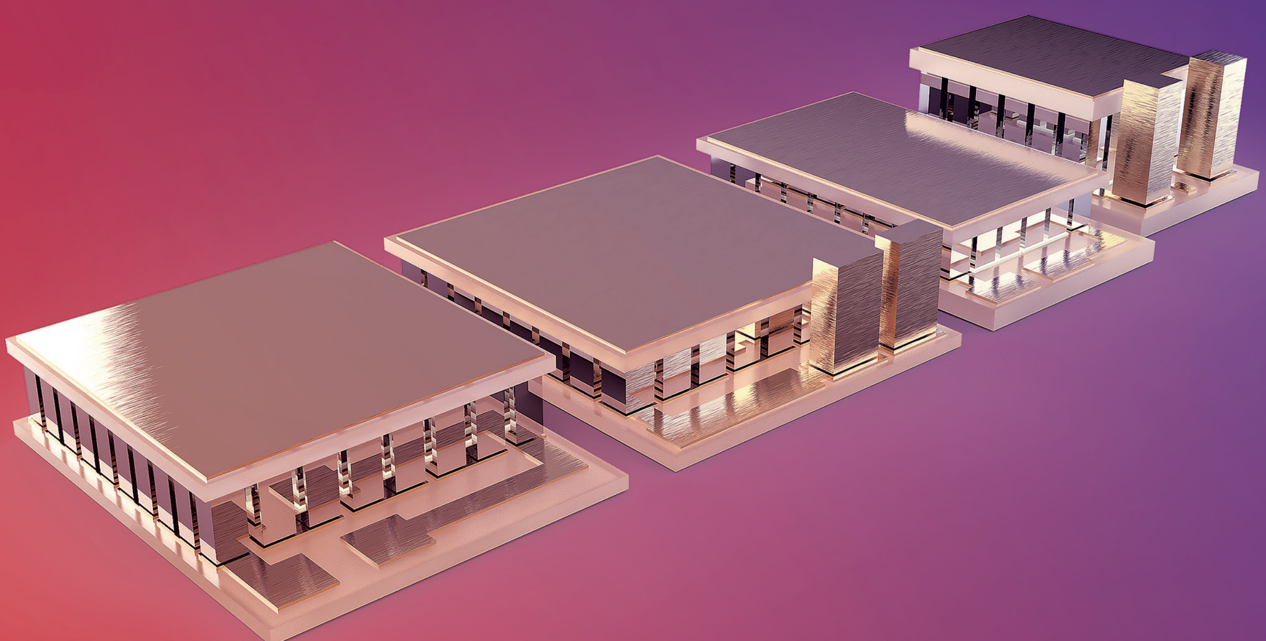
Designing TECs for Cost & Performance



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The Phononic Difference

WHO IS PHONONIC

Phononic is a global provider of groundbreaking semiconductor cooling — but we are so much more. We are powerful grocery solutions, delivering efficient, omnichannel growth. We are HVAC innovations, combining net-zero, all-electric commercial heating and cooling with a lower total cost of ownership. We are experts in optoelectronics, developing and manufacturing cutting-edge thermoelectric cooling applications that lead the industry in performance, reliability and quality. Phononic believes in a better, more sustainable future, and our transformative, solid state cooling technology is moving the world in the right direction.

What Sets Phononic Apart

Improving current TEC technology with an eye on the future

At Phononic, we're optimizing today's TEC technology, but that's just where the story begins. We understand that the path forward requires continuous improvements in performance, efficiency, reliability and manufacturing, so we constantly invest in materials science to enable higher mechanical strength and lower power consumption

To meet that end, we've stacked our Field Application Engineering (FAE) team with a deep roster of industry-leading experts. Their decades of experience and knowledge keep our TECs on the bleeding edge of today's technology, ensuring our customers can meet the current market's data demands. What's more, we vigilantly monitor upcoming bandwidth requirements, and we invest deeply in researching and developing the next generation of TECs to keep our clients prepared for the exponential increase in data consumption that is coming in the near future. When you work with Phononic, not only will our highly knowledgeable FAE team help you stay ahead of today's data needs — you'll be fully prepared to meet and exceed the skyrocketing bandwidth requirements of tomorrow.

