Optoelectronics

PHONONIC

Ebook

4 Key Thermal Design Considerations for Next-Gen TOSAs

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Trends Driving the Transceiver Industry

The optical transceiver industry is poised for rapid growth, with an anticipated CAGR of 6% through 2023.[1] Optical component and transceiver manufacturers need to prepare to take advantage of this growth and maximize profits.

Five significant technology trends are dominating the industry. Manufacturers need to recognize these trends - and their design challenges - in order to differentiate and stay ahead of competitors in a hot market.

Increasing heat dissipation density

1. Increasing heat dissipation density

Newer generation MSA (Multi-Source Agreement) transceiver form factors have shrunk dramatically over the years, and the predominant form factors under development today are QSFP-DD and OSFP. Power consumption ratings for these form factors are >10 Watts, which translates to a dramatic uptick in heat dissipation density (measured in Watts per unit volume). Increasing heat density at the transceiver level is being felt at the laser package level too. There has been an approximate 3X increase over just the last few years, with many packages today needing to pump 500mW or even up to 1W in the space of just a few millimeters.

Increasing maximum ambient temperature requirements

2. Increasing maximum ambient temperature requirements

More and more components today need to support the wider Industrial temperature (I-temp) range, which covers -40 to 85°C. This puts stricter performance requirements on TECs (thermoelectric coolers) within the laser packages to operate in the extreme ambient temperatures found in more demanding applications.

More stringent power consumption requirements

3. More stringent power consumption requirements

MSA specifications are demanding tighter power budgets on transceivers, including the laser package. In addition, the signal processing electronics (DSPs) inside the transceiver are taking up a growing percentage of that power budget. In any cooled package, the TEC can be one of the larger power consumers. In an industry where every milliwatt and every millimeter counts, the TEC may be the best opportunity to reduce overall power consumption.

On-board optics are moving closer to the CPU

4. On-board optics are moving closer to the CPU

In next-generation package designs, components including detectors and optics will be built directly into the board, replacing existing copper lines. This trend is driven by the need for increased speed. Engineers are aiming to perform as much data transmission at light speed as possible before moving to electronics.

Demand for non-hermetic packages

5. Demand for non-hermetic packages

Manufacturers are looking at cost-effective non-hermetic package designs as a key way to reduce costs and design complexity. Non-hermetics will most likely replace traditional gold box package types such as box TOSAs, rather than TO can packages. As with any new advancement, non-hermetics deliver significant benefits but bring their own challenges to the development process.

Evolving Data Transmission Rates

Data Rates Are Increasing. Consumption of data is growing exponentially, and the need to transmit that data is tracking along with it. Datacom optical component manufacturers are pushing for innovation to keep pace with customer demand, and the transition from 100G to 200G to 400G in the datacenter is anticipated to be fast. Increasing data rates, as well as the longer reach runs quickly becoming popular in co-located datacenters, require active cooling to ensure peak performance. Cooled optics are appearing in more and more applications, including 10G from 1577nm PON, 40km/ER TDM, and DWDM and Tunable devices, and certainly more often in TO can packages. In 100G, there's the 10km LR4 standard, and future requirements in wireless for I-Temp CWDM4 and I-Temp Single 100G. And in 400G, where PAM4 modulation abounds, cooled optics are being used for 400G DR4/FR4/FR8 and LR8 solutions. If and when Coherent technologies are adopted for client side modules for use inside the datacenter, the industry might see a TEC in every module for wavelength control.

10 Gbps
1577nm PON
40km EML-based
TDM DWDM Tunable
TO Can

→

100 Gbps
10km LR4
10km I-Temp CWDM4
10km I-Temp
Single-λ

→

400 Gbps+
PAM4 abounds
DR4/FR4/FR8/LR8
Coherent inside
the DC?

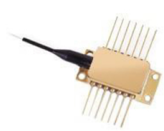
Laser Package Types & Applications

Cooled fiber optic TOSAs (Transmitter Optical Sub Assembly) are used in many laser package types. TECs have a long history in butterfly packages, commonly used in WDM (wavelength-division multiplexing) and pump laser applications. They are also commonly used in box TOSAs, which are closely aligned with the XMD MSA to establish compatible sources of 10Gbit/S TOSAs, but are also used across many application types. And while TECs weren't being used in TO can packages just a few years ago, today they are often used for 10G applications.

