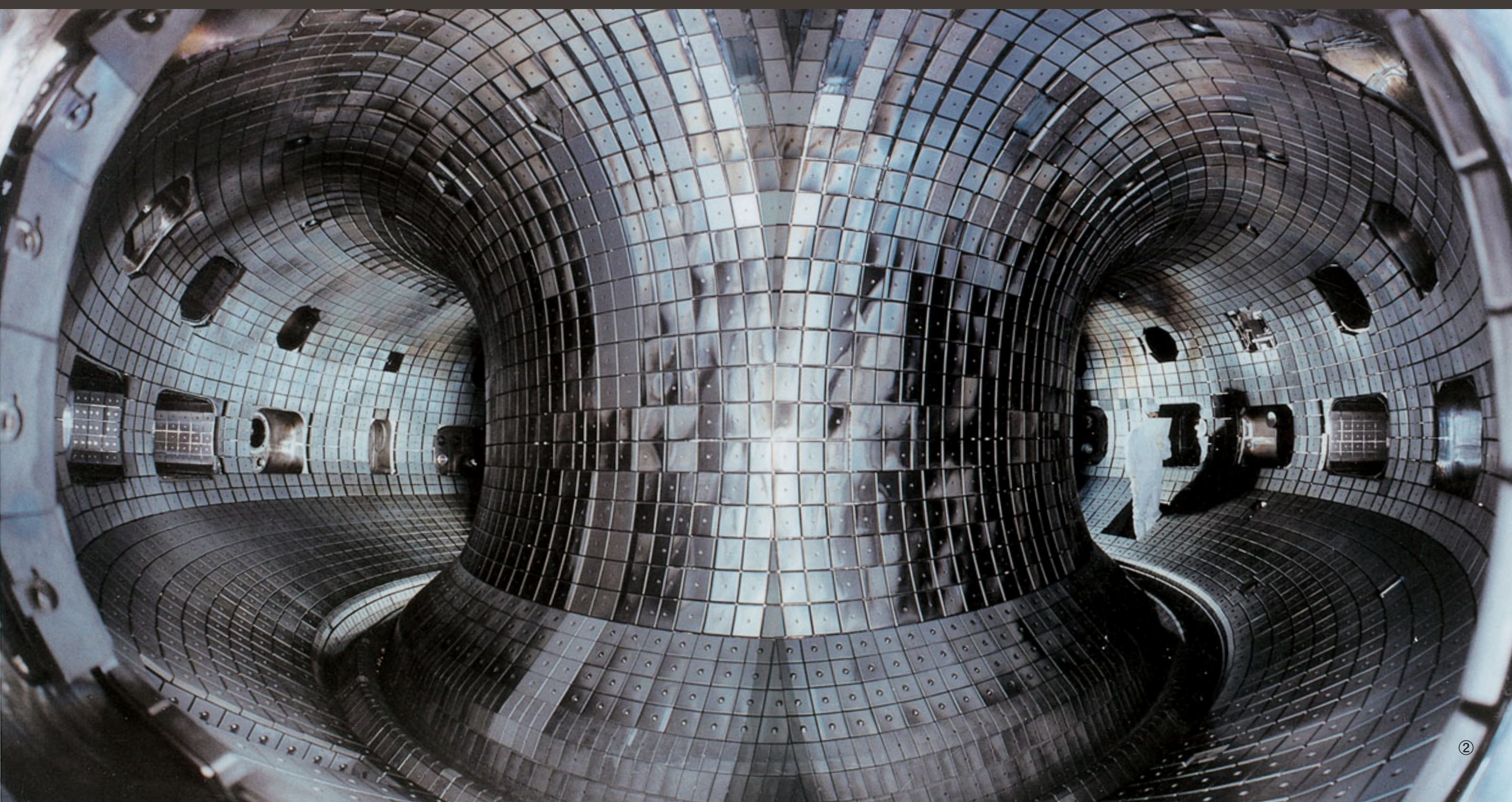
CARBON-GRAPHITE PRODUCTS

Special Graphite

① Single crystal silicon manufacturing equipment

② Critical plasma testing equipment (JT-60)
※Photographs provided by the Japan Atomic Energy Agency

①



②

Features of Special Graphite Products

The demand from the industry over the years has been for carbon with increasingly tighter and stable properties. In this context, Toyo Tanso was the pioneer in our industry in developing "isotropic graphite." This is a graphite material with micro particles and an isotropic structure and properties which created through Cold Isostatic pressing(CIP). Our isotropic graphite products are used across a wide field of industries. These include: the semi-conductor industry, where innovation is rapidly advancing; the environmentally friendly renewable energy industry; the mold industry, where accuracy is such a priority; and the atomic power industry, where high reliability is essential. Our excellence is recognized by our customers, with whom we grow together. The synergistic effect between our exclusive high purity technology and various coating technologies will ensure that in the future too, we use our position as a leading company to continue to unlock the unlimited potential of carbon.