Powerful Partnerships for Full-Scale Manufacturing & Distribution

Phononic has a deep understanding of the optoelectrical market's past, present and future. We pay close attention to the trends and technology driving optoelectronics forward. In doing so, it quickly became clear that there would soon be explosive demand for high-powered transceivers — and innovative TECs to optimize them. We were going to need trusted, high-volume manufacturing partners closer to our clients to meet this forecasted demand. That's why, in 2020, Phononic partnered with Fabrinet, a leading provider of advanced optical packaging and precision optical, electro-mechanical and electronic manufacturing services.

This partnership swiftly demonstrated its purpose: In record time, we were fully qualified with customers as we scaled global production of high-performance thermoelectrics, all without disrupting our supply chain.

And to ensure regional and global supply meets the growing demands of the optical transceiver market, Phononic has brokered partnerships with distributors like Photonteck (China), Seikoh Giken (Japan), Gillanix (Korea) and El-Gev Electronics Ltd (Israel).

PHONONIC

GLOBAL DISTRIBUTION PARTNERS

+

HIGH VOLUME MANUFACTURING PARTNER

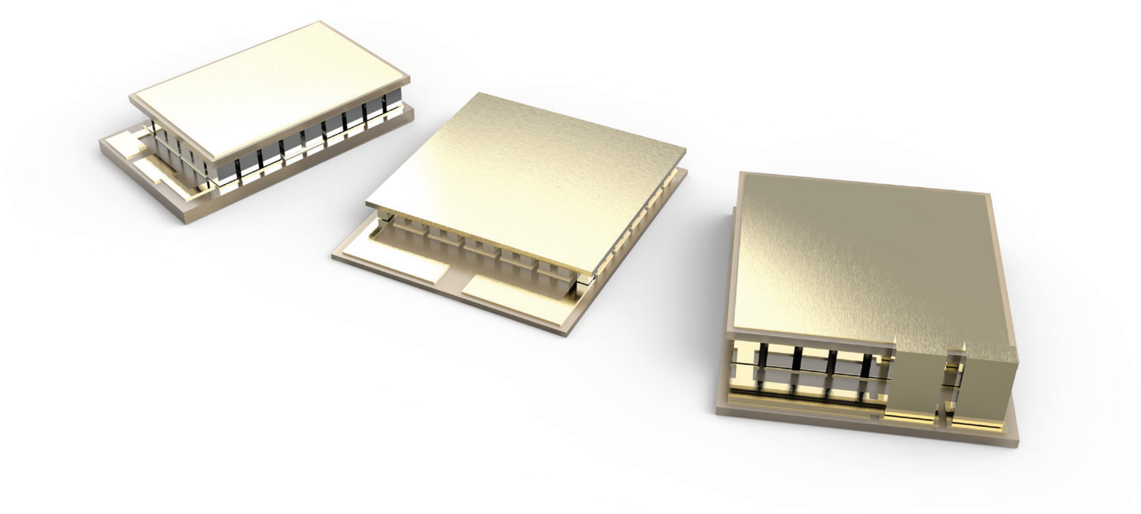
SEIKOH GIKEN

Gillanix

富泰科技 PHOTONTECK

EL-GEV Electronics Ltd.

fabrinet



Consistent Delivery of Dependable, High-Quality and Proven Technology

Tens of millions of Phononic TECs are actively being used around the world in a variety of applications, including data centers, telecom, fiber to the home, 5G & LiDAR.

At Phononic, we have imposed some of the most rigorous standards in the market upon ourselves, and we continuously invest in top-of-the-line methods to deliver the highest quality and reliability to maintain our status as an industry leader, and The International Organization for Standardization (ISO) has noticed. The ISO provides the world's most widely recognized certifications for Quality Management Systems (QMS) and Environmental Management Systems (EMS), and Phononic has earned certifications toward ISO 9001:2015 and 14001:2015 standard requirements.

In 2023, Phononic announced the first-ever thermoelectric strategic supplier agreement for high-performance TECs for cooling LiDAR optics with Luminar. By leveraging our proprietary TEC technology and scalable device architecture, we're uniquely positioned to reliably deliver high performance cooling that meets demanding automotive OEM standards unlike any other. In fact, we're already qualified in two major OEM vehicle platforms. Phononic is also the only TEC supplier certified toward the International Automotive Task Force (IATF) 16949 — a global quality management system standard for the automotive industry.