PACKAGE TYPE:

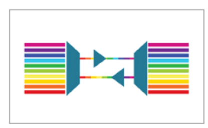
TO Can

Box TOSA



Butterfly Package

APPLICATION TYPE:



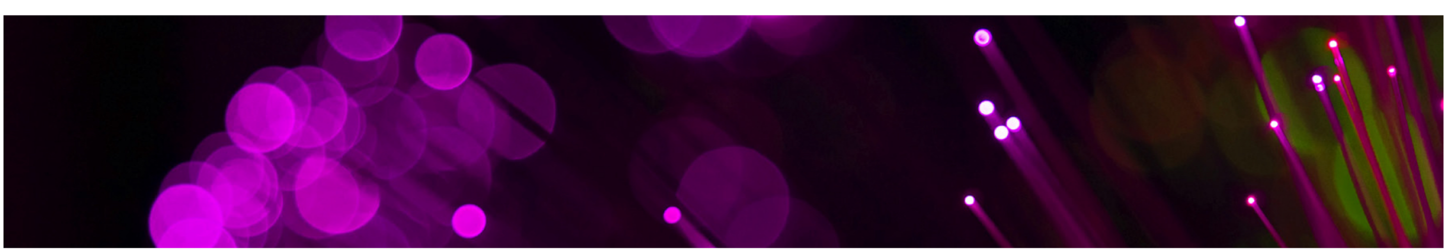
WDM/Tunable
Wavelength Control
High Datarate & Reach
DWDM: TSFP+, ITLA, ACO/DCO

Wireless Infrastructure
5G Rollout
-45-85OC (I-Temp) Support
I-Temp CWDM4 10km
25GBaud, 50G, 10km
I-Temp 100G λ, 10km

FTTx/PON
High Volume Deployment
Cost Sensitive
10G PON, NG-PON2
XGS-PON

100G/200G/400G Client Side
High Speed
PAM4 Modulation
LR4, DR1, FR1, DR4, FR4
ER/40km, ZR/80km

These trends are creating new design challenges.



New Thermal Design Challenges

More innovative forms of active cooling are needed to keep pace with this quickly evolving industry. However, these changes bring about their own thermal design challenges.

Smaller Form Factors

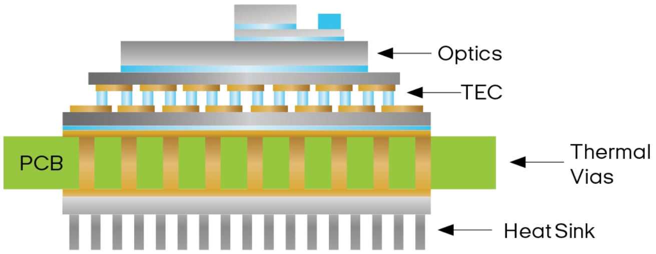
Form factors are shrinking much faster than power consumption rates, making power usage a key challenge. And ever-smaller form factors mean that TECs need to become smaller in all dimensions, particularly thickness. TECs designed for newer laser package designs are as thin as 600 or 700 microns. At the same time, the rate of release of new, smaller form factors is also getting faster, leaving less time between generations for engineers to resolve these thermal issues.

