Look Small to Go Big

How Micro-level Electronic Component Materials Deliver Macro Impact

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Executive Summary

Throughout human history, each era has been defined by its technology. Today is no exception. The information age, catalyzed by semiconductor innovations, has made technology pivotal in the global economy. It is also changing at record pace. By enabling remote work, distance learning, and global supply chains, technology's role has been elevated further, accelerating digital transformation and technology-enabled innovation across industries and communities around the world.

The result is unprecedented network and infrastructure expansion, with colossal demand for internet access points, bandwidth, and speed. Across data center architecture, wireless telecom infrastructure, and optical networks, this rapid expansion is simultaneously challenged by the need for increased performance to process more data at faster speeds and accommodate emerging developments such as **5G, Wi-Fi 6, and 400 GbE (Gigabit ethernet).**

Due to the significant scale of data centers, telecom infrastructure, and optical networks, improved performance is achieved at the electronic component level. Optimizing circuit board performance drives network and infrastructure outcomes. It's known as the butterfly effect, where tiny inputs, used in aggregate, can create the biggest outcomes. Printed circuit boards in active antenna units, router and switch line cards, and server motherboards are used in enormous quantities within data center and telecommunications networks. One small uptick in performance has a huge impact on overall infrastructure performance.

The industry must look small to go big, with the advanced materials used in electronic components that are propelling significant network and infrastructure outcomes. **Advanced materials include thermal gels, phase change materials, micro thermal interface materials (microTIMs), thermal GAP PAD® materials, bonding and gasketing materials, and solder,** to name a few. This paper illustrates why these innovative materials matter, how much they can sway outcomes, and how to leverage them in petite electrical powerhouses—namely, integrated circuits.

We encourage you to read on and learn how to elevate what is possible from digital technology, the socioeconomic driver of this century.

Network and Infrastructure Trends

Massive increases in demand for internet access points, bandwidth, and speed are causing expansion in network and infrastructure footprints of all kinds, such as wireless infrastructure, data center architecture and interconnects, and optical infrastructure. This growth is driving both investment levels and steep requirements for higher-level performance. While this trajectory may not be surprising, the solution to achieving new benchmarks in infrastructure performance and reliability may be.

Skyrocketing demands put increasing pressure on electronic components, the building blocks of networks and infrastructure. The key elements are the printed circuit boards, line cards, and motherboards, which comprise routers, switches, servers, and active antenna units. In addition, there are several emerging developments such as 5G, Wi-Fi 6, 400 GbE, and optical infrastructures, all of which require next-level electronic component performance, such as processing more data at faster speeds.

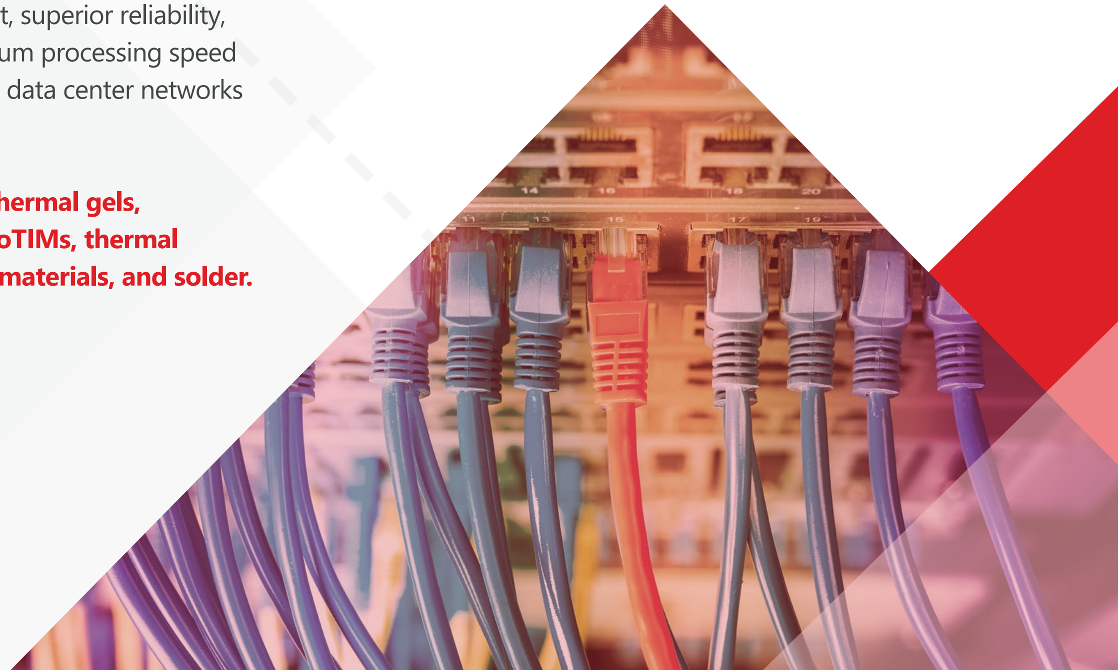
In terms of performance expectations, electronic components must do more within smaller footprints. Specifically, higher component and power densities must deliver more bandwidth and data processing capabilities. To meet these somewhat opposing challenges, the advanced materials used within the circuit board, line card, and motherboard help to deliver enhanced thermal management, superior reliability, increased lifecycles, and maximum processing speed and bandwidth, crucial for both data center networks and telecom infrastructures.