In fact, Phononic's technology has been met with such high regard, we've taken it to other industries with proven success. You can find our expertise the grocery and pharmacological industries, where we supply retail and automation/robotics solutions. We also are revolutionizing the commercial HVAC industry, where we've developed the world's first sustainable, solid state HVAC solution.

Optimizing the Design: The Phononic Application-Specific Design Process

Custom Device Design

You need a TEC designed to work with your specific technology, but you want to you want to ensure it meets your design and performance goals before committing to its creation. Phononic has you covered.

We start by developing a full 3D Thermal Model. This presents us with a complete accounting of package thermal properties, enabling us to both predict the operating point achieve the best possible TEC performance. It also provides insight into the package design to help reduce the package's operating power.

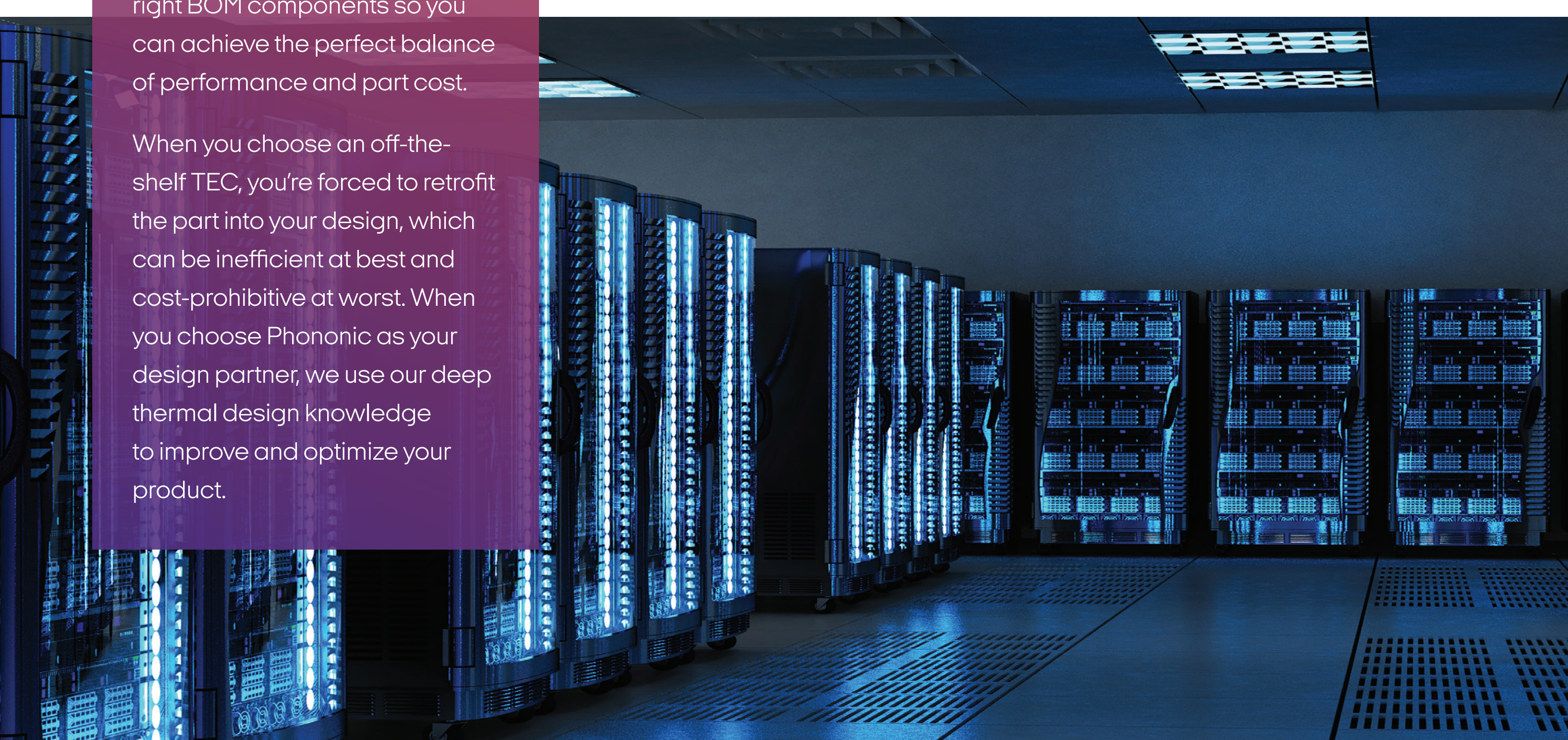
Comprehensive Manufacturing Capabilities

