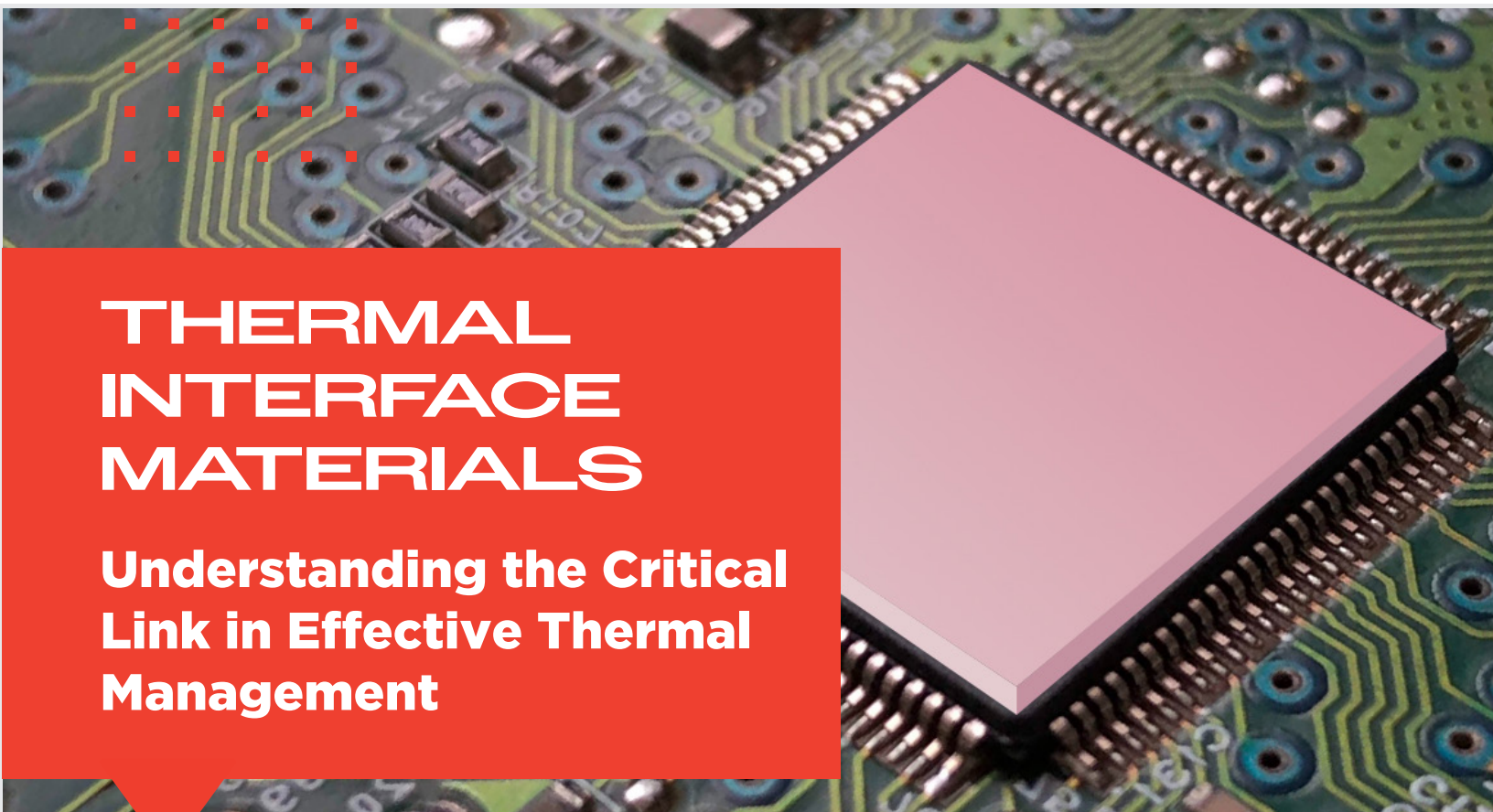


A close-up photograph of a microchip mounted on a green printed circuit board (PCB). The chip is a square component with numerous gold pins visible along its edges. A semi-transparent pink 3D block is placed on top of the chip, representing a thermal interface material (TIM).