■ Isotropic Graphite

Conventional graphite was anisotropic, which limited its use in many applications. However, isotropic graphite in the same cross section direction has no difference in its properties, making a material that is easy to design and use.

■ High Reliability

Isotropic graphite is stronger than conventional graphite due to its micro particle structure. This produces a highly reliable material with a small characteristic variation.

■ Ultra Heat Resistance

In an inert atmosphere, stable use is possible even in extremely high temperatures of 2,000°C or more. The material has low thermal expansion and a high coefficient of thermal conductivity, giving it excellent thermal shock resistance and heat distribution properties, with low thermal deformation. It also has a special characteristic whereby its strength increases as the atmospheric temperature gets higher up unitil 2500°C .

■ Excellent Electrical Conductivity

The high and excellent heat resistance mean graphite is the optimum material for applications such as high temperature heaters.

■ Excellent Chemical Resistance

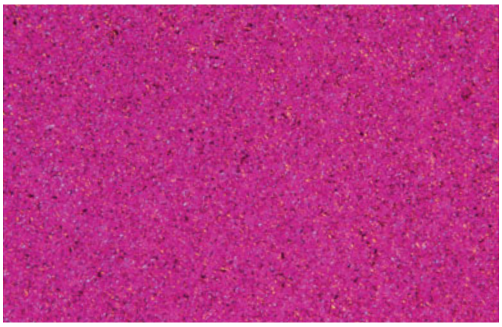
With the exception of some strong oxidizers, it is chemically stable. Graphite can be used stably even in environments that cause some metals to corrode.

■ Lightweight and Easy to Machine

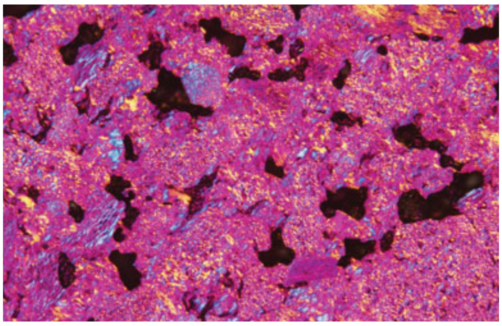
The bulk density is low as compared with metallic materials-enabling a lightweight design. In addition, it has excellent mechanical machining properties-facilitating accurate shaping processes.