Tighter Integration of Multiple Optical Functions

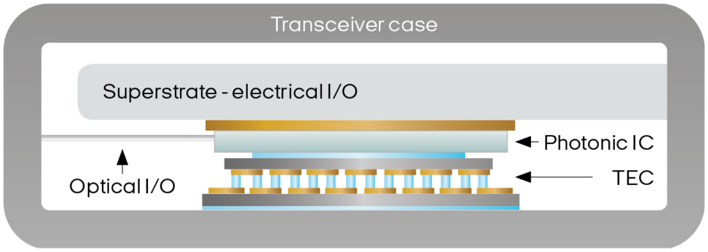
Manufacturers are looking to integrate multiple optical functions, such as light emission, gain, modulation, and multiplexing, on a single chip. This trend pushes more of the components closer to the laser. The ideal design is a monolithic integration of photonics and electronics on the same chip, enabling fewer transfers in and out of the optical fibers and free space optics, resulting in a significantly smaller footprint, cheaper packaging and simpler optical coupling.

This approach requires unique structures to couple light from waveguides on the chips into optical fibers. And it's changing how lasers are cooled. For example, silicon photonics were historically unocooled, but with tighter laser integration, these photonic integrated circuits will now sometimes require cooling.

Many optical component designers are looking beyond traditional hermetically-sealed gold boxes, essentially turning the transceiver case into the laser package. This opens the way for innovative, cost-effective package methods including surface mount, chip on board and wafer-level packaging.

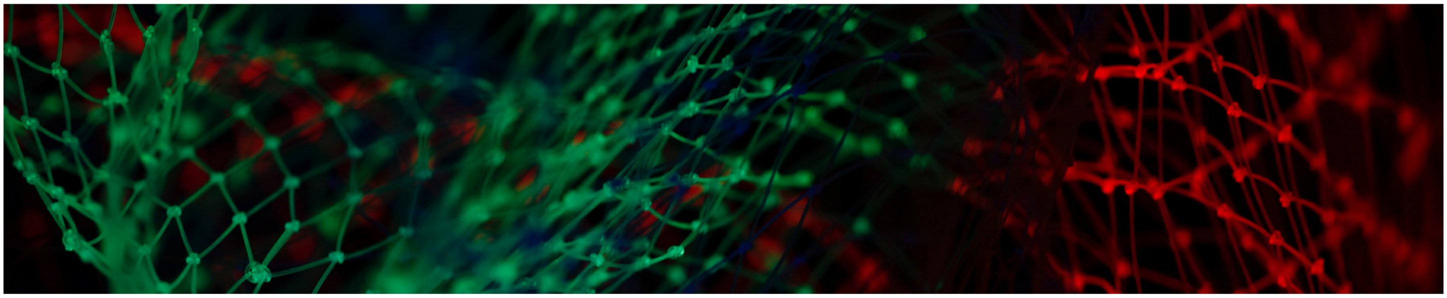


Thermal vias dissipate heat through PCB



Transceiver case acts as a heat sink (e.g. OSFP)

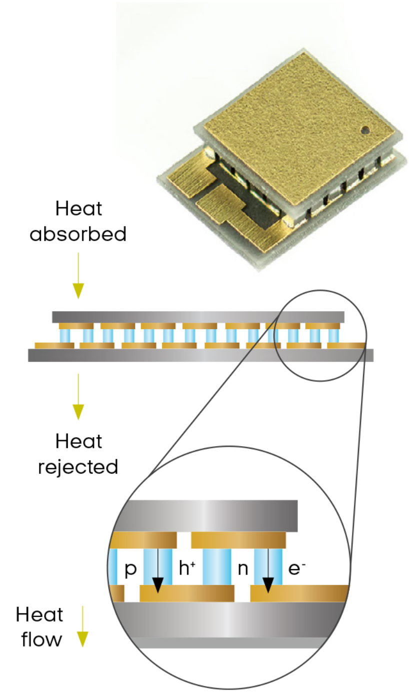
New approaches to active cooling are needed.