THERMAL INTERFACE MATERIALS

Understanding the Critical Link in Effective Thermal Management

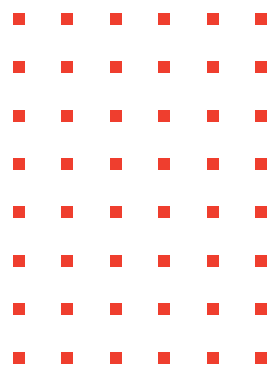
A graphic element consisting of a series of red and white chevrons pointing downwards.

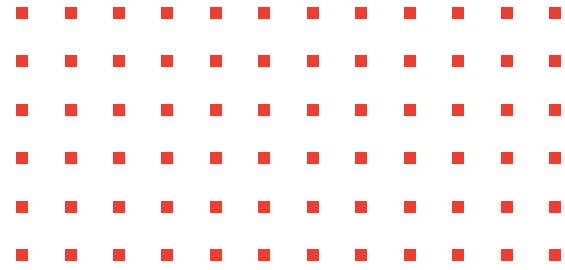
WHITE PAPER

As electronic devices become smaller, faster, and more powerful, managing heat has become one of the most important challenges facing product designers and engineers.

Thermal interface materials, or TIMs, help move heat away from sensitive electronic components by filling microscopic gaps between heat-generating devices and heat-dissipating surfaces. Selecting the right TIM requires more than comparing thermal conductivity values. Engineers must also consider gap size, contact pressure, material softness, electrical requirements, assembly methods, long-term reliability, and manufacturing conditions.

This paper provides a practical introduction to thermal interface materials, explains how they work, and outlines the factors engineers should evaluate when selecting a solution.

A decorative graphic in the bottom right corner consisting of a grid of small red squares.



WHY THERMAL MANAGEMENT IS CRITICAL

Heat is an unavoidable byproduct of electronic operation.

Processors, power modules, batteries, LEDs, communication equipment, automotive electronics, and industrial controls all generate heat while operating. As component density and power output increase, that heat must be transferred efficiently away from sensitive devices. If heat is not managed properly, operating temperatures may rise beyond the intended design range.

Excessive temperature can contribute to:

- ▶ Reduced electronic performance
- ▶ Shortened component life
- ▶ Premature system failure
- ▶ Changes in electrical behavior
- ▶ Reduced battery efficiency
- ▶ Mechanical stress caused by thermal expansion
- ▶ Increased cooling requirements
- ▶ Inconsistent operation under changing loads

Effective thermal management helps maintain components within their intended operating temperature range. It can improve reliability, stabilize performance, extend product life, and reduce the likelihood of thermally related failures.

A typical cooling system may include a heat-generating component, a heat sink or cooling plate, airflow, liquid cooling, and a thermal interface material placed between the component and the heat-dissipating surface. Although the TIM may be one of the smallest elements within the assembly, its effect on overall thermal performance can be significant.

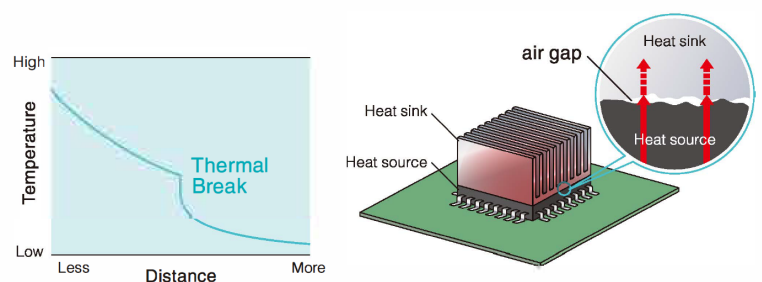
The Problem With Apparently Flat Surfaces

At first glance, the surface of an electronic component and the base of a heat sink may appear smooth and flat. At a microscopic level, however, both surfaces contain irregularities, machining marks, peaks, valleys, and variations in flatness. When the two surfaces are placed together, they make contact only at scattered points.

The remaining spaces are filled with air. Air is a poor conductor of heat compared with most engineered thermal interface materials. Even a thin layer of trapped air can create meaningful resistance to heat flow. A TIM conforms to these surface irregularities and displaces the air between the component and the heat sink. This creates a more continuous path through which heat can move.

The Purpose of a TIM

A thermal interface material does not create cooling on its own. Its purpose is to improve heat transfer between two surfaces by filling air gaps and reducing thermal contact resistance.



