Parameters

Affecting Vapor Chamber Performance

Vapor chambers are flat heat pipes with very high thermal conductance. The idea of heat pipe was first proposed by Gaugler [1]. However, only after its invention by Grover [2, 3] in the early 1960s, were the remarkable properties of heat pipe realized by scientists and engineers.

In electronics cooling, heat pipes are generally used to move the heat from electronics to heat dissipation devices. For example, in a desktop computer, multiple heat pipes are used to transfer heat from a CPU to an array of cooling fins, which dissipate the heat to ambient environment through convection. Vapor chamber are generally used to spread heat from a small size device to a larger size heat sink, as it is shown in Figure 1.

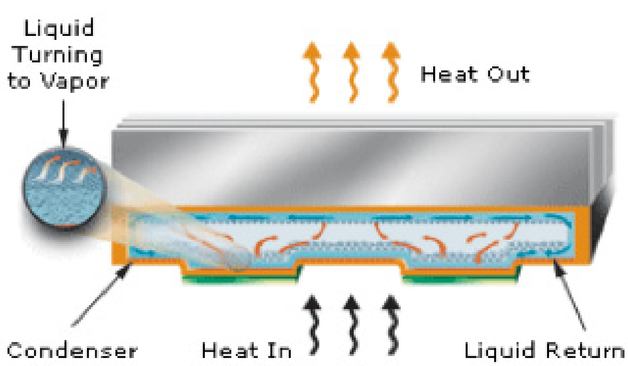

Figure 1. Vapor Chamber [4]

Just like heat pipes, vapor chambers use both boiling and condensation to maximize their heat transfer ability. A vapor chamber generally has a solid metal enclosure with a wick structure lining the inside walls. The inside of the enclosure is saturated with a working fluid at reduced pressure. As heat is applied to one side of the vapor chamber, the fluid at locations close to the heat source reaches its boiling temperature and vaporizes. The vapor then travels to the other side of the vapor chamber and condenses to liquid. In the process of condensation, it releases its latent heat. The condensed fluid returns to the hot side via the gravity or capillary action, ready to vaporize again and repeat the cycle. By using boiling and condensation, the vapor chamber can transfer and spread heat from one side to another side with minimum temperature gradient.

Compared to copper heat spreaders, vapor chambers have the following merits. They have much higher effective thermal conductivity. The pure copper has a thermal conductivity of 401 W/m.°C and the best conductive material (i.e., diamond) has a thermal conductivity of 1000-2000 W/m.°C. The effective thermal conductivity of a well designed vapor chamber can exceed 5000 W/m.°C, which is an order of magnitude higher than that of pure copper. The density of the vapor chamber is much lower than copper. Due to its hollow structure, the heat spreaders designed for vapor chambers are much lighter than those made of copper. These properties make the vapor chamber the ideal candidate for high heat flux and weight sensitive heat spreading applications. However, the cost of the vapor chambers is much higher than copper heat spreaders. Some design limitations also limit the usage of vapor chambers. Vapor chambers don't perform better than cooper heat spreaders in some application and this paper will address the research on the parameters affecting vapor chamber performance.

Wei and Sikka [5] used a conduction model built in FLOTHERM to study the thermal performance of a vapor chamber heat spreader and compared its performance with that of a copper heat spreader. In the FLOTHERM model, the vapor chamber is represented by multiple layers of material with effective thermal conductivities. The schematic of the vapor chamber model is shown in Figure 2.

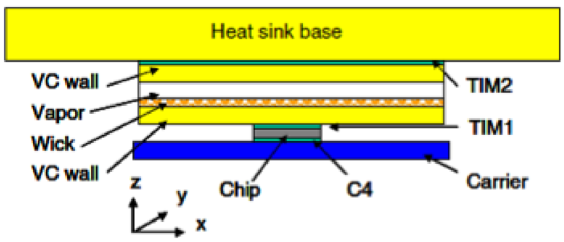

Figure 2. Vapor Chamber Model [5]

Parts	Model	Material/Thermal conductivity (W/m-K)	Dimension (mm)
Carrier	Cuboid	Ceramic/21	42.5x42.5x2
C4	Collapsed cuboid	Solder+underfill/5	10x10x0.075
Chip	Cuboid	Silicon/117 at 100ºC	10x10x0.785
TIM1	Cuboid	Thermal Paste/3.8	10x10x0.114
VC wall-bottom	Cuboid	Cu/385	40.5x40.5x1.5
Wick	Cuboid	Sintered Cu powder/30	40.5x40.5x0.5
Vapor	Cuboid	Water vapor/30000	40.5x40.5x1.0
VC wall-top	Cuboid	Cu/385	40.5x40.5x1.0
TIM2	Cuboid	Thermal Paste/3.8	40.5x40.5x0.1
HS base	Cuboid	Cu/385	90x90x4

