ADVANCED COOLING TECHNOLOGIES

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PASSIVE THERMAL SOLUTIONS FOR MEDICAL

Increasing demands for technical innovation and performance are a key driver for the medical devices industry. Next generation medical devices need to be smaller, faster, more precise and more reliable. Medical devices also have the human element to consider. For example, devices that directly contact the skin must be kept below the FDA mandated limits of 41°C. Material selection is also critical due to contamination concerns: copper, for example, can't be used in some devices. Noise from pumps and fans can be irritating and problematic for both the patient and the operator.

With these technical enhancements and the human element in mind, there is escalating importance for passive thermal solutions in medical devices.

EXAMPLES OF THERMAL MANAGEMENT ISSUES IN MEDICAL DEVICES

MRI MACHINES use a lot of power and must maintain tight temperature control to ensure they stay calibrated. Machines must be quiet as well.

SURGICAL DEVICES need to be kept below 80°C for brain surgery, 300°C for laparoscopy surgery to avoid burning tissue.

DNA REPLICATORS need to maintain very tight temperature control ± 0.2°C across the entire process surface.

LASERS have many medical applications. Need to keep temperature constant and footprint small.

ULTRASOUND MACHINES have 6’ water cooling lines to keep handles cool enough to touch. Lines risk of leaking and tripping.

While these are only a few examples, the following principles and technologies are applicable to these medical devices and many others.

TYPES OF THERMAL TECHNOLOGIES FOR MEDICAL DEVICES

Passive Technologies: Heat Pipes, HiK Plates, Vapor Chambers

- Require no input power
- Provide years of reliable operation
- Operate with virtually no noise

Phase Change Material (PCM) Heat Sinks provide the same benefits mentioned above and

- Can be used to handle short term peak loading of thermal input
- Allow system designers to size thermal solution on the average thermal load, not the peak load

Next, we will review each of these technologies, how they work and their benefits in different medical applications.

HEAT PIPES

Heat pipes are sealed vacuum devices that are housed in a metal tube. Inside the tube is a wick structure and a small amount of a working fluid, which will transfer phases from liquid to vapor and from vapor to liquid. Most applications are copper tube/copper mesh and water, but there are several other envelope materials, wick structures and working fluid combinations.

To work, a heat pipe must be in contact with a hot evaporator where the heat goes in and a cold condenser where the heat goes out. The hot and cold temperature difference, or delta T, is the driving force for the heat transfer.

The heat from the evaporator causes the working fluid to vaporize. The vapor then flows to the cooler end where it condenses to a liquid. The condensed liquid then returns to the evaporator by capillary force of the wick structure.

In this way there is constant two phase heat transfer which produces a very small temperature differential with in the heat pipe, typically 2-5°C.

A major benefit of heat pipes is the ability remove heat which enables devices to run at higher power without concerns of over-temping. Heat pipes have significantly higher thermal conductivity than metal conductors, having thermal conductivity ranging from 10,000 up to 100,000 W/mK, versus 400W/m-k for copper for example. Heat pipes require no pumps or compressors and are the lowest cost option beside pure conduction.

Further heat pipes can be bent and shaped to meet countless geometries without affecting its thermal performance. Finally Heat pipes are also rugged, shock and vibration tolerant with decades of good performance in real life environments.

USED FOR

- Discrete point cooling

WHEN TO CONSIDER

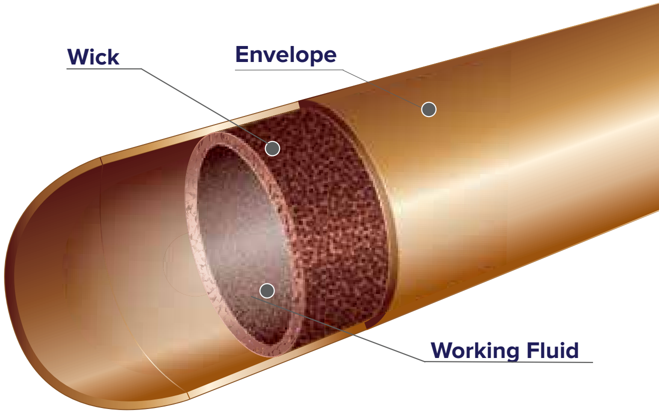
- Cooling of individual components by transferring heat to an external sink

