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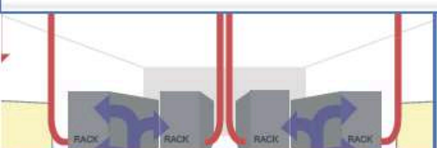







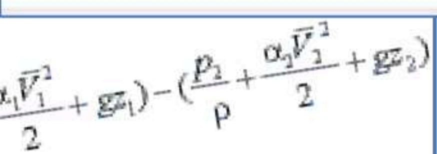





FUTURE COOLING

# Vapor Chambers and Their Use in Thermal Management

Increasing heat fluxes and decreasing sizes pose a major challenge for keeping electronic components below their critical junction temperatures. To cool a high power device with a small footprint requires a heat sink larger than the component. This size difference creates an added thermal resistance, called spreading resistance, which is usually in the same order of magnitude as the heat sink thermal resistance.

Spreading resistance is observed in combinations of very high performance heat sinks and small heat source sizes, e.g. 10 x 10 or 15 x 15 mm. There are many ways to reduce this added resistance. One is to use a highly conductive material, such as copper. It has a smaller spreading resistance than aluminum, although it is much heavier and costlier. Other ways to lower spreading resistance include the use of heat pipes, liquid cooling, vapor chambers, micro TECs (thermoelectric coolers), and the recently developed Forced Thermal Spreader (from Advanced Thermal Solutions, Inc.). The focus of this article, however, will be on the use of vapor chambers.

A vapor chamber (VC) is basically a flat heat pipe that can be part of the base of a heat sink. It is vacuumed and then injected with just enough liquid, e.g. water, to wet the wick. The theory of operation for a vapor chamber is the same as for a heat pipe. The heat source causes the liquid to vaporize on the evaporator side. The resulting pressure increase in this area forces the vapor into the condenser side, which is the base of the heat sink. Here, the vapor transfers the heat to the heat sink, and it then condenses back to liquid. The liquid is pumped back to the base through the capillary action of the wick structure.

It has been shown that for electronics cooling applications, sintered copper and water are the best choices for the chamber material and its internal liquid. The advantages of water are its high thermal conductivity, high surface tension, and non-toxicity.

A vapor chamber generally spreads the heat more uniformly than with a solid metal block. This is due to the chamber's high equivalent thermal conductivity. Figure 1 shows the temperature distribution in two heat sinks: one has a solid base and the other has a vapor chamber in its base. The heat sink without the VC shows temperature concentrated on top of the heat source, while the major portion of the heat sink is running cooler. The result is low thermal performance. On the other hand, the heat sink with the VC in its base shows a very uniform temperature distribution. The very high equivalent thermal conductivity of the vapor chamber has spread the heat uniformly, leading to more efficiency from the heat sink.

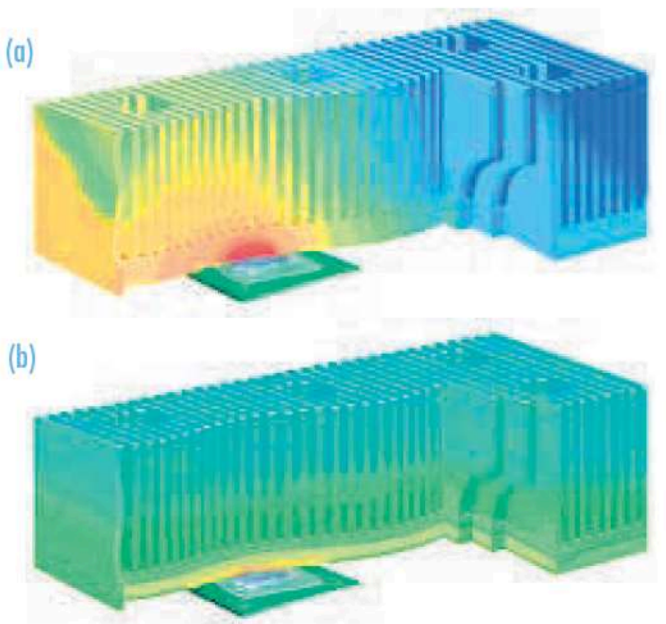


Figure 1. Schematic View of Heat Sinks with (a) Solid Base and (b) Vapor Chamber Base [1].