Table 1. Model Component Information [5]

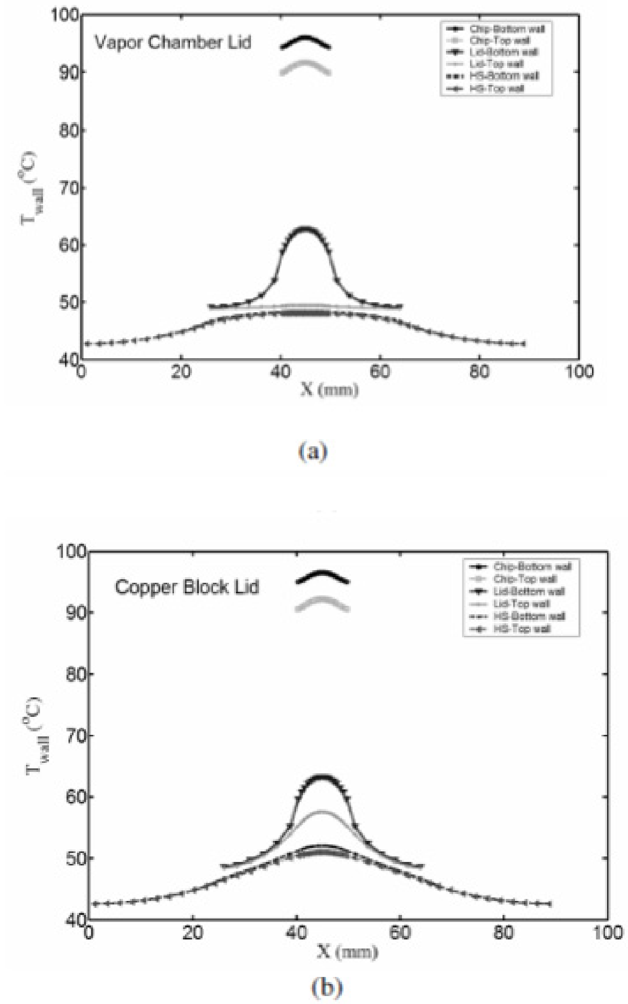

Figure 3. Temperature Distribution Along the Model Centerline (a) Vapor Chamber Heat Spreader (b) Copper Heat Spreader [5]

The size of the vapor chamber is 40.5 × 40.5 × 4 mm and the size of chip is 10 × 10 × 0.785 mm. The component information is shown in Table 1. In the model, all the boundary walls are assumed to be adiabatic except the top surface of the heat sink base, where an effective heat transfer coefficient of 1400 $W/m^2.^oC$ is applied. A uniform heat flux of 100 W/cm^2 is applied at the bottom side of the chip and the ambient temperature is assumed to be 35ºC. The effective thermal conductivities of vapor and sintered wick are assumed to be 3000 W/m.ºC and 30 W/m.ºC, respectively.

Figure 3(a) shows the temperature distribution along the centerline of the model with the vapor chamber as the heat spreader. Figure 3(b) shows the temperature distribution along the centerline of the model with a copper block (40.5 × 40.5 × 4 mm) as the heat spreader. Test results show that the die junction temperature is close for two cases. Across the heat spreader thickness, the vapor chamber has the larger temperature drop because of the low thermal conductivity of the wick (30 W/m.ºC). However, the vapor section of the vapor chamber heat spreader enhances the lateral heat spreading. Thus, it results in a much more uniform temperature at the bottom of the heat sink. In the simulation, the temperature drop across the TIM1 is largest among all components.

Due to its low thermal conductivity, the wick structure of the vapor chamber causes the largest temperature drop across the vapor chamber. To understand the effect of the wick structure, Wei and Sikka [5] did a sensitivity study by changing the wick structure's effective thermal conductivity while maintaining the vapor thermal conductivity at 30000 W/m.^{o}C. The simulation results are shown in Figure 4. By doubling the wick thermal conductivity to 60 W/m.^{o}C, the junction temperature drops 3.5 ^{o}C. The results of another sensitivity study by changing the vapor effective thermal conductivity while maintaining wick thermal conductivity at 30 W/m.^{o}C is shown in figure 5. Clearly the junction temperature is less sensitive to change of vapor effective thermal conductivity. So in the vapor chamber, the thermal resistance of the wick structure is the dominant factor.

