



# The Crystallizers

Our specialty graphites for  
the semiconductor industry

SIGRABOND  
SIGRAFINE®  
SIGRAFLEX®  
SIGRATHERM®



Graphite Solutions



< 5

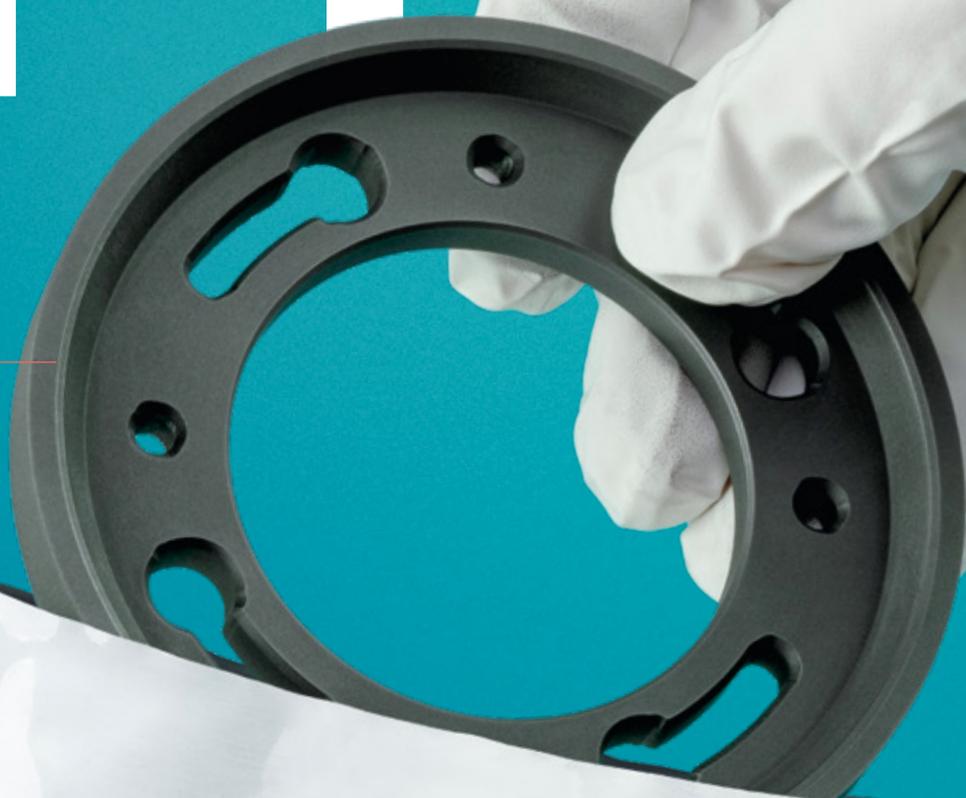
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## **SIGRAFINE<sup>®</sup>** **Purity first**

High purity is a crucial requirement for graphite used in semiconductor production processes – impurities should be kept under five parts per million. All of our highly purified graphite products meet this very high standard. Our lab employees are experts in impurity analysis, even taking an active role in defining the DIN and ASTM chemical analysis norms for graphite materials. As manufacturers of high purity products, we also guarantee proper handling and treatment throughout the entire production chain, including packaging and transportation, along with sound technical advice for specific applications. Our products and expertise are the ideal starting point for effective crystallization processes.

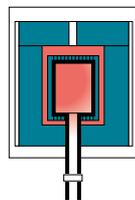


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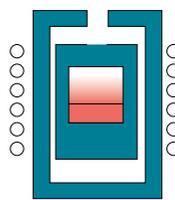


# Our specialty graphites for the semiconductor industry

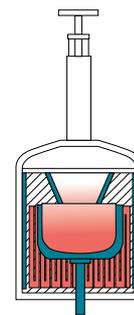
Benefit from the high purity of our graphites – developed especially for challenging processes like crystal growing, epitaxy, ion implantation and plasma etching, as well as for the production of LED chips.



↑ Sapphire single crystal growth



↑ SiC sublimation growth



↑ Si mono-crystal growth [CZ]

## Value chain

### Typical applications

### Products of SGL Carbon

### Materials used by SGL Carbon

## Growing single crystals

- Silicon
- Silicon carbide
- Sapphire
- Compound semiconductors

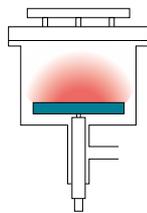
- Heaters
- Crucibles
- Heat shields
- Insulation

- SIGRAFINE® isostatic and extruded graphite
- SIGRABOND carbon fiber-reinforced carbon [C/C]
- SIGRATHERM® carbon and graphite felts
- SIGRAFINE® SiC Coating
- SIGRAFLEX® expanded flexible graphite foil

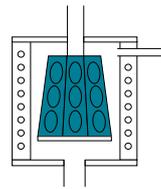
We manufacture our components according to your individual requirements and assist you in planning, design and optimizing your operations. You can rely on our extensive expertise in handling high-purity products, which we can guarantee through extensive certification according to your requirements.



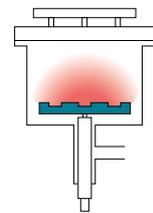
↑ Wafering



↑ Silicon epitaxy pancakes



↑ Silicon epitaxy barrels



↑ MOCVD

### Wafer slicing

- Silicon wafers
- Compound semiconductor wafers

- Slicing beams

- SIGRAFINE® isostatic graphites

### Epitaxy

- Silicon epi
- SiC epi
- MOCVD

- Single wafer susceptors
- Pancake susceptors
- Barrel susceptors

- SIGRAFINE® isostatic graphites
- SIGRAFINE® SiC Coating

# Products for the semiconductor industry

Our portfolio includes heaters, support crucibles, heat shields and insulating components for many single crystal-growing processes and materials. We also supply susceptors for silicon epitaxy and MOCVD. Known for our consistently high quality and individualized production, we offer application-specific finishing through cleaning, mechanical processing or coating.



