BOYD
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# Discussion of Thermal Management


## White Paper

One Company, Many Solutions

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## Boyd Corporation

With decades of experience and a wholly-owned global footprint, Boyd provides best-cost, engineered, specialty material-based energy management and sealing solutions through comprehensive technical materials and design expertise, world-class manufacturing quality and service reliability, and unparalleled supply chain management.

## Discussion of Thermal Management - An Introduction

**Andy Chou** is a Boyd Market Segment Manager with over 10 years of experience working in the area of thermal management solutions. He also leads Boyd's NPI team in developing new and innovative thermal management products and applications. With experience as a global technical engineer, key account manager and product manager, Andy is keenly in tune to the thermal management industry and attendant market trends.

**Richard Hartman** is Boyd's Director of Strategic Sourcing. His international experience and over 10 years of know-how in crafting conceptual applications and designs related to thermal mitigation techniques span a number of Boyd's key markets including telecommunications, aerospace, defense, consumer electronics, LED technology and medical device industries.

## Introduction

The electronics industry has made tremendous progress in recent years to become an integrated part of our daily lives. Progress has come on two main fronts: increased functionality in a single device and miniaturization of devices. Both of these developments have increased power and energy required or produced, thus increasing heat and the need for thermal management within devices.

There are many different methods to remove or transfer heat energy. Desktop PC's tend to use aluminum heat sinks with fans. Notebooks utilize heat pipes and thermal interface materials to connect a heat source to a metal chassis in conjunction with fans. More recently, synthetic and natural graphite has been used in enclosed environments such as smartphones, tablets, hyper-slim ultrabooks and other electronics-oriented devices where fans are limited or cannot be used due to space, environment or noise constraints. Boyd's discussion of *Thermal Management* will include various thermal applications within a host of diverse devices and end markets.

## Thermal Energy Transfer

Heat is associated with the inefficient transfer of potential and kinetic energy within a system. Thermal energy always moves from a warmer system to a colder system. The transfer or dispersion of heat can occur by three main mechanisms: conduction, convection or radiation.

***CONDUCTION*** is the flow of heat through solids and/or liquids via the vibration and collision of molecules and free electrons. This transmission method is most common in electronic devices regardless of having a sealed or ventilated system.

The formula to calculate the conductivity gradient for a given system is:

$$q = -kA\,(\Delta T/\Delta n)$$

Where $\Delta T/\Delta n$ is the temperature gradient in the direction of area A, and k is the thermal conductivity constant of the material obtained by experimentation in W/m-k.

***CONVECTION*** is the flow of heat via currents within a fluid (liquid or gas). Convection is the displacement of volumes of a substance in a liquid or gaseous phase. This mechanism is common in large devices with enough space for air or liquid circulation.

The formula for convection:

$q = hA (Ts - T\infty)$

Where h is the convective heat transfer coefficient, A is the area implied in the heat transfer process, Ts is for the temperature of the system and $T\infty$ is a reference temperature.

***RADIATION*** is heat transfer by electromagnetic waves or photons; it does not need a propagating medium. The energy transferred by radiation moves at the speed of light. For example, the heat radiated from the Sun can be exchanged between the solar surface and the Earth's surface without heating the transitional space.

The formula to calculate the amount of heat transferred by radiation is:

$q = e\, \sigma\, A\, [(\Delta T)^4]$

Where q is the heat transferred by radiation, E is the emissivity of the system, σ is the constant of Stephan-Boltzmann ($5.6697*10^{-8}$ $W/m^2.K^4$), A is the area involved in the heat transfer by radiation, and $(\Delta T)^4$ is the difference of temperature between two systems to the fourth or higher power.

## Thermal Management Options

In general, there are many factors that can affect the thermal performance of a device. For simplicity, we will segment thermal management into four major product categories: hardware, software, thermal interface and substrates.

***Hardware*** is sometimes referred to as active cooling systems, including several product sub-segments like fans and blowers used in conjunction with heat sinks, fan sinks, heat pipes, cold plates, liquid cooling systems and thermoelectric coolers. These solutions mainly utilize metal or specialty materials with high thermal conductivity as heat transfer media. Aluminum is the most common metal used for heat sinks, as illustrated in Table 1. Copper is used only in high performance heat sink applications due to high cost. Gold is only used in extreme applications where the anodic index creates an issue.

