Ultra-Thin Titanium Vapor Chambers:
Enabling a New Competitive Advantage in Mobile Devices

Overview

This paper discusses two-phase technologies and how advancements in vapor chambers, specifically the development of Ultra-Thin Titanium Vapor Chambers, are enabling the next generations of mobile and wearable devices. Currently these technologies offer a significant advantage in performance and user experience. However, with the increasingly rapid evolution of high performing mobile electronics, Titanium solutions and ultra-thin vapor chambers may eventually be the new standard solutions for cooling these devices. Utilizing Boyd Corporation's decades of expertise and experience in two phase and ultra-thin cooling technologies, this paper will provide an outline for the future use of Titanium Vapor Chambers for maximum performance and design flexibility.

THE CURRENT MARKET & MARKET TRENDS

As the global trend towards electronification continues, the market for wearables and mobile devices is evolving at an unprecedented pace. Devices that were previously cumbersome or limited in functionality are benefiting from the miniaturization of electronics. Every industry, especially Mobile, Medical, Telecommunications and 5G-related Consumer Electronics is leveraging more mature electronics and developing new applications for lightweight, mobile devices.

Engineers are struggling to effectively handle excess heat as consumers demand smaller, thinner, more powerful devices with more options and capabilities. Designing and manufacturing devices in reduced volumes with increased processing power generates high heat loads that need fast dissipation or will suffer device failure, lower reliability, shorter lifetime, and user discomfort. This is especially true for wearable and mobile devices that operate in close contact with the user and require lower touch temperatures such as smart watches, smart phones, medical treatment and testing devices and Augmented Reality (AR).

In just over 10 years, smart phones have gone from ~4GB to a capacity of over 500GB.

Portable & Wearable Medical Devices are more powerful for better patient care.

In addition to these consumer demands, the advent of 5G and the IOT has led to entirely new applications ranging from electric vehicles to smart home appliances to new portable medical monitoring and treatment devices. The expansion of these applications, as well as more powerful mobile devices, has led to a market need for longer battery life, smaller batteries and more efficient battery charging.

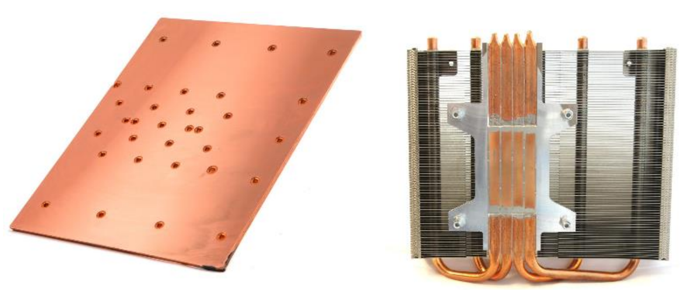
New portable applications, as well as worn and mobile devices, require lower touch temperatures for safety in the home and in the field. They also need to allow for burst or short duration, high performance modes. Applications that require this level of control range include gaming consoles and AR devices, portable medical devices that are safe for children & seniors and drones for home, commercial, or military use.

For each of these upward trends there is one major barrier: thermal management. Heat must be transferred and dissipated quickly, consistently, and reliably from processors, batteries, or heat sources to ensure the performance and safety of the device. This can be extremely difficult in powerful, compact packages that need to be mobile or portable. Active air cooling or liquid cooling alone are often too large and cumbersome and come with their own complications such as acoustics, weight, and vibration. To meet these usage restrictions, two-phase cooling, also known as phase change cooling, has emerged as the best option for managing heat in smaller applications, most notably ultra-thin heat pipes and vapor chambers.

New wearable technologies will revolutionize how we interact with our environment.

CURRENT USE OF TWO-PHASE COOLING IN WEARABLE & MOBILE DEVICES

Two phase cooling is a passive thermal technology that transfers heat quickly by utilizing a trace amount of liquid in a vacuum sealed envelope with a wicking structure to transfer heat through a cycle of condensation and evaporation. This is most often accomplished with a linear copper tube structure known as a heat pipe or in a flatter, planar geometry known as a vapor chamber. For more information on how two-phase cooling works, visit the boydcorp.com Two-Phase Cooling section.



Current Two-Phase Solutions.

Most Notable Features of Two Phase Cooling:

PASSIVE

Two-phase cooling has no moving parts and operates on the laws of thermodynamics and capillary forces, making these solutions silent, efficient and extremely reliable with no inner wear and tear. This enables longer product lifetimes with no degradation in performance, improved acoustics and better warranties due to lower temperatures.

