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Title: Thermal Management of Electronics and Data Centers

Significance

Electronics generate heat as they operate, due to high power density, and if this heat is not dissipated efficiently, it can lead to reduced performance, increased operating costs, component failure, and even safety hazards. In data centers, where large numbers of servers are housed in a small, confined space, efficient thermal management is particularly important to avoid hot spots, reduce energy consumption, and prolong the lifespan of the equipment. Overall, effective thermal management of electronics and data centers is critical for their optimal performance and longevity.

Every industry that has to deal with/ or incorporates electronic devices, and information storage and processing units needs to have an effective thermal management system. From the moment we wake up every day to when we sleep, and even during our sleep, we contribute to heat generation in electronics and data centers. Daily activities like using alarm clocks, mobile phones, TVs, cars, social media, air conditioning, internet browsing, etc. generates heat throughout the usage of electronics and data centers. Hence, it is imperative to have a good thermal management system for electronics and data centers, so you can go about your daily activities without any unwanted interruptions.

The global heat sinks market size attained a value of USD 6.92 billion in 2022. The market is further expected to grow at a CAGR of 6.50% between 2023 and 2028, to reach a value of USD 10.1 billion by 2028.[5] Furthermore, the global data center cooling market was valued at USD 9.4 billion in 2020. The market is further expected to grow at a CAGR of 10.7% between 2020 and 2025, to reach a value of USD 15.7 billion by 2028.[4] These are two of the many reasons why we should care about thermal management of electronics and data centers.

Background and Introduction

A thermal management system involves controlling temperature through technology. This technology is based on thermodynamics and heat transfer. Thermal management is a wide-ranging term covering various forms of heat transfer, including conduction, convection, and radiation, involving different processes. The system could be a specific area of focus, a component or a set of components. A key part of this thermal management is the material that makes up vital electronic components. These components provide insulation which supports reliability and efficiency, while making sure electronics systems meet the ongoing demand for faster performance. Various types of heat sinks and other thermal management solutions such as thermoelectric coolers, forced air systems and fans, heat pipes, etc. help to dissipate this heat, ensuring that the equipment operates within safe temperature ranges. In cases of extreme low environmental temperatures, it may actually be necessary to heat the electronic components to achieve satisfactory operation.

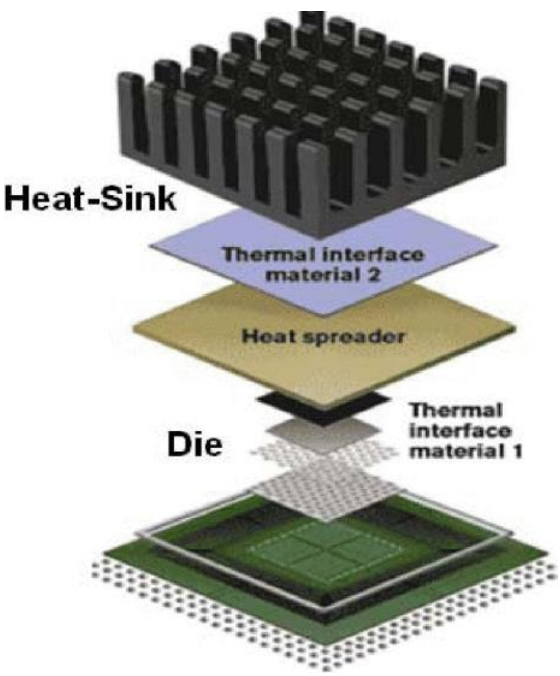
While heat sinks originally appeared in 19th century Europe, they were more widely adopted over the 20th century as people started discovering higher heat transfer coefficient materials like copper and lightweight materials like aluminum. Modern heat sinks that are used in computers were invented by Jeffrey P. Koplow and there are about 7 patents on his work. Developing on the initial works, companies such as Sunonwealth Electric Machine Industry Co. Ltd., Advanced Thermal Solutions, Inc., Aavid Thermalloy, LLC, Apex Microtechnology, CUI Inc., and Comair Rotron, among others, have emerged as the key players in the heat sinks market.[5]

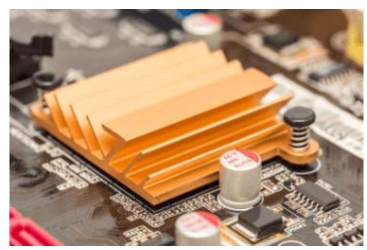
Furthermore, companies like Vertiv Holdings Co. (US), Schneider Electric SE (France), STULZ GmbH (Germany), Rittal GmbH & Co. KG (Germany), and Nortek Air Solutions, LLC (US) are some of the leading players operating in the data center cooling market.[4]

Technical Description

A good thermal management system needs a combination of materials and processes to control chip temperatures by reducing heat flux (the flow rate of heat per unit area) due to power leakage. To achieve this, the materials used need to possess high thermal conductivity, have low cost and the processes need to be energy efficient. The properties for these materials can be determined with the help of Ashby Plots.