HOW THERMAL INTERFACE MATERIALS WORK

Heat naturally moves from a higher-temperature region toward a lower-temperature region. In an electronic assembly, heat may travel from a processor, power device, battery cell, LED, or other component into a heat spreader, chassis, heat sink, cold plate, or another cooling structure. The efficiency of that transfer depends on every layer within the thermal path.

A simplified thermal path may include:

- ▶ The heat-generating component
- ▶ The component package
- ▶ A thermal interface material
- ▶ A heat sink or cooling plate
- ▶ The surrounding air or liquid-cooling system

Each layer introduces some resistance to heat flow. The role of the TIM is to reduce the resistance that would otherwise exist at the interface between two solid surfaces.

Thermal Conductivity and Thermal Resistance
Thermal conductivity describes a material's ability to conduct heat. It is commonly expressed in watts per meter-kelvin, or W/m-K. A higher thermal conductivity generally indicates that heat can move through the material more readily. However, conductivity alone does not determine how well a TIM will perform in an actual assembly.

Thermal resistance also depends on:

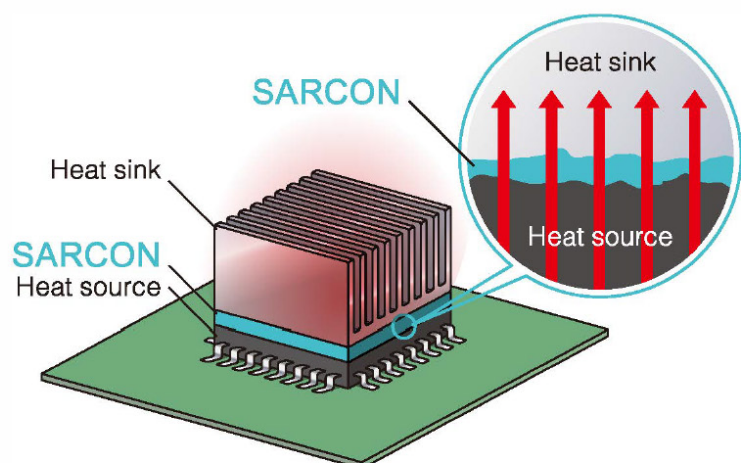
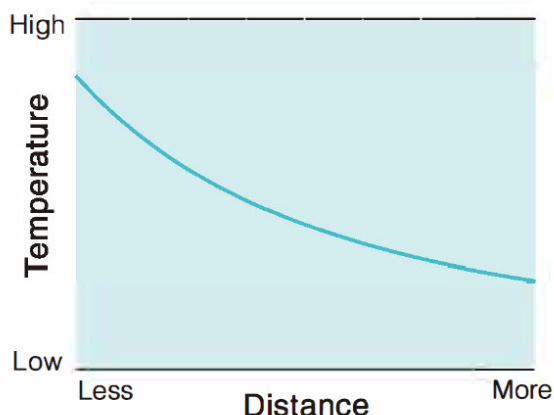
- ▶ Material thickness
- ▶ Material conformity
- ▶ Contact area
- ▶ Bond-line thickness
- ▶ Surface roughness
- ▶ Interface quality
- ▶ Contact pressure
- ▶ Installation consistency

A very thin material with moderate thermal conductivity may sometimes provide a lower thermal resistance than a much thicker material with a higher published conductivity. For this reason, engineers should evaluate the complete interface rather than selecting a TIM based on a single data-sheet value.

Contact Resistance

Contact resistance occurs where the TIM meets each solid surface. A material may have excellent bulk thermal conductivity but perform poorly if it does not make intimate contact with the component or heat sink. Soft, conformable materials can flow or compress into microscopic surface irregularities, helping reduce contact resistance.

The required level of softness depends on the application. A material must conform sufficiently without creating assembly, handling, durability, or mechanical-stability problems.



COMMON TYPES OF THERMAL INTERFACE MATERIALS

No single TIM is appropriate for every application. Different material formats are designed to address different gap sizes, surface conditions, production methods, performance requirements, and reliability expectations.

Thermal Gap Filler Pads

Gap filler pads are soft, conformable sheets designed to bridge larger or uneven spaces between heat-generating components and cooling surfaces.

