GRAFTech

GrafTech International Ltd.

ADVANCED ENERGY TECHNOLOGY INC.

Electronic Thermal Management

Electronic Thermal Management

GrafTech International Ltd.'s Advanced Energy Technology Inc. (AET) is part of a global company with over 100 years of experience in the carbon and graphite industry. AET's strategy is to work in concert with electronics industry leaders to develop customized thermal management solutions for their most demanding applications.

AET has developed and is continuing to develop and introduce highly engineered, advanced natural graphite products that satisfy the needs of design engineers today and tomorrow. The superior ability of AET's natural graphite electronic thermal products to manage heat will allow customers to design electronic devices to reduce noise, cost, size and weight while improving performance.

As a global supplier, AET's success hinges on its reputation for quality in its products and services, its people and its relationship with customers, vendors and suppliers. Beginning in the 1980's AET embarked on an ambitious program of continuous quality improvement in every facet of its operation.

The company was among the first in the industry to adopt Statistical Process Control (SPC) manufacturing methods to reduce product variation. At every stage of the manufacturing process – from raw material to final finishing – rigid programs and procedures produce the highest quality electronic thermal management natural graphite products in the world.

AET was also among the first to embrace a philosophy of total quality, achieving ISO-9002 certification in 1996 and QS-9000 in 2000.

AET's philosophy of Total Quality permeates the entire organization from its stringent product and process standards to its innovative management methods. This philosophy led to the company wide adoption of, The Theory Of Constraints (TOC), a systems-based approach to management through the process of knowledge based improvement.

Pursuing the company's mission to guide customers through thermal issues at all stages of product design has positioned AET as the leading provider of thermal engineering and thermal management solutions.

These, together with the investment made in advanced manufacturing technologies, have positioned AET to be the Total Integrated Solution for Cooling Electronics, delivering:

- World-class thermal design services
- Thermal flow analysis
- Worldwide, quick ramp-up, high-volume manufacturing

AET provides total design and management integration of customer focused thermal solutions including: thermal modeling, prototyping, performance verification, manufacturing and supply chain management.

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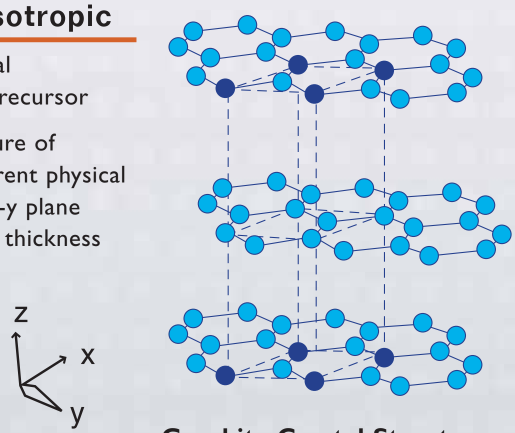
eGraf® Products are Transversely Isotropic

- Made from a natural Graphite mineral precursor
- The layered structure of graphite gives different physical properties in the x-y plane versus through the thickness (z-direction)

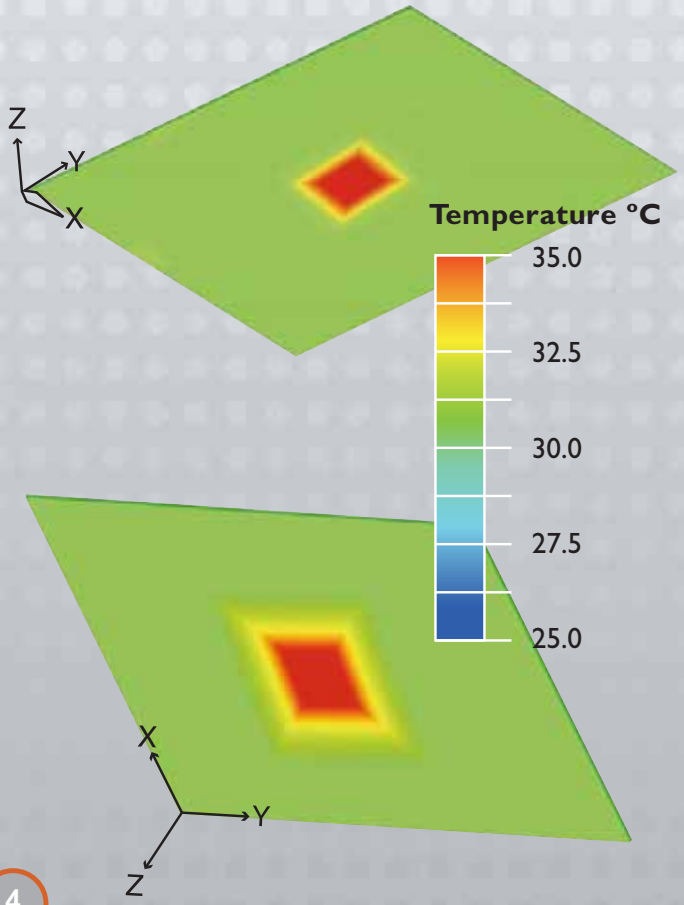


Graphite Crystal Structure

	Thermal Conductivity (W/mK)	Electrical Conductivity (Siemens/m)	Density (g/cm³)
eGraf Products (x-y)	100-500	˜2 x 10⁵	0.7-1.9
(z)	5-10	˜100	
Artificial Graphite	100	2.0 x 10⁵	˜1.8-2.2
Stainless Steel	15	2.0 x 10⁶	8.0
Aluminum	200	3 x 10⁷	2.7
Copper	380	6 x 10⁷	8.96