Advanced materials include thermal gels, phase change materials, microTIMs, thermal GAP PAD materials, bonding materials, and solder.

These advanced materials deliver micro-improvements within integrated circuits to drive macro-improvements at the network and infrastructure levels. Electronic components that use advanced materials are known as high-efficiency hardware. In addition to enabling maximum performance and reliability, these advanced materials can substantially reduce operating expenses (OpEx) in the areas of power and cooling costs, as well as overall maintenance.

> The smallest parts can deliver the biggest outcomes.

The tiny footprint of advanced materials is disproportional to the measurable improvements it can generate. In other words, **the smallest parts can deliver the biggest outcomes.** Performance-enhancing materials are applied in relatively minute amounts to already small-sized integrated circuit components, which power thousands of servers and other devices in data center and telecom environments. Despite electronic components' miniature size, their impact in aggregate creates an outsize result—a real-world instance of the butterfly effect.



Skyrocketing Growth

Network and infrastructure growth is spurred by rising trends in data-rich applications, such as next-gen workloads, artificial intelligence/machine learnings (AI/ML), Augmented Reality/Virtual Reality (AR/VR), analytics, and smart cities. These trends are compounded by new information technology architectures, such as cloud computing and the Internet of Things (IoT), as well as increased use of the internet and wireless devices.

Just how big is this skyrocketing growth?

Corporate spending and market size are two indicators of the magnitude of network and infrastructure expansion.

Corporate Spending

There have been vast increases in data center spending, especially hyperscale data centers from the world's four largest operators or hyperscalers: Amazon, Microsoft, Google, and Facebook. Capital expenditure (CapEx) spending for these four hyperscalers was in excess of **$149 billion (USD) in one year,** from May 2020 to May 2021, according to Synergy Research Group.

Market Size

The global telecom infrastructure market size is forecasted to **exceed $100 billion by 2026** based on the rising use of wireless devices and the resulting demand for smart cities, according to MarketWatch. Further, worldwide telecom services spending (wherein telecom operators earn revenue by leasing network connectivity to other telecom companies, internet service providers, and large corporations) is estimated to be a **$1.44 trillion market in 2021.** The global data center systems market will reach **$237 billion in 2021,** according to Gartner's most recent IT spending forecast.