With a 20,000 sq. ft. materials foundry and design engineering facility in North Carolina's Research Triangle Park and Fabrinet's Thailand-based, fully automated production line for high-volume, high-quality and highly scalable manufacturing, Phononic is fully ready to deliver your application-specific TECs on time and as specified.

TEC DESIGN WITH PHONONIC

Choosing the right team will ensure that you can quickly converge on a TEC design that satisfies all of your design requirements while optimizing COP and reducing cost. Phononic's engineers know how to optimize for device size, parasitic temperature deltas, processing temperature range, integration options and more. They will help you identify the right BOM components so you can achieve the perfect balance of performance and part cost.

When you choose an off-the-shelf TEC, you're forced to retrofit the part into your design, which can be inefficient at best and cost-prohibitive at worst. When you choose Phononic as your design partner, we use our deep thermal design knowledge to improve and optimize your product.



	Parameter	Test Method	Condition	Sample Size	QBP
Mechanical / Physical	Mechanical Shock	JES022-B104, Condition B GR-468-CORE	Peak acceleration 1500g, 0.5ms/shock 5 shocks/axis, 6 axes, 30 shocks total TEC attached to Au-plated CuW substrate, no cold side weight	22	
	Mechanical Vibration	JES022-B103, Condition 1 GR-468-CORE, Condition A	Acceleration 20g, Min/Max frequency: 20/2000Hz, 4 sweeps/direction TEC attached to Au-plated CuW substrate, no cold side weight	22	
	Bonding Post Shear	MIL-STD-883, Method 2019	100µm/s shear force applied perpendicular to longest side of post	11	
	Element Shear	MIL-STD-883, Method 2019	100µm/s shear force applied perpendicular to longest side of post	11	
Environmental / Endurance	Low Temp Storage	JESD22-A119, Condition A	-40°C, 100hrs	22	Yes
	Temp Cycling	JES022-A104, Condition N GR-468-CORE	-40°C to 85°C, Single Zone, Ramp 10.4°C/min, Soak 10min, Cycle time 44min, 100 cycles; 500 cycles	22	Yes
	Power Cycling	GR-468-CORE	$I = I_{max}$ ON for 20 sec / OFF for 20 sec T_{hot}=75°C MIN; 5,000 cycles MIN TEC attached to metallized 30mil Al_2O_3 substrate	22 (11 for QBP)	
	Power Cycling	GR-468-CORE	$I = I_{max}$ ON for 1.5 min / OFF for 4.5 min T_{hot}=75°C MIN; 5,000 cycles MIN TEC attached to metallized 30mil Al_2O_3 substrate	22	Yes
	High Temp Storage	GR-468-CORE	85°C, 2,000hrs	22	Yes
	High Temp Storage	JESD22-A103, Condition A GR-468-CORE	125°C, 500hrs	22	Yes

Quality Control at Every Turn

Phononic relies on several statistical process control metrics to ensure your application-specific TECs are designed to perfection. We use our state-of-the-art optical imaging techniques combined with Statistical Process Control (SPC) for every µ-TEC and p-TEC manufactured in our assembly factory, as well as ensuring all of those TECs' key and critical-to-quality device parameters are in-control (with high Cpk). Plus, all TECs are measure to ensure proper solder volume dispense and uniformity.

Phononic also uses Confocal Scanning Acoustic Microscopy (CSAM) to obtain quick, non-destructive analysis of critical device interfaces, such as solder joints. We use this process on 100% of parts to monitor and ensure element/header junction interface integrity, and we often use it to assess die and substrate bonding efficacy in package-level assemblies.