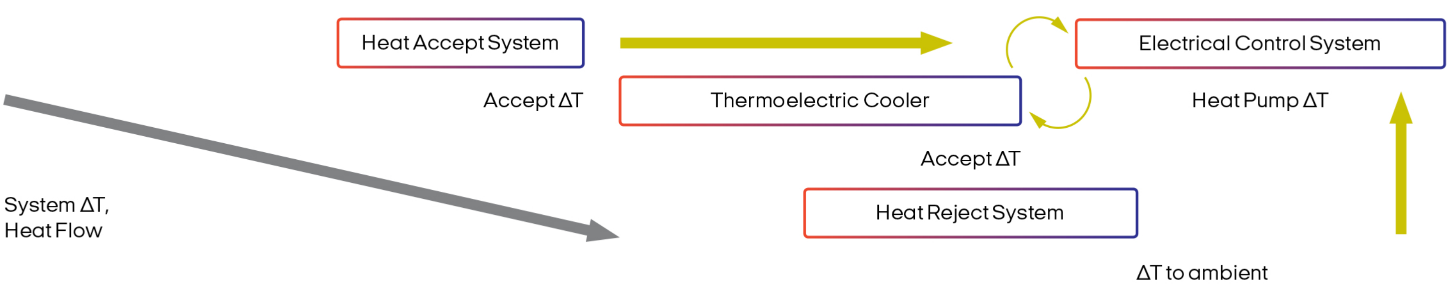


Breakdown of a Thermoelectric System

Anatomy of a TEC
A TEC is a solid-state heat pump composed of two parallel plates. Between these plates are pillars of semiconductor material, typically connected electrically in series, but thermally in parallel. These pillars work together to transfer heat from a source, similar to a heat sink. Using the Peltier effect, TECs convert an external electrical supply into heat flow. This can provide cooling or heating with accurate temperature control.

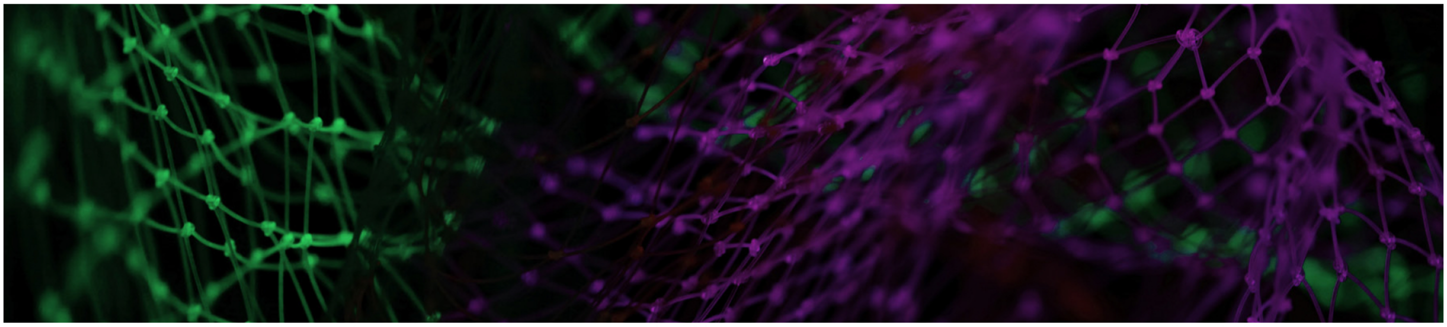
Anatomy of a Thermoelectric System
A thermoelectric system is composed of a laser assembly attached to the cold side of a TEC (the Accept side), the TEC itself, a heat reject system (often the laser package base to which the TEC is mounted), and a driver circuit, which uses temperature feedback to maintain the laser at a desired temperature. Because the layers between the laser and the TEC have finite thermal resistance, the TEC cold side will always be slightly colder than the laser when in cooling mode, which is referred to in the figure as the "Accept ΔT". Conversely, because the hot side of the TEC is dissipating heat, it will always be slightly hotter than the ambient temperature, which is referred to as the "Reject ΔT" and "ΔT to ambient" in the figure. TECs are most efficient when extraneous temperature deltas (ΔT's) are minimized and the TEC ΔT is close to the laser-to-ambient ΔT.