■ Isotropic Graphite and Anisotropic Graphite

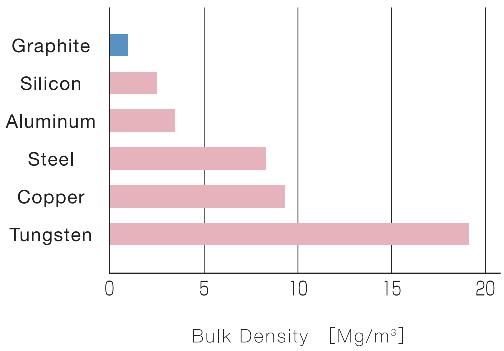
Isotropic High Density Graphite 100μm



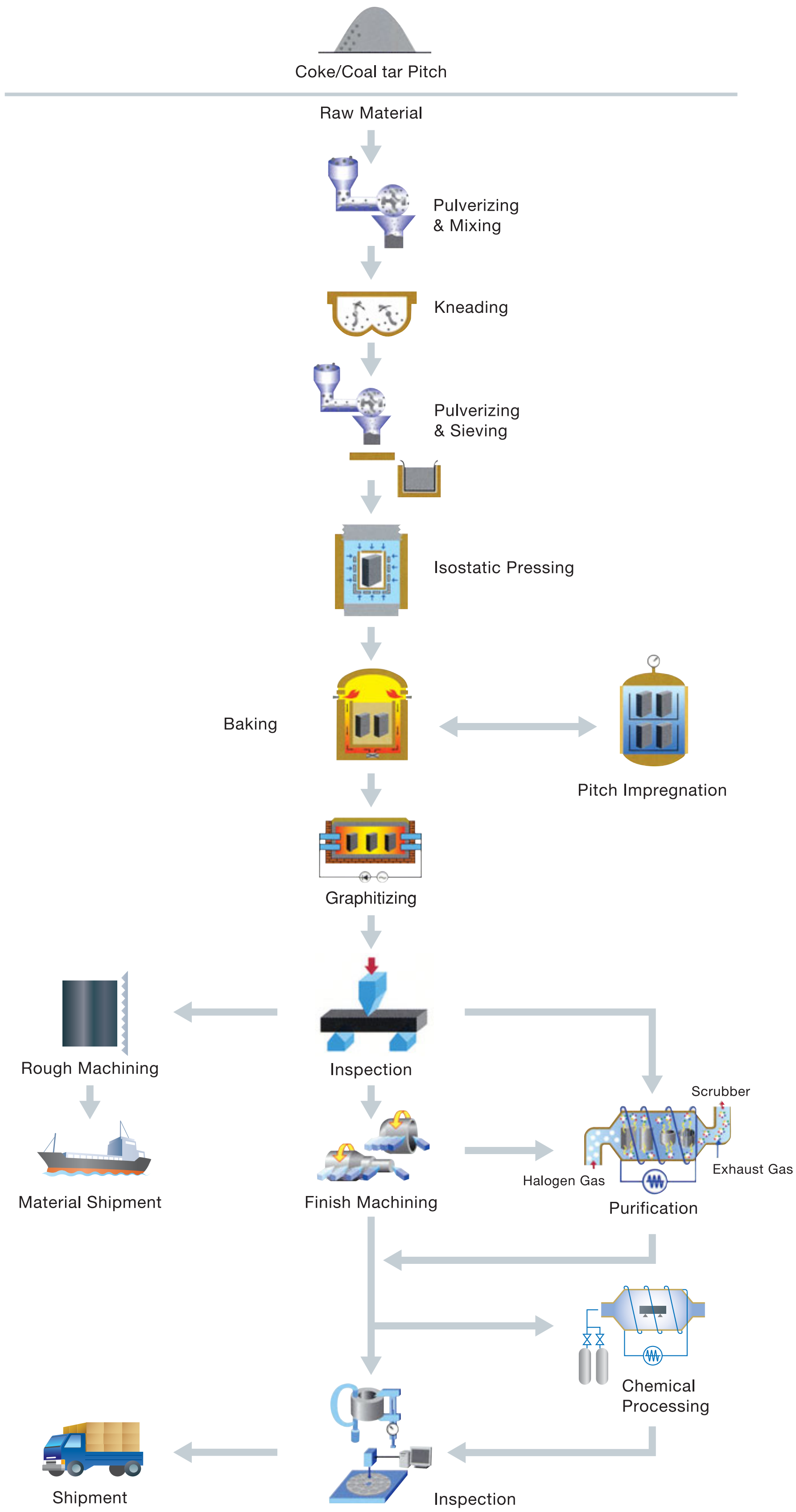
Anisotropic Graphite 100μm



Isotropic high density graphite is different from conventional graphite in that it is isotropic and has a micro particle structure, creating a very strong and highly reliable material with a small variation. This isotropic graphite material resolves the problems associated with conventional anisotropic graphite.



Manufacturing Process

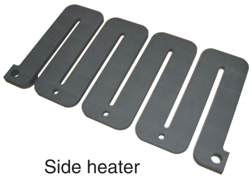


Application

Toyo Tanso's special graphite products are highly regarded for their excellent performance and reliability and are used across a wide range of fields that are essential in our everyday lives. In the environmental and energy industry, our products are used for solar cell manufacturing, atomic power and aerospace applications. In the electronics industry, we provide materials for various manufacturing process such as polycrystalline silicon and single crystal silicon, white LEDs, and high-frequency device. Basic applications of our products include industrial furnaces, continuous casting dies such as those for copper alloys, optical fibers, and EDM electrodes for mold manufacture.

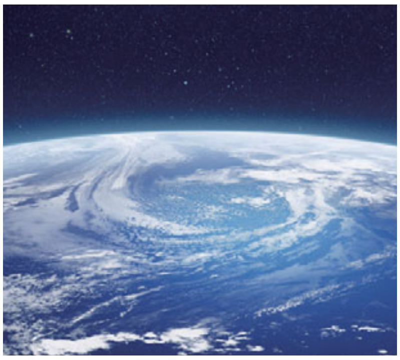
■Environment and Energy

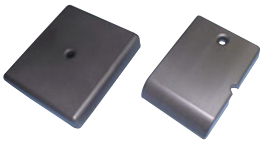
- Solar Cell and Wafer Manufacturing
- Atomic Power : High Temperature Gas Cooled Reactor, Nuclear Fusion
- Fluorine Electrolysis
- Fuel Cells
- Aerospace



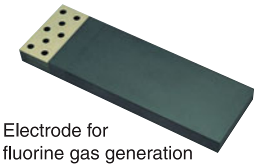
Side heater

Core component for
High Temperature Gas-cooled Reactor
※Photographs provided by the
Japan Atomic Energy Agency





Nuclear Fusion Reactor
Plasma First Wall
※Photographs provided by the
Japan Atomic Energy Agency



Electrode for
fluorine gas generation

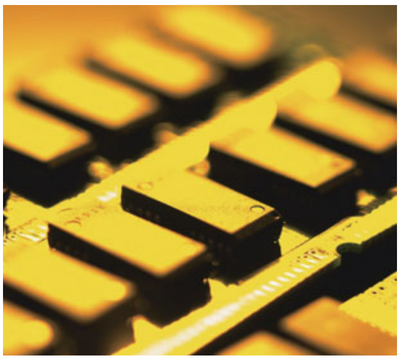
■Electoronics

- Silicon Semi-conductor Manufacturing Applications

  Polycrystalline silicon manufacture
  Single crystal silicon manufacturing equipment
  Susceptors for epitaxial growth
  Plasma CVD electrodes
  Ion implantation
  Hermetic sealing jigs