They are commonly used when:

- ▶ The gap is too large for grease or thin film
- ▶ Multiple components have different heights
- ▶ The assembly must accommodate tolerance variation

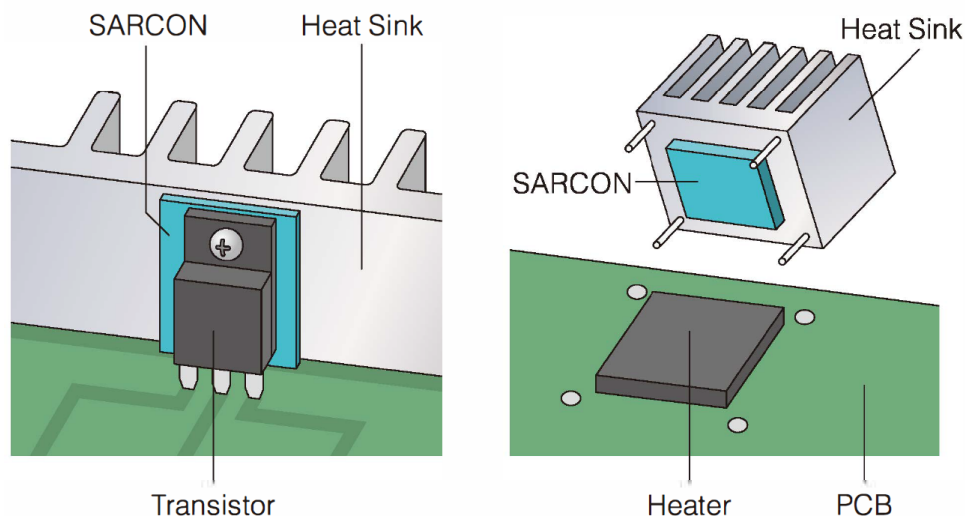
Gap fillers can be supplied in sheets, rolls, or converted shapes. They may also include liners, reinforcement, adhesive, or other handling features.

Thermal Greases

Thermal greases are highly conformable materials that can form very thin bond lines. Because grease flows easily, it can fill microscopic surface irregularities and provide low contact resistance. It is often used where the mating surfaces are relatively close and a thin interface is possible.

Potential design considerations include:

- ▶ Dispensing control
- ▶ Pump-out under thermal cycling
- ▶ Migration
- ▶ Messy handling
- ▶ Long-term stability
- ▶ Rework and service requirements



Phase-Change Materials

Phase-change materials are solid or semi-solid during handling and soften when they reach a defined operating temperature. As the material softens, it can flow into surface irregularities and reduce interface resistance. These materials may offer cleaner handling than grease while still supporting a thin bond line. Engineers must consider activation temperature, pressure, cycling behavior, and long-term material movement.