Why TECs are So Critical
Temperature fluctuations have a dramatic effect on laser performance. One clear example is wavelength shift. As package temperatures rise, lasers drift to longer wavelengths, called "red shift". When transmitting multiple wavelengths across a single optical fiber, particularly over very long reaches, such as metro-DCI or the thousands of kilometers of fiber for mobile broadband, you cannot tolerate wavelengths shifting to a nearby channel. In DWDM (dense wavelength division multiplexing) applications, the spacing between wavelengths is < 1nm (50-100GHz), so small changes in laser temperature can lead to channel overlap and in turn signal loss.
In addition to wavelength shift, rising temperatures can also lead to reductions in modulation frequency, bandwidth, laser efficiency and output power. Longevity and reliability of the optical transceiver also play a role in maintaining performance.

Good design exploits the system for maximum efficiency.



4 Considerations for Thermal Design

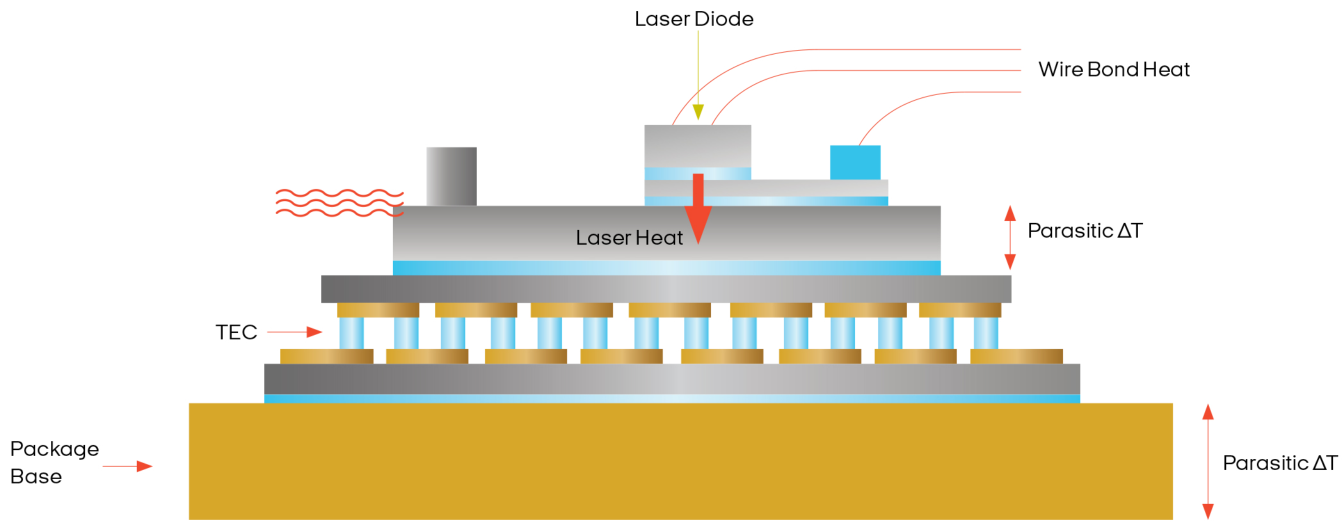
Start with Clear Requirements
In order to end up with the right TEC solution that maximizes efficiency and delivers top performance, engineers must properly define all thermal requirements during the initial design process.

1. Operating temperature range
The operating temperature range is the first requirement to consider. Remember that increasing ambient temperatures into the I-Temp range are becoming common. The ability to predict performance in the extreme temperature case is critical (for example, 85° C ambient for I-temp rated transceivers). Since TECs are one of the larger power consumers in a cooled laser package, it's important to consider heat pumping efficiency at multiple operating points.

2. Active heat load v. total head load
TECs pump heat away from a laser and out of a device. It's easy to account for active heat load, which generally equates to the amount of input power consumed by the laser and other components on the TEC. However, total heat load must be considered. This includes the active heat load, any additional active loads (from drivers or modulators), and any passive heat loads. Passive loads may consist of heat from convection or conduction through the wires of the laser assembly, and are parasitic in nature. They can be as large as the active heat load itself.