Meander heater for CZ units

# Specialty graphites for growing semiconductor crystals

## The hot zone challenge

All processes used to grow semiconductor crystals operate at high temperatures in aggressive environments – whether CZ for silicon, HEM for sapphire or PVT for SiC bulk growth. This is why the hot zones of industrial crystal growth furnaces are generally equipped with heat- and corrosion-resistant graphite components.

## Our materials for every type of furnace

We produce materials for a wide range of typical parts, including heaters, crucibles, reflectors and heat shields made from high-strength, homogenous fine-grain graphite or carbon-reinforced carbon (CFRC), and insulating components in either rigid or soft felt and SIGRAFLEX foil. Our experts rely on decades of experience to select the best materials at the highest purity to fit into every type of crystal-growing furnace. Together with our Modelling and Simulation Group we offer thermomechanical and gas-flow dynamics optimization of crystal growth furnaces of all kinds.

## SiC for extended lifetime

We developed an ingenious SiC coating to extend the lifetime of high-demand parts used in especially challenging applications and environments.



↑ Support crucible made from C/C



↑ Rigid felt cylinder for insulation



↑ Graphite components for CZ units

## Specialty graphites for silicon and SiC epitaxy

A wafer needs to pass through several steps before it is ready for use in electronic devices. One important process is silicon epitaxy, in which the wafers are carried on graphite susceptors. The properties and quality of the susceptors have a crucial effect on the quality of the wafer's epitaxial layer.

### High purity and certified compliance

Special advantages of our SiC-coated graphite susceptors include extremely high purity, homogenous coating and an excellent service life. They also have high chemical resistance and thermal stability properties.

We maintain very close tolerances when applying the SiC coating, using high-precision machining to ensure a uniform susceptor profile. We also produce materials with ideal electrical resistance properties for use in inductively heated systems. All finished components come with a purity and dimensional compliance certificate.

### Broad susceptor portfolio

We supply susceptors and graphite components for all currently used epitaxy reactors. Our portfolio includes barrel susceptors for Applied Materials, Moore and LPE reactors, pancake susceptors for LPE, CSD and Gemini units, as well as single-wafer susceptors for Applied Materials and ASM machines.

All of our susceptors are made of high-strength isostatic graphite. Our exhaustive quality controls ensure that our customers always receive top-quality, fully traceable products.

### Ion implantation and dry-etching

We also manufacture components for ion implantation devices and dry-etching equipment.



↑ Susceptors for epitaxy reactors

## Specialty graphites for LED chip production

Planetary susceptors or carriers move the substrate wafers during the extensive coating process in the MOCVD reactor. The properties of the susceptor material greatly influence the quality of the coating, and, in turn, the chip reject rate.

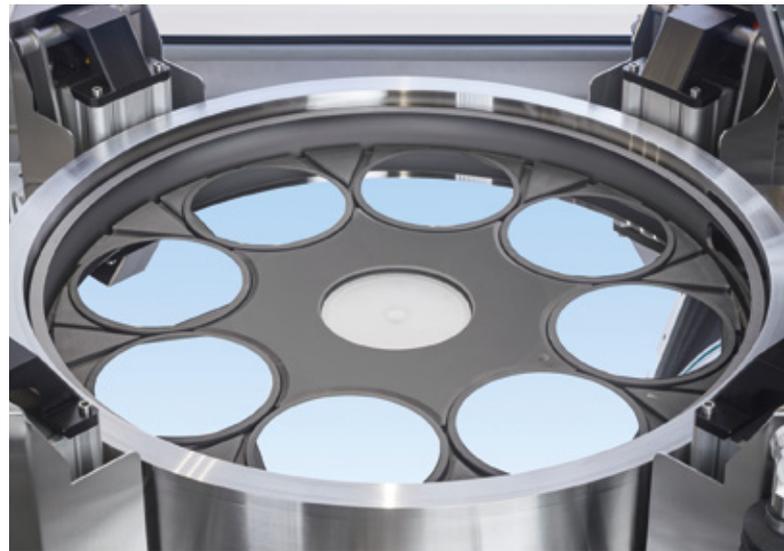
### High precision

Our SiC-coated susceptors make the manufacture of high-quality LED wafers more efficient, keeping wavelength deviation to a minimum. Many important factors contribute to this, including the very high purity and uniform thermal conductivity of our isostatic graphite and SiC coatings. We carefully select the graphite grades for our susceptors and carriers. High-precision machining and homogeneous coatings ensure that the wafer carrier pockets have a uniform profile with minimal flatness deviation. Our extensive quality controls help us to supply fully traceable products of consistently high quality.

### Increasing chip yield, minimizing deviation

We are always enhancing our materials and components in close collaboration with manufacturers and operators of MOCVD units. Together, we want to increase chip yields in the production of LED wafers while minimizing wavelength deviation.

We also supply other graphite components for all currently used MOCVD reactors. We can apply SiC coating to nearly every component, even with those diameters exceeding 1 m [3'].



↑ Planetary susceptor for LED production in AIXTRON 2800 G4 MOCVD reactor (courtesy of Aixtron SE)

# Graphites and carbon-based materials for the semiconductor industry

We supply fine-grain graphite, SiC coating, graphite soft and rigid felts, and carbon-reinforced carbon for a great diversity of applications and SIGRAFLEX graphite foil. All of our materials are synonymous with high purity, outstanding mechanical strength and excellent corrosion heat resistance, and can be delivered in a wide range of sizes.



## SIGRAFINE® fine-grain graphites

SGL Carbon produces several isostatic graphite grades, each with distinct properties that make it ideally suited for specific application environments.

R6300 is our heater grade. The electrical resistivity shows a constant high temperature above ~ 1000 °C, which is very beneficial for use as heating elements.

R6340 and R6500 are proven work horses when it comes to multiple uses of isostatic graphite. Both grades are used around the world for many different parts, including crucibles, fixtures, electrodes or others. The main difference between both grades is the density and grain size, which also results in different thermal expansion and conductivity values.

