



GUIDE TO MATERIALS

Metals with high melting point

Tungsten

(W) Atomic number: 74

Properties

Melting point (°C)	3387	(the highest from all metals)
Thermal conductivity (W/(m·K))	172	
Thermal expansion coefficient (×10 ⁻⁶)	4.5	(the lowest from all metals)
Specific gravity	19.3	(equal to gold)
Hardness (Hv) (GPa)	4.2	
Young's modulus (GPa)	345	

◇Heat-resistant, high heat conductivity, high specific gravity

Application

- Filaments for illumination, crucible;
- Vacuum furnace for heaters as well as construction materials;
- All kinds of electrodes for discharge lamps, electrical contacts;
- Heat screen material, TIG welding electrodes;
- Source components for semiconductor ions;
- Sputtering targets;
- Balance weight

Carbide: extremely hard (WC)

Molybdenum

(Mo) Atomic number: 42

Properties

Melting point (°C)	2623
Thermal conductivity (W/(m·K))	142
Thermal expansion coefficient (×10 ⁻⁶)	5.3
Specific gravity	10.2
Hardness (Hv) (GPa)	2.6
Young's modulus (GPa)	276

◇Heat-resistant, high heat conductivity

Application

- Illumination parts, light bulb filament support wire;
- Heaters used in hot water kilns as well as shields;
- Crucible, sinter board;
- Parts for power devices;
- Magnetron parts used in microwave ovens;
- Sputtering targets material

Tantalum

(Ta) Atomic number: 73

Properties

Melting point (°C)	2990
Thermal conductivity (W/(m·K))	57.5
Thermal expansion coefficient (×10 ⁻⁶)	6.3
Specific gravity	16.7
Hardness (Hv) (GPa)	0.7
Young's modulus (GPa)	185

◇Heat-resistant

Application

- Parts for heat exchanger;
- High temperature reactor components;
- Source components for semiconductor ions

Powder: condenser, target materials;

Oxide: optical lenses' additive;

Carbide: cemented carbide tool

Niobium

(Nb) Atomic number: 41

Properties

Melting point (°C)	2415
Thermal conductivity (W/(m·K))	54
Thermal expansion coefficient (×10 ⁻⁶)	7.0
Specific gravity	8.6
Hardness (Hv) (GPa)	0.8
Young's modulus (GPa)	107

◇Heat-resistant

Application

- Iron and steel additive

Carbide: cemented carbide tool;

Intermetallic compound: superconducting magnet;

Compound metal: sputtering target material

Universal metal

Silver
(Ag) Atomic number: 47

Properties

Melting point (°C)	960
Thermal conductivity (W/(m·K))	420
Thermal expansion coefficient (×10 ⁻⁶)	19.0
Specific gravity	10.5
Hardness (Hv) (GPa)	0.9
Young's modulus (GPa)	73

◇High heat conductivity, high electric conductivity

Application

- Electric lines (low electric resistance);
- Audio cables;
- Wiring handling high frequency;
- Tableware, jewels, dentist treatment;
- Water purifiers (sterilization);

Can be used as a compound metal

Copper
(Cu) Atomic number: 29

Properties

Melting point (°C)	1084
Thermal conductivity (W/(m·K))	398
Thermal expansion coefficient (×10 ⁻⁶)	16.6
Specific gravity	8.9
Hardness (Hv) (GPa)	0.8
Young's modulus (GPa)	130

◇High heat conductivity, high electric conductivity

Application

- Wiring materials for electric appliances;
- Electric lines (electric resistance is low and it is cheaper than silver);
- Coins, building materials;

Can be used as a compound metal brass products etc.

Aluminum
(Al) Atomic number: 13

Properties

Melting point (°C)	660
Thermal conductivity (W/(m·K))	237
Thermal expansion coefficient (×10 ⁻⁶)	23.2
Specific gravity	2.7
Hardness (Hv) (GPa)	0.5
Young's modulus (GPa)	71

◇Light weight

Application

- Coins, beverage cans, pots and pans;
- Building materials, car parts;
- Petrol engines;
- Universal machine parts

Can be used as a compound metal duralumin etc.

Stainless steel
(SUS) steel alloy

Properties

Melting point (°C)	1450
Thermal conductivity (W/(m·K))	16.3
Thermal expansion coefficient (×10 ⁻⁶)	18.0
Specific gravity	7.9
Hardness (Hv) (GPa)	2.0
Young's modulus (GPa)	200

◇Corrosion-resistant

Application

- *Austenite type:*
kitchen equipment, tableware, utensils used in chemical medicine, universal machine parts;
- *Martensite type:*
kitchen knives, high-durability quenching machine parts;
- *Ferrite type:*
pots using electromagnetic cooker, etc.

Ceramics 1

Alumina (Aluminum oxide) Al_2O_3

Properties

Melting point (°C)	2054
Thermal Shock Resistance (°C)	200
Thermal conductivity (W/(m·K))	30
Thermal expansion coefficient ($\times 10^{-6}$)	5.3
Specific gravity	3.9
Hardness (Hv) (GPa)	18

◇High intensity, abrasion-resistant, heat-resistant, corrosion-resistant

Application

- Insulators, parts insulating electricity;
- Furnace walls, furnace parts, jigs;
- Nozzles, spinning tube;
- Reaction crucible, reaction vessels;
- Semiconductor-related parts;
- Liquid crystal production parts;
- Electron tube parts, pumps, grinding materials

Aluminum nitride AlN

Properties

Melting point (°C)	2200
Thermal Shock Resistance (°C)	400
Thermal conductivity (W/(m·K))	160
Thermal expansion coefficient ($\times 10^{-6}$)	2.4
Specific gravity	3.3
Hardness (Hv) (GPa)	13