3. Thermal resistance
During design, consider the TEC's operating temperature difference (ΔT). This delta is critical when defining operating point and efficiency, and will always be larger than the temperature difference between the laser and the ambient temperature. Parasitic temperature differences are caused by the finite thermal resistances of the materials in the thermal path. While thermal resistance is a characteristic of a component such as a heat sink, thermal resistivity is a characteristic of a material. Designs should factor in the thermal resistivity and resultant additional ΔT of submounts, carriers and attachment materials, such as solder or thermal epoxy.

Other factors to consider include heat spreading, which is normally controlled via surface area but needs to account for small footprints, and thermal shunt resistance (shunts create a low resistance path in parallel through which heat can flow and essentially "short out" a thermal circuit). Good package design targets low "series" thermal resistance and high "parallel" thermal resistance to minimize these parasitic temperature differences.



4 Cooled non-hermetic laser packages

The industry is under pressure to reduce costs without sacrificing performance or reliability. Sales price and cost-per-bit of optical components are decreasing every year. Unlike traditional telecoms, hyperscale datacom customers such as Facebook, Google and Amazon order bulk at large discounts, contributing to price erosion. Non-hermetic laser packages offer a breakthrough way to hit cost reduction goals, but they introduce unique design challenges.

Humidity, condensation, corrosion, and even ice are all potential problems. Condensation inside the laser package, which happens when the laser Chip-On-Carrier (CoC) assembly is cooled below the dew point of the environment, is a major concern. In powered 85°C/85% RH testing such as HAST (highly-accelerated stress testing), the dew point is approximately 81°C. With that, a laser/TEC cold side temperature of 40-50°C will cause condensation on the TEC, which will happen regardless of TEC design.

These environmental effects can corrode electrical contacts and contacts on an unprotected TEC, interrupt the optical pathway (leading to coupling loss), degrade laser performance, and result in thermal shorting due to water bridging, which ultimately results in loss of temperature control. All of this degrades the TOSA performance significantly. These environmental effects degrade laser slope efficiency and increase coupling losses, reducing data transmission rates, reach and usable lifespan. Manufacturers considering a non-hermetic solution should look for options that have been tested and proven reliable.

4 KEY DESIGN CONSIDERATIONS

Operating temperature range	Active heat load v. total head load	Thermal resistance	Cooled non-hermetic laser packages

For the most effective solutions, find a partner with deep thermal design expertise.