R6510, also known as CZ5 in the market, has become a standard in the industry when it comes to all parts in direct contact with Si-O gaseous environments. Crystal heat shields and funnels made of R6510 used in silicon CZ growth have proven to show long service life and low dusting behavior enabling high crystal quality. We also prefer the R6510 grade for SiC coating due to its thermal expansion properties. These are in line with our SIGRAFINE SiC coating over an extended temperature range.

Our R6520, or CZ5.2, was developed with a property range somewhere between R6500 and R6510. It has shown very good results in semiconductor and photovoltaic applications.

R6650 is a high-density grade for even more demanding applications in aggressive media, such as molten silicon or gaseous silicon-oxide.

R6710 is SGL Carbon's finest ISO graphite grade at 3 µm average grain size. It is possible to machine very fine and fragile parts from this grade, including ones for use in ion implantation. It has the highest flexural strength of all of our isostatic graphites.

R6810 is our ISO graphite grade with the highest thermal conductivity. Like the R6510, this grade works very well for SiC coating.

SGL Carbon also produces a vast range of SIGRAFINE extruded and vibration-molded graphite grades, as well as SIGRAFLEX® graphite foil and SIGRAFINE porous graphite rods used in bulk SiC growth.

Please contact one of our experts for further information on any materials or technology-related advice.

### Material data of our isostatic SIGRAFINE® fine-grain graphite

Typical properties*	Units	R6300	R6340	R6500	R6510	R6520	R6650	R6710	R6810
Average grain size	µm	20	15	10	10	10	7	3	20
Bulk density	g/cm <sup>3</sup>	1.73	1.72	1.77	1.83	1.80	1.84	1.88	1.82
Resistivity	µΩm	16	12	14	13	13	14	10	10
Flexural strength	MPa	40	45	50	60	55	65	85	45
Compressive strength	MPa	85	90	110	130	120	150	170	100
Thermal expansion 20–200 °C (68–392 °F)	10 <sup>-6</sup> K <sup>-1</sup>	2.7	3.2	4.2	4.2	4.2	4.1	4.7	4.1
Ash content	ppm	≤ 200	≤ 200	≤ 200	≤ 200	≤ 200	≤ 200	≤ 200	≤ 200

\* Typical average values of different rectangular and round block sizes. The actual individual block values might vary depending on dimension and format.

### Typical level of purity after purification

Code	Ash value	Element concentration (typical values in ppm)													
		Al	B	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	P	Si	Ti	V
P30	< 30 ppm	0.05	0.1	0.2	< 0.02	< 0.02	< 0.02	0.5	0.1	< 0.01	1	< 0.1	< 2	0.2	0.5
P5	< 5 ppm	< 0.01	< 0.02	0.01	< 0.01	< 0.01	< 0.01	0.02	0.01	< 0.01	< 0.01	< 0.02	< 1	0.01	0.01

# SIGRAFINE® SiC Coating

## High resistance – excellent conductivity

SIGRAFINE SiC Coating is a dense, wear-resistant silicon carbide coating. It has high corrosion and heat resistance properties as well as excellent thermal conductivity. We apply SiC in thin layers onto the graphite using the chemical vapor deposition (CVD) process.

## Extended service life of graphite and C/C components

The coating improves product quality and increases process efficiency, thus reducing overall operating costs for our customers. This coating extends the service life of graphite components and achieves the high-purity surface structures required in processing semiconductor materials.

## Wide range of applications

We supply SiC-coated products made from high-strength isostatic graphite and carbon fiber-reinforced carbon. These include components for fluidized-bed reactors and STC-TCS converters, as well as reflectors for CZ units and wafer carriers for PECVD, Si epitaxy, and MOCVD units.

## Purity data of SIGRAFINE® SiC coating [glow discharge mass spectroscopy]

Element	ppm	Element	ppm
Sodium	<0.05	Copper	<0.01
Magnesium	<0.01	Zinc	<0.05
Aluminum	<0.04	Gallium	<0.05
Phosphorus	<0.01	Germanium	<0.05
Sulfur	<0.04	Arsenic	<0.005
Potassium	<0.05	Indium	<0.01
Calcium	<0.05	Tin	<0.01
Titanium	<0.005	Antimony	<0.01
Vanadium	<0.001	Tungsten	<0.01
Chromium	<0.05	Tellurium	<0.01
Manganese	<0.005	Lead	<0.01
Iron	<0.01	Bismuth	<0.01
Nickel	<0.005		



↑ Micrograph of SiC surface

## Material data of our SIGRAFINE® SiC coating

Typical properties	Units	Values	Analysis technique
Structure		beta (cubic) 3C polytype	XRD
Orientation	Fraction [%]	111 preferred	XRD
Bulk density	g/cm <sup>3</sup>	3.2	XRD
Stoichiometry		1:1 Si/C	XPS
Hardness	GPa	40	Nanoindentation
Fracture toughness	MPa m <sup>1/2</sup>	3.0	Vickers indenter
Thermal expansion 100 – 600 °C [212 – 1112 °F]	10 <sup>-6</sup> K <sup>-1</sup>	4.3	Dilatometer
E-modulus	GPa	435	Nanoindentation
Typical film thickness	µm	100	Beta backscatter
Surface roughness	µm	2.5	Profilometer

# SIGRAFLEX® flexible graphite foil

## Hot zone solution

SIGRAFLEX products, manufactured from expanded natural graphite, improve the performance of systems and processes in semiconductor applications, minimize energy consumption and guarantee reliability.

SIGRAFLEX high-purity flexible graphite foils are free of adhesives and binders and can be provided in ultra-high purity to prevent product contamination.

## Up to 3000 °C

Demonstrating its extraordinary properties, it can be used in ultra-high temperature applications ranging up to 3000 °C in an inert atmosphere or vacuum. Superior thermal and electrical conductivity makes it a suitable material for a wide range of parts and components in semiconductor production equipment, for example heat shields, insulation material, flexible layer, and sealing material. Flexible graphite foil can be produced to customer specification.