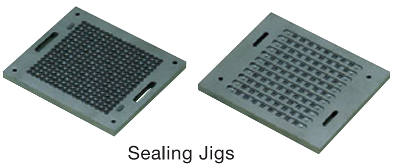
Single crystal silicon
manufacturing equipment

Crucible

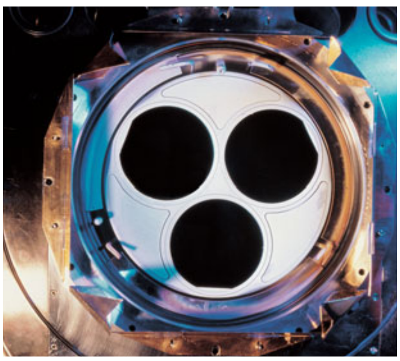


Reflector

Heater



Sealing Jigs



Electoronics

●Compound Semi-conductor Manufacturing Applications

Crystal Manufacturing Equipment Parts
MOCVD Susceptors

●LCD Panel Manufacturing Applications

Heater Panels
Electrode for plasma Etching

●Hard Disk Manufacturing Applications

Sputtering Targets

MOCVD susceptor

Pancake susceptor

Metallurgical

●Continuous Casting

Dies
Mandrels

●Hot Press

Dies
Punch
Sleeves
Spacers

●Industrial Furnace

Heaters
Trays

●Vacuum Evaporation Crucibles

●Gas Analysis Crucibles

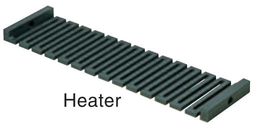
●Optical Fiber Manufacturing Applications

Heaters
Muffle Tube

●EDM Electrodes

Hot Press Mold
(Cut Model)

Continuous Casting Dies



Heater

Vacuum Evaporation Crucibles

EDM Electrodes

Property Data

■ Typical Properties

Grade	Bulk Density	Hardness	Electrical Resistivity	Flexural Strength	Compressive Strength	Tensile Strength	Young's Modulus	Coefficient of Thermal Expansion	Thermal Conductivity	Standard Size
	Mg/m^3	HSD	$\mu\Omega\cdot$m	MPa	MPa	MPa	GPa	10^{-6}/K	W/(m·K)	(mm)
IG-11	1.77	51	11.0	39	78	25	9.8	4.5	120	305×620×1000 410×410×2040 D585×1050
IG-12	1.78	55	12.5	39	88	28	10.8	4.7	100	305×620×1000 D585×1050
IG-15	1.90	60	9.5	54	103	29	11.8	4.8	140	230×620×1000
IG-19	1.75	60	17.0	38	88	25	9.5	4.6	80	D585×1050 305×620×1000
IG-43	1.82	55	9.2	54	90	37	10.8	4.8	140	300×540×850
IG-45	1.88	55	9.0	60	110	40	12.0	4.9	140	300×540×850
IG-56	1.77	57	12.2	43	88	27	10.3	4.7	100	190×620×1500 D1150×560
IG-70	1.83	58	10.0	47	103	31	11.8	4.6	130	305×620×1000 D460×1050
ISEM-1	1.68	45	13.5	36	69	20	8.8	4.2	90	305×620×1000
ISEM-2	1.78	55	11.0	41	83	25	9.8	4.6	120	305×620×1000
ISEM-3	1.85	60	10.0	49	103	29	11.8	5.0	130	305×620×1000
ISEM-8	1.78	63	13.4	52	106	34	10.1	5.6	90	305×620×1050～1200
ISO-63	1.78	76	15.0	65	135	46	12.0	5.6	70	230×540×1000
ISO-66	1.82	75	14.4	70	134	46	12.6	7.1	80	180×450×850
ISO-68	1.82	80	15.5	76	172	54	13.2	5.6	70	230×540×1000
TTK-50	1.80	70	13.0	60	130	40	11.5	5.1	100	305×620×1000 230×540×1000
TTK-4	1.78	72	14.0	73	135	49	10.9	5.0	90	210×510×950
TTK-5	1.78	80	15.5	80	150	53	11.6	5.7	80	210×510×950
TTK-8	1.77	78	15.0	80	155	55	12.0	5.3	80	150×400×700
TTK-9	1.77	90	18.0	92	180	67	13.0	5.8	70	150×400×700
SIC-6	1.85	60	10.0	49	103	29	11.8	5.0	130	305×620×1000
SIC-12	1.77	65	14.1	47	93	29	10.8	5.0	80	305×620×1000
HPG-51	1.78	73	14.3	75	140	50	11.0	5.1	90	210×510×950
HPG-53	1.78	81	15.7	80	156	55	11.8	5.8	80	210×510×950
HPG-59	1.91	88	13.5	100	210	74	12.7	5.7	95	100×500×950
HPG-81	1.77	80	15.1	83	161	58	12.2	5.2	80	150×400×700
HPG-83	1.77	92	18.2	96	187	70	13.3	5.9	70	150×400×700

※The figures above are typical values, and are not guaranteed.
※The measurement temperature range for the coefficient of thermal expansion is 350 to 450°C.
※Unit conversion: $\mu\Omega\cdot$m＝$\mu\Omega\cdot$cm×0.01 MPa＝kgf/cm^2×0.098 GPa＝kgf/mm^2×0.0098 W/(m·K)＝kcal/h·m·°C×1.16
※There are other product sizes in addition to those described above. Contact Toyo Tanso for details.