The effective thermal conductivity of heat pipes and vapor chambers is estimated to be 5,000-20,000 W/m°C [1]. It should be noted that when a heat pipe is attached to the base of a heat sink the extra interfacial resistance from this bonding can degrade the effective thermal conductivity to about 4,000 W/m°C. A vapor chamber, however, has the advantage of being part of the heat sink base, eliminating the interfacial resistance.

Figure 2 gives a schematic view of a typical vapor chamber. Its successful performance depends on many factors, as explained in the following paragraphs.

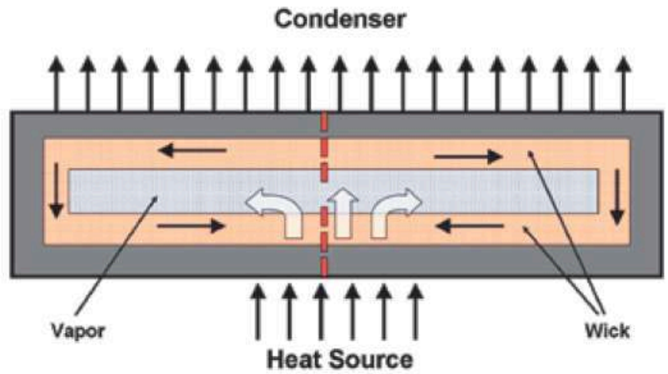


Figure 2. Schematic of a Vapor Chamber.

The thermal conductivity of a vapor chamber's wick has a strong influence on its overall effectiveness. Wicks are typically made from copper powder. Heat must travel through the wick structure to vaporize the water. The low thermal conductivity of water compared to that of copper powder can degrade the chamber's performance.

The effective thermal conductivity of a wick can be expressed as shown below [2]:

$$K_w = \frac{\pi}{8}\left(\frac{r_c}{r_s}\right)^2 K_S + \left[1-\frac{\pi}{8}\left(\frac{r_c}{r_s}\right)^2\right]\left[\frac{K_l K_S}{\varepsilon' K_S + K_l(1-\varepsilon')}\right] \quad (1)$$

$$\varepsilon' = \frac{\varepsilon}{1-\frac{\pi}{8}\left(\frac{r_c}{r_s}\right)} \quad (2)$$

Where

$K_w$ = Wick effective thermal conductivity

$K_l$ = Water thermal conductivity, W/m°C

$K_s$ = Copper thermal conductivity, W/m°C

$R_c$ = Capillary radius, m

$R_s$ = Particle sphere radius, m

The above equation yields a value of 40 W/m°C for water inside a sintered copper wick.

Another variable to consider is the effective thermal conductivity of the vapor space [3]:

$$K_{vapor} = \frac{H^2_{fg} P \rho d^2}{12 R \mu T^2} \qquad (3)$$

Where

$K_{vapor}$ = Vapor space effective thermal conductivity

$H_{fg}$ = Heat of vaporization, J/Kg

P = Pressure, N/m$^2$

ρ = Density, Kg/m$^3$

d = Vapor space thickness, mm

R = Gas constant per unit mass, J/K.Kg

μ = Dynamic viscosity, N•sec/m$^2$

T = Vapor temperature, °C

As shown in Figure 3 below, when $K_{vapor}$ is plotted against temperature, the above equation demonstrates that the effective vapor space conductivity is very low at low temperatures. This has a significant implication for low heat flux or start up conditions [4].

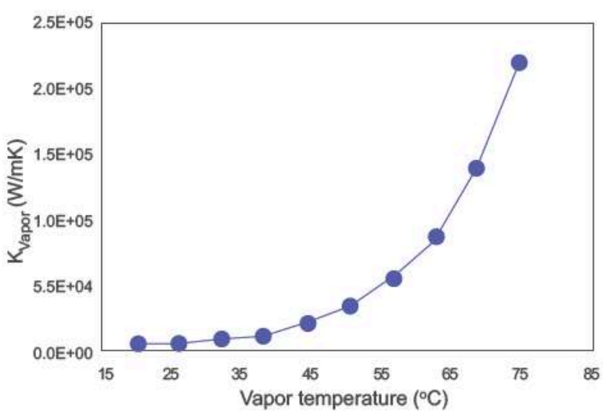


Figure 3. Effective Thermal Conductivity of Vapor Space as a Function of Temperature.[1]