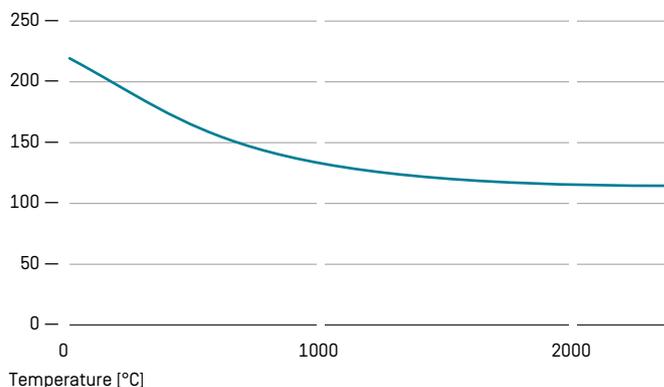
For ultra-high purity requirements our SIGRAFLEX THP can be used. Even special requirements due to single elements can be considered in the production of SIGRAFLEX products.

## System supplier

SIGRAFLEX is often used in combination with SIGRATHERM soft and rigid felts, SIGRABOND carbon fiber-reinforced carbon and SIGRAFINE synthetic graphite.

## 超高温度でも優れた熱伝導性を発揮

Thermal conductivity [ $\text{Wm}^{-1}\text{K}^{-1}$ ]



## Material data of SIGRAFLEX® TH with a bulk density of 1.0 g/cm<sup>3</sup>

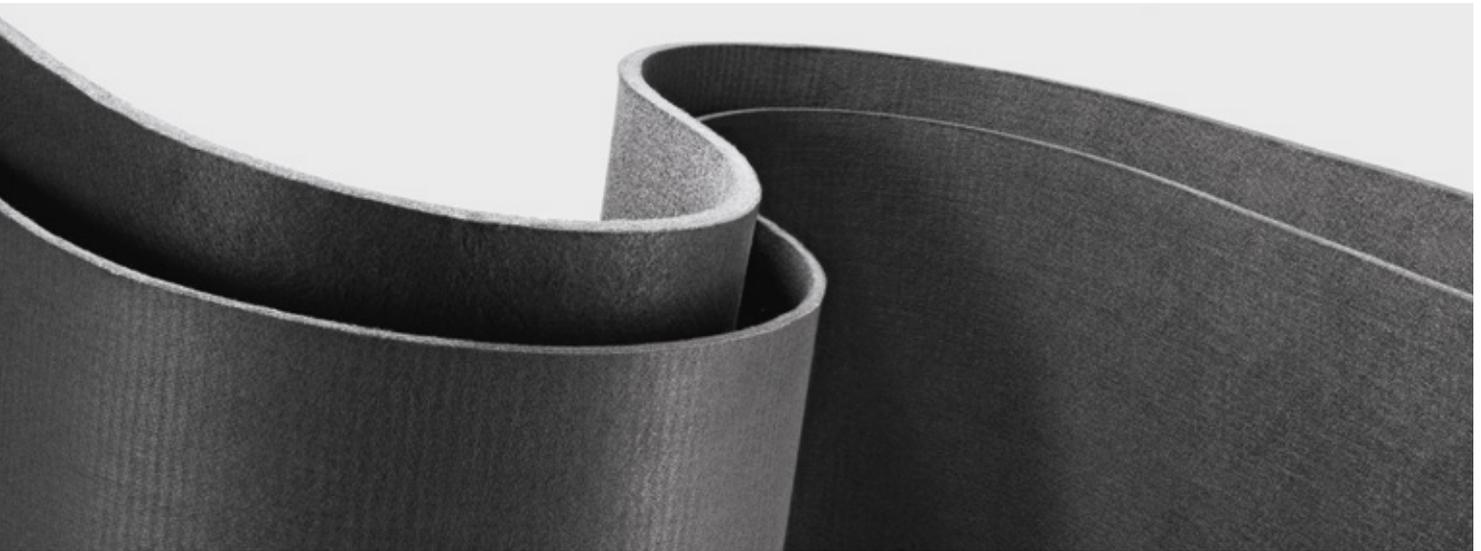
Typical properties	Units	Values
Sublimation temperature	°C	> 3000
Temperature resistance	in air	approx. 400
	in inert gas and vacuum	approx. 3000
Specific electrical resistivity [20 °C]	parallel to surface	11
	perpendicular to surface	$\mu\Omega\text{m}$ 700
Thermal conductivity [20 °C]	parallel to surface	220
	perpendicular to surface	$\text{Wm}^{-1}\text{K}^{-1}$ 5
Specific heat capacity [20 °C]	$\text{kJkg}^{-1}\text{K}^{-1}$	0.7
Thermal expansion coefficient [20 – 1000 °C]	parallel to surface	approx. 1
	perpendicular to surface	$10^{-6}\text{K}^{-1}$ approx. 50
Shore hardness [D]		30
Elongation at break	%	$\geq 1$
Tensile strength	$\text{N/mm}^2$	$\geq 4$
Permeability coefficient for air perpendicular to surface	$\text{cm}^2/\text{s}$	$2 \times 10^{-5}$
Coefficient of emission [1500 °C]		0.65
Ash content	%	approx. 0.1

Other values or dimensions on request



↑ SIGRAFLEX high-purity graphite foil

## SIGRATHERM® graphite soft felts



↑ SIGRATHERM soft felt

### Preferred choice for hot zone insulation

Our graphite soft felts offer a unique combination of thermal, chemical and textile properties. For decades now, many crystal growth companies around the globe have made our GFA felts their preferred choice for hot zone insulation material.

We also supply SIGRATHERM soft felt in high purity and customer-specific dimensions, as well as in pre-assembled insulation packages.