■ Impurity Analysis Example

Unit: mass ppm

Element	Content			Measurement Method
	Ultra High Purity Graphite	High Purity Graphite	Regular Graphite	
Li	<0.001	<0.001	<0.03	ICP-MS
B	0.10	0.15	3	ICP-MS
Na	<0.002	<0.002	<0.5	ICP-MS
Mg	<0.001	0.004	0.2	ICP-MS
Al	<0.001	0.012	14	ICP-MS
Si	<0.1	<0.1	2	UV
K	<0.03	0.04	2	FL-AAS
Ca	<0.01	0.08	6	FL-AAS
Ti	<0.001	<0.001	33	ICP-MS

Element	Content			Measurement Method
	Ultra High Purity Graphite	High Purity Graphite	Regular Graphite	
V	<0.001	0.018	40	ICP-MS
Cr	<0.004	0.006	<0.3	ICP-MS
Mn	<0.001	<0.001	<0.2	ICP-MS
Fe	<0.02	0.06	26	ICP-MS
Co	<0.001	<0.001	<0.3	ICP-MS
Ni	<0.001	0.006	4	ICP-MS
Cu	<0.002	<0.002	<1	ICP-MS
Zn	<0.002	<0.002	<0.6	ICP-MS
Pb	<0.001	<0.001	<1	ICP-MS

※The figures above are examples of actual measurements, and are not guaranteed.
※ICP-MS: Inductively Coupled Plasma Mass Spectrometer, FL-AAS: Flameless Atomic Absorption Spectrometer, UV: Absorption Spectrophotometer.
※The impurity content of regular graphite is approximately 400 mass ppm; however, a higher purity is required for applications such as semi-conducting industries. At Toyo Tanso, we can use a high temperature halogen treatment to purify the graphite to the mass ppm levels requested by our customers.

Chemical Properties

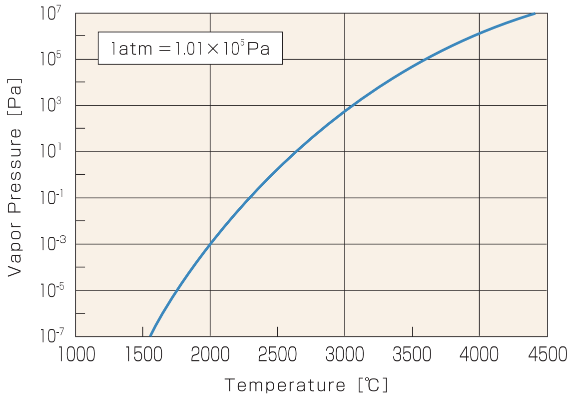
Initial Reaction Temperatures With Various Substances

※Extracted from other publications

Reactant	Initial Reaction Temperature	Compound of Reaction
Aluminum	800℃	Al_4C_3
Boron	1600℃	B_4C
Iron	600~800℃	Fe_3C
Sodium	400~450℃	$C_{64}Na$ Intercalation compound (when O^2 is present)
Cobalt	218℃	CoC, Co_3C
Molybdenum	700℃	Mo_2C
Nickel	1310℃	Ni Carbonizing in Ni
Silicon	1150℃	SiC
Copper	―――	
Magnesium	―――	
Lead	―――	
Tin	―――	
Tungsten	1400℃	W_2C, WC (in hydrogen)
Potassium	300℃	C_8K Other intercalation compounds
Lithium	500℃	Li_2C_2
Beryllium	900℃	Be_2C (in a vacuum or He)
Boron oxide	1200℃	CO, B
Vanadium oxide (V)	438℃	CO, V
Iron oxide (III)	485℃	CO, Fe
Titanium oxide (IV)	930℃	CO, Ti, TiC
Silicon dioxide	1250℃	CO, Si, SiC
Alumina	1280℃	CO, Al, Al_4C_3
Beryllium oxide	960℃	CO, Be, Be_2C
Magnesium oxide	1350℃	CO, Mg
Zirconium oxide (IV)	1300℃	CO, Zr, ZrC

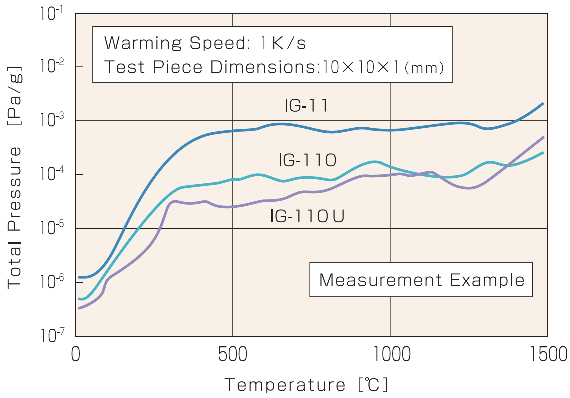
Vapor Pressure

※Extracted from other publications



Graphite is an extremely stable material in temperatures under 2,200°C. However, the vapor pressure increases in higher temperatures and high vacuums, so caution must be exercised with regard to the accelerated wearing of graphite.

