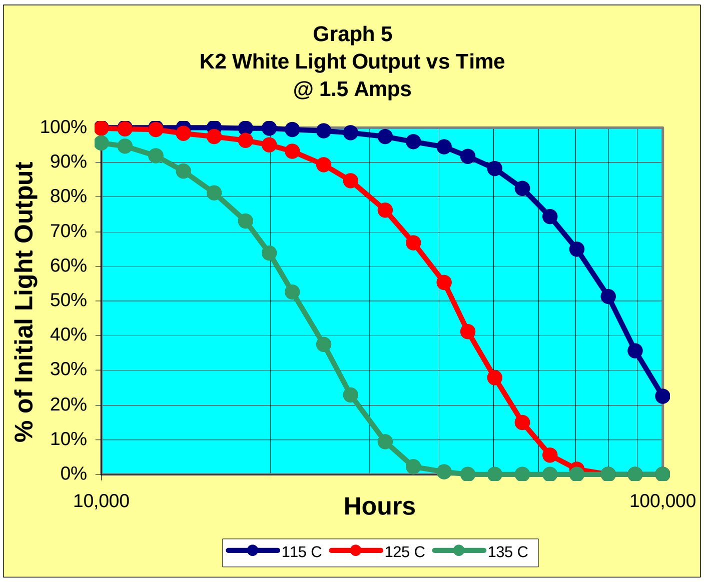



EFFECTIVE LIFETIME

Recently, Philips LumiLEDs published "Understanding Power LED Lifetime" describing the effects of junction temperature and power on the degradation of the light output in their K2 package. It is a seminal paper for our industry.

Graphs 5 and 6 show the decline in light output by varying the junction temperature [Graph 5] or by varying the forward current [$I_F$] [Graph 6]. If we stop for a minute and think about the implications of this, we realize that the thermal resistance of the LED is important in promoting longer life time. The die attach should be eutectic and not epoxy. The heat sink thermal resistance for the package should be as low as possible. If these two approaches are not followed, then the effective lifetime of the LED is reduced and in some cases, greatly reduced.

A fuller discussion can be found in AN-103.

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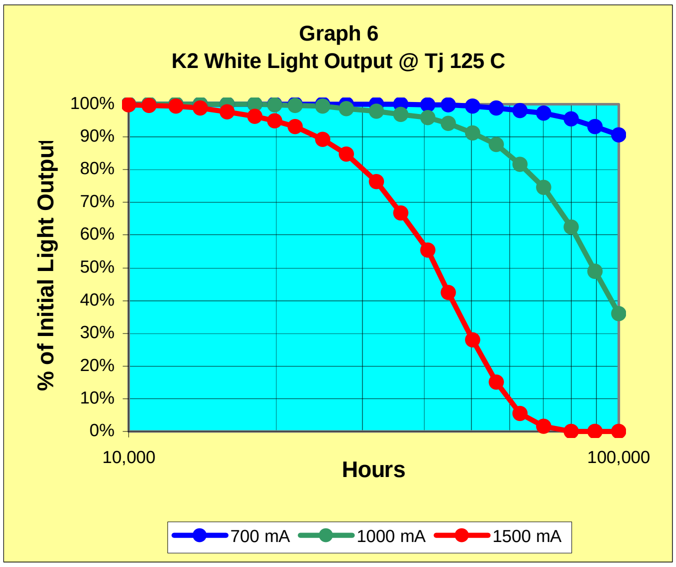
Graph 6
K2 White Light Output @ Tj 125 C
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of Initial Light Output
10,000
100,000
Hours
700 mA
1000 mA
1500 mA