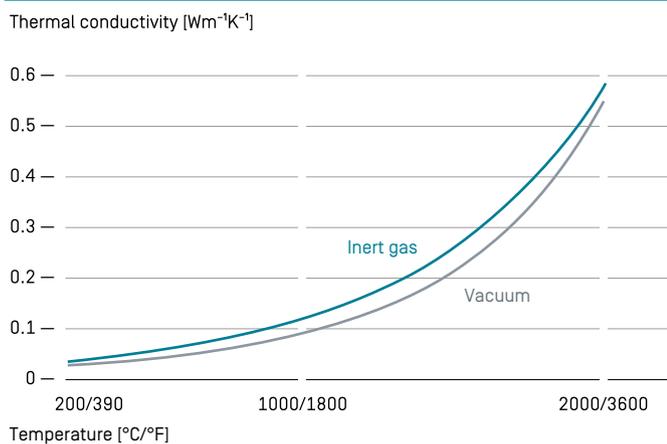
### Material data of SIGRATHERM® GFA

Typical properties	Units	GFA5	GFA10	GFA15
Thickness	mm [in]	6 [1/4]	11.5 [1/2]	16 [5/8]
Area weight	g/m <sup>2</sup>	500	1000	1500
Width (max.)	mm [in]	1350 [53]	1350 [53]	1350 [53]
Length	m [ft]	25 – 30 [82 – 98]	25 – 30 [82 – 98]	25 – 30 [82 – 98]
Ash content	ppm	1000	1000	1000
Ash content (purified grade)	ppm	< 20	< 20	< 20
Max. application temperature	°C [°F]	2000 [3600] in vacuum or inert gas	2000 [3600] in vacuum or inert gas	2000 [3600] in vacuum or inert gas



↑ SGRATHERM flexible carbon felts for the thermal insulation

**Thermal conductivity of SGRATHERM GFA as a function of temperature [inert gas and vacuum atmosphere]**



**Consistently low thermal conductivity**

Our special manufacturing process gives SGRATHERM graphite soft felts very low thermal conductivity. They have an extremely homogenous thickness and density distribution throughout the roll length, guaranteeing a consistently high insulating effect.

## SIGRATHERM® graphite rigid felts

### For structural and stable thermal insulation parts

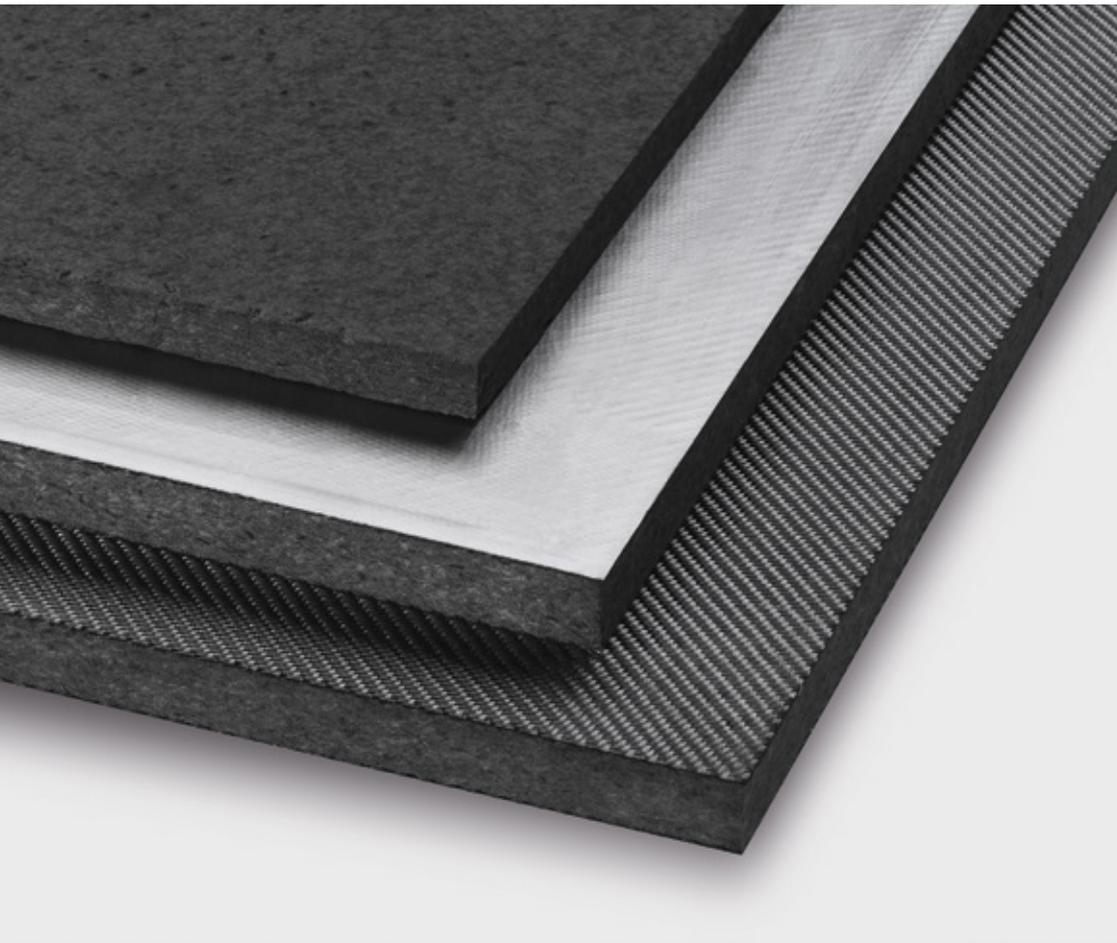
SIGRATHERM rigid felts are shape-retentive insulating materials made from graphite fibers and a carbon binder. The material is carbonized and then graphitized to guarantee applications at temperatures up to 2200 °C (3992 °F).