SpreaderShield™ Heat Spreaders

SpreaderShield™
Thermal model depicting heat spreading



Advanced Technology for ElectronicThermal Management

eGraf® SpreaderShield™ natural graphite heat spreaders from AET are electronic thermal management solutions that can be combined with plastics, metals or elastomers for final finished components.

eGraf® SpreaderShield™ natural graphite heat spreaders have the unique ability to distribute heat evenly in two dimensions, eliminating "hot spots" while simultaneously reducing touch temperature in the third dimension. In addition, the thermal properties of eGraf® SpreaderShield™ natural graphite heat spreaders can be custom designed, tailorable up to 500 W/mK, with form factors to meet any customer needs.

eGraf® SpreaderShield™ heat spreaders can be used to cool components in place of or combined with traditional cooling solutions. Fans, heat sinks, or heat pipes can be combined with SpreaderShield™ to shield other components from heat sources as well as reduce skin temperature of electronic products.

eGraf® SpreaderShield™ natural graphite heat spreaders are ideal where space is limited and/or weight is critical.

eGraf® SpreaderShield™ natural graphite heat spreaders are available with or without a pressure sensitive adhesive (PSA). They can also be sold in sheet form and laminated with a number of materials and are able to be easily roll or die cut formed to any size and shape, and come in a large variety of thicknesses.

Advantages of eGraf® Heat Spreaders

High Thermal Conductivity with Directional Heat Flow

eGraf® thermal management materials are unique because they combine excellent thermal conductivity with the directional properties of graphite.

Compared to typical aluminum alloys used for heat management, eGraf® components exhibit up to 200% higher thermal conductivity with values comparable to copper. Further, aluminum and copper are isotropic, making it impossible to modify the conductivity in a preferred direction.

With the thermal conductivity of eGraf® materials as high as 500 W/mK along the length and width, packaging components can be designed so that heat is quickly transferred away from electronic components that can fail due to overheating.

Economical High-Performance Spreader Materials

eGraf® SpreaderShield™ materials are designed for use in applications requiring high in-plane thermal conductivity. The high in-plane thermal conductivity of eGraf® SpreaderShield™ materials makes them suitable for heat spreading applications.

eGraf® SpreaderShield™ materials are manufactured entirely from natural graphite, with no fillers or binders. eGraf® SpreaderShield™ materials do not dry out and no outgassing occurs under vacuum conditions. eGraf® SpreaderShield™ materials are useable at temperatures up to 400 °C and lower than -40 °C.

eGraf® SpreaderShield™ EMI Value Added Capability

eGraf® SpreaderShield™ can be combined with other materials, such as metals, plastics or elastomers, to meet additional performance criteria such as mechanical, electrical or EMI requirements. Most importantly, the thermal performance of the eGraf® SpreaderShield™ is maintained as it is combined with the other materials. For example, thin metal foils are laminated to the eGraf® SpreaderShield™ to allow it to be formed into complex 3-Dimensional shapes, such as the eGraf® Fredda™. Metal foils, such as copper and aluminum, can also provide increased levels of EMI attenuation. Electrically conductive adhesives can provide electrical connectivity, thereby providing reliable grounding of the eGraf® SpreaderShield™. The eGraf® SpreaderShield™ can be designed to provide multiple performance characteristics and potentially eliminate additional components.

Thermal conductivity can be varied
- 100-500 W/mK in-plane thermal conductivity
- 5-10 W/mK through thickness

Very lightweight
- 20% lighter than polymeric spreaders
- 30% lighter than aluminum
- 80% lighter than copper

Easily laminated with metals, plastic or elastomer to:
- Form into complex 3-Dimensional shapes
- Provide electrical connectivity for grounding
- Enhance EMI attenuation

