Honeycomb Heat Sinks

for LEDs

LEDs, or light-emitting diodes, are a form of solid-state lighting. An LED light is often made of a small piece of semiconductor, an integrated optical lens used to shape its radiation pattern, and a heat sink, used to dissipate heat and maintain the semiconductor at low operating temperature. LED lights present many advantages over incandescent light sources, including lower energy consumption, longer lifetime, improved physical robustness, smaller size and faster switching. LED lights are powerful enough for room and street lighting, are relatively expensive and require more precise current and heat management than traditional incandescent and compact fluorescent lamp sources of comparable output.

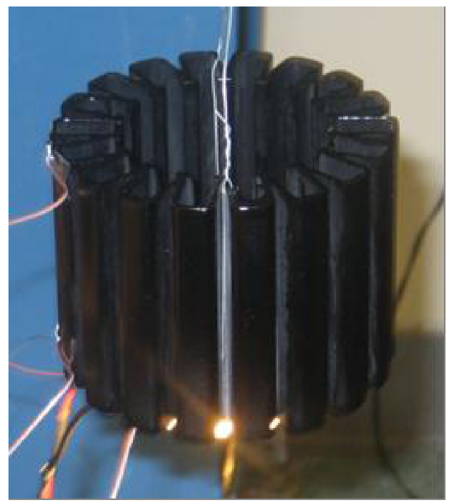

Figure 1. Generic LED Heat Sink

The performance and life expectation of a LED light directly links to it operating temperature. The lower the operating temperature, the better performance and the longer life. To increase durability and the lighting quality of the LED lights, thermal management is a critical aspect of the LED lights design. LED lights are generally cooled with a heat sink by natural convection. Figure 1 shows a generic heat sink for an LED light and Figure 2 shows a star shaped LED heat sink designed by Advanced Thermal Solutions, Inc.

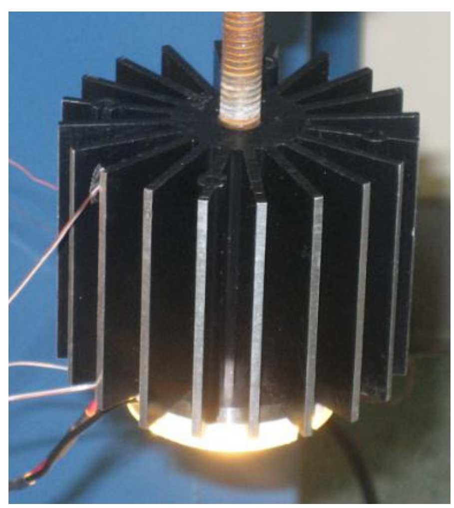

Figure 2. Star LED Heat Sink (Advanced Thermal Solutions, Inc.)

To better cool some LED lights, Ma *et al.* [1] proposed to use the honeycomb heat sinks as thermal management device. They suggested that the honeycomb heat sinks have larger surface area and smaller weight than other LED heat sinks.

Numerical simulations and experimental tests were conducted to investigate the performance of the honeycomb heat sinks under natural convection condition. Their founding are discussed in this article.

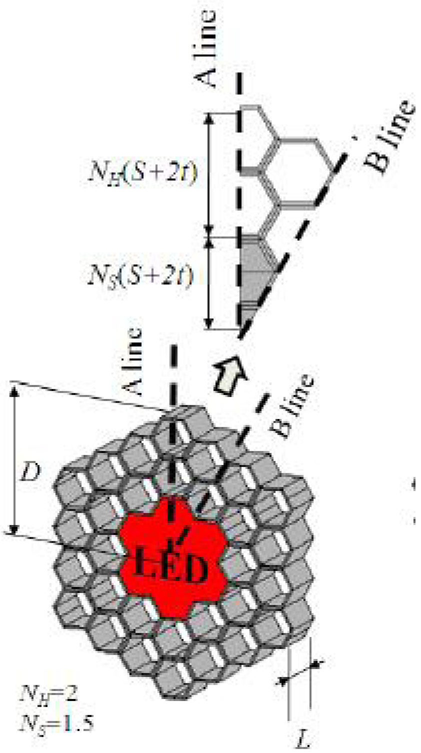

Figure 3. Single Heat Source Honeycomb Heat Sink Model [1]

Figure 3 shows the single heat source honeycomb heat sink model proposed by Ma *et al*. The LED chip is located at the center of the heat sink. The air passing through the hexagonal holes carries the heat away from LED chip. Figure 4 shows the detailed dimension of a single honeycomb cell.