### Easy to process

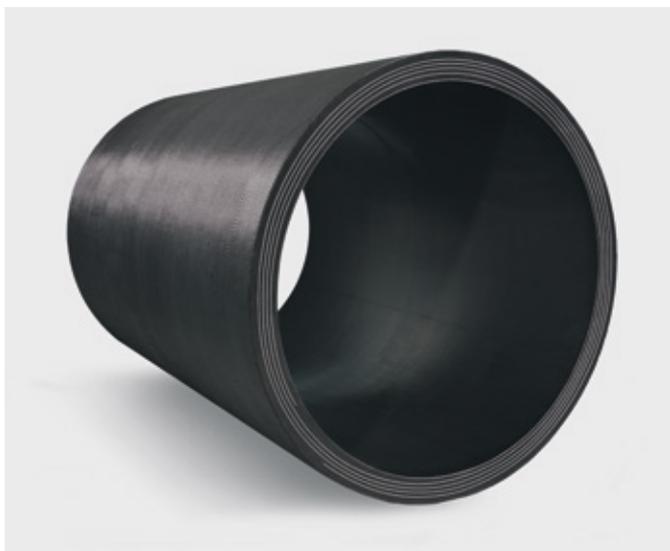
Our MFA grade is the preferred choice for standard insulation plates and customer-specific structural parts. It offers great machinability and is easy to process into complex forms and larger self-supporting insulation components.

### Material data of SIGRATHERM MFA

Typical properties	Units	MFA
Density	g/cm <sup>3</sup>	0.17
Compressive strength	MPa	0.7
Flexural strength	MPa	0.8
Moisture absorption	%	< 1.0
Ash content	ppm	1000
Ash content (purified grade)	ppm	< 20
Max. application temperature	°C [°F]	2000 [3600] in vacuum or inert gas



↑ SIGRATHERM rigid felt with different surface layers



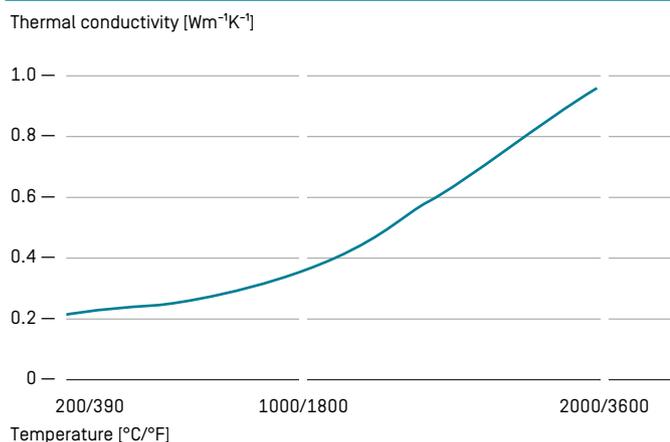
↑ SGRATHERM rigid felt cylinder

**Solutions for special demands**

We typically recommend our RFA grade for larger insulation cylinders with diameters up to ~2000 mm. It has similar insulation properties as the MFA grade. One or more layers of graphite foil can be applied as a convection barrier and reflective coating. We also supply an insulating composite comprising rigid felt covered with a C/C fabric for mechanical surface protection.

All of our rigid felt parts can be gas purified to comply with demanding semiconductor purity standards.

**Thermal conductivity of SGRATHERM MFA as a function of temperature (inert gas atmosphere)**



**Order information of SGRATHERM MFA**

MFA	-	FF	1524 x 1219 x 40 mm [60" x 48" x 1.57"]
		Surface coating, optional: FF = both sides covered with SIGRAFLEX® foil CC = both side covered with C/C	Board dimensions
		Rigid felt composite board	

**Forms supplied**

Standard dimensions: 1524 x 1219 mm [60" x 48"]  
 Thickness: 30/40/45/50 mm [1.18"/1.57"/1.77"/1.97"]  
 Customer-specific sizes and surface coatings on request.

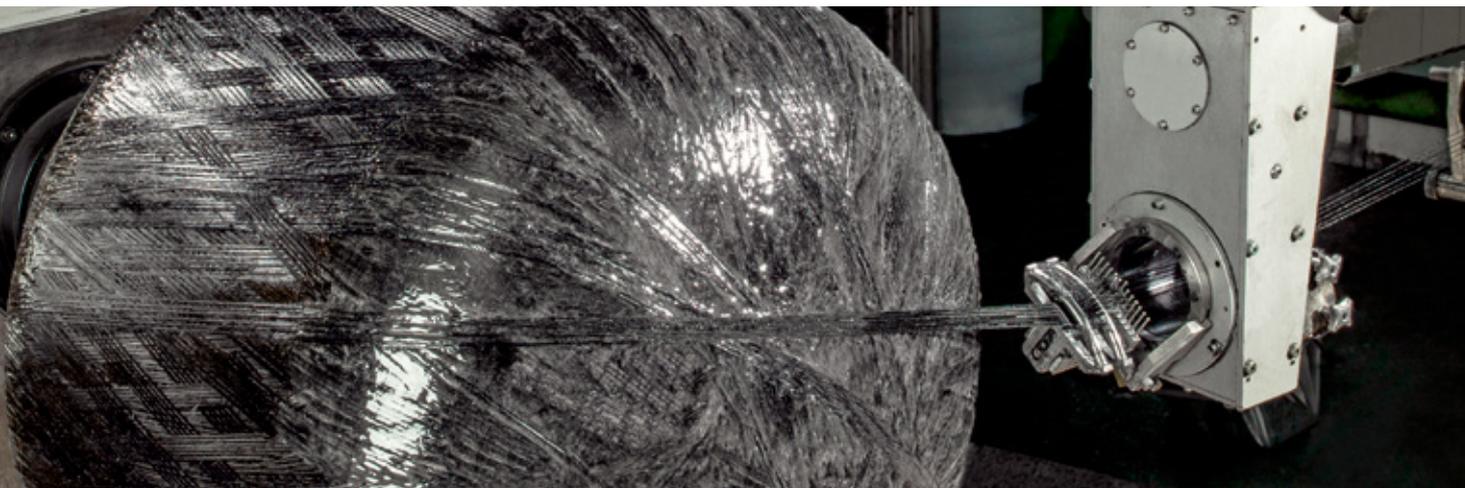
## SIGRABOND carbon fiber-reinforced carbon [C/C]

### For lightweight, rigid and durable structural parts

SIGRABOND carbon fiber-reinforced carbon materials show a very high mechanical load bearing capacity at a very light weight. They are extremely resistant to corrosion and demonstrate high thermal stability.