Testing & Reliability through Intensive Metrology

Phononic implements factory-wide control plans using statistical process control as defined by your specific product. We also use comprehensive reliability testing in accordance with JEDEC, Telcordia and Mil Spec Standards, and we have the flexibility to adjust any and all reliability tests based on your specific needs.

Test for Reliability — and Test Rigorously

Phononic has developed a rigorous reliability test plan. Once you agree to advance the TEC design to our reliability test, we perform a series of "Qualified by Platform" tests (see below). Any TEC considered to be a new platform is subject to all tests. Our Pass/Fail Criteria is ΔACR >5% or ΔZT >10%.

Considerations for Designing TECs for Cost & Performance

When designing a laser package, you need to maximize performance while minimizing component cost to keep your solution competitive. A major tenet of good TEC design is maximizing COP (coefficient of performance), which is the measure of a TEC's (thermoelectric cooler) heat pumping efficiency.

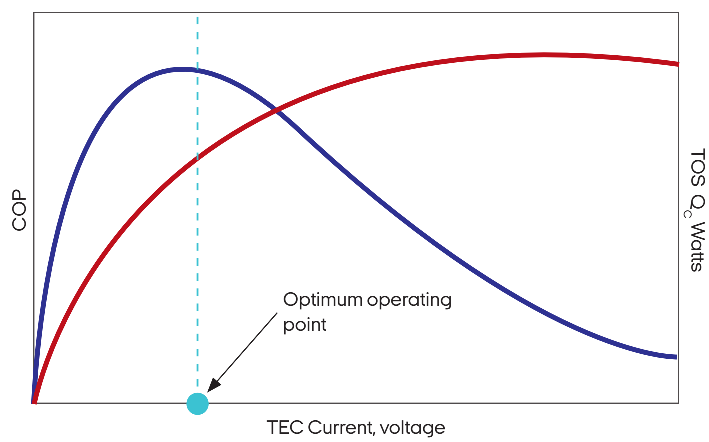
It calculates the amount of heat removed by a TEC as compared to the amount of work required to remove it. The higher your COP, the better in-package performance you'll realize. Also, going uncooled is no longer a sure bet cost reducer. Cutting-edge, high bandwidth, uncooled EMLs are a sizable cost premium over their cooled counterparts and can increase the overall cost of the package if performance expectations are not met across the entire operating temperature range. By using a cooled architecture, you don't have to sacrifice cost efficiency for performance — or vice versa. The ideal TEC design is optimized to deliver on both, even at the package level.