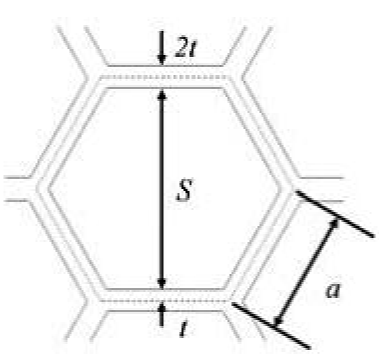

Figure 4. Honeycomb Heat Sink Model Cell Dimension [1]

The rib-space ratio ε of the honeycomb is defined as:

$$\varepsilon = \frac{2t}{S}$$

Where 2t is the thickness of the rib and S stands for both the space length and the hydraulic diameter of the cells.

The cell aspect ratio of the honey comb heat sink with a height of L is defined as:

$$AR = \frac{S + 2t}{L}$$

Obviously, the performance of a honeycomb heat sink is affected by the number of cells surrounding the heat source, the aspect ratio of the honey comb cell, and the rib-space ratio. Ma *et al* investigated the effects of honeycomb heat sink parameters numerically by using CFD simulation. Figure 5 shows the CFD model of a one-twelfth section of a honeycomb heat sink. An isothermal of 67 °C (340 K) condition is set as the boundary of the heat source, which represents the case temperature of the LED light. The ambient air temperature is chosen to be 27 °C (300 K). They calculated the total heat flux the honeycomb heat sink can dissipate under natural convection conditions and used it as a main parameter for the heat sink performance comparison. Figure 6 illustrates a typical velocity and temperature distribution of the honeycomb heat sink at different cross sections.

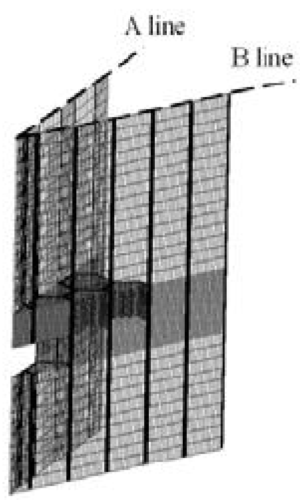

Figure 5. CFD Model of a One-Twelfth Section of Honeycomb Heat Sink [1]

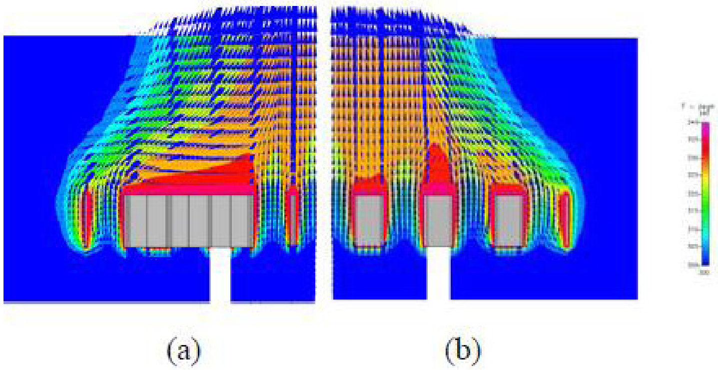

Figure 6. Velocity and Temperature Distribution of the Honeycomb Heat Sink (a) at the Cross Section of the A Line, and (b) at the Cross Section of the B Line [1]

In their simulations, Ma *et al* first fixed the rib-space ratio (ε=0.125) and varied the cell aspect ratio (AR) by setting S+2t=7.794mm and increasing the height (L). Figure 7 shows that a heat sink with a larger height (smaller aspect ratio) can dissipate more heat. This is because the larger heat sink height means more convection surface area. However, the average convection heat transfer coefficient decreases with an increase of the height of the heat sink, due to the developing boundary layer on the cell wall. In Figure 7, H is the average heat transfer coefficient based on overall heat flux (dissipated by both convection and radiation) and h_m is the average heat transfer coefficient based on convection only.

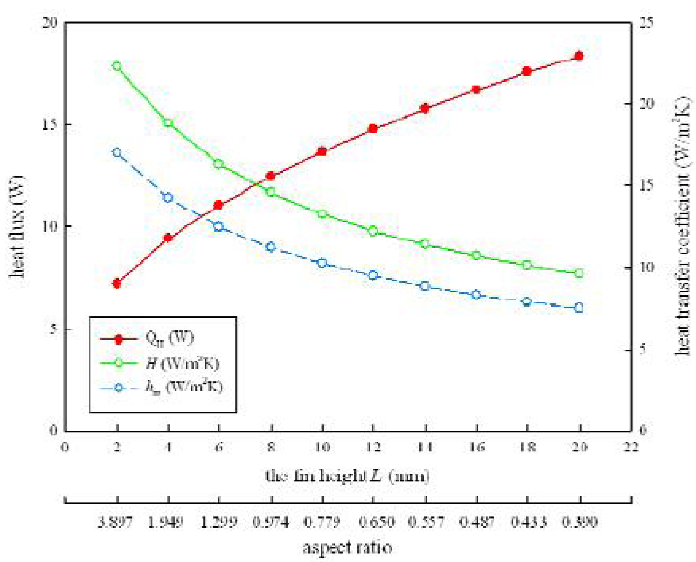

Figure 7. Heat Flux as a Function of Different Cell Aspect Ratio [1]