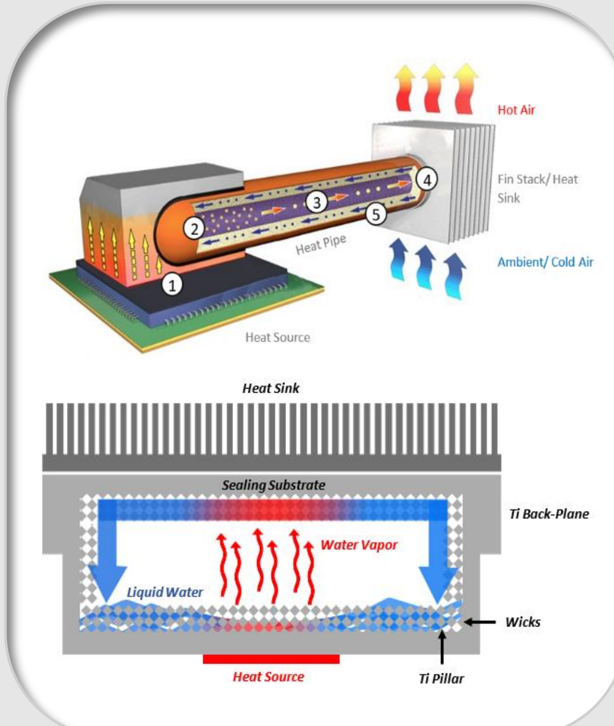
HIGHLY EFFICIENT

Vapor chamber solutions and heat pipes have a conductivity of 10X – 100X that of solid thermally conductive materials such as copper, aluminum, and graphite. They are also much lighter and use less material than solid conductors. This means that they can transport more heat with less weight in the same volume, or, vice-versa, they can transport the same amount of heat in a much smaller weight and volume.

This feature enables slimmer, lighter applications with higher performance that allow product development teams, thermal architects, & engineers a competitive advantage in size and features.

Vapor chambers are especially effective as they are utilized for planar, X-Y spreading while heat pipes are typically relegated to enhancing heat sink base spreading or increasing their fin efficiency. Spreading the heat from single or multiple chips over the increased surface area of vapor chambers creates more uniform heat transfer, enables skyline geometries and improves cooling.

How Two-Phase Cooling Works



1. *Heat enters the heat pipe or vapor chamber.*
2. *Small amount of fluid evaporates into a vapor.*
3. *Vapor carries the heat to the cooler part of the solution.*
4. *Vapor condenses back to a working fluid, releasing the heat.*
5. *Fluid is pulled back down the inner wick structure through capillary action.*
6. *Cycle Repeats.*

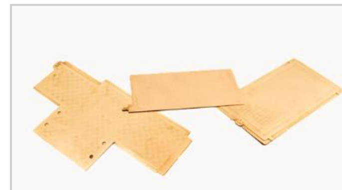
The high efficiency and efficacy of both vapor chambers and heat pipes also enable lower, more regulated touch temperatures. Improved heat spreading also improves user safety and comfort and decreases the likelihood of overheating if the device is left running constantly or for longer than average use times. This mitigates user complaints of device failure due to overheating, acoustic issues or even catching fire.

Ultra-Thin Titanium Vapor Chambers

ENABLING A NEW COMPETITIVE ADVANTAGE IN MOBILE DEVICES

COST EFFICIENT

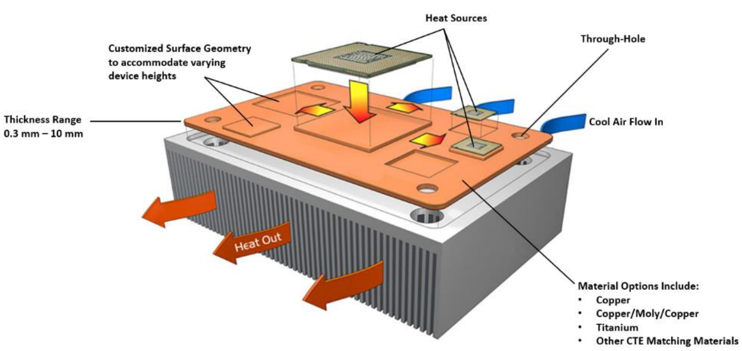
Less weight and materials and improved performance also generate cost savings. Better cooling allows for smaller solutions and BOM savings or more room for more components and added functionality. Cost savings can be further augmented with advanced engineering and Design for Manufacture (DFM) techniques like those utilized at Boyd. Through effective modeling and testing for optimal performance and designing specifically for scalable manufacturing from prototypes to high volume, cost savings can be further improved and passed on to the end customer.