THERMAL CONDUCTIVITY RANGE

- 10,000 to 100,000 W/m-K

BENEFITS

- Decrease hot spots to increase maximum power output
- Isothermal, passive
- Low Cost. Only baseline conduction is cheaper
- Flexibility. Can be formed to fit countless geometries



HIGH CONDUCTIVITY (HiK™) PLATES

HiK™ plates take the isothermal properties of heat pipes and embed them into a standard aluminum plate with epoxy or solder to increase the overall conductivity. The heat pipes are strategically placed to get good thermal results while not effecting current geometry or mounting features. Embedding heat pipes into these aluminum plates can increase the effective thermal conductivity from ~200 w/m-k up to 500-1200 w/m-K, depending on the number and location of heat pipes.

Properly placed heat pipes within the HiK™ plate reduce the hot spot locations. HiK™ solutions are compatible with both liquid and air cooled chassis and can increase fin efficiency and lower fin weight.

The heat pipes and solder are similar in weight to aluminum which makes the overall plate weight similar with or without embedded heat pipes, but the HiK™ version has a conductivity nearly 3 to 5 times greater than bare aluminum. These plates can also be used as structural components within systems.

The main HiK™ specific parameter is plate thickness. The HiK™ plate thickness needs to be able to fully contain a heat pipe that has sufficient diameter so that there is adequate vapor space to move heat.

And while aluminum is the most common HiK™ plate material, magnesium can be used to increase thermal conductivity almost up to same level achieved with Aluminum but with reduced plate weight. AlSiC can be used to directly attach devices onto the plate without a thermal interface material.

USED FOR

- Selected and strategic heat spreading

WHEN TO CONSIDER

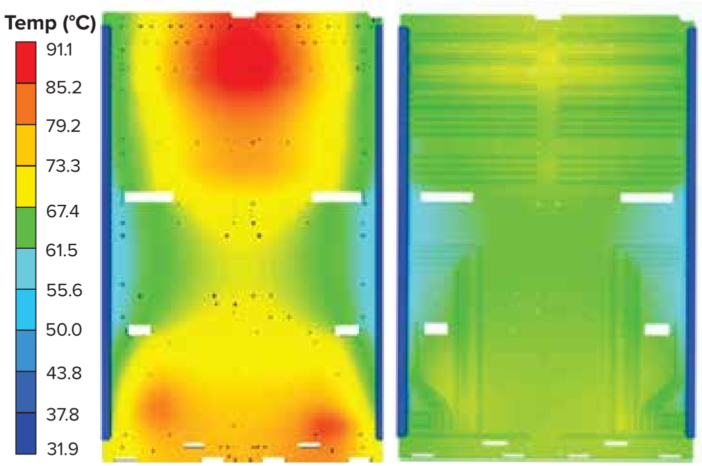
- Heat dissipation/spreading for multiple heat sources on the base plate

THERMAL CONDUCTIVITY RANGE

- 500-1,200 W/m-K

BENEFITS

- Inexpensive
- Preferred thermal spreading in a chosen direction
- Direct bonding



(Left) Temperature Profile of an edge cooled aluminum plate with various high powered electronic components (Right) Temperature Profile of a HiK™ plate that has the same components as (Left)

The conventional aluminum plate's highest temperature of 90.3° C was reduced to 69.1° C when the HiK™ aluminum plate was substituted.

VAPOR CHAMBERS

Like conventional cylindrical heat pipes, vapor chambers transport heat from a heat source to a heat sink with a very small temperature gradient. However, vapor chambers have a different form factor and enable concentrated heat inputs to be spread in two directions. This provides for excellent heat spreading across the heat output surface. Typical vapor chambers are 2 to 3 times more dense than a HiK™ plate, and cannot be used as a structural element, but provide a 10 to 100 times improvement in thermal conductivity versus a HiK™ plate.

Vapor chambers are best suited for applications where there is a concentrated heat flux, as in many laser treatment applications. The vapor chamber can transform the heat flux from the heat input source to a very uniform temperature gradient across the heat output, offering the potential for smaller light weight fins.

Vapor chambers do have some size restrictions. The minimum thickness is nominally mm to ensure there is adequate vapor space. The maximum foot print is approximately 25 x 50 cm, as larger areas may not provide the same excellent thermal uniformity.

Maximum heat flux for most standard copper water vapor chambers is 60-70 W/cm^2. Although 500W/cm^2 heat flux has been demonstrated on a high performance vapor chamber.