Investment

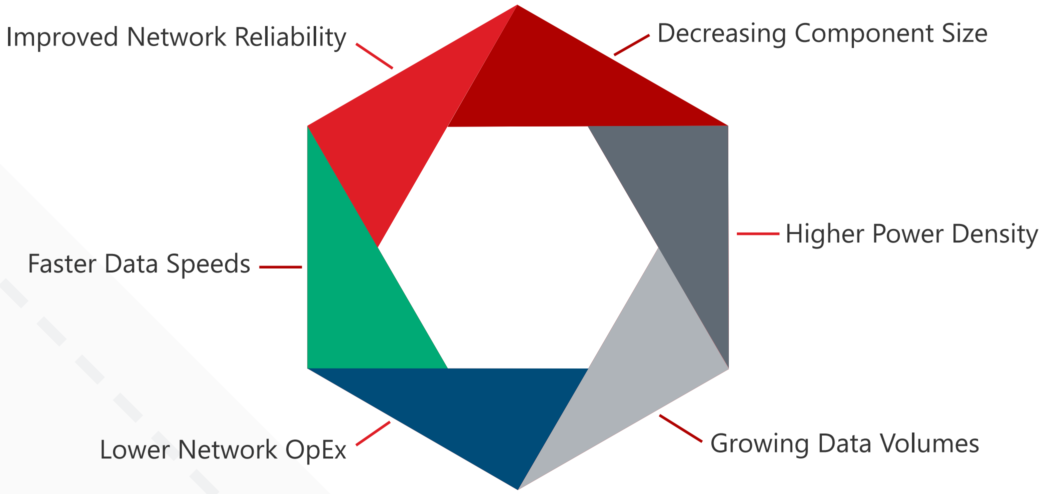
Private equity accounted for 80% of all data center acquisitions in 2019 and is viewed as one of the best ways for global investors to make money. Telecommunications companies are now touted as one of the most essential industries and will likely remain that way for the foreseeable future, spurring additional investment. Per Gartner, the 5G network infrastructure revenue alone was set to double in 2020 and reach **$8.1 billion.** Investors are also keen on the booming telecom sector and the stable, predictable cash flow from the scaled, ultra-high-speed data 5G telecom infrastructure. Because 5G requires more transmission towers to achieve full network coverage, there is more opportunity for leasing revenue.

Challenges to Profitable Growth

- Data Center OpEx Threatens to Erode Company Profits
- Networks and Infrastructure Must Operate at Maximized Bandwidth (Volume) and Speed
- The Importance of Stress Management
- Optical Networks Have Unique Needs

Challenges to Profitable Growth

Accompanying this massive growth and investment are increasing challenges to sustaining profitable network and infrastructure operations. Current inefficiencies must be addressed to reduce operating costs while simultaneously developing, implementing, and managing new capabilities. As cloud traffic, data volumes, and speeds escalate, achieving improvement becomes a multifaceted challenge. This, in turn, places more focus on the promise and performance of electronic components, which in aggregate can significantly sway network performance.



Given the enormous size of hyperscale data centers and telecom infrastructures, these limitations—if left under-optimized or unresolved—can create restrictions in performance and profitability that add up to serious consequences.

Let’s take a look at the challenges, followed by their solutions, segregated into four discrete pieces.

Data Center OpEx Threatens to Erode Company Profits

OpEx and Efficiency

As IT infrastructure and architecture modernizes to accommodate the growing need to move more information at faster speeds, data center and telecom applications of all types and sizes must grapple with limiting factors such as power, cooling, lifecycle considerations, and space requirements. Thus, concurrent to network expansion are inherent operational inefficiencies and limitations that increase costs and must be addressed to enable profitable growth.

Let's get more specific with two examples.

In the Data Center

In data center spending, about 50% of costs are for hardware and software, and a large percentage is spent on ongoing maintenance. Typically, a large corporate data center **spends $10-25 million per year on OpEx.** While that is a large number, let's put it in context to make the urgency and magnitude of the issue abundantly clear.

Per McKinsey:

25%
Data center expenses comprise 25% of corporate IT budgets

20%
Costs to run data centers are increasing 20% per year

6%
IT budget to cover those expenses are increasing 6% per year

In Telecom

Telecom infrastructure, growing rapidly to meet demand, is focused on better controlling its two major cost components: CapEx and OpEx. According to a PwC survey, telecom operators indicate that up to 20%, or $65 billion per year in CapEx is wasted due to under-optimized CapEx. In the area of OpEx, telecom tower structures (tall towers) and remote locations necessitate ongoing reduction of maintenance and maximum component durability and lifespan.

60%
Reduction in antenna weight

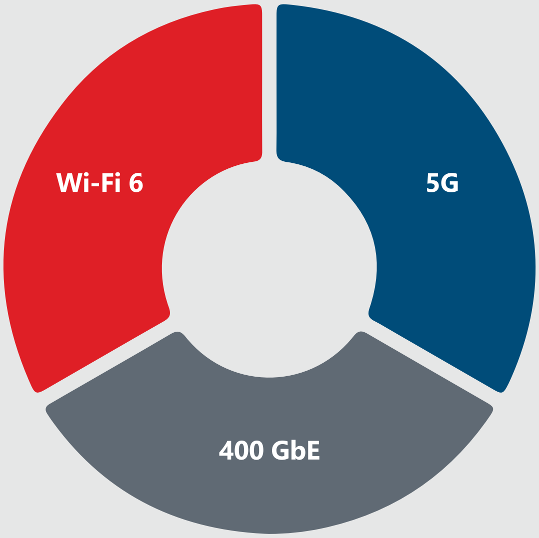
Reducing construction costs is directly correlated with hardware weight.