Thermal Desorption Spectrum (TDS)



Graphite emits absorbed gas when in high temperatures. Some applications such as semi-conducting industries must use highly purified or ultra highly purified graphite, which emits less gas.

Reactivity With Various Atmosphere/Gas species ※Extracted from other publications

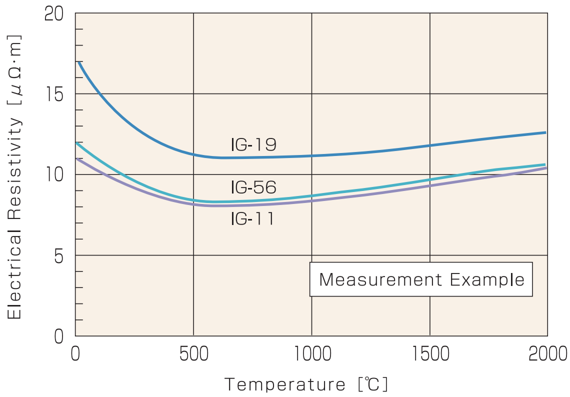
Atmosphere/ Gaseous species	Initial Reaction Temperatures/ Reaction Temperatures	Genesis phenomenon or Produced Compound	Remarks
Air	420~460℃	Oxidation/CO, CO_2	Aprox.100℃ higher in case of high purity graphite
Oxygen (O_2)	420~460℃	Oxidation/CO, CO_2	React with atomic oxygen at normal temperature
Steam(H_2O)	Aprox.650℃	Oxidation/CO, CO_2, H_2	
Carbon dioxide (CO_2)	Aprox.900℃	Oxidation/CO	
Hydrogen(H_2)	Aprox.700℃	Methanation/CH_4	Produce C_2H_2, C_2H_4, C_2H_6 or so at more high temperature
Nitrogen(N_2)	Inert at more than room temperature	Sublimation	Produce CyanogenC_2N_2 during discharge and in 2700℃ high pressure N_2 atmosphere
Chlorine(Cl_2)	Inert at more than room temperature	Sublimation	Produce intercalation compound in a lower temperature than 0℃
Fluorine (F_2)	420~1900℃	Fluorination/CF	Produce CF_4, C_2F_6 or so up to temperature
Argon(Ar)	Inert in any temperature	Sublimation	
Vacuum	—	Sublimation	In the higher temperature and vacuum atmosphere, the easier sublimate

In an oxidizing atmosphere, graphite reacts with oxygen at a relatively low temperature. However, in a non-oxidizing atmosphere, graphite is chemically and thermally and extremely stable material, enabling a broad range of applications.

Property Data

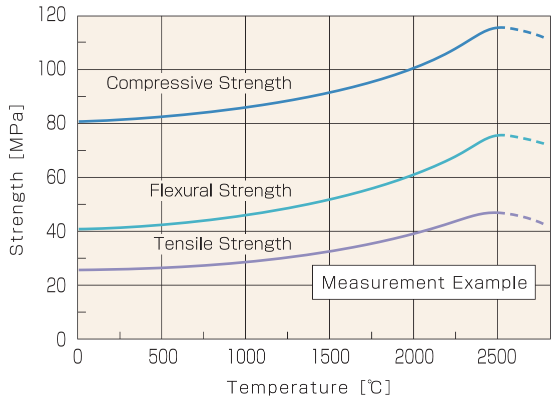
High Temperature Properties

Electrical Resistivity



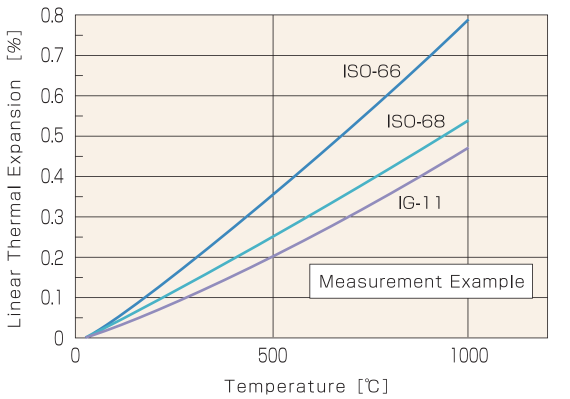
Since thermal characteristics differ from grade to grade, the coefficient of electrical resistivity must be carefully studied when selecting a grade for a heating element.