Table 1: Raw material list of thermal conductivity

| Thermal Conductivity - *k – unit: W/(m.K)* | | | |
|---|---|---|---|
| **Material/Substance** | **Temperature - $^oC$** | | |
| | **25** | **125** | **225** |
| Aluminum | 205 | 215 | 250 |
| Copper | 401 | 400 | 398 |
| Carbon Steel | 54 | 51 | 47 |
| Gold | 310 | 312 | 310 |
| Iron | 80 | 68 | 60 |
| Platinum | 70 | 71 | 72 |
| Stainless Steel | 16 | 17 | 19 |
| PTFE | 0.25 | | |
| Polyvinylchloride, PVC | 0.19 | | |
| **Vacuum** | **0** | | |
| Air, atmosphere (gas) | 0.024 | | |
| Water | 0.58 | | |

***Interface:*** Thermal Interface Materials (TIMs) are products that stand between a heat sink and the device to be cooled. Their function is to improve the thermal transfer in the joint between the heat sink and the device to be cooled by wetting or connecting to both surfaces and eliminating air gaps, which cause thermal insulation. In some cases, the interface actually performs the job of the heat sink. This role has become increasingly common in applications in which, due to the height or weight constraints of a system, conventional hardware like a heat sink is not feasible. This segment includes several product sub-segments including thermal grease, thermal compounds, thermal pads, thermal tapes, epoxy, phase change materials, etc.

Computational models, enabled via advanced ***Software***, allows for analysis of the thermal characteristics of a system, including computational fluid design (CFD), computational heat transfer (CHT), power management, circuit design and other electronic design automations (EDA). Good software capability maximizes the value of a heat sink or thermal module by confirming, through design, the most effective heat transfer path before device design is locked down.

***Substrate:*** having been developed specially to enhance the thermal handling capability of an electronic component, this sub-segment includes two phase heat spreaders, graphite heat spreaders, diamond heat spreaders and silicone-based heat spreaders. Recently, graphite has been chosen as a lead substrate product in smartphones and other sealed system devices due to its thin profile, high in-plane thermal conductivity and low weight.

## Where is Thermal Management Most Commonly Needed?

Major consumers of thermal management products reside in industries like consumer and enterprise electronics, telecommunications, automotive, medical devices and industrial applications. The most common thermal management solution is the heat sink (aluminum or copper in Figure 2) or cooler module (heat pipe in Figure 3) laminated with interface material such as a gap pad. If the design permits, a fan is installed for accelerated heat dissipation.

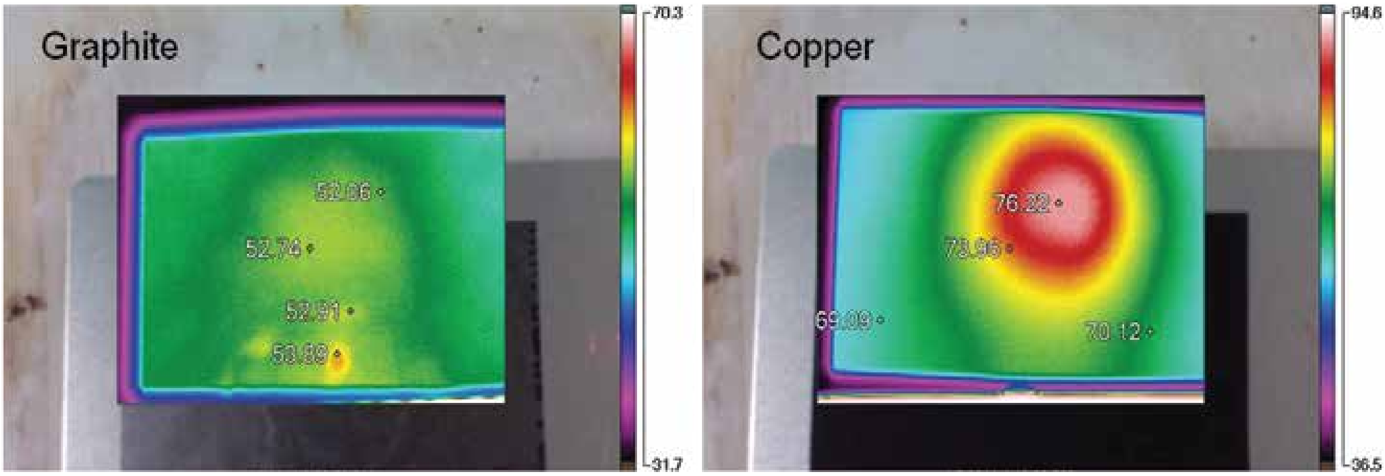
Figure 2: Personal Computer PCB and Heat Sink

Figure 3: Notebook Heat Pipe and Fan

Sealed system thermal management is an entirely different topic when discussing heat dissipation due to system design. In an open system, we can easily use air circulation to exchange heat to the environment. Sealed systems, however, typically have no room for tall heat sinks and inherently do not allow air circulation within the device. The most common thermal management technique in a sealed system uses a thermal spreader or shield, typically made of graphite, to either increase the available surface area with which to spread a hot spot, or, in conjunction with an air gap, shield a sensitive component from a heat source.