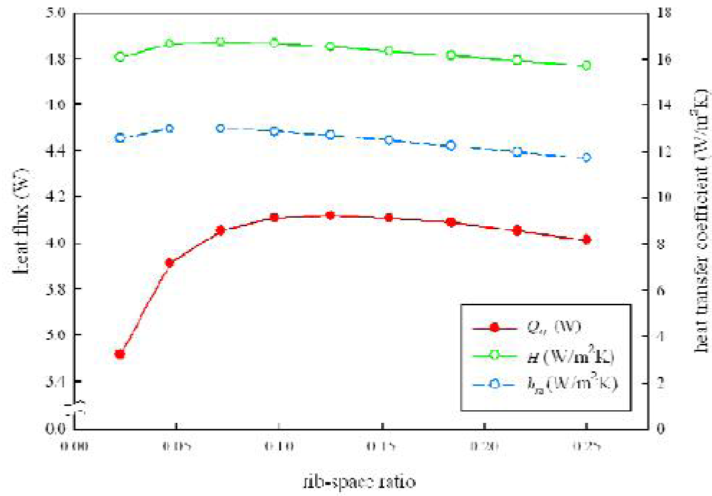

Figure 8. Heat Flux as a Function of Different Rib-Space Ratio [1]

Ma *et al* then fixed the cell aspect ratio (AR=1.3) and varied the rib-space ratio (ε) by setting a=4.5mm and changing the t. The simulation results are shown in Figure 8. There exists an optimal ratio for the heat sink rib-space ratio. For the case of heat sink height of 6 mm, the maximum heat flux is predicted at the rib-space ratio of 0.125.

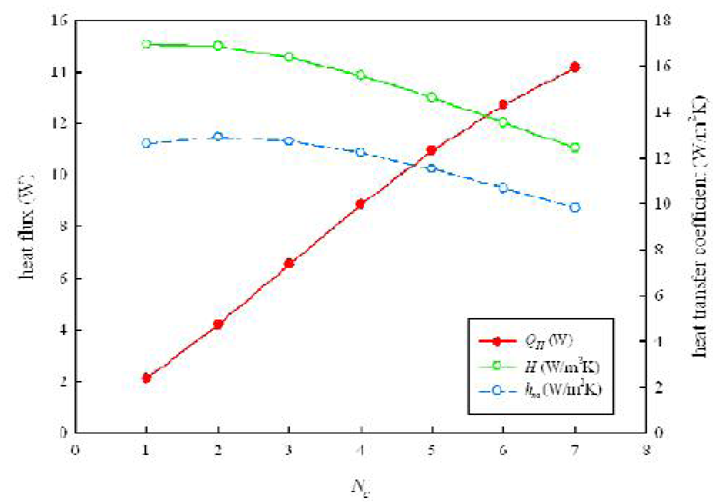

Figure 9. Heat Flux as A Function of Different Number of Cells [1]

The number of cells in the honeycomb is a crucial parameter in view of cost and space considerations. Figure 9 illustrates the effect of the number of cells on heat sink heat dissipation ability. Obviously, the large cell number results in more heat flux dissipation. However, the size restriction of the heat sink will limit the number of the cells in a heat sink.

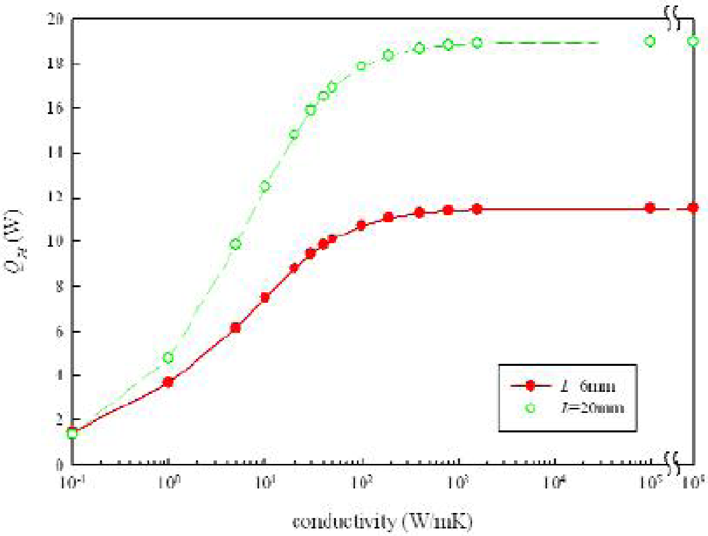

Figure 10. Heat Flux as A Function of Thermal Conductivity [1]