The most common approach towards thermal management of electronics is the use of heat exchangers such as heat sinks in combination with heat spreaders and thermal interface materials (or thermal pastes). [1] While the devices can be passively cooled using fins or actively cooled using forced convection or liquid cooling, the main idea is to remove heat from the devices. The most common heat exchanger materials used are Copper CDA110 and Aluminum 6061, 6063, 1050, 1100. The advantages of aluminum alloys are that they are lighter, have less cost, but the disadvantage is that they have lower thermal conductivity (half) than copper. On the other hand, Copper CDA110 (391 w/mK) is heavy, and expensive, but has higher thermal conductivity. Alternatively, both materials can be used together (as bonded fins) to achieve an optimal solution.[2]

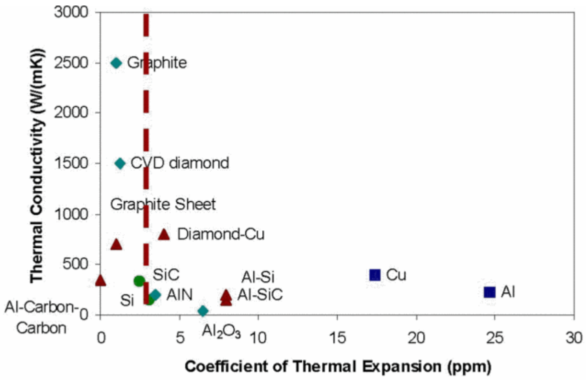




Passive Heat Sinks

Active Heat Sinks

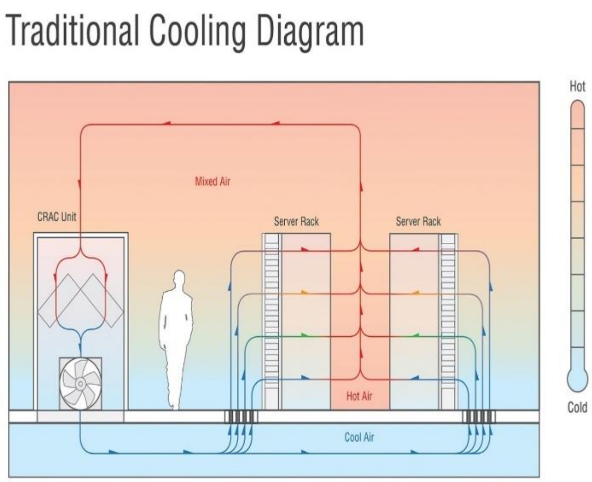
In recent times, heat exchangers are fabricated from functional materials such as carbon-nanotubes. Other materials that are also considered for use are graphite, CVD diamond, beryllia, aluminum nitride, cubic boron nitride, silicon carbide, alumina, molybdenum, copper molybdenum, copper tungsten and other composites.[1]



Material	Thermal conductivity	CTE 10^{-6}/K	Price/
CVD diamond	>1300	2.0	High
Aluminium Nitride	260	4.0	Medium
Cubic boron nitride	200-250	1	High
Silicon Carbide	200	2.8	Medium
Alumina	30	5	Low
Copper	400	16	Low
Aluminium	200	23	Low
Molybdenum	138	5.1	Low
Copper Molybdenum	165-215	6.8-9.5	Medium
Copper Tungsten	175-235	6.5-9	Medium

For thermal interface materials and heat spreaders, it is ideal to match the coefficient of thermal expansion to that of the material of which the electronic component is made.

A data center is a facility of one or more buildings that house a centralized computing infrastructure, typically servers, storage, and networking equipment in a confined space. Thermal management of data centers involves a good heating, ventilation, and air conditioning (HVAC) system that controls the room temperature and relative humidity based on size of the space, the floor plan, and the types of equipment present inside the data center. The guidelines for these temperatures and relative humidity values are given by organizations such as ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers). They can be determined using psychrometric charts.



The traditional data center cooling process can be broken into the following steps:

1. Server Cooling: Removing heat from IT Equipment

2. Space Cooling: Removing heat from the space housing the IT Equipment

3. Heat Rejection: Rejecting the heat to a heat sink outside the data center

4. Fluid Conditioning: Tempering and returning fluid to the white space, to maintain appropriate conditions within the space. [3]

More recently, advanced cooling technologies like heat pipes, vapor chambers and thermosiphons are being used for space constrained devices, high heat flux applications, rugged environments, and situations where heat needs to be moved long distances. Heat Pipes are used to move heat from the heat source to a remote fin array using a sintered wick bonded to the entirety of its inside walls. Vapor Chambers are used to spread heat across the base of a local fin array. Thermosiphons can carry two to three times more heat than heat pipes of the same diameter over a much longer distance than heat pipes, but they can only operate when the liquid-return phase is gravity aided i.e., when the evaporator (heat source) is below the condenser (heat sink). This can be countered using partially sintered wick thermosiphons.[2]

Exam style questions

1. For thermal interface materials and heat spreaders, it is ideal for:
   a) the coefficient of thermal expansion to be higher than that of the material of which the electronic component is made.
   b) the coefficient of thermal expansion to be lower than that of the material of which the electronic component is made.
   c) the coefficient of thermal expansion to be close to that of the material of which the electronic component is made.
   d) None of the above.

   Answer: c)

2. Which of the following are steps for traditional cooling of data centers:

   a) Heat Rejection
   b) Server Cooling
   c) Space Cooling
   d) None of the above.

   Answer: a), b), c)

3. Which of the following are advanced cooling technologies:

   a) Passive Heat Sinks
   b) Thermosiphons
   c) Heat Pipes
   d) All of the above.

   Answer: b), c)

References

[1] C. Bailey, "Thermal Management Technologies for Electronic Packaging: Current Capabilities and Future Challenges for Modelling Tools," 2008 10th Electronics Packaging Technology Conference, Singapore, 2008, pp. 527-532

[2] https://celsiainc.com/technology/heat-sink/#

[3] https://journal.uptimeinstitute.com/a-look-at-data-center-cooling-technologies/

[4] https://www.marketsandmarkets.com/Market-Reports/data-center-cooling-solutions-market-1038.html#:~:text=Data%20Center%20Cooling%20Market%20Players,the%20data%20center%20cooling%20market.

[5] https://www.expertmarketresearch.com/reports/heat-sinks-market#:~:text=to%20the%20report%3F-,Sunonwealth%20Electric%20Machine%20Industry%20Co.,market%2C%20according%20to%20the%20report.

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