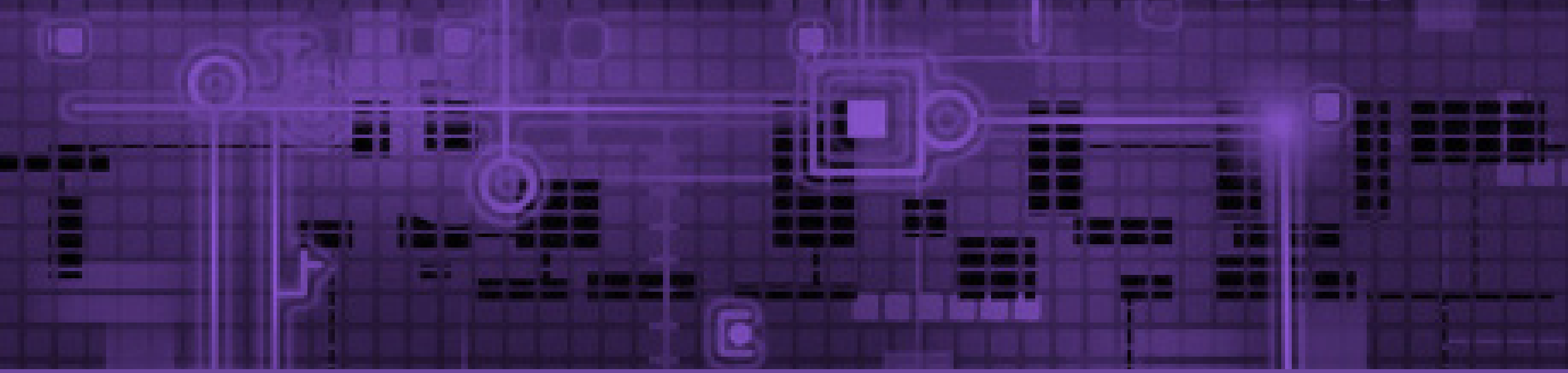

Modeling Vapor Chambers

as a Heat Spreading Device in CFD

As the power dissipated by the devices increases, and the devices get smaller, the heat densities increase rapidly, and heat dissipation gets more localized. The heat fluxes approach 100 W/cm^2 and local heat fluxes at hot spots are even higher, however the proper junction temperature must be maintained to meet performance and reliability requirements. In some cases this temperature has to be as low as 85^{o}C or even lower. This trend drives the need for the fast heat spreading. One such device is a vapor chamber.

Wei et al. [1] attempted to evaluate the feasibility of integrating vapor chambers into a device package as a heat spreader or lid to enhance the heat spreading and to reduce the conduction resistance. In addition, they attempted to quantify the thermal benefit of vapor chamber heat spreader as compared to a solid metal heat spreader. A vapor chamber, just as a heat pipe, is a heat spreading device with large effective thermal conductivity due to the phase change phenomenon. A typical vapor chamber consists of two thin layers of sintered copper powder with a vacuum space in the middle enclosed by two thin stamped copper parts. There is also a small amount of liquid, typically water, saturated in the wick. Unlike the heat pipe, the vapor chamber consists of only two sections, an evaporator and a condenser, and the condenser covers the entire top surface of the evaporator. Heat enters the evaporator section located on top of the heat source. The liquid saturated in the wick evaporates, and the vapor carries the heat into the vapor space. The vapor flows from the higher pressure region in the evaporator to the condenser section and rejects the heat to the ambient air through condensation and external cooling. The liquid flows back to the evaporator section through the capillary action in the wick structure.

Wei at al [1] built 2 conduction models of the thermal interface between the heat generating chip and the ambient air in the CFD computational tool called Flotherm. One of the models had a vapor chamber as the heat spreader to quantify the thermal performance, the other model had a solid copper lid, to compare the performances. As a model the study used a single chip package with a chip size of 10x10 mm mounted on 42.5x42.5 mm carrier. In the studies with the fixed size of the lid, the size of both the vapor chamber lid and the copper lid was 40.5x40.5x4 mm.

