Vapor Chambers

A vapor chamber is a high-end thermal management device that can evenly dissipate heat from a small source to a large platform of area (see Figure 1). It has a similar construction and mechanism as a heat pipe except that a heat pipe typically refers to a tube that transfers heat from one single point to another while a vapor chamber refers to a plate that spreads heat from one point to a two-dimensional area (see Figure 2).

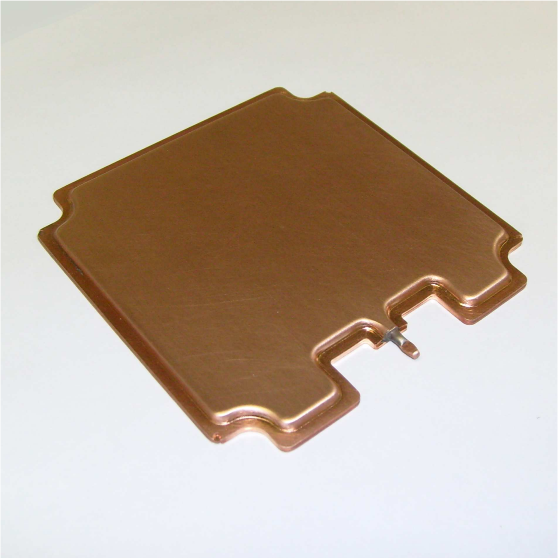
Figure 1: Example of vapor chamber

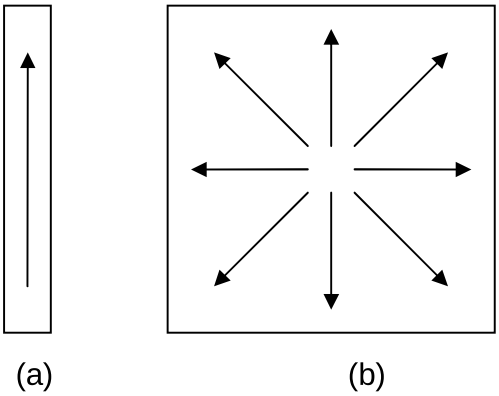
(a) (b)

Figure 2: Comparing the heat pipe and vapor chamber. (a) Heat pipe transfers heat from one point to another, (b) vapor chamber spreads heat in a 2-dimensional pattern

Benefits of Using Vapor Chambers

A properly designed vapor chamber with heatsink can improve the thermal performance by 10-30% over copper, and heat pipe based solutions. In mission-critical applications, it not only lowers the temperature by a number of degrees, but sometimes eliminates the need for using a fan on top of the heatsink plus significantly prolongs the life expectancy of the system and lowers the noise. It is also perfect for low profile applications where height vs. performance is critical.

In addition, a vapor chamber is much lighter than copper, due to its internal chamber structure. In many cases, a vapor chamber based heatsink weighs similar to an extruded aluminum heatsink, but works much better than a copper heatsink

How It Works

A vapor chamber consists of a sealed vacuum vessel, with an internal wicking structure, and a small amount of working fluid that is in equilibrium with its own vapor.

The low pressure inside the chamber allows the fluid to vaporize at a temperature much lower than its normal boiling temperature. When heat is applied to the vapor chamber, the fluid near that location immediately vaporizes and rushes to fill the entire volume of the chamber (driven by pressure difference). When the vapor comes into contact with a cooler wall surface, it condenses, and releases its latent heat of vaporization. The condensed fluid returns to the heat source by capillary action of the wick structure. As the vaporization and condensation cycle repeats, heat is moved for the heat source to the entire volume of the chamber, resulting in a uniform temperature distribution on its surface.

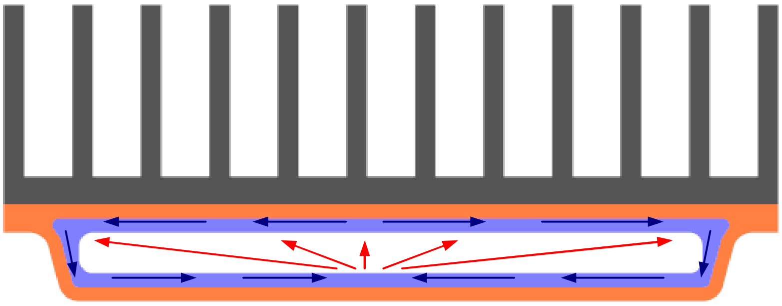

Figure 3: Vapor chamber mechanism (red arrows indicate vapor flow direction; blue arrows indicate liquid flow direction)

Material

The vacuum vessel is typically made of copper, and sealed around the perimeter. The wick can be made of many different substances. The most common way is to sinter copper powder to the inside wall of the vessel.

Many fluids can be used as the working fluid of the vapor chambers. But in most CPU, GPU and LED cooling applications, water is selected as the working fluid, because of its high latent heat, high surface tension, high thermal conductivity and right boiling temperature, not to mention the environmental concerns and cost.

Effective Thermal Conductivity

The effective thermal conductivity of a vapor chamber is usually 5 to 100 times the conductivity of copper, but it is application specific.

The thermal resistance of a vapor chamber comes from many sources. The 2 major factors are the evaporation resistance and transport resistance. Transport resistance is distance dependent, but it is relatively small compared to the evaporation resistance. Since the dominating evaporation resistance is independent of size, the larger the vapor chamber is compared to the heat source, the greater is the effective thermal conductivity.

In a coarse calculation or CFD simulation, it is not uncommon that a uniform and isotropic thermal conductivity, say 10000 W/m-K which is 25 times the thermal conductivity of copper, is assigned to the entire volume of the vapor chamber.

Reliability

Like heat pipes, vapor chambers are very reliable thermal devices. They do not have any moving parts or use any corrosive materials. The working fluid and wick structures are permanently sealed in a copper vessel. There is no mechanical or chemical degradation over time that has been reported by Radian customers. The following tests are routinely performed to confirm the durability and reliability of vapor chambers:

- Thermal Shock Test
- Accelerated Life Test
- Freeze Thaw Test
- Burst Test
- Cosmetic Degradation Test

Integration of Vapor Chamber to Heatsink

A vapor chamber can be integrated with both aluminum or copper heatsinks. The simplest method is to solder a vapor chamber to the base of an extruded heatsink. A more thermally efficient method is to solder a stack of stamped fins directly to the surface of a vapor chamber. To improve the dimensional integrity, these fins are often interconnected by locking tabs produced in the stamping stage.

Gravity and Centrifugal Forces

The return of fluid to its boiling location is primarily driven by the capillary force, but gravity and centrifugal force can also contribute to some degree. To utilize the external forces, it is important to design the vapor chamber, such that the gravity or centrifugal force, is working in the direction that drives the fluid from its cold side to the hot side. For example, in a spinning system, the heat source (hot spot) should be located in the outer side of the PCB, and the fins should be located closer to the spinning center.

Design Guidelines

The following table shows the suggested operation conditions for typical applications. They are not necessarily the maximum capabilities of vapor chambers.

Ambient temperature	0 - 85 ºC
Power	20 - 300 W
Heat Flux	Up to 300 W/cm^2
Size (width and length)	50 to 200 mm
Thickness	3 mm and up
Flatness	0.1 mm in every 25x25 mm area
Life (MTBF)	80000 hours
Through Holes	Allowed
Thermal cycling	Tested 200 cycles between -40 and 85 ºC