### A variety of grades for different applications

We produce C/C plates in two different grades: SIGRABOND Standard and SIGRABOND Performance, which has an improved rigidity to allow for even lighter-weight components.



↑ SIGRABOND FilWound C/C crucible production with an automatic fiber winding machine

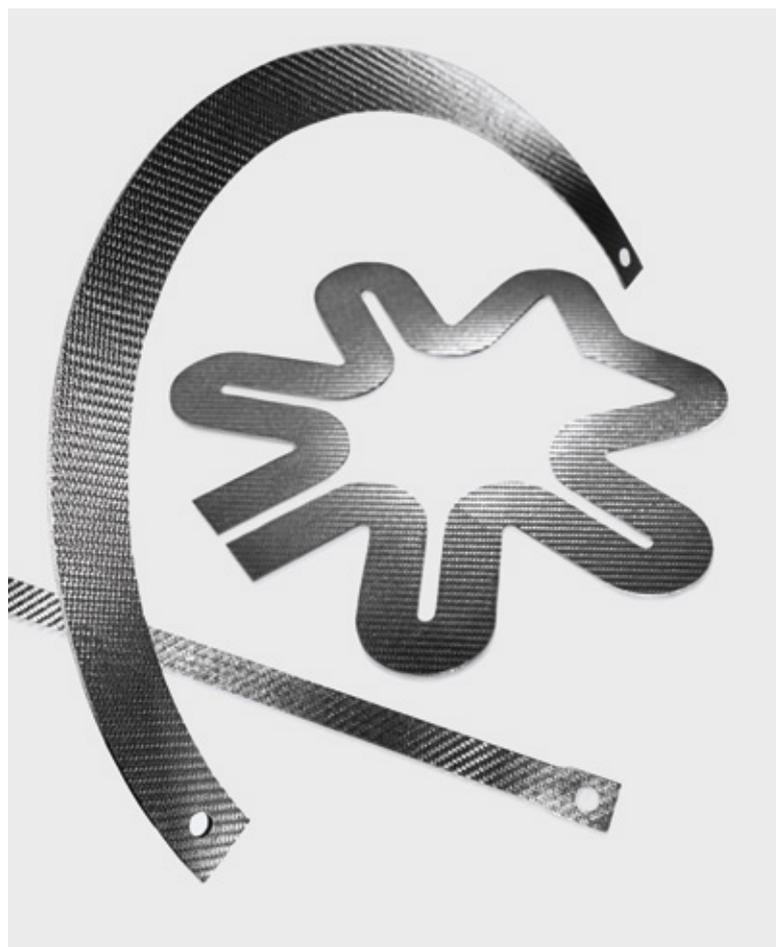
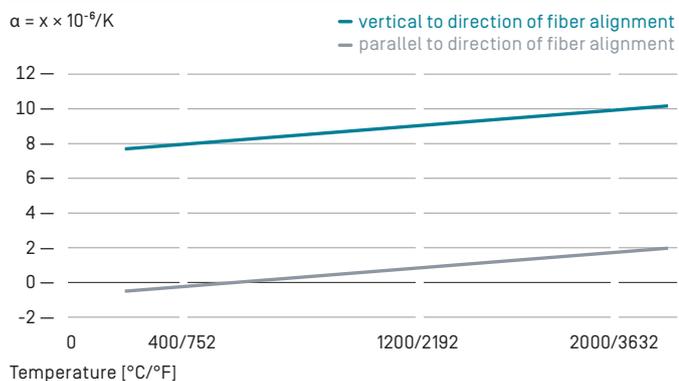
### Material data of our SIGRABOND carbon fiber-reinforced carbon

Typical properties	Units	Performance		Plates	Rotationally symmetric parts
				Standard	FilWound
Bulk density	g/cm <sup>3</sup>	1.5		1.5	1.4
Flexural strength	MPa	200		150	depending on the structure of the lay-up
Elastic modulus	GPa	70		60	
Interlaminar shear strength	%	8		8	
Ash content	ppm	≤ 1000		≤ 1000	≤ 1000
Ash content (purified)	ppm	≤ 10		≤ 10	≤ 10
Length/Width <sup>1)</sup>	mm	1220 x 1220 / 2450 x 1220		1220 x 1220 / 2450 x 1220	-
	in	48 x 48 / 96 x 48		48 x 48 / 96 x 48	-
Diameter <sub>max</sub> /Length <sub>max</sub>	mm [in]	special dimensions on request		special dimensions on request	2000/2500 [79/98]
Thickness	mm [in]	1.8 – 15 [0.07 – 0.6]		1.7 – 30 [0.03 – 1.2]	-
Wall thickness <sub>max</sub>	mm [in]	-		-	100 [4]
Maximum application temperature	°C [°F]	2000 [3600] in vacuum or inert gas			

We also produce rotationally symmetrical components such as crucibles and cylinders. We typically manufacture these parts in grade SIGRABOND FilWound for specific customers using automatic fiber winding machines.

All of our SIGRABOND C/C parts can be gas purified to meet demanding semiconductor purity standards.