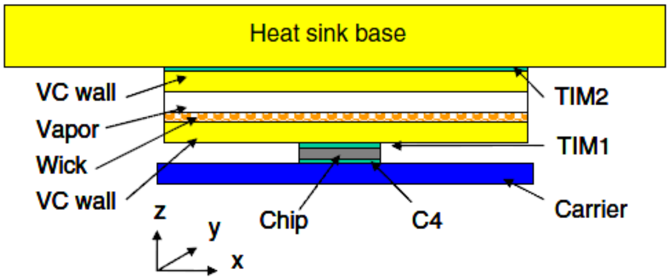

Figure 1. Schematic of the Physical Model [1]

The vapor chamber is represented by multiple solid layers, as shown on Fig. 1, with effective thermal conductivities as follows:

1. For the vapor chamber wall thermal conductivity of copper was assigned at 385 W/m·K

2. For the wick structure consisting of sintered copper powder thermal conductivity was assigned at 30 W/m·K

3. For the water vapor effective thermal conductivity was assigned at 30,000 W/m·K

The results of the simulation showed that the thermal performance for both cases was similar. However, the temperature drop across the lid thickness was higher for the vapor chamber because of the relatively low thermal conductivity of the wick structure. On the other hand, the temperature across the width of the lid was a lot more uniform for the vapor chamber because of the aggressive lateral heat spreading. It was also clear that the resistance of the thermal interface material, located between the chip and the lid, is the dominant resistance.

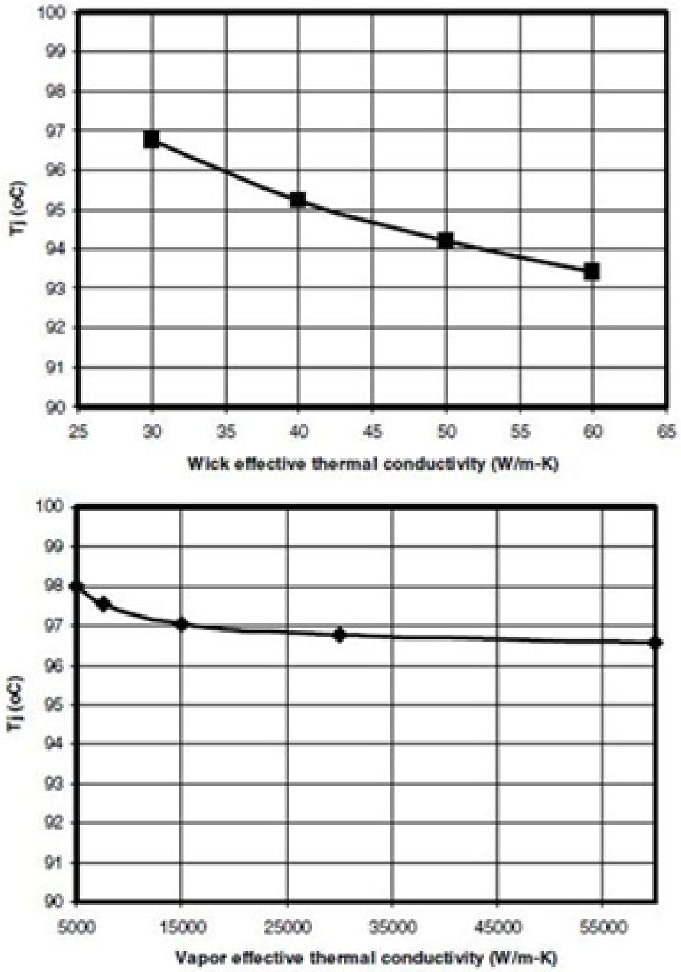

Figure 2. Effects of Wick and Vapor Thermal Conductivity [1]

A parametric study was conducted to explore the effect of various parameters of the interface as follows:

1. A sensitivity study was conducted to determine the effect of thermal conductivities of the wick structure and the vapor space.

In the first part of this study, the vapor effective thermal conductivity was fixed at 30,000 W/m·K while the wick thermal conductivity varied between 30 and 60 W/m·K.

In the second part of this study, the wick thermal conductivity was fixed at 30 W/m·K with the vapor thermal conductivity varying between 5,000 and 60,000 W/m·K.