Available as die-cut flat sheet or press-formed parts

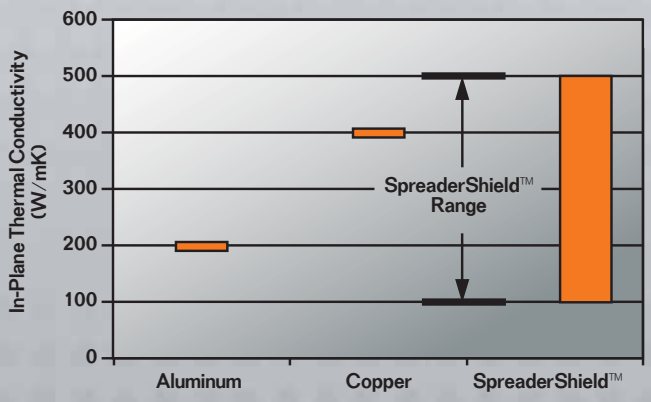
Thickness from 0.075 to 1.5 mm

Readily available laminates allow for thicker parts

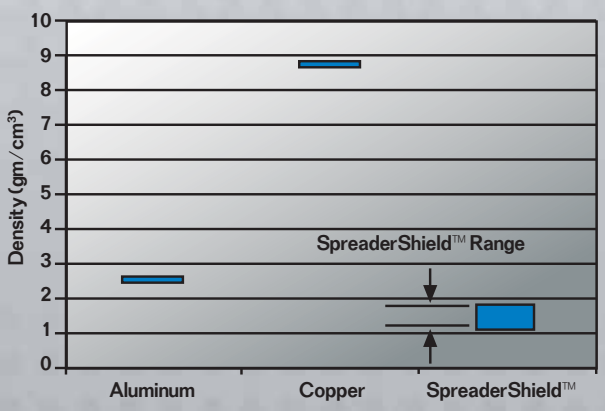
Ideal where space is limited and/or weight is critical

Can be adhesive backed for peel and stick easy attachments

In-Plane Thermal Conductivity of SpreaderShield™ Compared to Conventional Materials



Density of SpreaderShield™ Compared to Conventional Materials



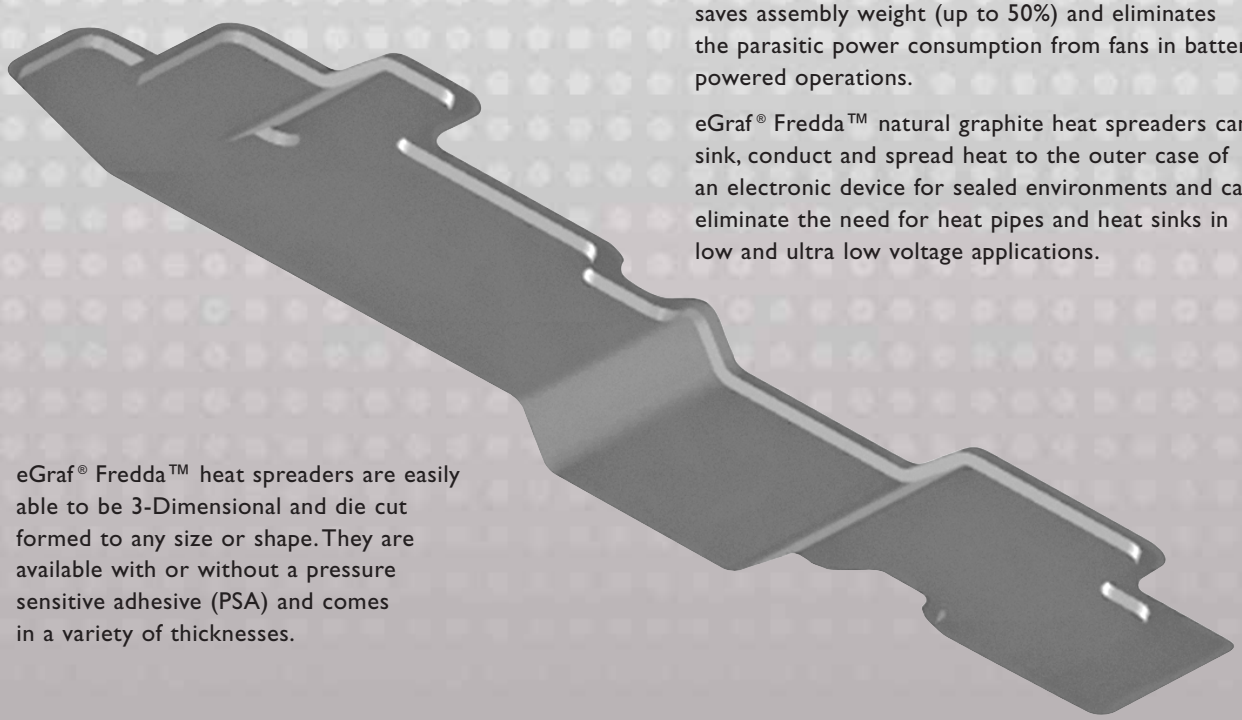
Fredda™ 3-Dimensional Heat Spreaders

eGraf® Fredda™

eGraf® Fredda™ is a 3-Dimensional heat spreader solution laminated with thin aluminum foil to maintain its form factor. Fredda™ natural graphite heat spreaders will outperform a similar copper solution with a weight savings of 80%.