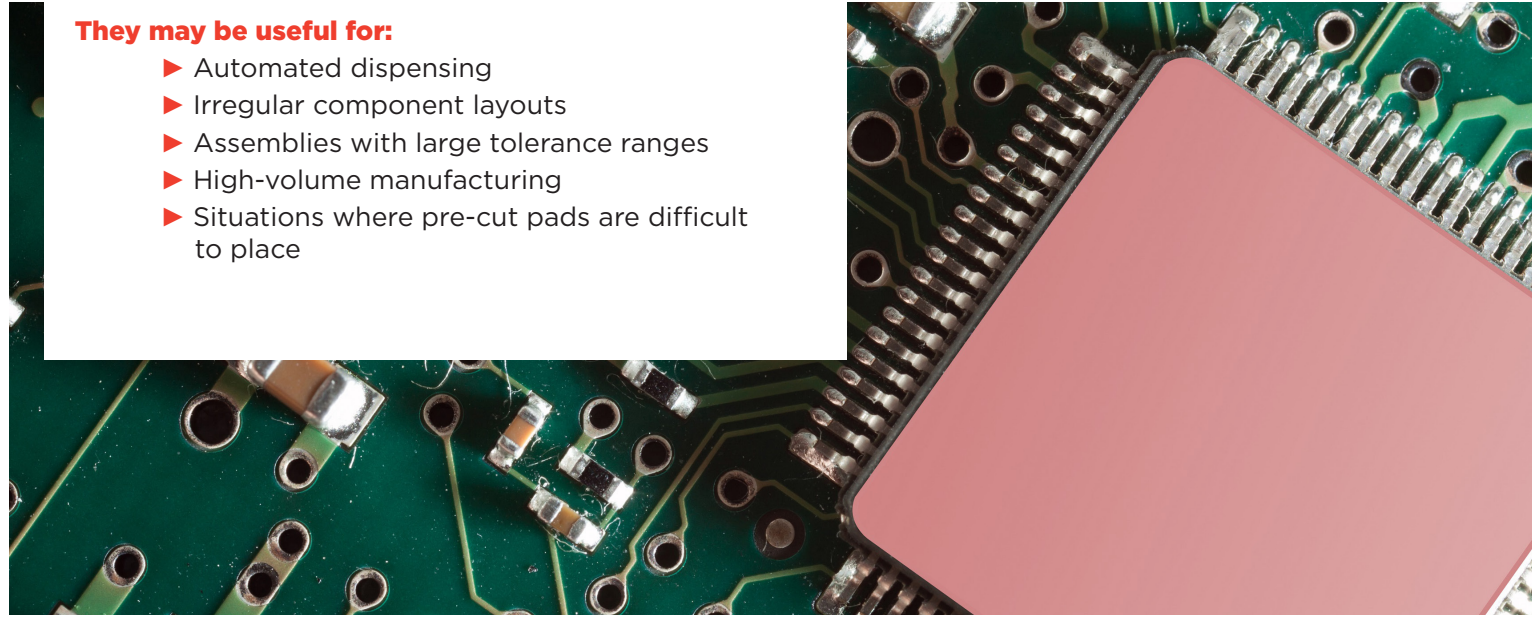
COMMON TYPES OF THERMAL INTERFACE MATERIALS

Thermal Putty and Dispensable Gap Fillers

Dispensable thermal materials are applied in a paste-like or liquid form and can conform to complex geometries and variable gaps.

They may be useful for:

- ▶ Automated dispensing
- ▶ Irregular component layouts
- ▶ Assemblies with large tolerance ranges
- ▶ High-volume manufacturing
- ▶ Situations where pre-cut pads are difficult to place



Because the material is dispensed directly into the assembly, it can establish good contact with surrounding surfaces. However, the process must control volume, placement, cure behavior, and final bond-line thickness.

Thermally Conductive Adhesives

Thermal adhesives combine heat-transfer capability with mechanical bonding.

They may reduce the need for clips or fasteners, but the adhesive function can make rework more difficult. Engineers must evaluate bond strength, cure conditions, thermal performance, electrical behavior, and compatibility with the joined materials.

Insulators and Thin Films

Thin thermally conductive insulators are used where electrical isolation is required between a component and a heat sink or chassis.

These materials may provide:

- ▶ Dielectric strength
- ▶ Puncture resistance
- ▶ Controlled thickness
- ▶ Mechanical reinforcement
- ▶ Clean handling

Because they are typically less conformable than soft gap fillers or greases, surface finish and assembly pressure become especially important.



SELECTING THE RIGHT TIM

TIM selection should begin with the application rather than the product data sheet. The following factors help determine which material type and construction are most appropriate.

Gap Size and Tolerance

The engineer must understand both the nominal gap and the full tolerance range. A TIM must be thick enough to maintain contact at the maximum gap while avoiding excessive compression at the minimum gap. For assemblies with multiple components or uneven surfaces, the material may need to accommodate substantial variation.

Compression and Contact Pressure

Many TIMs perform better when compressed because compression increases surface contact and can reduce bond-line thickness. However, excessive pressure may:

- ▶ Damage sensitive components
- ▶ Bend circuit boards
- ▶ Distort housings
- ▶ Force material out of the interface
- ▶ Increase assembly stress
- ▶ Make manufacturing more difficult

Low-pressure applications often require softer, more conformable materials.