Above: Heat Pipe Assemblies
Below: Thin Vapor Chambers

INCREASED DESIGN FLEXIBILITY

The wicking structure allows vapor chambers and heat pipes to operate in any orientation, including against gravity with the evaporator higher than the condenser, with minimal effects on performance. This ability makes them ideal for mobile, portable, and consumer electronics that need to operate in various orientations including landscape, portrait and inverted.



In addition to multiple orientations, these solutions offer increased design flexibility for unique and high tolerance geometries. Vapor chambers are especially flexible in design as they can accommodate various device heights and through holes for mounting. Utilizing alternate materials, such as titanium, increases the level of customization, offering better performance and key market differentiation.

As Boyd continues to innovate, our techniques have evolved to make the best use of design and materials to further enhance these features for the most optimal cooling and ideal form factors for mobile, portable and wearable devices. Boyd two-phase innovations incorporate new manufacturing processes and advanced additive manufacturing practices to further improve cost savings, ease of manufacture, design flexibility and overall thermal performance.

Key innovations include:

- Reaching an unprecedented level of wick customizations and performance matching to highly specific or varying application and user requirements.

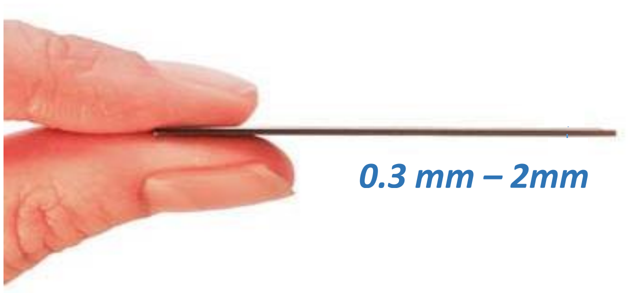
- Proprietary methods for enabling unique and complex geometries in a way that traditional methods could not produce easily or with the required level of cost efficiency.

- Advanced manufacturing techniques to integrate multiple geometries and features in a single process to reduce fabrication times. This enables cost savings in labor and materials as well as shorter lead times.

The consideration and optimization given to thermal management has become a key selling point for many of our customers marketing new technologies. Heat is one of the final barriers to end-user device innovation. Breakthroughs such as Ultra-Thin Titanium Vapor Chambers are a new tool that can help create a competitive advantage to those who employ them.

INNOVATION SPOTLIGHT: BOYD ULTRA THIN TITANIUM VAPOR CHAMBERS

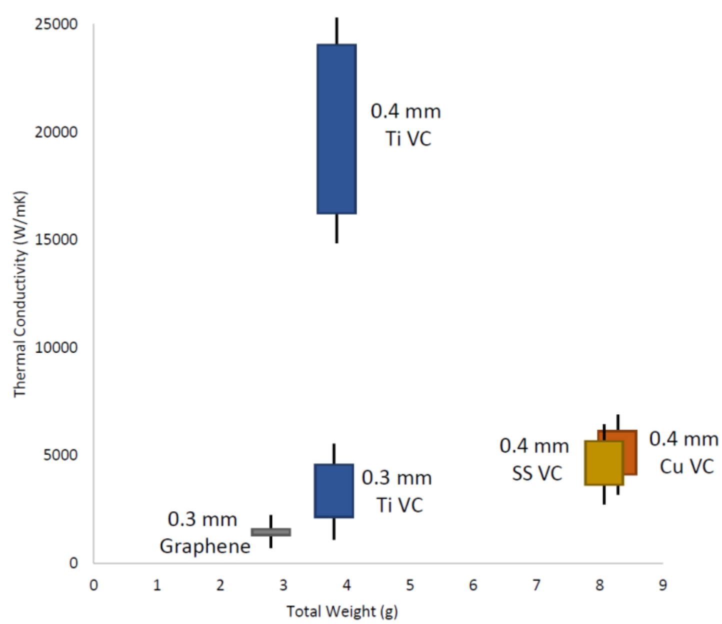
Boyd vapor chamber innovations have recently culminated with the development of Ultra-Thin Titanium Vapor Chambers. Electronic devices, especially mobile applications, are pushing the boundaries of performance, capacity, and capabilities to the brink of what can be accomplished with traditional cooling technologies. And yet, consumers continue to demand smaller, better performing, faster, quieter and more reliable devices than ever before, all without significant impact on cost. Extremely thin, lightweight Titanium vapor chambers are the logical and logistical step in the evolution of thermal management and market differentiation for these applications.