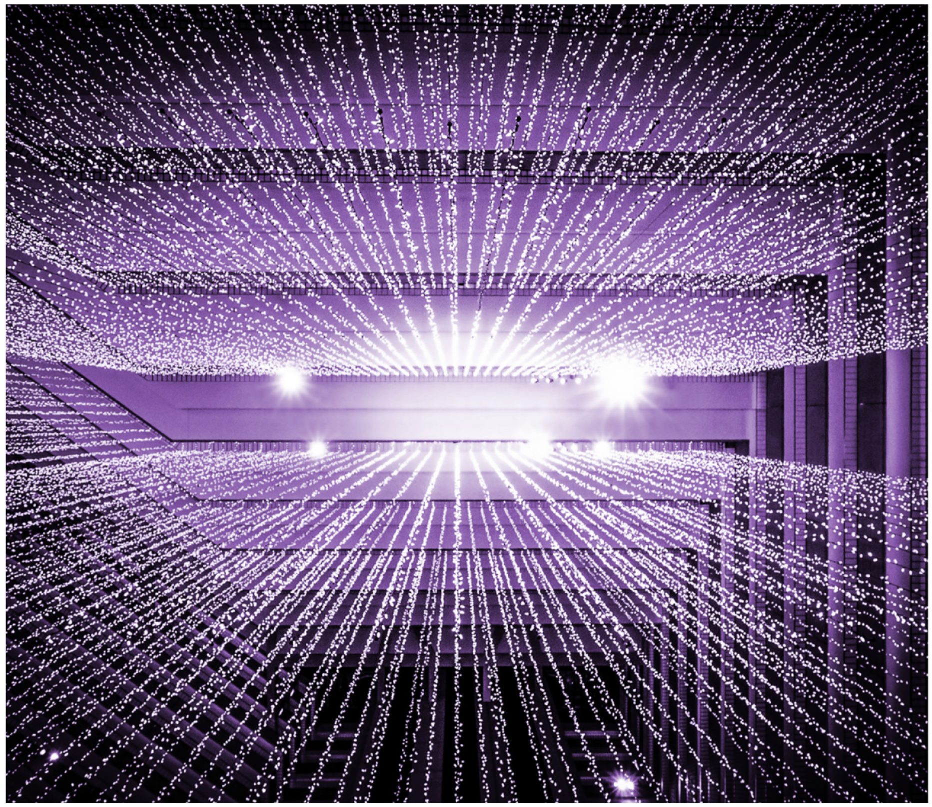
Key Takeaways

1. As data transmission rates increase, innovative active cooling is required for shorter range applications.

2. Unique designs such as non-hermetics are becoming available, which enable lower cost, but also create new thermal challenges that need to be addressed.

3. Non-hermetic TEC solutions need to deliver cost savings without sacrificing performance and efficiency, and be able to withstand environmental factors such as condensation within the package.

4. Finding a partner with the thermal design expertise to address these challenges will unlock better performance and higher ROI - remember, the TEC is the best opportunity to reduce power consumption and meet tightening industry requirements.



Meet Phononic

At Phononic, our mission is simple but bold. We push the limits of what's possible in active cooling and thermal management with thermoelectrics. As one example, we're currently producing high-performance TECs that are sub-700 microns thick. And we support our customers with deep thermal design expertise. Our design and manufacturing process delivers consistent, repeatable results. With extremely tight process control, we deliver unrivaled quality and reliability. Right now, our TECs are being delivered for optical components used in FTTx and Access applications with stringent, telecom-grade lifespan requirements. This is possible because we do our assembly in a US-based automated manufacturing facility that scales quickly from design into production, reducing NPI timelines while guaranteeing performance.

PHONONIC DELIVERS:

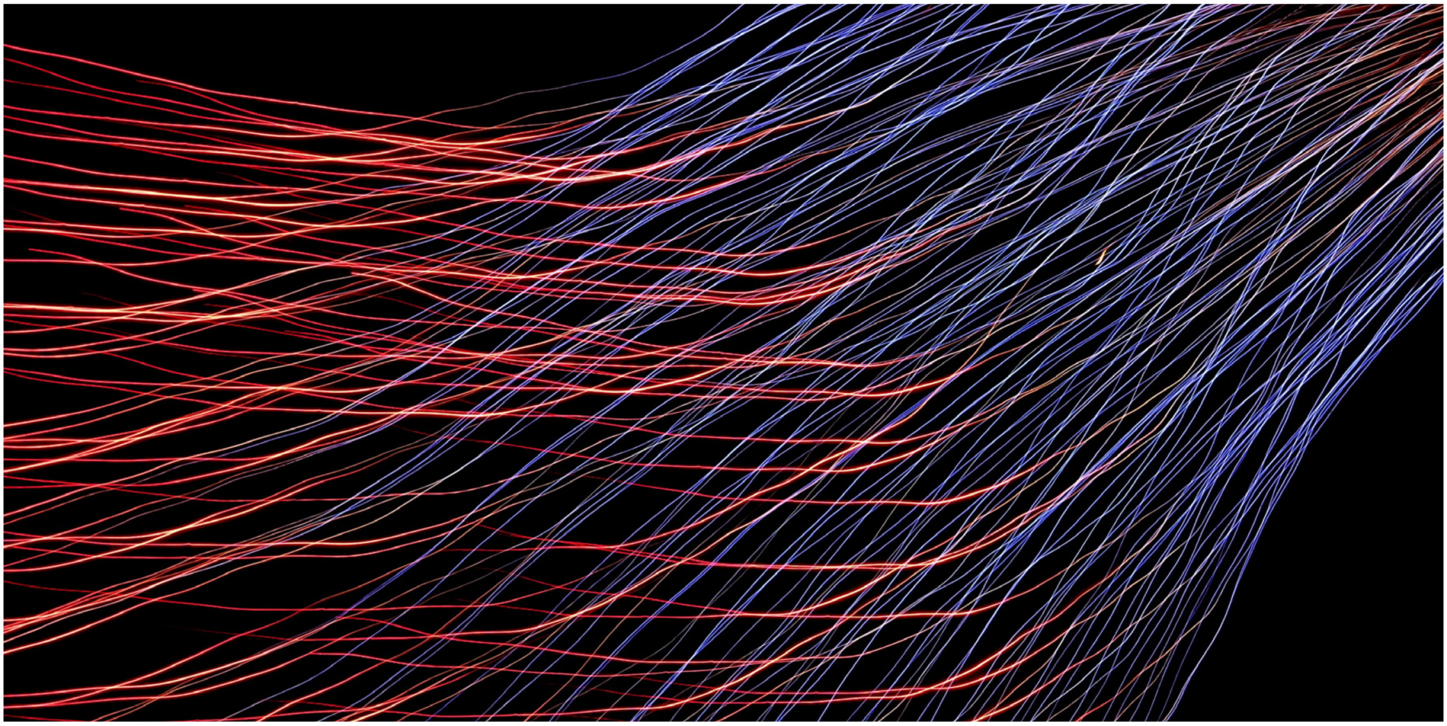
Up to 60% better heat pumping density

Proven reliability

Up to 30% lower power consumption

New integration schemes

Thermal design expertise



Non-Hermetic Solutions

There is heavy pressure for transceiver manufacturers to reduce package costs, and to meet these cost reduction targets without sacrificing performance or reliability. New technologies like non-hermetic laser packages enable dramatic TOSA cost reductions, which will help companies achieve aggressive cost reduction goals.

But the environmental challenges facing cooled, non-hermetic packages are very different from those facing hermetically-sealed packages, and can severely impact laser performance and reliability. This makes it critical to implement non-hermetic TECs that protect against humidity, condensation, and corrosion in order to ensure optimum performance and durability.

Other non-hermetics are still in R&D, but we are leveraging our experience with refrigerators and countless hours of reliability testing, and now have tens of thousands of non-hermetic devices in the field at hospitals and pharmacies around the world. This guarantees that when you design in our non-hermetic TEC, it will pass reliability targets.

Some approaches to non-hermetic TECs are short-term fixes that are impossible to quality check, and attempt to cover up failure modes in non-condensing environments. They drastically degrade cooling performance, increasing power consumption. Our non-hermetic TEC platform is a fundamental re-engineering of the device that solves the root cause of failure in condensing environments. Our solutions have a negligible impact on performance relative to hermetic-rated TECs, with little to no efficiency loss. As such, your laser package design won't compromise performance for cost.

Thermal Design Expertise You Can Trust

We have extensive experience designing cooling systems that do not suffer from high levels of thermal loss and are resistant to condensation and other challenges. The cooling engines in our compressor-free refrigerators face harsh environments every day. We offer our best-in-class TECs as well as our expertise to help you design and commercialize both hermetic and non-hermetic laser packages and avoid potential pitfalls early in the design cycle.

But most importantly, we are focused on your specific thermal needs. Our thermal design consulting has helped customers in the optical components space converge on a highly efficient TEC design, as well as improve thermal design and performance of their TOSA package. We will even review your package CAD drawing so we can design the perfect application-specific configuration for your needs.

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Phononic is reimagining cooling and heating in ways never thought possible. Its breakthrough solid-state technology is transforming industries and creating new markets with innovative solutions that disrupt antiquated business models and incumbent technologies. Phononic is the critical element of innovation needed to radically change what it means to be efficient, effective and sustainable. The company has been named to the 2016, 2017 and 2019 CNBC Disruptor 50 lists, received the US EPA's 2017 Emerging Tech Award, R&D 100 Award and more.

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