Thermal Performance

Thermal conductivity is important, but it should be considered together with:

- ▶ Thickness
- ▶ Contact resistance
- ▶ Compression
- ▶ Total thermal resistance
- ▶ Operating temperature
- ▶ Surface condition
- ▶ Heat-flow area

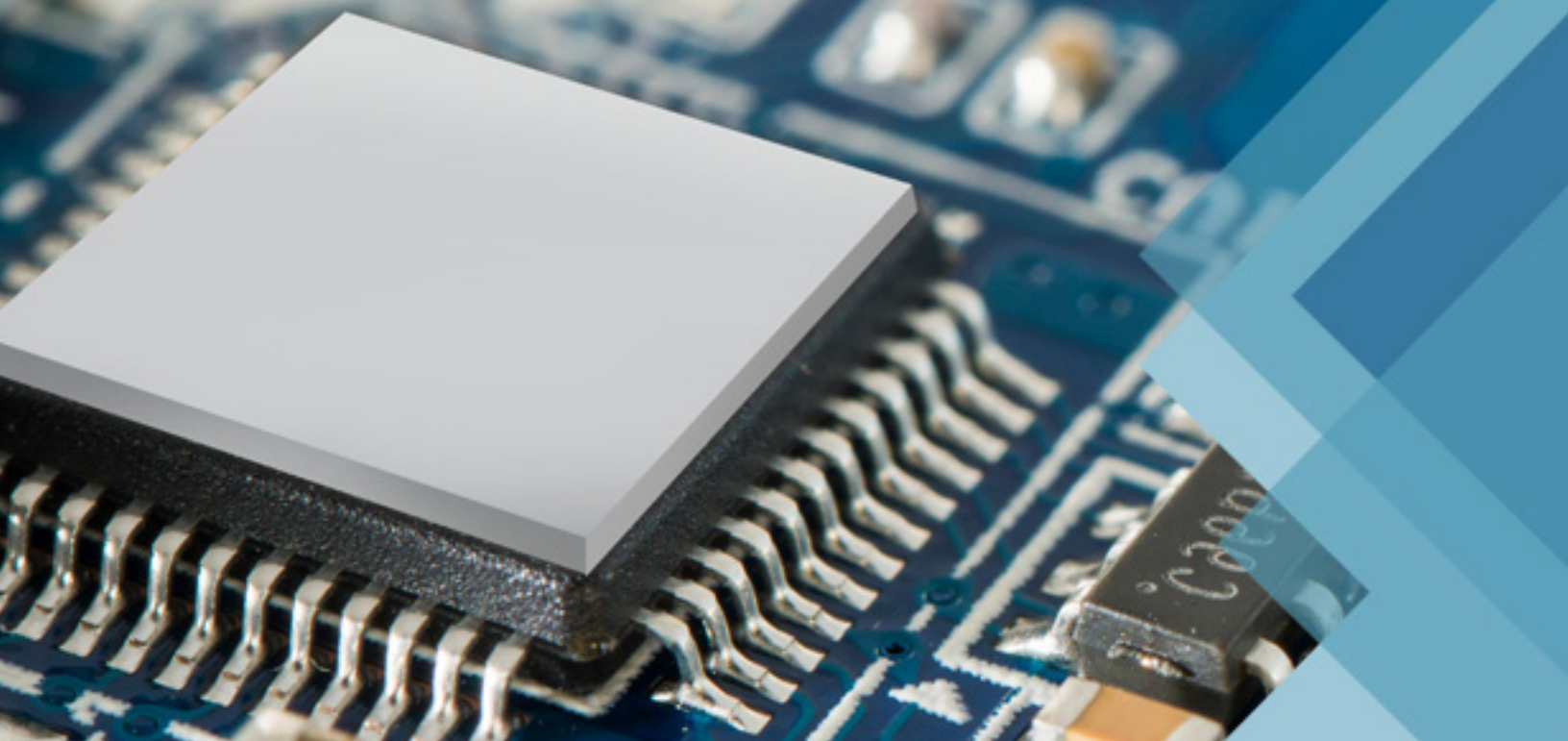
Testing within a representative assembly is often more meaningful than comparing conductivity values alone.

Electrical Requirements

Some applications require electrical isolation between the heat source and the heat sink. Important properties may include:

- ▶ Dielectric breakdown voltage
- ▶ Volume resistivity
- ▶ Surface resistivity
- ▶ Material thickness
- ▶ Puncture resistance
- ▶ Flame-resistance requirements

Other applications may require electrical conductivity or grounding in addition to heat transfer. The electrical function must be identified early in the design process.