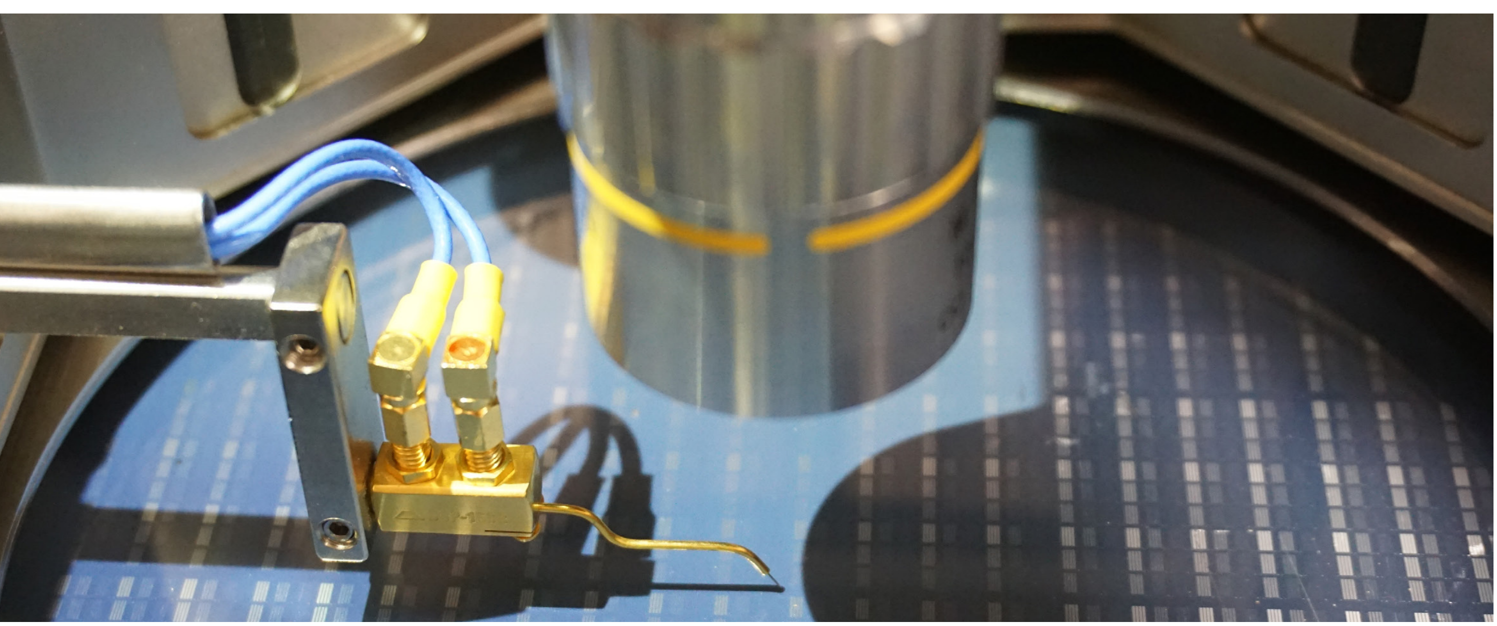
Good TEC Design

Optimizes coefficient of performance (COP) at TOSA operating condition

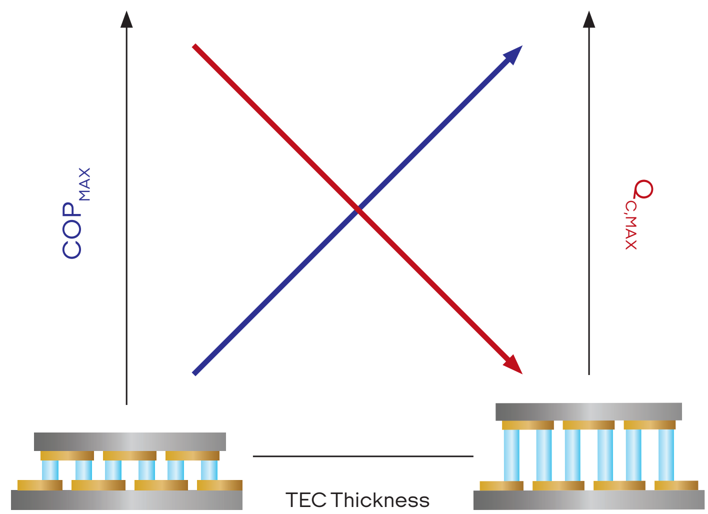
$COP = Q_C/P_{TEC}$.

COP reaches maximum when QC << $Q_{C,max}$





Top Considerations for Performance



TEC size

TEC thickness and element layout are critical design parameters. All other things being equal, increasing element height (thus TEC thickness) will increase the maximum achievable COP, but the maximum heat pumping capability will decrease. Therefore, thicker TECs are also not always the best choice for maximizing performance, particularly in higher heat density applications. Also, smaller TEC sizes (~3x3 mm) are often more cost effective than larger ones (~8x8 mm), so it is often beneficial to design in a smaller and thinner TEC to optimize both performance and cost effectiveness.

Heat pumping capability

This relates to the total amount of thermoelectric material within the TEC. As the cross-sectional thermoelectric element area increases, so will the heat pumping capability. That said, this can also lead to a less cost-effective TEC. However, remember that efficiency and heat pumping capacity are trade-offs with TEC thickness, which, as mentioned above, is also a key factor in cost management.

Package heat density

Heat density increases as component form factors shrink. Bear in mind that you could be looking at up to 12W or more in QSFP-DD (Quad Small Form Factor - Double Density) or OSFP (Octal Small Form Factor) optical transceiver modules.

