Heat Spreading

with Copper, Silicon, and Heat Pipes

Power dissipation is a drastic issue to be tackled due to the continued integration, miniaturization, compacting and lightening of electronics systems [1]. Heat spreaders are not only chosen for their thermal performance; other design parameters include weight, cost and reliability. Depending on the application, different priorities will influence the design parameters. For example, weight and reliability are important for a space application. This article covers heat pipe technology, including a discussion of the different types of heat pipes. Additionally, the article provides comparisons between aluminium, silicon, copper and heat pipe-based heat spreaders.

Tubular Heat Pipes

A heat pipe is a heat transfer device that uses two phase flow to transfer heat energy. A heat pipe system is composed of a sealed, evacuated container, partially filled with a liquid so that liquid/vapor equilibrium is obtained. A wick structure or a specific envelope shape enables efficient capillarity. Heat applied to the evaporator section by an external source is conducted through the pipe wall and wick structure where it vaporizes the working fluid. The resulting vapor pressure drives the vapor through the adiabatic section to the condenser, where it condenses, releasing its latent heat of vaporization to the heat sink. The capillary force created by the menisci in the wick pumps the condensed fluid back to the evaporator section. This provides the driving force for liquid in the heat pipe. The operating principle as described here is shown schematically in Figure 1. More details on wicks and the orientation dependency for the performance of heat pipes can be found in [2].

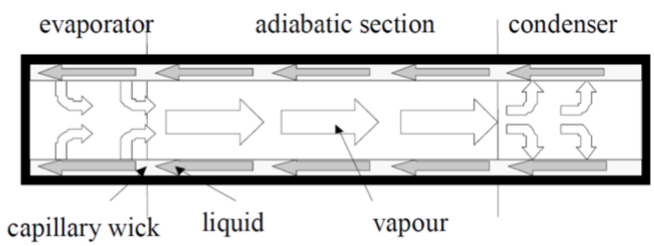

Figure 1. Operating Principle of a Heat Pipe [1].

Flat Heat Pipes

In order to dissipate very high heat flux densities, the required heat sink must often be larger than the devices [3]. Temperature gradients occur in the heat sink base due to the heat spreading resistance in the material. The results are hot spots and a non-uniform heat flux at the heat sink level. Consequently, the heat sink performance is reduced. A method for lowering the spreading resistance in the heat sink base is to use higher conductivity materials as the base material, such as copper. Alternatively, materials with higher thermal conductivity than the heat sink can be embedded on the heat sink base. The added material can be copper or even diamond.

Yet another choice to the aforementioned material is the use of flat heat pipes. A flat heat pipe functions like a convectional tubular heat pipe, the main difference being the form the wick takes to enable liquid distribution over a wide surface area [4]. The operating principle is quite different because the evaporator and the condenser are on opposite faces of the heat pipe [3], as shown in Figure 2. As in a conventional heat pipe, the capillary wick transports the liquid to the heated region. The benefits of a flat heat pipe include multi- component array temperature flattening, multi-component array cooling and its additional use as a module wall or mounting plate [4].

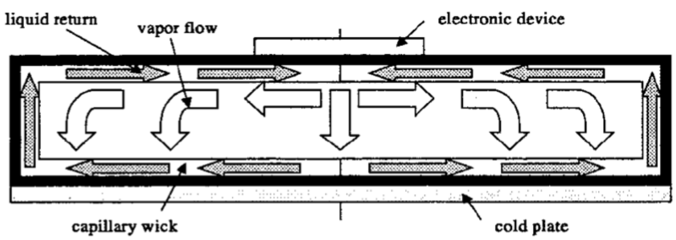

Figure 2. Operating Principle of a Flat Heat Pipe being used as a Heat Spreader [3].

Avenas et al. have published data comparing heat pipe performance with that of plain copper and plain silicon [3]. Each comparison features the same dimensions between the heat pipe and the plain solid material. Figure 3 shows that there is an average improvement of 56% against plain copper and an average 36% against plain silicon.

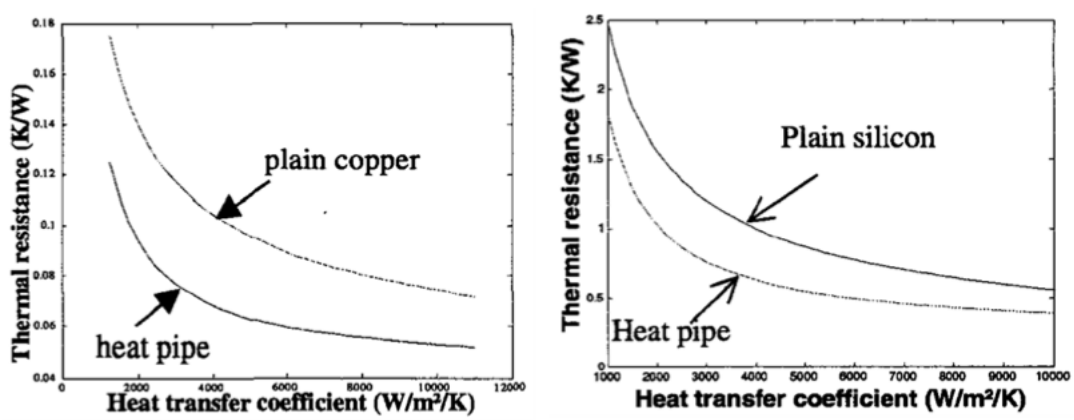

Figure 3. Comparison of the Thermal Resistance of a Heat Pipe vs. Plain Copper (a) and vs. Plain Silicon. Each Comparison features the Same Dimensions between the Heat Pipe and the Plain Solid Material [3].