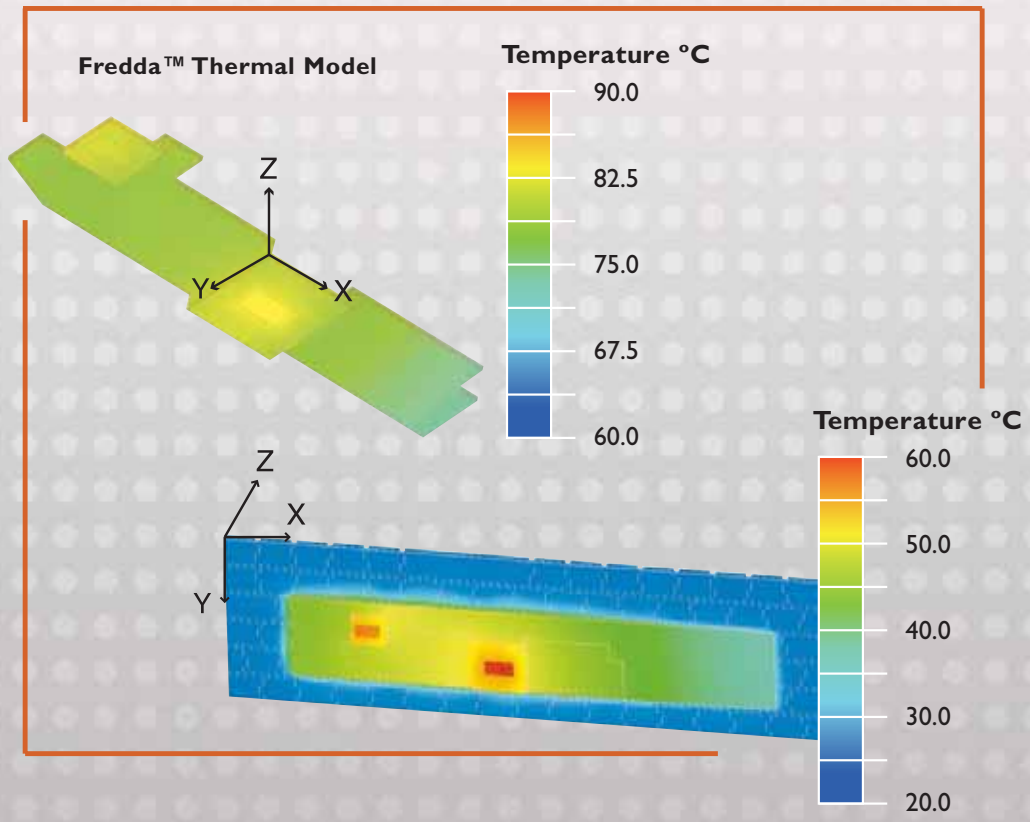
In some applications eGraf® Fredda™ heat spreader material can eliminate a fan/heat sink assembly, which saves assembly weight (up to 50%) and eliminates the parasitic power consumption from fans in battery powered operations.

eGraf® Fredda™ natural graphite heat spreaders can sink, conduct and spread heat to the outer case of an electronic device for sealed environments and can eliminate the need for heat pipes and heat sinks in low and ultra low voltage applications.



eGraf® Fredda™ heat spreaders are easily able to be 3-Dimensional and die cut formed to any size or shape. They are available with or without a pressure sensitive adhesive (PSA) and comes in a variety of thicknesses.

Natural graphite core remains continuous even after forming Fredda™ spreader



eGraf® SpreaderShield™ and eGraf® Fredda™ Applications:

- Ultra Low/Low Voltage Notebook Computers
- Notebook Computers
- PDPs – Plasma Display Panels
- LCDs - Liquid Crystal Displays
- LEDs - Light Emitting Diodes
- Servers – Rack-mount, Blade, Hyper-blade
- Audio Amplifiers – Home & Automotive
- Avionics
- Rugged Computers
- Handheld & Tablet Computers
- Set-top Cable Boxes
- Automotive Electronics
- Consumer Electronics
- PDAs /Smart Cell Phones
- AC/DC Converters
- DC/DC Converters
- IGBT Modules

eGRAF®

Thermal Management Engineered Components

Heat Sinks

Heat Rizers™

Today's thermal design engineers are confronted with conflicting priorities. eGraf® thermal management components offer several advantages for electronic applications. They are designed to eliminate the potential negative impact of heat generating components in computers, communications equipment and other electronic devices.

eGraf® components include heat sinks, heat spreaders and Heat Rizers™. All offer excellent thermal conductivity, are a fraction of the weight, and provide significantly greater design flexibility when compared to copper or aluminum.

eGraf® thermal management products take advantage of the highly directional properties of graphite to move heat away from sensitive components. They are engineered to meet the needs of each specific application. The versatility of graphite allows the designer to select the thermal properties necessary to obtain optimum heat dissipation over a range of operating temperatures.

Heat Sinks

Improving thermal performance without increasing weight. Trying to solve these conflicting priorities with traditional aluminum heat sink materials can lead to designs which incorporate expensive options like copper fins and base plates.

AET's eGraf® HS-400™ materials can provide the answers to tough design issues. eGraf® HS-400™ material can be designed to create a thermal barrier in order to protect sensitive parts and also reduce the overall weight of the package.

eGraf® HS-400™ material has a density that is typically 28% lighter than aluminum and 78% lighter than copper.

eGraf® HS-400™ material, a natural graphite – epoxy composite, is inert and will not corrode in most common environments.

AET's team of thermal design and Computational Fluid Dynamics (CFD) engineers work with product development groups to leverage the benefits of eGraf® materials in a multitude of applications.

High Power Heat Sinks that offer Superior Performance at a Reduced Weight

Heat Sink Optimization

eGraf® HS-400™ heat sinks are custom designed to meet the thermal and mechanical performance specification required in each application. CFD software is used to optimize the fin thickness and spacing and base plate shape and size.

Heat Sink Base Designs

2-Dimensional Heat Flow All Graphite Heat Sinks

This type of Heat Sink is recommended for a large heat source (e.g., multi-chip module) near the size of the base and where heat sources line up in the low k direction.