Cost savings (e.g., lower cooling costs/ energy requirements) and higher efficiency in data center and telecom operations are essential and escalating in need.

Networks and Infrastructure Must Operate at Maximized Bandwidth (Volume) and Speed

Faster Speeds, Greater Bandwidth, and Wire-to-Fiber

Along with this greater scale and increasing volume, there are also dynamically emerging trends and requirements for faster speed as data moves around the network, as well as within and between data centers. For example, there are innovations currently underway that have significant impact on network requirements and performance, including Wi-Fi 6 (wireless network), 400 GbE (wired network), and 5G (mobile network).



400 GbE

Wired ethernet connections are an important facet in the global network infrastructure. In wired networks, the new 400 GbE is four times as fast as the current 100 GbE. With a denser configuration, 400 GbE also improves economy of scale, resulting in a better price per port.

Wi-Fi 6

Today, homes have an average of nine Wi-Fi devices, forecasted to grow to 50 devices per home in the next several years. Wi-Fi 6 promises capacity for 9.6 Gbps (Gigabits per second) vs. 3.5 Gbps (Wi-Fi 5), improving the network when many devices are connected to it. Relative to its role alongside 5G, Wi-Fi 6 is well-suited for indoor enterprise networks, as well as locations where access points will serve many users, such as sports venues and convention centers.

5G

5G will remit data 10 times faster than 4G to support video streaming, AR, VR, and IoT. As 5G replaces 4G, it offers more volume and greater speed alongside escalating network performance requirements. To handle all of these expanding requirements simultaneously, electronic components must improve. Coexisting with Wi-Fi 6, 5G is expected to primarily serve outdoor networks, such as smart cities and connected cars.

The Importance of Stress Management

Reliability and Durability

As integrated circuits are tasked to move more data at faster speeds, their reliability and durability comes into even sharper focus as a key performance parameter. Thermal and mechanical stresses can accelerate electrical stresses that then lead to premature failure. The integrity of micro-connections on printed circuit boards, line cards, and motherboards; the robustness of solder joints; and the ability to endure variable thermal cycles are all key determinants of network infrastructure reliability and durability.

Downtime is the bane of any network.

Downtime is the bane of any network. Even when brief lapses in power occur, they can cause domino-effect delays in reboot, recovery, and repair times and, in turn, negatively impact businesses. Always-on network infrastructure is a ubiquitous goal.

Telecom infrastructures face additional durability challenges due to outdoor environments. They must withstand varying weather conditions and temperatures, mechanical stresses, and electromagnetic interference. Mitigating the impact of these factors is key to ensuring the maximum reliability and durability of electronic components. The goal is near-zero functional failures as repairs are not easy or inexpensive, and the snowball-effect costs of network downtime can be significant.

Optical Networks Have Unique Needs

Optical Networks

Optical networks are a key part of the overall network, with speeds approaching 1 Gb (Gigabit) as connections between data centers and racks move from wired to fiber-optic. The primary advantage of optical infrastructures is ultra-fast data transfer across long distances. A key focus is to minimize cost per bit transported on the optical infrastructure. This requires ultra-high baud rates **(800 Gbit/s tested in the last year)** and higher channel capacity to achieve minimum cost-per-bit transport. These new innovations add stress to optical receivers due to high speeds and volumes of big data.

Optical communication devices, such as optical transceivers, optical switches, and optical components, must deliver maximum sign power into the optical fiber to enable high-speed data transmission and high-bandwidth applications. In addition, multiple optical components within optical modules—OSAs, fiber array units, optics for coupling, wavelength separators/combiners, and optics for focus and switching devices—must be precisely aligned for maximum light transmission and durably bonded for reliable, long-term device stability and functionality.

Data centers and telecom infrastructure environments each have unique attributes and components. However, both are dedicated to optimizing performance and reliability, and they share several of the same challenges. Advanced materials in electronic components can help data centers and telecom infrastructure providers address these challenges.