To address the effects of different variables on the performance of a vapor chamber, a conduction model was put together as shown in Figure 4 [4]. In this model, a 10 x 10 mm heat source was mounted on a 42.5 x 42.5 mm ceramic chip carrier. The model was analyzed using Flotherm computational fluid dynamics (CFD) software. Different layers of the resistance network were constructed using their effective thermal conductivities, which were known or could be calculated as shown in the previous equations. The vapor chamber was modeled as a combination of the vapor chamber wall, wick structure, and vapor space. An effective heat transfer coefficient of 1,400 W/m$^2$K was assigned based on the performance of the heat sink. The ambient air temperature was assumed to be 35 °C and a uniform heat flux of 100 W/cm$^2$ was applied at the base. Figures 5 and 6 reveal some interesting findings about the performance of the vapor chamber.

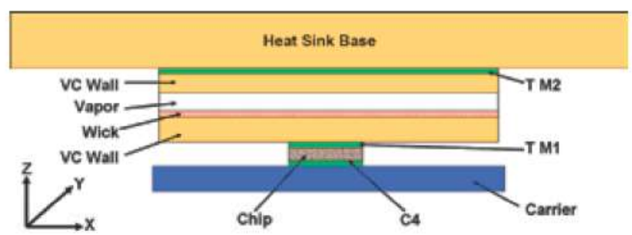


Figure 4. Schematic of a Vapor Chamber Physical Model for CFD [4].

Figure 5 shows the junction temperature ($T_j$) as a function of wick effective thermal conductivity. The vapor space thermal conductivity was assumed to be 30,000 W/mK. The graph shows that the chip junction temperature drops from 97 °C to 93.5 °C for wick conductivities of 30 and 60 W/mK, respectively. In other words, the performance of the vapor chamber is strongly influenced by the wick's thermal conductivity.

However, Figure 6 shows that junction temperature is a very weak function of vapor space thermal conductivity. This is due to the fact that even an equivalent thermal conductivity of 5,000 W/mK, the lowest on the X-axis, is still a large number. However, if the vapor temperature is below a certain value, such as 35 °C, then the vapor space effective thermal conductivity will drop drastically, impacting the junction temperature.

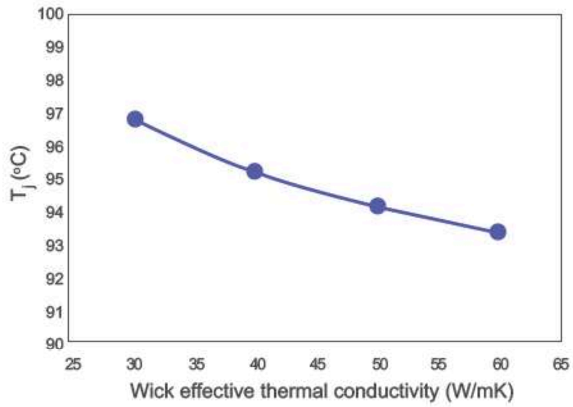


Figure 5. Junction Temperature as a Function of Wick Effective Thermal Conductivity [1].

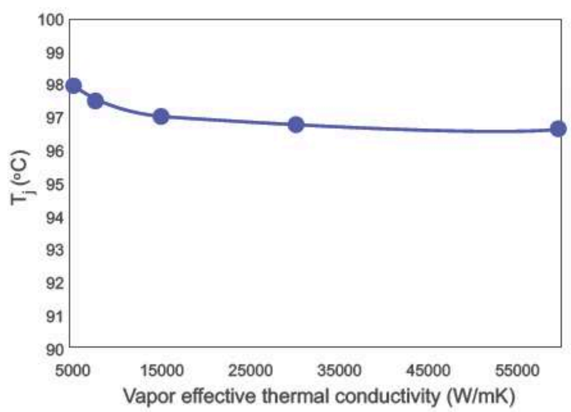


Figure 6. Junction Temperature as a Function of Vapor Space Thermal Conductivity [1].