SELECTING THE RIGHT TIM

Mechanical Properties

Hardness, softness, resilience, tensile strength, elongation, and compression set can influence both installation and long-term reliability. A soft material may conform well but require additional support during handling. A reinforced material may be easier to assemble but less able to conform to irregular surfaces.

Operating Environment

The TIM must remain stable throughout the expected service conditions. Engineers should consider:

- ▶ Minimum and maximum temperature
- ▶ Thermal cycling
- ▶ Humidity
- ▶ Vibration
- ▶ Mechanical shock
- ▶ Chemical exposure
- ▶ Outdoor environments
- ▶ Vacuum or low-pressure conditions
- ▶ Long-term aging
- ▶ Assembly and Manufacturing

A material that performs well in laboratory testing may still create production difficulties.

Manufacturing considerations include:

- ▶ Manual or automated placement
- ▶ Release-liner removal
- ▶ Tack or adhesive requirements
- ▶ Die-cutting and part geometry
- ▶ Dispensing speed
- ▶ Cure time
- ▶ Storage conditions
- ▶ Shelf life
- ▶ Reworkability
- ▶ Installation errors

The most effective TIM solution must support both thermal performance and repeatable production.

ENGINEERING NOTE

Design the Interface, Not Just the Material

TIM performance depends on the interaction between the material, heat source, cooling surface, mechanical structure, assembly pressure, and manufacturing process.

COMMON TIM SELECTION MISTAKES

Thermal interface problems often result from evaluating the material independently from the mechanical and manufacturing design.

Selecting by Conductivity Alone

A higher W/m-K value does not automatically produce a cooler component.

A high-conductivity material that is too thick, too hard, or unable to conform may produce greater thermal resistance than a softer material with a lower published conductivity.

Ignoring the True Gap Range

Designs are often based on a nominal gap without accounting for component height, board flatness, heat-sink tolerance, fastener variation, or enclosure distortion. If the actual gap exceeds the expected range, the TIM may lose contact. If the gap becomes too small, the material may be over compressed.

Overlooking Long-Term Behavior

The interface must remain effective after repeated heating and cooling. Long-term concerns may include:

- ▶ Compression set
- ▶ Pump-out
- ▶ Dry-out
- ▶ Oil bleed
- ▶ Material migration
- ▶ Delamination
- ▶ Hardening or softening
- ▶ Loss of adhesion
- ▶ Changes in electrical insulation

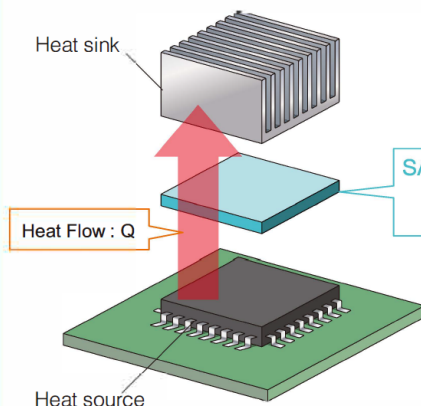
Waiting Too Long to Select the TIM

Thermal interface materials are sometimes treated as a final detail after the mechanical design has already been completed. That approach can force the TIM to compensate for an unrealistic gap, inadequate pressure, poor flatness, or limited installation access.

Involving thermal-material specialists earlier can help optimize the complete interface and reduce late-stage redesign.

How to Choose SARCON (Tips)

Thermal conduction can be expressed by Fourier's law of heat conduction.



Here are some tips to improve the heat transfer in your design:

- An interface material with higher thermal conductivity is better.
- It is better that the thickness (distance) of the material is thin (short).
- It is better to have a large surface area.

Following these tips will help achieve efficient heat transfer.

Several material options are available to accommodate other application conditions.

Please contact FUJIPOLY to help choose your SARCON material.

SARCON Area of SARCON : A
Thermal conductivity of SARCON : λ
Thickness of SARCON : T

Heat flow from Heat source

$$Q = \Delta T \times A \times \lambda / T$$

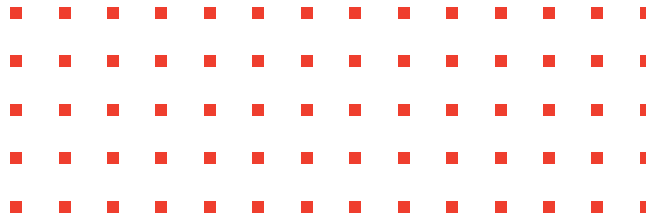
Q : Heat flow(W)

ΔT : Temperature difference between heat source and heat sink(K)

A : Area of SARCON(m²)

λ : Thermal conductivity of SARCON(W/m-K)

T : Thickness of SARCON(m)



TESTING AND VALIDATION

Published material properties provide a useful starting point, but final performance should be validated within conditions that represent the intended application.