Micro Heat Pipes using Silicon as the Heat Pipe Material

Babin [5] states that a micro heat pipe is a heat pipe in which the mean curvature radius of the liquid-vapor interface is comparable in magnitude to the channel hydraulic radius. Unlike tubular and flat heat pipes, micro heat pipes do not contain a wick material. The capillary force necessary for transporting the condensate to the evaporator is attributed to the sharp edges in the grooves inside the heat pipe structure. Therefore, the design of the capillary structure is critical to the maximum heat transfer rate of the micro heat pipe. Triangular, rectangular, star and rhombus groove micro heat pipes have been explored in different applications.

Hopkins et al. [6], Plesch et al. [7] and Cao et al. [8] provide theoretical and experimental results on rectangular grooved copper heat pipes with water as their working fluid. Plesch et al. [7] and Launay et al. [9] have published data for silicon-based micro heat pipes using water or methanol as the working fluid. It was found that the effective conductivity of the heat pipe increased by 10 % [7] to 300 % [9] when compared with pure silicon.

The flat heat pipe discussed in the previous section had dimensions of 127 x 76 x 5 mm [3]. Micro heat pipes that have been discussed in the literature can be in the order of 50 x 50 x 1 mm [1]. A schematic of a micro heat pipe is shown in Figure 4. Figure 5 presents a top view of the capillary wick structure in the micro heat pipe.

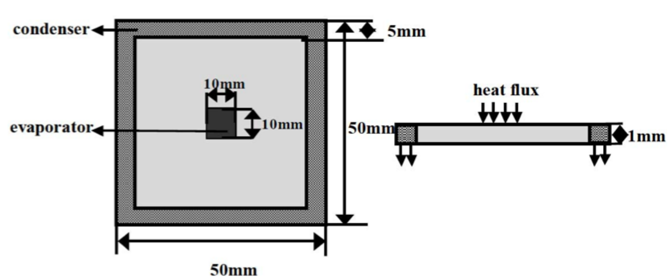

Figure 4. Silicon Heat Pipe Design [1].

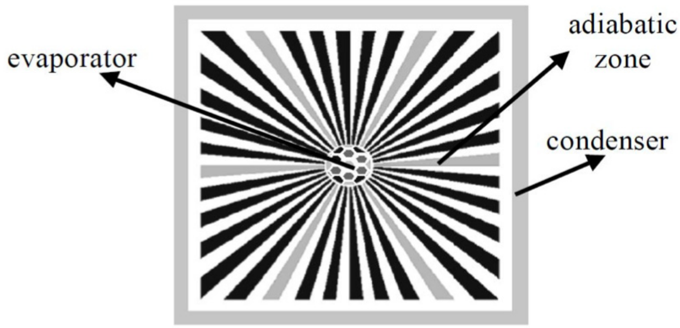

Figure 5. Capillary Wick Design of the Heat Pipe [1]

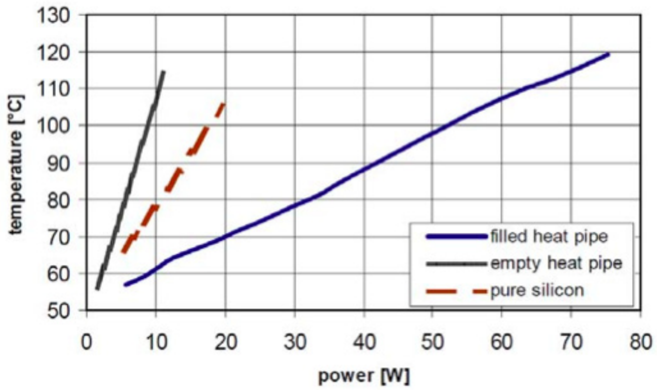

Figure 6. Maximum Temperature on the Dissipative Component Depending on the Input Power [1].

The micro heat pipe discussed by Ivanova et al. [1] is a heat pipe with a capillary structure which is able to assure heat spreading from the dissipative components to the metallic frame in two directions. Silicon was chosen due to the critical weight requirement of the system. The heat pipe had a mass lower than 6 g. Integration of a micro heat pipe provides better transfer of the heat flux dissipated by the components to a cooler (e.g. cool box, heat exchanger) and then reduces the thermal resistance between the component and the cooler [1]. The temperature on the substrate is homogenized and the occurrence of hot spots is eliminated.

Figure 6 shows the maximum temperature at the chip level versus the input power for three configurations: an empty micro heat pipe, a silicon plate and a filled micro heat pipe. The water temperature in the copper cold plate is fixed at 50°C. The operational heat pipe has a capacity to spread more than 70 W/cm^2 with a temperature on the resistor level less than 120°C. For the pure silicon spreader only 20 W/cm^2 of heat flux can be achieved.

Summary

This article has discussed the use of heat pipe heat spreaders and micro heat pipes for heat spreading applications. Their performance was compared to that of pure silicon and copper heat spreaders. For heat pipe heat spreaders there was an average improvement of 56% and 36% respectively when compared to equivalent silicon and copper heat spreaders. When a micro heat spreader was used, the effective conductivity of the heat pipe increased from 10% [7] to 300% [9] when compared with pure silicon. A micro heat pipe design by Ivanova et al achieved 70 W/cm^2 of heat dissipation where the equivalent silicon design was only able to dissipate 20 W/cm^2. It has been shown that heat pipes are an interesting alternative to plain solid material heat spreaders. Their application becomes more common as the component size diminishes. Their use in space applications, where the outside ambient temperature is around -60°C, is highly recommended.

References:

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