Figure 7 shows junction and case temperatures as a function of vapor chamber size (lid) using examples that compare a solid heat sink base and a vapor chamber. The graph shows that for this particular configuration, a solid copper block outperforms a vapor chamber below the 40 mm lid size. But, above 40 mm the vapor chamber is a better choice. The superior performance of the VC over solid copper is due to its enhanced lateral heat spreading on larger surfaces.

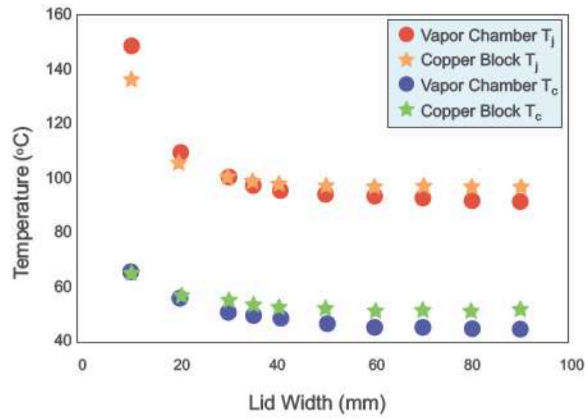


Figure 7. Junction Temperature as a Function of Lid Size for Vapor Chamber and Solid Copper Base [1].

Figure 8 shows the temperature as a function of lid size for heat transfer coefficients of 400 and 50,000 W/m²K. These extreme values of heat transfer coefficients represent low performance and very high performance heat sinks. The graph shows that with a low performance heat sink, the cross over point between the copper block and the vapor chamber is at 40 mm. From here the VC starts to outperform the copper block. For a very high heat transfer coefficient, such as with a liquid cooled cold plate, the size of the VC needs to be much larger to have an advantage over the copper block. In other words, if a large (80 x 80 mm) liquid cooled plate is used, a solid copper block will provide the same performance as a vapor chamber.

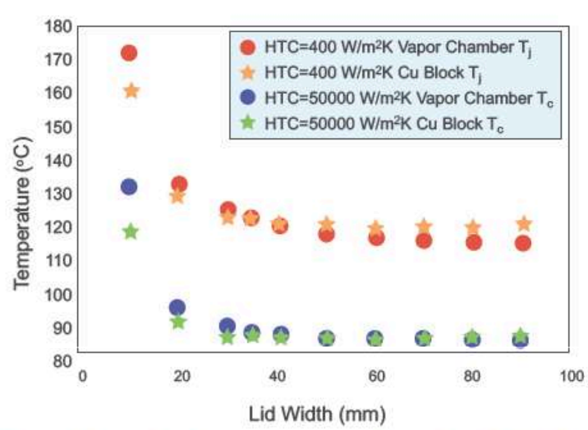


Figure 8. Junction Temperature as a Function of Lid Size for Vapor Chamber and Solid Copper Base for 400 and 50,000 W/m²K Heat Transfer Coefficients [1].

## Conclusion

This article shows that while a vapor chamber presents exciting technology, some calculations should be made to justify its use. As shown above, in some situations a solid copper block might provide better thermal performance than a VC. To use a VC instead of solid copper must be justified, for example, to reduce weight. Some vapor chambers have a power limit of 500 Watts. Exceeding this value might cause a dry out, as with a heat pipe, and could increase the vapor temperature and the pressure. The increase in internal pressure can deform the VC surfaces, or cause leakage from the welded joints. Other factors that need to be addressed include, cost, availability, and in special cases, the vapor chamber's manufacturability.

## References:


1. Mehl, D., Dussinger, P., Use of Vapor Chambers for Thermal Management, ThermaCore Inc.
2. Chi, S., Heat Pipe Theory and Practice, Hemisphere Publishing, 1976.
3. Prasher, R., A Simplified Conduction Based Modeling Scheme for Design Sensitivity Study of Thermal Solution Utilizing Heat Pipe and Vapor Chamber Technology, J. Electronics Packaging, Vol. 125, 2003.
4. Wei, X, Sikka, K., Modeling of Vapor Chamber as Heat Spreading Devices, ITHERM 2006.