Ma *et al* also investigated the effects of material thermal conductivity on honeycomb heat sink performance. The results from 6-mm high and 20-mm high heat sinks are shown in Figure 10. The heat fluxes do not show large variations, when the thermal conductivity is over 50W/m.K. For example, the performance difference between the copper (K=400 W/m.K) and aluminum alloy (K=190 W/m.K) is less than 1%.

To validate the simulation results, aluminum honeycomb heat sinks with Nc=2 (Nc is the number of cells on the radius) and ε=0.125 were made and tested by Ma *et al*. Figure 11 shows the honeycomb heat sink machined from single piece of metal. Figure 12 shows the honeycomb heat sink assembly made of 5 layers of individual heat sinks. Figure 13 shows the heat flux comparison between numerical simulation and experimental results.

Figure 11. Honeycomb Heat Sink [1]

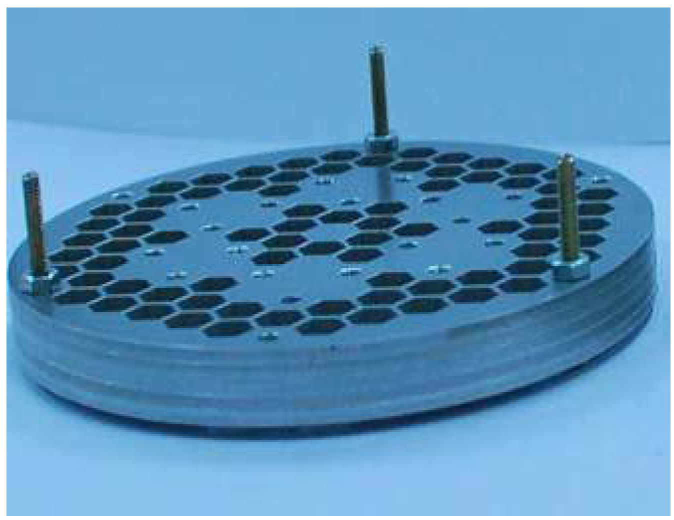

Figure 12. Honeycomb Heat Sink (5 Layers) [1]

Through their numerical simulation and experimental test, Ma *et al* found that the honeycomb heat sink design can effectively dissipate heat more than 10W by natural convection and reduce weight for application in LED lights. Based on their research, they concluded that the performance of a honeycomb heat sink can be improved by increasing the number of cells, aspect

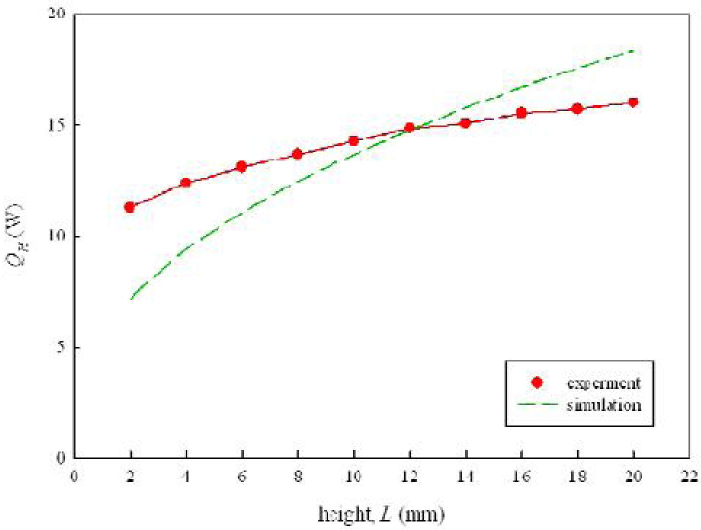

Figure 13. Comparison of Numerical and Experimental Results [1]

ratio and the proper rib-space ratio at the fixed cylindrical radius. Their simulated results indicated that thermal conductive resistance is a small portion of the total thermal resistance. Therefore, the heat fluxes did not have large variation when the conductivity was over 50 W/m.K. More work is needed in this area to prove that if honeycomb heat sinks are a viable technique for LED lights cooling.

Reference:

1. Ma, H.K., Chen, B. R., Lan, H.W., and Chao, C.Y., "Study of an LED Device with a Honeycomb Heat Sink", 26th IEEE SEMITHERM Symposium, February 2010, Santa Clara, California, USA.