Package operating temperature range

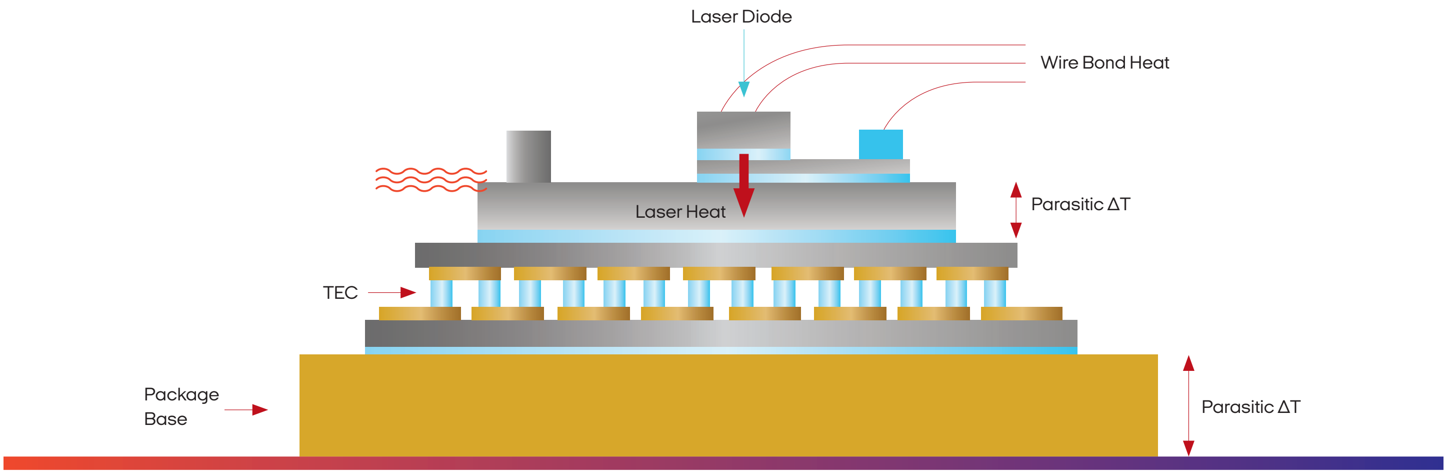
Many applications are migrating from the C-Temp (Commercial) range, which is from about 0° to 70°C, to the I-Temp (Industrial) range, which is much broader at -40° to 85°C. This trend requires TECs to perform in more demanding environments.

Power consumption

Transceiver power consumption is always a primary consideration in MSA specifications. TECs can be one of the biggest consumers of power within a laser package - but they are also a big opportunity to improve efficiency if you choose the right solution.

Active heat load vs. total heat load

Active heat load is the input power consumed by the optical components in a TEC. Total heat load also includes any additional actives (loads from drivers or modulators) and any passive heat loads. Passive loads, which are parasitic, include heat convection or conduction through the wires that connect to the laser assembly. Heat load will increase as more wire bonds are added to an assembly, and head load will also increase with decreased wire bond length. Wire bond heat loads can equal the active heat load, so they are a significant consideration. Proper design aims to find the balance between minimizing power consumption and increasing heat load.



Thermal resistance

To minimize parasitic temperature differences, good package design targets low series thermal resistance and high parallel thermal resistance. Thermal resistivity and additional temperature deltas across submounts, carriers and attachment materials such as solder or thermal epoxy must also be accounted for.

Reducing cold side thermal resistance

The TEC's cold side will always be a lower temperature than the laser diode temperature. Reducing TEC-to-laser-diode temperature deltas will reduce the TEC's power consumption. Consider using solder rather than epoxy, as solder has a lower thermal resistance. Also consider spreading resistance. Poor heat spreading from a small laser chip to the larger TEC cold side results in an increased cold side TEC temperature delta, which results in increased power consumption. The laser diode submount should be similar in size to the TEC's cold side to help improve heat spreading. Remember that thermistor-to-laser-diode offset can also change with ambient temperatures, which can affect your ability to precisely control laser wavelength.

Reducing hot side thermal resistance

Both hot side thermal resistance and the TEC attach material impact TEC power consumption. Solder drives higher thermal conductivity, leading to a lower temperature delta, which results in lower power consumption. Solder attach can reduce TEC power consumption by up to 20% as compared to epoxy attach. Pre-tinned solder is another design option to consider for your TEC.