Optical components require maximum light transmittance properties, must be built to last, and must have strong, reliable electrical interconnects.

Solutions

How Advanced Materials in Integrated Circuits Help

When innovative, advanced materials are used within the network infrastructure, they help to solve these four challenges. Let's take a look at which materials are employed and how they are used in the construction of electronic components.

It Starts with Thermal Management

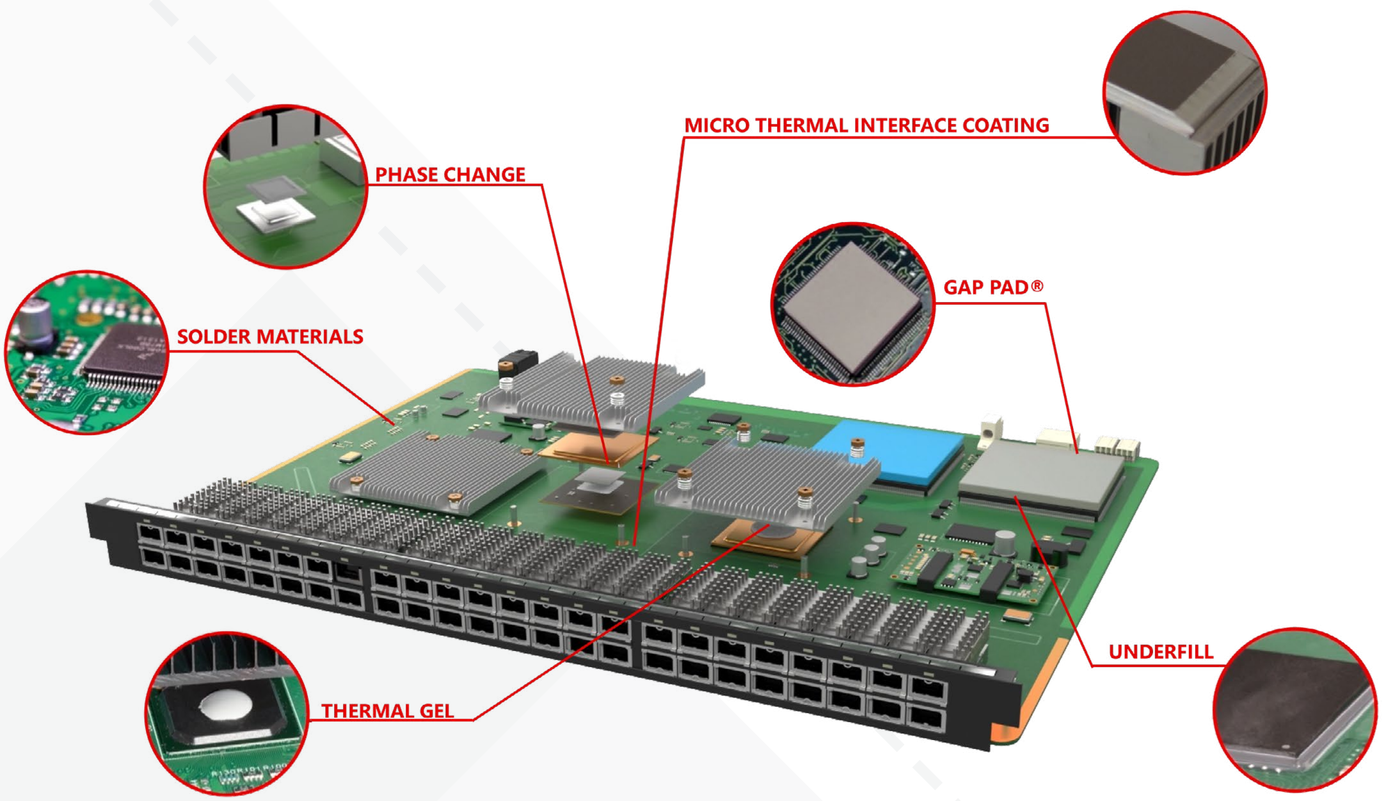
Thermal management helps provide cost savings (Challenge #1) and enables maximum bandwidth and speed (Challenge #2). It also helps boost reliability and durability as it is a foundational element to many other performance parameters.