### Coefficient of thermal expansion



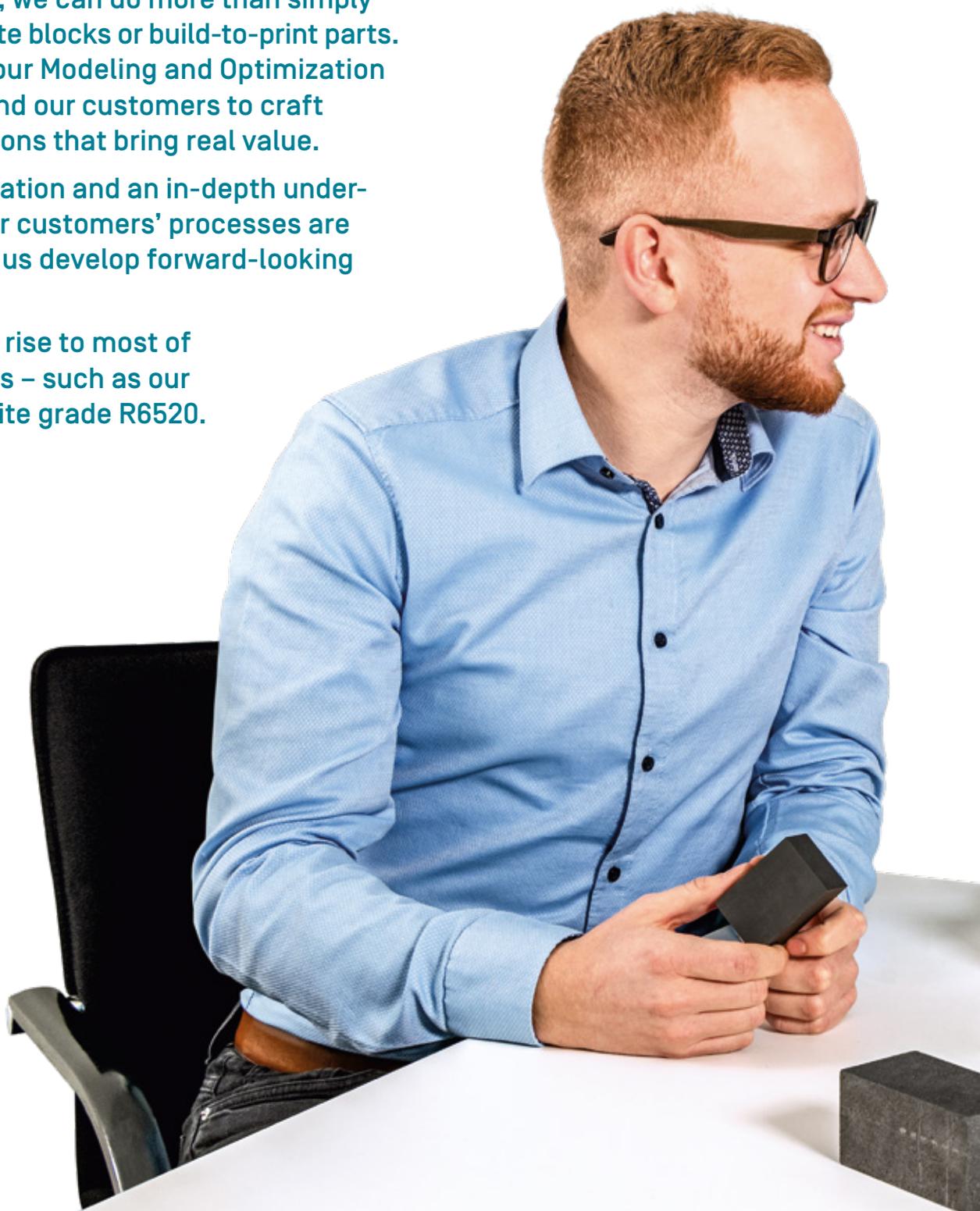
↑ SIGRABOND heating elements

# Successful together

At SGL Carbon, we can do more than simply provide graphite blocks or build-to-print parts. We work with our Modeling and Optimization Department and our customers to craft tangible solutions that bring real value.

Close collaboration and an in-depth understanding of our customers' processes are key to helping us develop forward-looking solutions.

This has given rise to most of our innovations – such as our new ISO graphite grade R6520.





## Improving performance in silicon crystal growth

Silicon crystal growth for semiconductor applications is a delicate technology tailored to the technical requirements of the respective device technology to be built on the wafers.

It's also essential to have a high yield rate of top-quality wafers to be successful in this business.

We worked with our Modeling and Simulation group and in close collaboration with our customer to identify the ideal geometric shape of CZ puller hot zone parts, along with the set of material properties needed to fulfill both requirements.

Our newly developed ISO graphite grade SIGRAFINE R6520 fits perfectly into this scheme. The hot zone parts made from this grade coupled with the optimized geometry have considerably improved the yield rate of top-quality wafers. This is a great example of our attitude towards our work: "successful together".

# Smart Solutions

Be it materials, components or production processes, we focus our thinking and actions on the customer and keep an eye on the big picture. Our solutions already anticipate the future today.

The following examples show a selection of our unique product range.

## Mobility

- Lightweight components and structural parts based on fiber-reinforced composites for automotive and aerospace manufacture
- Graphite anode material for lithium-ion batteries in electric vehicles
- Carbon-ceramic brake disks for sports cars and luxury sedans

## Energy

- High-temperature solutions based on specialty graphites and fiber materials for the photovoltaic industry
- Carbon fiber materials for rotor blades
- Gas diffusion layers for fuel cells
- Systems for more efficient heat exchange and heat recovery
- Carbon fibers for pressurized gas containers

## Digitization

- Carbon, graphite, and CFC components for polysilicon and monocrystal pulling in the semiconductor industry
- High precision, coated graphite carriers for the production of LEDs

→ State-of-the-art green production with the world's largest isostatic press



# SGL Carbon

We are leaders in the development and manufacture of products based on carbon, graphite, carbon fibers, and fiber-reinforced composites. In partnership with our customers, we develop intelligent, trendsetting, and sustainable solutions that deliver a clear benefit.

With our in-depth material, engineering, and application know-how, we make a substantial contribution to the major future topics mobility, energy, and digitization.



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