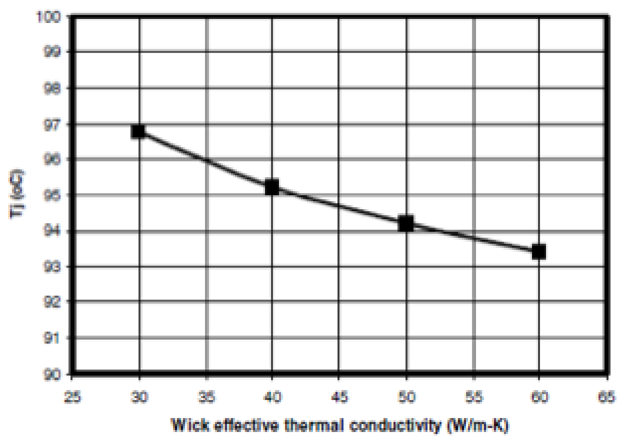

Figure 4. Effects of Wick Thermal Conductivity on Junction Temperature [5]

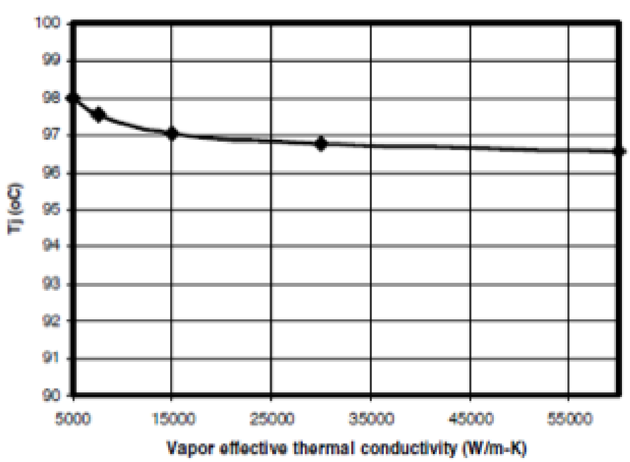

Figure 5. Effects of Vapor Thermal Conductivity on Junction Temperature [5]

of heat sink on junction temperature for vapor chambers and copper heat spreaders. The results are shown in Figure 6. When the heat sink has a low convection heat transfer coefficient, the vapor chamber outperforms the copper heat spreader. With an increase of the convection heat transfer coefficient, the difference between two heat spreaders narrows and the copper heat spreader even outperforms the vapor chamber at a high convection heat transfer coefficient. It is obvious that the vapor chambers are best suited for air-cooled heat sinks and copper heat spreaders are good for liquid- cooled cold plates.

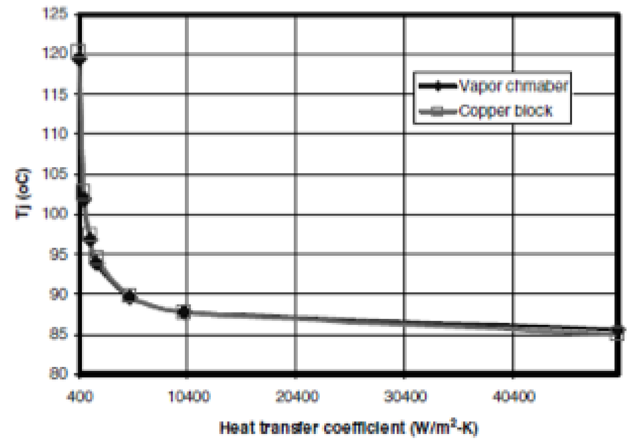

Figure 6. Effects of Heat Sink Convection on Junction Temperature [5]

The effects of the size of heat spreader on die junction temperatures are shown in Figure 7. As shown below, the vapor chamber outperforms the copper heat spreader with its large heat spreader size, which enables it to fully utilize its lateral heat spreading ability.