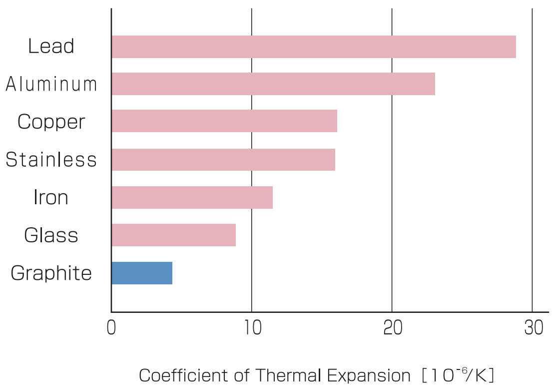
Strengths (IG-11)



An unparalleled characteristic of graphite, which makes it indispensable in high temperature applications, is that as the temperature rises (up to 2,500C), the strength also increases. Strength reaches levels approximately double those at room temperature.

Linear Thermal Expansion



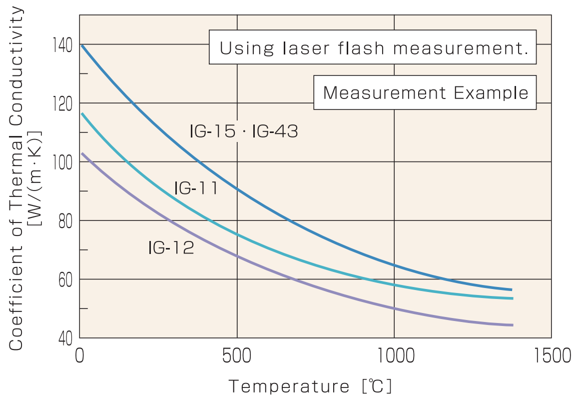


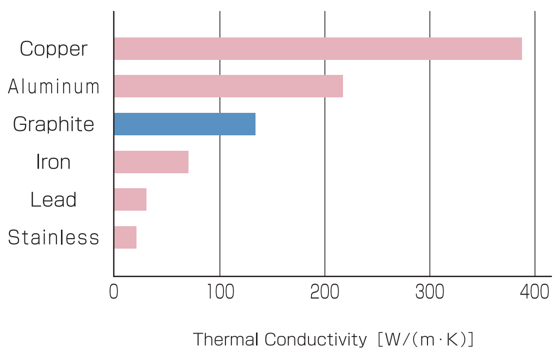
Compared with general metals, the coefficient of thermal expansion for graphite is extremely low. As a result, when used in high temperature applications, the dimensional accuracy is very stable.

Reference:

$$\text{Coefficient of Thermal Expansion } (10^{-6}/K) = \frac{\text{Linear Thermal Expansion } (\%) \times 10^{-2}}{\text{Temperature Difference } (℃)}$$

Thermal Conductivity

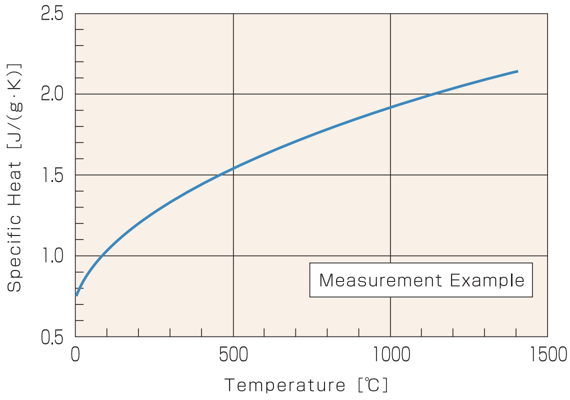




The thermal conductivity of graphite is fairly high, while the coefficient of thermal expansion is very low. These characteristics contribute to its superior thermal shock resistance. The relationship between thermal conductivity and electrical resistivity of graphite in room temperature is indicated below.

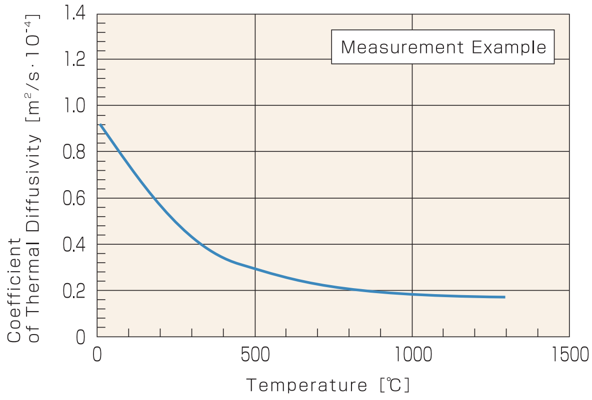
$$\text{Thermal Conductivity } [W/(m \cdot K)] = \frac{0.13 \times 10^{4}}{\text{Electrical Resistivity } (\mu\Omega \cdot m)}$$

Specific Heat



Due to the anisotropic nature of its crystals, the specific heat of graphite at room temperature stays at 1/3 of that of general solids. The specific heat value is essential in various thermodynamic functions. At high temperatures, specific heat values are similar regardless of the graphite grades.