The results clearly showed that the effective conductivity of the wick structure affects the performance more significantly than the vapor thermal conductivity. Given the fact that the effective thermal conductivities for the wick structure and the vapor space are still not well defined due to the complexity of the geometry and the phase change phenomena, a conservative estimate should always be used for the wick structure thermal conductivity. For the vapor thermal conductivity it is safe to use a typical high number since the overall performance is not sensitive to this value.

2. A sensitivity study was conducted to determine the effect of the convective heat transfer coefficient.

In the main study, the effective heat transfer coefficient was fixed at 1,400 W/m^2·K at the surface of the heat sink base. However this coefficient can vary significantly for different air flow conditions, and different types of heat sinks. In this study the heat transfer coefficient varied from 400 to 50,000 W/m^2·K using a vapor chamber lid and a solid copper lid. The results showed that at a low heat transfer coefficient, the vapor chamber provides a better hat transfer than the solid copper lid. The performance difference decreases with increasing heat transfer coefficient. The solid copper lid actually outperforms the vapor chamber at the extremely high heat transfer coefficient of 50,000 W/m^2·K. With the high heat transfer coefficient, the heat flow pattern is close to one dimensional, which overcomes any benefit of vapor chamber lateral spreading. Therefore, the vapor chamber is more effective in air-cooled heat sinks with a limited heat transfer capability.

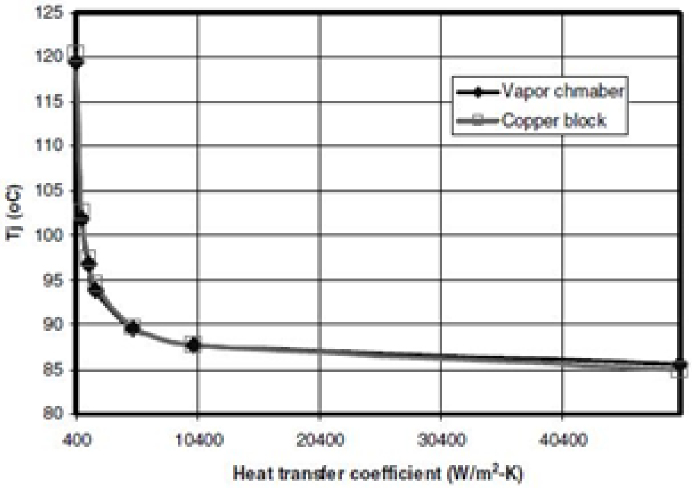

Figure 3. Effects of Effective Convective Heat Transfer Coefficient [1]

3. A sensitivity study was conducted to determine the effect of the lid width.

In this study the lid width varied from 10 mm to 90 mm using a vapor chamber lid and a solid copper lid. The results of the study showed that a solid copper lid outperforms a vapor chamber lid of the same size at a smaller footprint area. Since the major benefit of the vapor chamber is the enhanced lateral spreading, the vapor chamber is a lot more effective when a large surface area change and large spreading resistance occurs. From the purely thermal point of view, the vapor chamber is more suitable for direct heat sink attachment where the entire heat sink base is available for heat spreading.

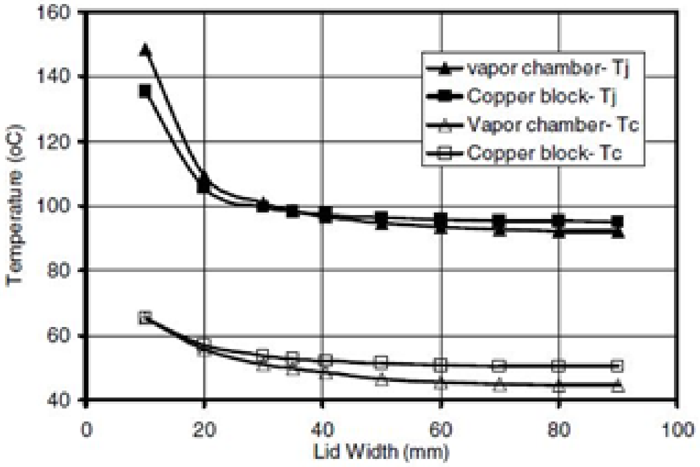

Figure 4. Effects of lid Width on the Thermal Performance of both Vapor Chamber and Copper lid [1]

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