Thermal Management

Heat dissipation within a high-density, small-footprint integrated circuit can enable operations at maximum bandwidth and speed. Similarly, enhanced heat dissipation at the electronic component level can save OpEx costs:

- Data centers save in power and active cooling at the aggregate level
- Telecom infrastructure better manages cooling and keeps components from overheating, which extends reliability and durability

Advanced materials that enhance heat dissipation include thermal gels, phase change materials, microTIMs, and thermal GAP PAD materials. As shown below, advanced materials are used throughout a circuit board configuration and help optimize performance of the electronic components that house them—such as active antenna units (AAUs), routers, switches, and servers.



Above is a diagram example of how advanced materials can be used in a circuit board configuration to keep it at maximum operating capacity and performance.

Solution 1

Let’s look at thermal management impact in data centers and telecom environments.

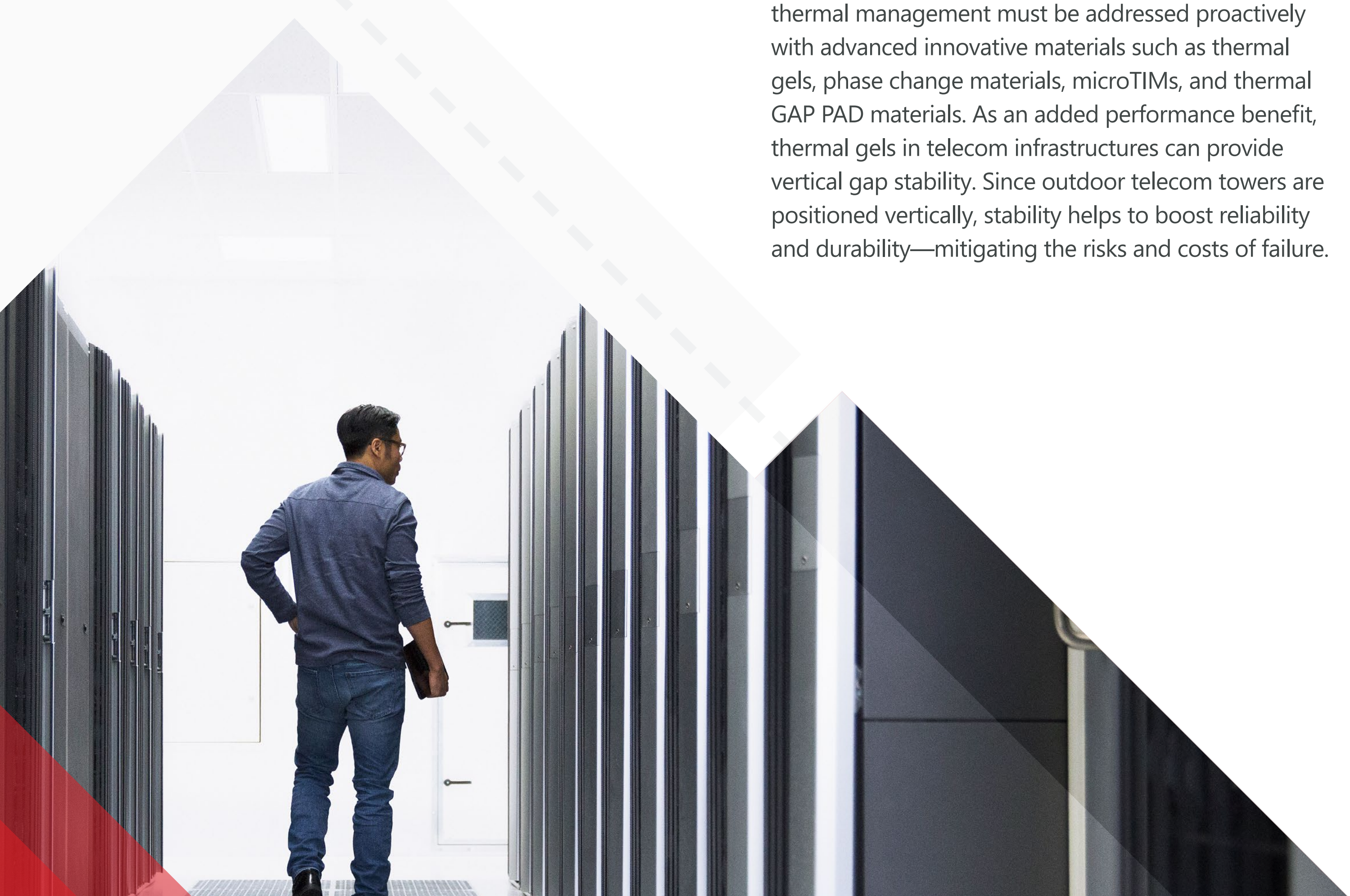
Data Centers

In data centers, enormous scale and size are leveraged to provide massive computing power. A data center may house **50,000-80,000 servers** and some of the hyperscalers likely leverage well above that number of servers to provide computing power. The limiting factor for number of servers per data center is either the power or the cooling, both of which also represent significant OpEx. The use of advanced materials to enhance thermal management in server motherboards and line cards for routers and switches provide a huge upside in scale, performance, and cost reduction.

Telecom

Telecom equipment is “always on,” operating in outdoor environments. Repairs are challenging due to remote locations and more difficult-to-access structures, such as telecom wireless towers. Thus, telecoms require minimal maintenance and maximum lifespans. For example, printed circuit boards in AAUs must be built to last 10-15 years per electronic device. With constant exposure to variable outdoor conditions—temperature, humidity, and wind vibration—alongside limited cooling options and fast processing speeds, thermal management in telecom electronic components represents a unique challenge. And, as 5G rolls out, thermal management needs to escalate further.

Left unaddressed, overheating erodes electronic component performance and shortens lifecycles. Thus, thermal management must be addressed proactively with advanced innovative materials such as thermal gels, phase change materials, microTIMs, and thermal GAP PAD materials. As an added performance benefit, thermal gels in telecom infrastructures can provide vertical gap stability. Since outdoor telecom towers are positioned vertically, stability helps to boost reliability and durability—mitigating the risks and costs of failure.



Solution 2

Solder materials, underfills, and bonding materials help provide reliability and durability by enhancing the ability to withstand outdoor conditions (precipitation, temperature, wind) in telecom applications and bolstering electrical and mechanical resilience in data center environments. (Challenge #3)