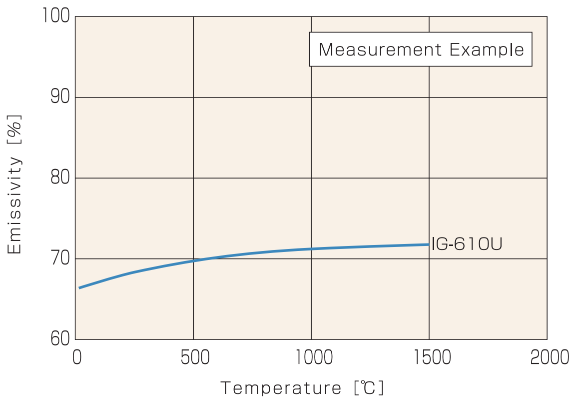
Coefficient of Thermal Diffusivity



This chart shows that the higher the temperature rises, the faster the heat is transmitted. The thermal diffusivity of graphite is superior to other materials.

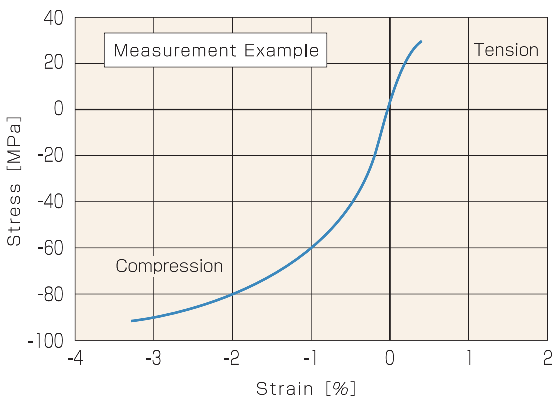
Reference:
Coefficient of Thermal Diffusivity $= \dfrac{\text{Thermal Conductivity}}{\text{Specific Heat} \times \text{Density}}$

Emissivity



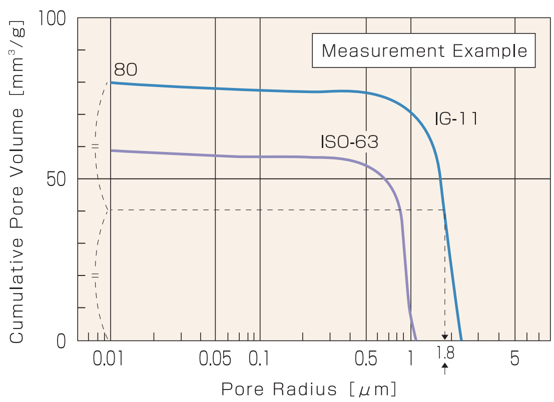
Physical Properties

Stress Strain Curve (IG-12)



Graphite generally shows elastic-plastic deformation. The fracture behavior is different under tension and under compression, so caution must be exercised.

Pore Distribution Curve



This shows the pore distribution through the mercury penetration method. The pore distribution has a close relationship with gas permeability and other unique properties of graphite. The halfway position of the cumulative pore volume indicates the average pore radius.

Example: For IG-11 80/2=40mm^3/g→1.8μm

Machining

Surface Roughness Standards

Since carbon products are porous, it is difficult to obtain a surface finish that is equivalent to metal. The table on the right shows the correspondence of the "Surface Finish Symbol" and surface roughness standards, Ry & Ra & Rz.

Surface Roughness Standards

Finish Symbol (For refarence)	Machining Surface Roughness for Carbon			Finishing Method	Machining Surface Roughness for Metal		
	Ry	Ra	Rz		Ry	Ra	Rz
▽▽▽▽	√Ry3	0.75	√Rz3	Honing Lapping	√Ry0.8	0.2	√Rz0.8
▽▽▽	√Ry12	3.0	√Rz12	Grinder, Lathe Miller	√Ry6.3	1.6	√Rz6.3
▽▽	√Ry35	8.75	√Rz35	Lathe Miller	√Ry25	6.3	√Rz25
▽	√Ry100	25	√Rz100	Lathe Miller	√Ry100	25	√Rz100
～	No particular standard			Saw Machine	No particular standard		

※ 3.0 means that Ra 3.0 micro miter is the maximum.

Machining Dimension Tolerance

If the tolerance is not specified on the customer drawing, apply the intermediate grade of JIS B 0405.

Dimension Tolerance Standards

Unit:mm

Nominal Dimension Category		Tolerance
0.5 or more	6 or less	±0.1
Exceeding 6	30 or less	±0.2
Exceeding 30	120 or less	±0.3
Exceeding 120	400 or less	±0.5
Exceeding 400	1000 or less	±0.8
Exceeding 1000	2000 or less	±1.2

※The above information can be applied when graphite is machined by Toyo Tanso in Japan.

Toyo Tanso has a wide range of carbon and graphite grades available to meet your requirements. Before actually using one of our products, please be sure to contact our sales department to consult on selecting the most appropriate grade.