Another important point is the maximum temperature that current copper water vapor chambers can operate at is 105°C. At the higher temperatures the vapor chamber can “pillow”, causing deformation of the structure and non uniformities in performance.

The most common vapor chamber envelope material is copper, but aluminum nitride with direct bond copper is also available for high performance applications.

USED FOR

• Selected and strategic heat spreading

WHEN TO CONSIDER

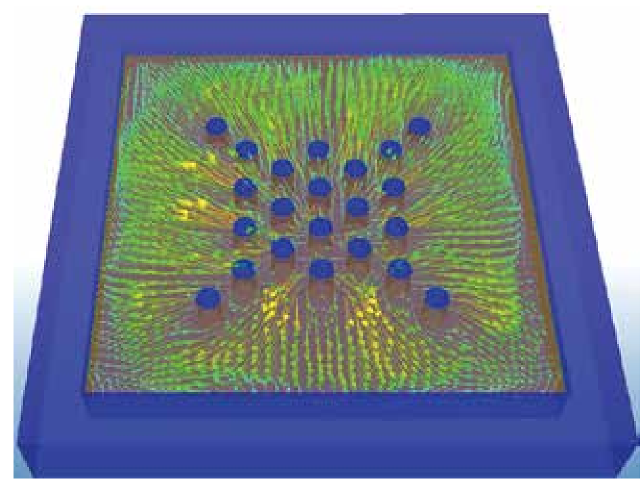
• Heat spreading of concentrated high heat fluxes (i.e. laser) or highly uniform condenser for minimal heat sink or uniform thermal processing

THERMAL CONDUCTIVITY RANGE

• 500-100,000 W/m-K

BENEFITS

• Excellent temperature uniformity (1-2° C) across the condenser surface



Vapor Chamber model

PCM HEAT SINK

Using a properly designed PCM heat sink can reduce or eliminate temperature increases from running multiple cycles by ensuring there is enough PCM and enough off time to enable the device to return to its original temperature at the beginning of each cycle.

Many hand-held laser medical devices operate in a transient on/off mode. During the on-cycle they utilize a lot of power and the devices can get quite hot. Fortunately duty cycles are relatively short - typically between 2 and 10%.

Locating PCM near the heat source can aid in increasing performance reliability and extending life of these devices. An illustration of how PCM heat sinks operate can be seen in the graph on the lower right. As the device heats up, the solid PCM warms up in a sensible heat regime. At it's melting point, seen in light blue, the PCM undergoes a solid to liquid phase change, but does not increase in temperature. Once all of the PCM is melted, it will return to the sensible heat regime. During the off-phase the PCM will dissipate the heat and return to its solid state. As we have seen the melting provides some stability in temperature and so very high temperatures from repeat cycles are avoided.

In these applications ensuring the proper amount of PCM, enough to absorb all of the heat during the on-cycle, while also being able to dissipate all of the heat in the off-cycle is important. Part of the system design should include volume change during phase transition and calculation of the minimum distance between the heat source and the PCM to avoid parasitic effects.

USED FOR

- Temporary heat storage

WHEN TO CONSIDER

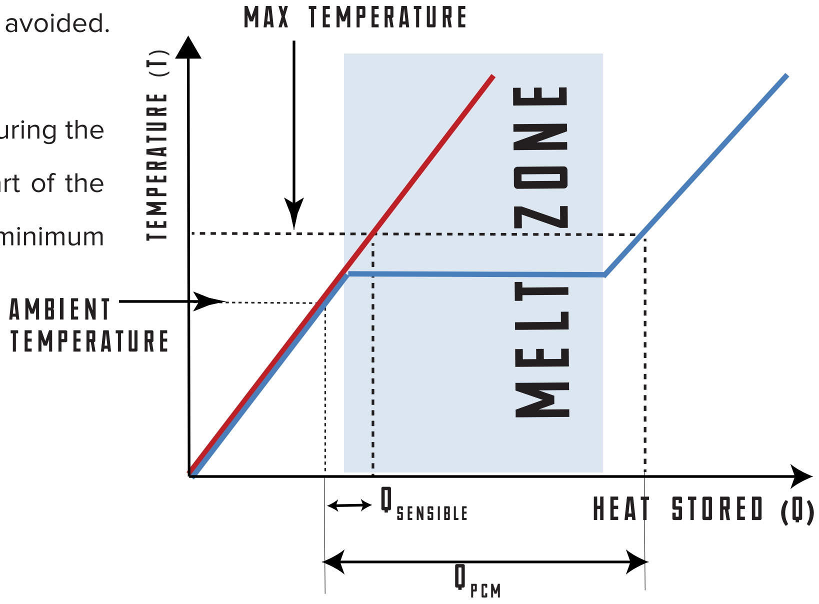
- Transient on/off operation like small hand-held lasers

THERMAL CONDUCTIVITY RANGE

- PCM materials have low thermal conductivity in the range of 3-5 w/m-K. PCM heat sinks are designed to maximize heat into and out of PCM.