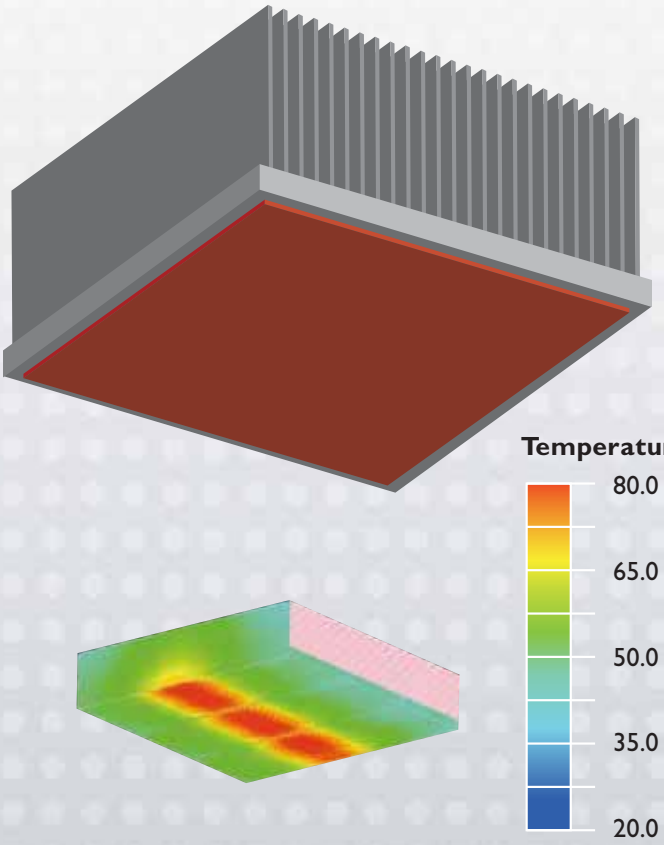
They offer:

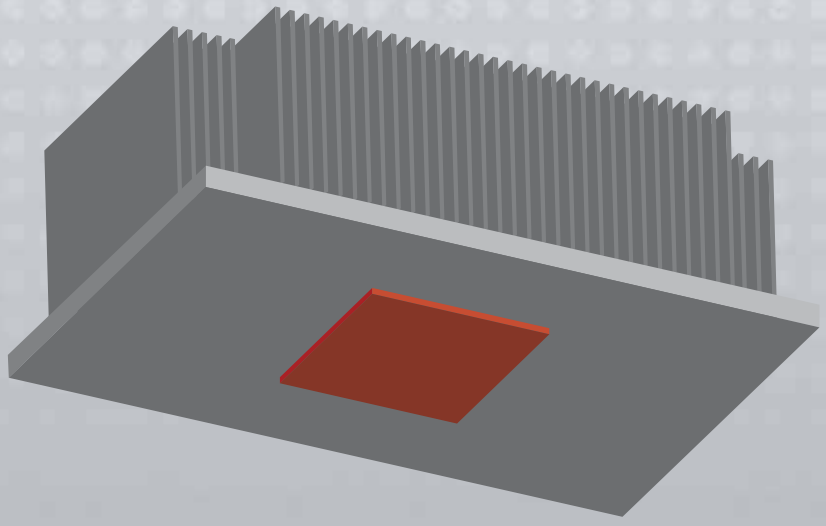
Very High Thermal Conductivity

Fins made from eGraf® HS-400™ material, a composite of natural graphite and epoxy resin, have a thermal conductivity which exceeds 370 W/mK, and rival that of copper. The aluminum alloys 6061 or 6063, commonly used in extruded heat sinks, have thermal conductivities of only 166 to 201 W/mK respectively.