Introducing Boyd Ultra-Thin Titanium Vapor Chambers

Boyd's development of Titanium as well as Stainless Steel vapor chambers enable the benefits of additional structural strength, reduced weight, and streamlined assembly which can accommodate inherent complexities for the growing matrix of mobile, wearable, and portable applications. They offer significantly improved thermal conductivity over 0.3mm graphite solutions with increased design flexibility. Boyd's Ultra-Thin Titanium Vapor Chambers are also designed to increase uniformity for heat spreading and transfer, enabling these solutions to cool more efficiently.

The use of Titanium allows for even thinner solutions with maximum performance at a 0.30-0.5mm thickness, much thinner than even ultra-thin heat pipes that average at 1.0-1.5 mm.



Uniform, more efficient heat spreading in lower profile applications.

Sample Size: 100mm x 50 mm	Total Weight (gr)	Thermal Conductivity (W/m.K)
0.3 mm Stacked Graphene	2.8	1300
0.4 mm Copper VC	8.1	4000 ~ 6000
0.4 mm SS VC	8.2	3700 ~ 5700
0.4 mm Ti VC	3.9	16000 ~ 24000
0.3 mm Ti VC	3.8	2000 ~ 4500

Material	Tensile Strength (Mpa)	Density (kg/m^3)	Specific Strength (kNm/kg)
Copper (Cu)	220	8960	24.5
Stainless Steel (SS)	505	7700	65.5
Titanium (Ti)	480	4500	106.6

Titanium has as much as 5-10x the specific strength (KN-m/kg) and yield strength (MPa) to similar structures comprised of copper with a much lower coefficient of linear thermal expansion (CTE) than copper or aluminum. This enhanced mechanical strength enables the vapor chamber to be designed to function as both a thermal device and a mechanical structure, allowing product designers to remove standalone mechanical infrastructures and frames. The integrated functionality of a Titanium Vapor Chamber creates more space within the design for additional components and allows better integration with other technologies such as system components or EMI Shielding to further optimize device performance and reduce overall product costs. This dual functionality combined with Titanium Vapor Chambers' design flexibility and Boyd's ability to integrate a multitude of material and thermal technologies complementary to the vapor chamber results in simplified sourcing requirements, lower bill of material expenses, faster speed to market, and overall reduced device costs while maintaining the highest performance and reliability in the market.

The evolution of the vapor chamber does not stop at design and improved materials for the envelope; Boyd vapor chamber innovations also include utilizing advanced working fluids. Although water is still the primary working fluid and highly effective, some applications such as those used in aerospace and extreme environments have requirements that make water unsuitable. This is especially true in environments with extreme temperatures or thermal cycling. It is imperative to match fluid and material properties to allow for proper functionality. Using incompatible materials can lead to corrosion, shorter lifetimes or loss of performance.

WHAT IS NEXT?

The capacity and potential for Ultra-Thin Titanium Vapor Chambers in mobile and wearable devices is as limitless as processing power, storage and features continue to evolve. Customer demands continue to grow as end users expect smaller profiles, lighter weight, better reliability, improved features and connectivity, and faster processing. The most significant barrier to satisfying these demands is handling the vast amount of heat generated in these smaller packages without hindering mobility, user safety and comfort and performance.

Smart technology will keep evolving to be more prevalent, smaller, lighter and better connected.

This requires that our cooling methods advance ahead of the products to accommodate new generation technologies and market demands. Preparing now, ahead of new product design projects, by delving into these new cooling methods is the best way to engender true competitive advantage in the wearable and mobile marketplaces. Advancements in two-phase cooling and integrated two-phase technologies are the most promising next steps in delivering adequate cooling to these devices so they can deliver the level of innovation that customers seek.

Boyd Corporation's decades of innovation expertise, experience, resources and unique approach to integrating multiple functionalities into a streamlined product have the company poised to produce Titanium Vapor Chamber solutions in 2020. Boyd has been tackling thermal challenges for over 90 years and has contributed to every major advancement in two-phase cooling technologies for the last 30 years, including being the first to bring Ultra-thin Titanium Vapor Chamber solutions into mass production. These new Titanium Vapor Chambers are the next step in that evolution as they provide the thinnest, most efficient cooling while offering the adaptability of design necessary for mobile and wearable devices.

To receive more information regarding Boyd Ultra-Thin Titanium Vapor Chambers, please visit the TiVC section at www.boydcorp.com.