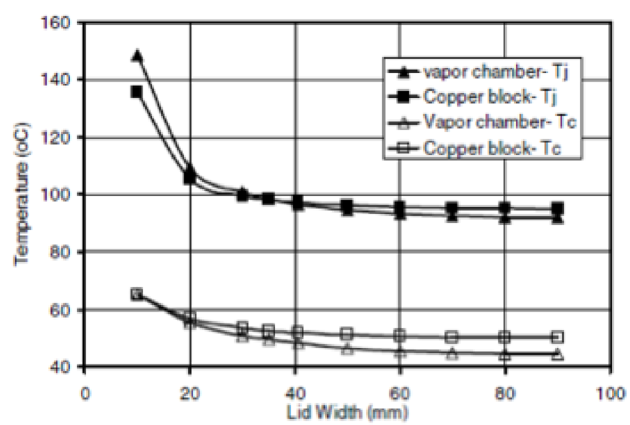

Figure 7. Effects of Heat Spreader Size on Junction Temperature [5]

performance of a vapor chamber and a copper heat spreader. They utilized Infra Red (IR) imaging to visualize the temperature distribution of different heat spreaders under the same heat flux. The dimensions of the vapor chamber and copper heat spreader they studied is 250 × 200 × 5 mm. An electric heat cartridge was embedded in an aluminum block (100 × 50 mm) as a heat source. The aluminum block was mounted at the center of the heat spreaders.

The surface temperature distributions of the tested vapor chamber and copper heat spreader at 40 W/cm^2 heat flux are shown in Figures 8 and 9, respectively. Clearly, the temperature on the vapor chamber surface is lower and more uniform. Because the heat spreading area ratio is larger, the vapor chamber fully demonstrates its superiority over the copper heat spreader.

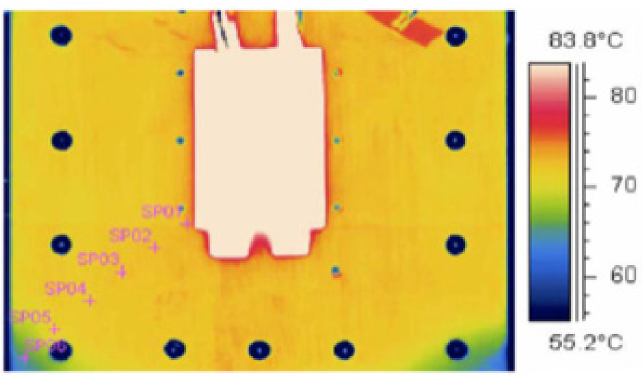

Figure 8. Temperature Distribution of Vapor Chamber Surface [6]

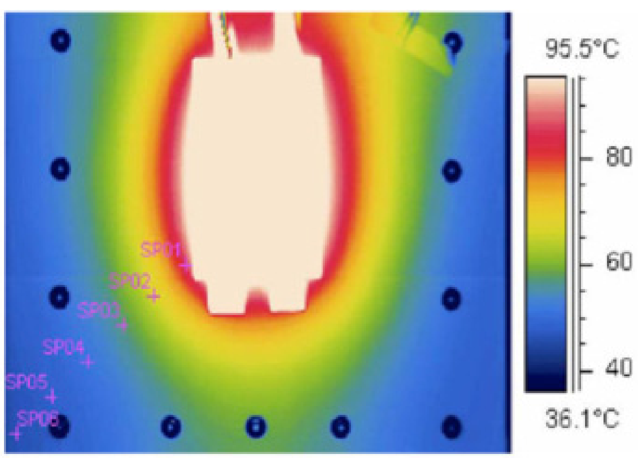

Figure 9. Temperature Distribution of Copper Heat Spreader Surface [6]

To select an appropriate heat spreader for a demanding application, engineers should understand that the performance of the heat spreader is affected by a many parameters, such as device and heat sink size, heat sink thermal resistance and heat spreader thickness. In most high heat flux cases, the vapor chamber is a better choice than the copper heat spreader in terms of performance. They can lower device temperature and make heat sink temperatures more uniform, which will reduce the heat sink thermal resistance. But, in some cases, as mentioned in this paper, the performance differences between a vapor chamber and a copper heat spreader are very small. If the cost and weight of the heat spreader are critical for the application, engineers have to find some intuitive ways or make a compromise to choose or design the right heat spreader.

Reference:

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2. Grover, G. m., US Patent 3229759. Filed 1963.

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6. Boukhanouf, R., Haddad, A., North, M.T., and Buffone, C., Experimental Investigation of A Flat Plate Heat Pipe Performance Using IR Thermal Imaging Camera, Applied Thermal Engineering 26 (2006) 2148-2156, 2006.