In addition to the thermal management capabilities, mechanical and electrical stresses can compromise performance—at the electronic component level and in aggregate at the network level. Using innovative solder materials as well as novel bonding materials and applications helps to mitigate the impact of those stresses.

Solder Materials

Performing at high bandwidths and speed requires robust electrical connections within complex designs and high power densities. Connections simply cannot fail. As integrated circuits include more complex designs, solder requirements do too. At micro levels of quality, solder joint reliability must be optimized for proper performance and must mitigate solder joint defects, solder voids, and electrochemical reliability. Innovative solder materials ensure performance under electrical and mechanical stresses, ensuring solid connections that power the network—across data centers and telecom environments.

Data Centers

Line card and motherboard mechanical stress can arise from climbing and cyclical temperature patterns in data center operations. Solder joints are susceptible to this stress and can fail during end use (within the data center) if compromised in quality and integrity at a micro level. Thus, innovative solder materials help ensure reliable data center performance via mechanical and electrical solder joint integrity.

Telecom

Repairs on outdoor telecom infrastructures must be minimized because of their remote locations and more difficult-to-access structures, such as telecom wireless towers. Printed circuit boards in AAUs must be built to last; typical lifespan requirements exceed 10-15 years per electronic device. These units must handle temperature, precipitation, and wind/vibration. Solder, underfills, and bonding materials can help significantly via stable, sustainable lifespans.

In telecom infrastructures, a reduction in construction costs can be directly correlated with hardware weight. Reducing active antenna weight in telecom towers by an estimated 60%, or from 50 kg to 20 kg, results in an in-kind decrease in installation costs and labor expenses. Weight can be reduced by decreasing hardware size and replacing screws with high-performance bonding materials or liquid gaskets and other novel design factors. These bonding materials provide cost-effective ways to reduce hardware weight and construction costs.

Underfills

Underfills provide additional mechanical reinforcement to the solder joints and solder balls that connect a chip to a printed integrated circuit. The underfill reinforces the package to the board via capillary action. This helps to prevent mechanical fatigue and extend the lifespan of the assembly.

Bonding Materials

Bonding materials play multiple roles throughout the network infrastructure. First, they provide sub-component stability and enhanced reliability within electronic components across data centers and telecom environments. Secondly, they offer solutions to reduce hardware weight via liquid gasketing. Third, they provide protection against mechanical stresses as described earlier.