BENEFITS

- Provides temporary heat storage
- Reduces weight of large metal heat sinks



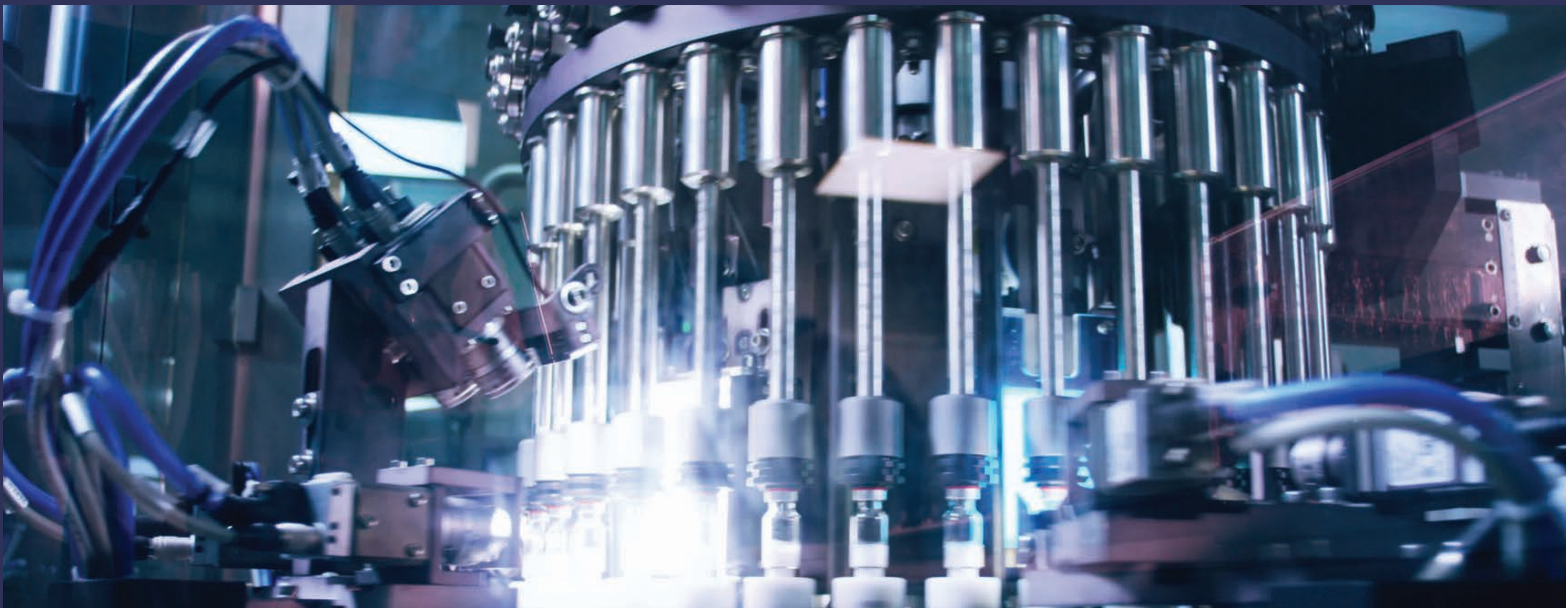
The thermal technologies reviewed, when applied to the appropriate medical device, can provide excellent thermal management.

Heat pipes and HiK™ plates are highly reliable, utilize no power and produce no noise.

Vapor chambers are great for spreading concentrated heat fluxes and produce a very isothermal surface for either temperature sensitive cycling or space efficient heat dissipation.

Phase change material (PCM) heat sinks are being utilized to reduce conventional heat sink sizes for devices that have transient mode. They can be successfully implemented in both large stationary devices and small hand held ones.

All of these thermal solutions have provided reliable thermal management for medical devices and as new treatments and devices emerge, will continue to do so.



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