Light Weight

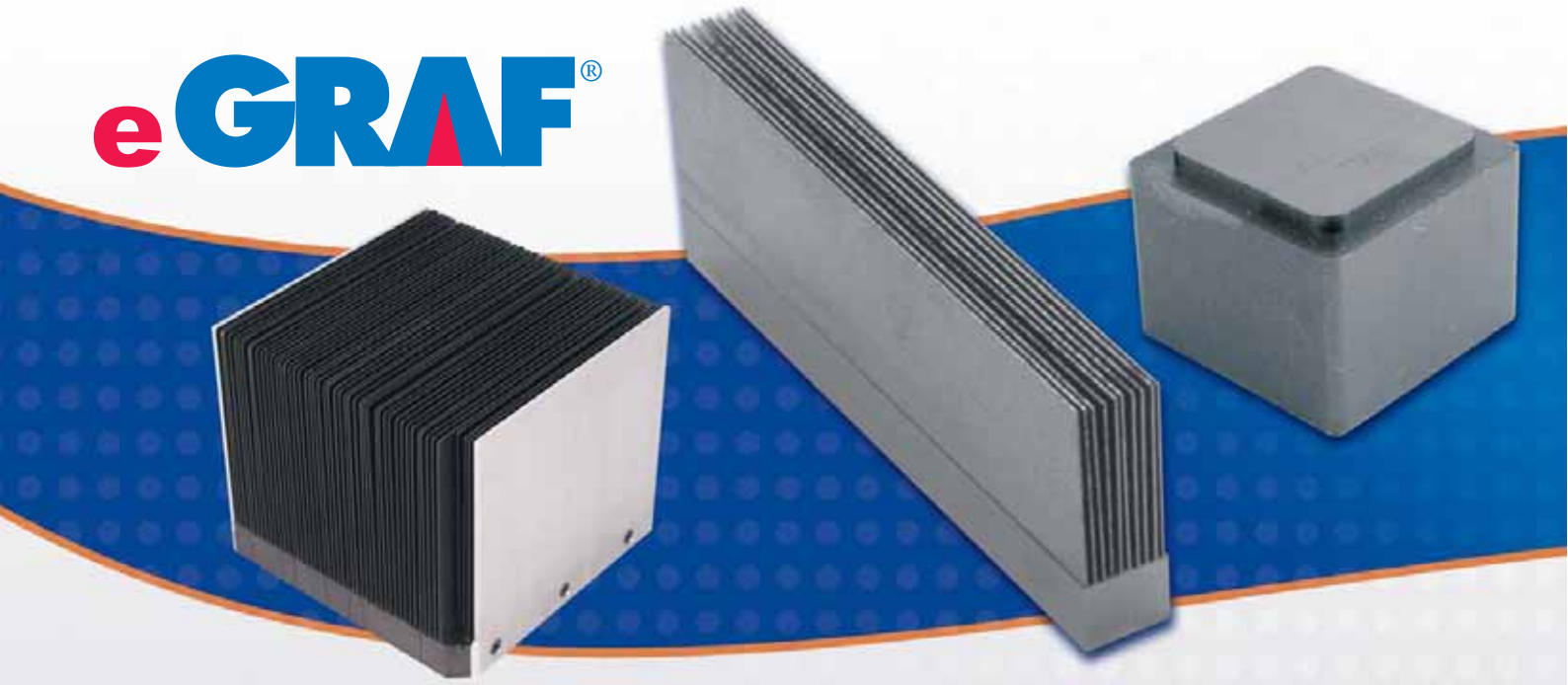
eGraf® HS-400™ material offers significant weight savings, with a density of only 1.9 g/cm³ it comes in at 1/5th the weight of copper and 3/4th the weight of aluminum. This alleviates the need for complex and costly retention mechanisms and helps improve shock and vibration performance.





3-Dimensional Heat Flow Heat Sink — Metal Base/HS-400™ Fins

This type of heat sink is recommended for a focused or concentrated heat source with a need for reduced weight but high performance; i.e., the thermal performance of a graphite finned/copper base heat sink has performance extremely close to that of an all copper heat sink but at 40% of the weight.



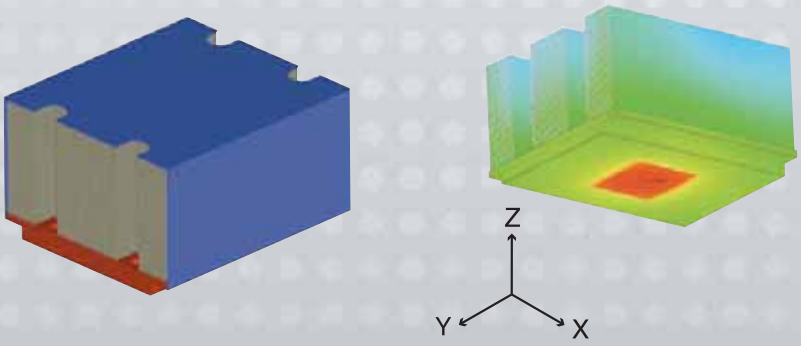
AET Can Custom Design Heat Sinks With Any Type Of Base Designs;

- Cu base/graphite fin
- Cu base w/heat-pipes/graphite fin
- Al base/graphite fin
- Al base w/heat pipes/graphite fin

Depending on the required thermal performance and the mechanical stress placed on the high power heat sink, AET can custom design a heat sink to meet your needs.

eGraf® HS-400™ fins are bonded to the metal base with a high thermal conductive epoxy, similar to that used with conventional aluminum bonded fin heat sinks. Bonding techniques developed by AET, allow eGraf® heat sinks to have the required thermal performance, and mechanical reliability, while remaining cost effective.

Thermal Model of a 3-Dimensional Heat Sink



Copper Base / Graphite Fins / Aluminum Shroud

Dimensions:
88.9 x 79 x 51 mm

Base Thickness: **8 mm**

Fin Number: **39**

Fin Thickness: **0.6 mm**

Maximum Temperature: **75.9 °C**

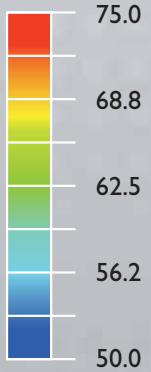
Thermal Resistance from case to ambient: **0.215 °C/W**

Power Dissipation: **120 W**

Ambient Temperature: **50 °C**

In a weight to thermal performance ratio, graphite outperforms copper.