Representative Testing

A useful evaluation should reproduce, as closely as practical:

- ▶ Actual component and heat-sink materials
- ▶ Surface finishes
- ▶ Gap size
- ▶ Compression level
- ▶ Heat load
- ▶ Operating temperature
- ▶ Mounting method
- ▶ Assembly orientation
- ▶ Environmental conditions

Prototype testing can identify differences that are not visible from material data alone.

Comparing Candidate Materials

When comparing TIM options, engineers should keep the test configuration consistent. Changing material thickness, pressure, component geometry, or heat-flow area can make direct comparisons misleading. Relevant evaluation criteria may include:

- ▶ Component temperature
- ▶ Temperature difference across the interface
- ▶ Thermal resistance
- ▶ Compression force
- ▶ Assembly ease
- ▶ Electrical isolation
- ▶ Material movement
- ▶ Appearance after aging
- ▶ Performance after thermal cycling

Prototype testing can identify differences that are not visible from material data alone.

Customization and Application Support

Complex designs may require more than an off-the-shelf material. TIMs can often be customized through:

- ▶ Material thickness
- ▶ Hardness
- ▶ Thermal conductivity
- ▶ Die-cut geometry
- ▶ Surface tack
- ▶ Adhesive placement
- ▶ Reinforcement
- ▶ Liner configuration
- ▶ Packaging format
- ▶ Automated-assembly features

Fujipoly's Customer Engineering Resource Center works with engineers to evaluate application requirements, review mechanical conditions, recommend material options, and support testing. Early collaboration can help ensure that the TIM is selected as part of the total thermal and mechanical design rather than as an isolated component.

WHERE TIM TECHNOLOGY IS HEADED

The demands placed on thermal interface materials continue to increase.

Artificial intelligence, data centers, electrified vehicles, renewable energy, high-power electronics, advanced communication systems, and increasingly compact devices are creating greater heat density within smaller spaces.

Future TIM development is expected to focus on combinations of:

- ▶ Higher thermal performance
- ▶ Lower interface resistance
- ▶ Greater softness and conformability
- ▶ Improved long-term reliability
- ▶ Easier automated application
- ▶ Reduced assembly pressure
- ▶ Greater electrical functionality
- ▶ Improved environmental performance
- ▶ Materials designed for advanced cooling systems

As cooling architectures evolve, TIMs will continue to serve as the critical connection between heat-generating devices and the systems designed to cool them.

Conclusion

Thermal interface materials play a small but essential role in electronic-system performance. By filling microscopic air gaps and improving contact between surfaces, TIMs create a more efficient path for heat to move from electronic components into heat sinks, cooling plates, enclosures, and other thermal-management structures.

Successful selection requires more than choosing the material with the highest thermal conductivity. Engineers must consider gap size, bond-line thickness, compression, contact resistance, electrical requirements, material format, operating environment, long-term reliability, and manufacturing needs. The most effective solution is the one that balances all of these factors within the actual assembly.

As electronic systems become more powerful and compact, early attention to the thermal interface will become increasingly important. By approaching the TIM as an integrated part of the thermal, mechanical, and manufacturing design, engineers can improve system reliability, reduce development risk, and create more effective cooling solutions.

ABOUT THE AUTHOR

Christian Miraglia

Applications Engineering Manager

Fujipoly America Corporation

Customer Engineering Resource Center

Christian Miraglia supports engineers with thermal-management design, material selection, application testing, and the development of customized silicone solutions. He works with customers to evaluate complex interface requirements and identify practical material solutions for demanding electronic applications.

LEARN MORE

Need help selecting a thermal interface material for your application?

Contact Fujipoly to discuss gap size, thermal requirements, electrical properties, assembly conditions, custom material formats, and application testing.

Christian Miraglia | cmiraglia@fujipoly.com

Learn More: <https://www.fujipoly.com/white-papers-webinars>