Solution 3

Maximum light transmittance properties in advanced materials and strong, reliable interconnects are key must-haves for optoelectronic components, such as transceivers, POM, and laser diodes. (Challenge #4)

Within network infrastructures, optical transceivers play an important and unique role. Transceivers convert electric data signals from data switches into optical signals (and vice versa). Light transmittance properties determine data transfer speed and efficiency. And they do so extremely fast; nanoseconds matter. Thus, optical components must provide the proper refractive index to mitigate loss of speed. They also must be non-conductive.

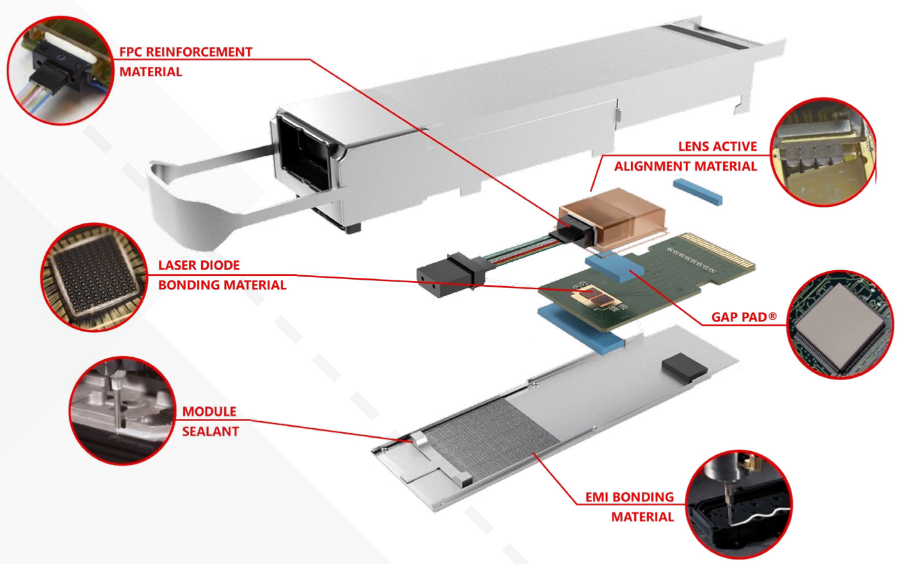
Further, optical transceiver sub-assemblies need precise alignment and dimensional stability. Advanced materials can make a notable difference in this regard, such as ensuring the proper lens position, both during assembly and throughout the transceiver's operational life.

POM Example

In optical networks, thermal management is also a concern. One example of successful thermal management in optical components (used on a server) is the POM, or pluggable optical module. With the transition to 400 GbE modules, the power level per POM—there may be as many as 32 per line card—can reach as high as 15 watts. microTIMs facilitate greater heat dissipation from the module, reducing operational temperature at a rate of 0.33° C per watt. For a 15-watt module, temperature reduction is upwards of 5° C, which is significant in aggregate across the line card.

Further, advanced coatings used in microTIMs can enable significantly more plug inserts and pulls before incurring notable perishability, thus extending the life of POMs. Reliability and durability are enhanced once again, boosting network infrastructure performance.

In the mammoth scale of data centers, telecom infrastructures, and optical networks, achieving next-level performance depends on looking small to go big. Advanced materials used in electronic components hold the key to improving outcomes within current challenges and delivering the next level of performance required for future innovation.



The effective use of advanced materials in an optical transceiver is shown in the diagram above.

Summary

The butterfly effect applies to network and infrastructure environments. The tiny elements of electronic components add up to big results, improved performance, and enhanced reliability across data centers, telecom infrastructures, and optical networks. Using advanced materials in integrated circuits can improve outcomes for both technical and business challenges and deliver the performance required for future innovation.

Designing and selecting innovative, advanced materials is vital in our current era of information technology. Providing connection, protection, and thermal management is a powerful catalyst to data center and telecom performance. Benefits from using advanced materials in component design include decreased data latency and improved efficiency, reliability, and thermal management for ongoing reduction of operational and maintenance costs.

The path to achieving next-level capabilities and outcomes is to align with an innovative, advanced materials partner to source and, in some cases, co-innovate advanced material development. Henkel stands ready to work with you toward that goal.