Temperature °C



Typical Heat Sink Applications

- Servers – Rack, Blade, Hyper-blade
- Raid Controllers
- Power Electronics
- Peltier Devices
- DC-DC converters
- IGBT Modules
- RF Transistors
- Diode & Thryristor Modules
- BGAs - Ball Grid Array
- Electrolytic Capacitors
- LED Emitters
- Ruggedized Industrial / Military / Aerospace Computers

Heat Sink Shroud

To protect eGraf® HS-400™ fins, an aluminum shroud is typically attached to the base plate. This shroud ducts the air through the fins and can be used to attach a fan to the heat sink.

Thermal Interface Material

To assure a good thermal contact between the device and the heat sink, a graphite thermal interface such as eGraf® 1200 thermal interface material or eGraf® HiTherm™ thermal interface material is recommended. eGraf® thermal interface solutions can be pre-attached to the heat sink.

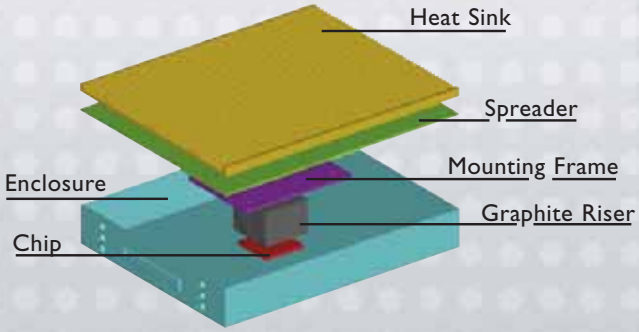
eGraf® Heat Rizers™

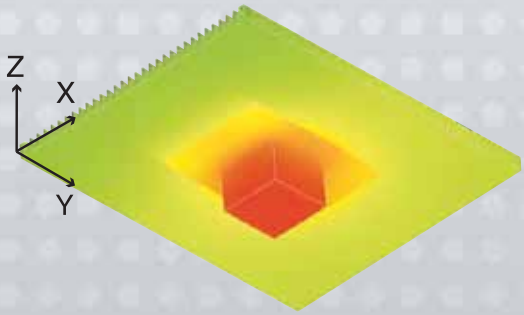
HS-400™ Heat Rizers™- A Simple Solution

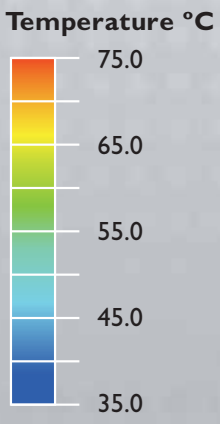
- Suited for 1U/2U type systems
- Ideal for closed "ruggedized" devices
- Moves heat from internal components to outer case
- Allows inner components to be cooled by external fans
- 400 W/mK
- 20% the weight of copper

Heat Rizers™

HS-400™ HEAT RIZERS™ PERFORMANCE







Rizer Height (mm)	10		25		50	
	HS-400™	Al	HS-400™	Al	HS-400™	Al
Thermal Resistance (°C/W)	0.01	0.05	0.025	0.1	0.08	0.20
Weight (gram)	23	33	64	92	127	183

eGRAF®

Thermal Interface Material

eGraf® Thermal Interface products are key components for the next generation of high power electronics, providing superior performance and flexibility to meet advanced thermal design requirements.

- Performance superior to other thermal tapes
- HiTherm™ performance near that of Phase Change Materials
- UL 94V-0
- No Reflow or Rework required
- Mess of Grease and Gels eliminated
- High Volume Manufacturing allows extremely attractive cost / value equation

eGraf® 700 & 1200 Thermal Interface Material

Economical Thermal Interface Materials

The eGraf® 700 and 1200 class of Thermal Interface materials are designed for use in applications requiring low contact resistance and high thermal conductivity.

eGraf® 700 and 1200 materials are manufactured entirely from natural graphite, with no fillers or binders. eGraf® 700 and 1200 materials will not dry out, and no outgassing under vacuum conditions. eGraf® 700 and 1200 materials are usable at temperatures up to 400 °C.

eGraf® 700 materials have a higher thermal conductivity in-plane than eGraf® 1200 materials. This makes them more suitable for heat spreading applications. eGraf® 700 materials are available in thicknesses ranging from 0.003 in (0.076 mm) to 0.060 in (1.5 mm).

eGraf® 1200 is an economical thermal interface material. The conformable nature of eGraf® 1200 materials optimizes thermal properties. Excellent contact is maintained for the life of the assembly. eGraf® 1200 material is available in a wide range of thicknesses.

All eGraf® 700 and 1200 materials are available with an optional pressure sensitive adhesive (PSA), and/or a polyester edge seal. eGraf® 700 and 1200 materials are available in cut sheet, wide roll, and slit to width roll or die cut form. eGraf® 700 and 1200 materials can be easily cut to any size or shape.