Thermal interface processing

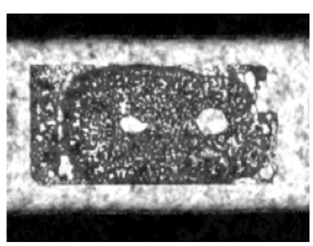
Solder/epoxy type, reflow/cure temperature and process thermal budget must all be carefully designed to ensure optimized TEC performance. Characterization tools, such as X-ray or scanning acoustic microscopy, can be used as quality checks on buried interfaces. Poor, voided hot side interface such as the type shown below prevents the TEC from performing up to expectations. By comparison, a good hot side interface enables good TEC performance.

TEC driver

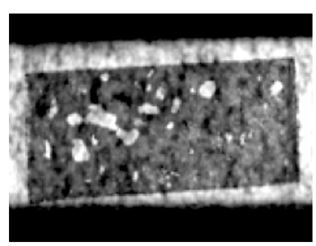
The TEC driver can have a significant impact on TEC power consumption at the TOSA level. Remember to balance the driver efficiency roll-off that occurs at low TEC current with improved driver efficiency at higher TEC loads [TEC V_{op} /I_{op}].

Epoxy		Solder	
Low temperature curing	✓	Superior thermal conductivity	✓
Low-cost processing	✓	Reworkable	✓
Difficult to control bond thickness	✗	Voiding can affect performance	✗

Hot Side Thermal Interface Characterization



Voided/poor hot side interface, leading to poor TEC performance



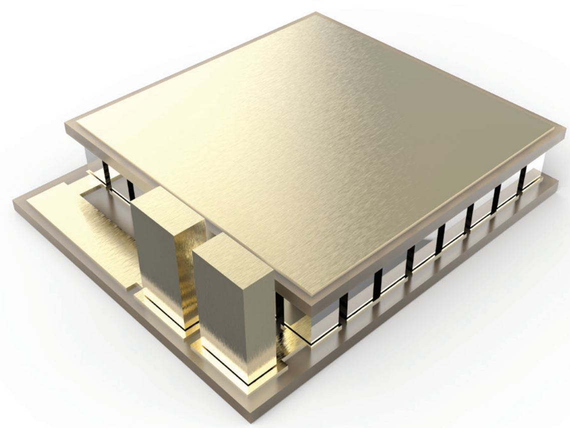
Good hot side TEC interface, leading to good TEC performance

Considerations for Cost

Au-containing solder: Solder alloys that contain gold can provide the benefit of increasing maximum processing temperatures that the TEC can withstand, but are less cost effective. We can work with you to review your integration process temperature requirements and make recommendations for the TEC solder that strikes the best balance of cost and thermal budget.

Use of posts

Adding a post may streamline TEC integration, but it also adds to the overall BOM, increasing cost. If your TEC can support direct wire bonding, you can omit posts from the design and reduce cost.



Non-hermetic packages

Non-hermetic package designs are a way to reduce overall TOSA package cost and design complexity. These package types will likely replace traditional gold box packages such as box TOSAs in many applications, particularly in cooled TOSAs inside data centers. However, non-hermetic TOSA packages create their own thermal design challenges, such as managing condensation. Be aware that some approaches to non-hermetic TECs are actually "quick" fixes that can't be checked for quality, and try to cover up failure modes in non-condensing environments. This significantly degrades cooling performance and subsequently increases power consumption. Phononic's non-hermetic TEC platform actually solves the root cause of failure in condensing environments with negligible impact on performance relative to hermetic-rated TECs, and little to no efficiency loss. This enables dramatic package cost reductions without skimping on performance.

Phononic's expert team of Application and Design engineers is ready to help you uncover the optimized TEC design that you need for your specific technology.

Learn more:

About Phononic: As the global leader in solid state cooling technology, Phononic is driving the world to a more sustainable way to cool. Its transformational technology reduces greenhouse gas (GhG) emissions and supports climate goals, while meeting the demanding performance needs of the market. The company's thermoelectric devices and integrated products are mission critical to how people work and communicate; automobiles 'see'; the protection and effective delivery of life-saving vaccines and drugs; last mile solutions supporting e-commerce; and innovative methods to cool living and workspaces.

Learn more at: **www.phononic.com**

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