Graphite, due to its layered molecular structure, is anisotropic, meaning it spreads heat in plane much more quickly than through plane. As a result, graphite eliminates hot spots very well compared to isotropic materials, such as metal, which move heat in all directions uniformly, as illustrated in Figure 4.

Figure 4: Graphite and Copper Heat Spreading Performance




Graphite has two major functions:

***Thermal Spreading:*** when in contact with a heat source, graphite spreads heat across its surface area, increasing area available to dissipate heat, and cooling down a heat source.

***Thermal Shielding:*** when designed with an air gap between the graphite and the heat source, graphite can uniformly distribute the heat of a hot spot and reduce the surface temperature of the opposite side, relative to the heat source, of a device.

## Thermal Management Drivers

As a result of the widespread introduction of microelectronics across market segments, together with the increasing demands on functionality and reliability, thermal management has become an important issue in almost every branch of the technology world, including professional and consumer electronics systems as well as automotive electronics, set top / home gateway boxes, LED lamps and medical devices.

Figure 5: The Risk of Thermal Runaway

From a thermal management perspective, there is a significant price to pay for the increase in device functionality. Device operating frequency and gate counts are increasing rapidly, dissipating greater amounts of power as heat. The buildup of excessive heat is a major cause of failure in electronic systems. Electronics industry reports indicate 55% of all failures are caused by “temperature”, and further recommend that decreasing electronic component temperature by 10˚C could on average double the lifespan of a device (refer to Arrhenius’ Law of Chemical Activity in Illinois Capacitor Inc. report on life calculator).

Since the generation of heat is representative of inefficient use of energy, it stands to reason that several global energy conservation and power management standard initiatives, such as the Environmental Protection Agency’s (EPA) Energy Star, the European Union’s (EU) Blue Angel and the Advanced Configuration and Power Interface (ACPI) in the computer industry, benchmark thermal performance as an illustration of energy efficiency.

As electronic devices have increased in power, consumers have seen media coverage featuring devices catching fire and discussing theories of thermal runaway. Thermal runaway is chain of cyclical reactions of temperature rise that build upon one another, increasing device operating temperature to critical levels, often leading to device shut down from overheating. In rare cases, thermal runaway can lead to ignition but, thus far, there is no direct evidence to indicate overheating causing electronic device ignition. There may not be a thermal management mechanism failure in these situations, but consumer perception of device overheating causing ignition is something we work to minimize by designing appropriate heat management into devices.

## Thermal Management Applications

Figure 6: Graphite in Mobile Phone


For more than a decade, Boyd has provided thermal management solutions for market segments and applications including:

- Automotive: ECU (Electronic Control Unit) featuring thermally conductive adhesives, heat spreaders and TIMs
- LED TV Displays: backlights cooled with graphite and power modules cooled with TIMs
- Mobile Computing: CPU, power amplifiers and displays featuring heat spreaders made of graphite (illustrated in Figure 6), copper and aluminum
- Enterprise Electronics: CPU, chips and heat sinks featuring TIMs for heat transfer
- Lighting: thermally conductive adhesives and TIMs used in LED chips and heat sinks
- Hybrid or Electric Vehicles: TIMs for battery temperature management

Boyd has a fully capable thermal analysis lab to support customer product evaluations. Test capabilities include thermal conductivity (z-axis) and thermal impedance measurement (ASTM D5470 and ASTM E1530), x and y-axis thermal conductivity, thermal imaging, dielectric breakdown voltage testing, hardness testing, adhesion testing, real device testing, material character analysis and environmental chamber tests. Boyd's excellent analysis capability and market experience provides an unmatched ability to assist its OEM customers, EMS partners and suppliers in designing solutions to solve thermal management challenges.

Boyd provides best-cost, engineered, specialty material-based energy management and sealing solutions through comprehensive technical materials and design expertise, world-class manufacturing quality and service reliability, and unparalleled supply chain management. For your thermal challenges, engage Boyd early in the design cycle to ensure that the most functional and cost effective designs are in place prior to emergent situations at product launch. Use Boyd's years of experience and engineering support in concert with your engineering / technical expertise to ensure your thermal challenges are solved in a cost effective, leading edge way.