AET's unique materials and process technology enables the production of the thinnest available graphite interface products, resulting in the lowest thermal resistance. AET's products are also available with proprietary adhesives, assuring ease of assembly while maintaining high conductivity.

eGraf® HiTherm™

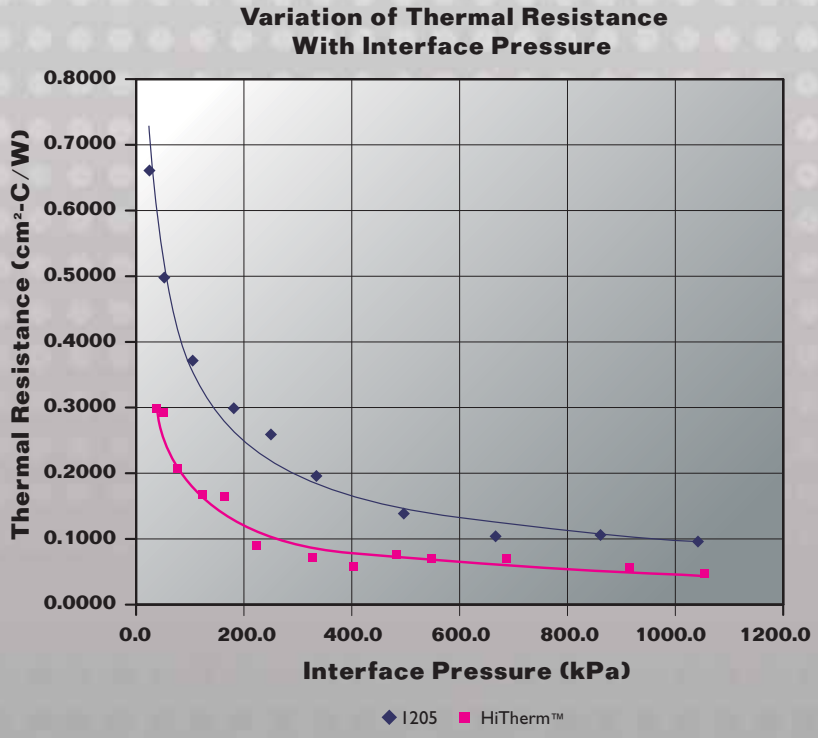
High performance materials formulated for use with today's high power components, which require minimal thermal resistance for maximum heat transfer efficiency.

eGraf® HiTherm™ thermal interface materials are designed for use in applications requiring low contact resistance and high thermal conductivity at low clamping loads.

eGraf® HiTherm™ materials are manufactured from natural graphite and a polymer additive. The addition of this polymer additive to highly conductive natural graphite minimizes the thermal resistance at low contact pressures.

Advancements

- 40% improvement in thermal conductivity
- 45% reduction in thermal resistance
- Flammability Rating – UL 94V-0
- Available in rolls and cut sheets
- 0.005" (0.127 mm)
- 0.010" (0.254 mm)
- HiTherm™ A – adhesive backed
- HiTherm™ ES – adhesive backed polyester edge seal



eGraf® Thermal Interface Material Applications

Servers- Burn-in, Chip Testing
Aerospace
Lighting
Power Electronics
Telecom
LEDs - Light Emitting Diodes
IGBT Modules
Power Supplies
Telecom Switching Hardware
Desktop and Notebook Computers
Audio & Video Components
Automotive Control Units
Motor Controllers
General High Pressure Interfaces
DC/DC Converters
Memory Modules
Handheld Portable Electronics
Wireless Communication Hardware

Options, Versatility, Packaging, Total Thermal Solutions

Thermal solutions go beyond the heat dissipater itself. A total thermal solution includes an efficient thermal interface and means of mechanical attachment.

AET has a full line of interface materials that can be pre-applied or supplied as accessory items. Utilizing these options wisely will provide the most cost effective solutions to thermal problems.

Thermal Interface Material Options

To assure a good thermal contact between the device and the heat sink, a graphite thermal interface such as eGraf® 1200 thermal interface material or eGraf® HiTherm™ thermal interface material is recommended. eGraf® thermal interface solutions can be pre-attached to heat sinks or Heat Rizers™.

Mechanical Attachment Options

AET can provide numerous options for attachment of heat sinks, Heat Rizers™, and heat spreaders to printed circuit boards, sockets, or CPUs.

Design Versatility

eGraf® thermal management materials when incorporated during a initial electronic product design stage can reduce the time to market of new high-power electronic components and products. AET can custom design its complete range of electronic thermal management products to effectively manage any electronic thermal need.

Whether it is customized eGraf® Heat Sinks, Heat Rizers™, or eGraf® SpreaderShield™/Fredda™ natural graphite heat spreaders, AET will make sure all electronic thermal and design requirements are fully met. And, with the superior performance of eGraf® thermal management components, power can be increased to new levels with more reliability through a reduction of the possibility of heat-related failures.

Total Thermal Packaging Solutions

eGraf® thermal management components are brought to you by Advanced Energy Technology Inc., the leader in natural graphite technology.

We have over 30 years of experience in the development and manufacture of high performance materials for heat management.

Complementing our eGraf® thermal management components, we also offer graphite-based thermal interface products that provide the lowest contact resistance and best overall thermal conductivity of any sheet-based thermal interface.

GRAFTech

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eGraf®, eGraf® Fredda™, HiTherm™, Spreadershield™, HS-400™ Heat Sinks, Heat Rizer™ thermal management products are covered by one or more of the following U.S.A. patents: 4,911,972; 4,961,991; 5,149,518; 5,198,063; 5,830,809; 6,245,400; 6,482,520; 6,503,626; 6,538,892; 6,746,768; 6,758,263; 6,777,086.

Other U.S.A. and foreign patents granted or pending.

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