◇High heat conductivity

Application

- Crucible;
- Components for heat sink, heat-resistant sheets;
- Semiconductor devices' parts: heaters, ESC, dummy wafers, susceptor rings, shower plates, chambers, RF-windows

Silicon nitride Si_3N_4

Properties

Melting point (°C)	1600
Thermal Shock Resistance (°C)	650
Thermal conductivity (W/(m·K))	13
Thermal expansion coefficient ($\times 10^{-6}$)	1.5
Specific gravity	3.2
Hardness (Hv) (GPa)	16

◇High intensity, abrasion resistive, thermal shock-resistant

Application

- Parts for engines;
- Gas turbine parts;
- Bearing, guide rolls;
- Cutting tools, pulverizer parts;
- Gas burner parts;
- Mixing blades

Silicon carbide SiC

Properties

Melting point (°C)	2730
Thermal Shock Resistance (°C)	450
Thermal conductivity (W/(m·K))	150
Thermal expansion coefficient ($\times 10^{-6}$)	2.9
Specific gravity	3.1
Hardness (Hv) (GPa)	24

◇High solidity, high rigidity, high heat conductivity

Application

- Parts using hot water;
 - Slide parts: bearing, mechanical seals
- DPF components (filters collecting dust)

Ceramics 2

Zirconia
(Zirconium dioxide) ZrO_2

Properties

Melting point ($^{\circ}C$)	2715
Thermal Shock Resistance ($^{\circ}C$)	280
Thermal conductivity ($W/(m \cdot K)$)	3
Thermal expansion coefficient ($\times 10^{-6}$)	7.7
Specific gravity	6.0
Hardness (Hv) (GPa)	13

◇High tenacity, high intensity, abrasion-resistant

Application

- Industrial purposes cutlery;
- Scissors, kitchen knife;
- Gauges:
 - pin gauge, block gauge, wrecking ball;
- Various wear resistant parts

Boron nitride
BN

Properties

Melting point ($^{\circ}C$)	2700
Thermal Shock Resistance ($^{\circ}C$)	1500
Thermal conductivity ($W/(m \cdot K)$)	63
Thermal expansion coefficient ($\times 10^{-6}$)	1.4
Specific gravity	1.8
Hardness (Hv) (GPa)	0.8

◇High temperature insulation resistance, thermal shock-resistant

Application

- High temperature atmospheric furnace insulator;
- Various semiconductors;
- Compound semiconductor crucible;
- Electrical part assembly jigs;
- Heat sinks

Powder: high temperature lubrication additive, release agent cosmetic products

Semi-metal

Silicon
(Si) Atomic number : 14

Properties

Melting point ($^{\circ}C$)	1400
Thermal Shock Resistance ($^{\circ}C$)	-
Thermal conductivity ($W/(m \cdot K)$)	148
Thermal expansion coefficient ($\times 10^{-6}$)	4.2
Specific gravity	2.3
Hardness (Mohs)	6.5

Application

- Semi-conductor parts;
- Semi-conductor manufacturing equipment parts;
- Solar battery

Glass

Quartz glass

Properties

Melting point ($^{\circ}C$)	1700
Thermal Shock Resistance ($^{\circ}C$)	1000
Thermal conductivity ($W/(m \cdot K)$)	1.4
Thermal expansion coefficient ($\times 10^{-6}$)	0.5
Specific gravity	2.2
Hardness (Hv) (GPa)	9

◇Thermal shock-resistant, low expansion

Application

- Optics:
 - optical lens and prisms, various lasers lenses;
- Chemistry:
 - solvent distilling container, chemical experiment equipment;
- Semi conductor industrial uses:
 - CVD, all kinds of furnace tube for diffusion purposes, photomasks and etc.

Metal Material Properties Table 2

※Published data is for reference only

Material		Universal metals							
		Niobium	Copper	Aluminum	Iron	Stainless steel	Gold		
Data	Unit	Ni	Cu	Al	S45C	SUS304	Ag		
Material symbol		Ni	Cu	Al	S45C	SUS304	Ag		
Component amount [%]		99.0%~99.95%	99.9%~99.99%	99.0%~99.999%			99.99%~99.999%		
Machining properties	Density	[g/cm ³]	8.90	8.90	2.70	7.83	7.90	10.50	
	Hardness	Vickers hardness Hv1	[GPa]	0.90	0.80	0.50	2.45	2.00	0.88
		20°C	[MPa]	335	195	55	828	520	
	Tensile strength	600°C	[MPa]						
		800°C	[MPa]						
		1000°C	[MPa]						
	Yield strength	[MPa]							
	Dilation	[%]							
	Flexural rigidity	[GPa]							
	Young's modulus	[GPa]	209	130	71	210	200	73	
Poisson's ratio	-								
Thermal properties	Max. use temp.	Depending on atmosphere [°C]		400	400	550	700		
	Recrystallization temperature	[°C]							
	Melting point	[°C]	1455	1084	660	1535	1450	960	
	Boiling point	[°C]							
	Linear expansion coefficient	RT	[*10 ⁻⁶ /°C]						
		RT~100°C	[*10 ⁻⁶ /°C]	13.7	16.6	23.2	11.9	18.0	19.0
		RT~500°C	[*10 ⁻⁶ /°C]						
		RT~1000°C	[*10 ⁻⁶ /°C]						
		RT~1500°C	[*10 ⁻⁶ /°C]						
	Thermal conductivity	20°C	[W/(m·K)]	91	398	237	41	16	420
100°C		[W/(m·K)]							
500°C		[W/(m·K)]							
1000°C		[W/(m·K)]							
1500°C		[W/(m·K)]							
Specific heat	[J/(kg·K)]	440	380	900	440	502	233		
Electrical characteristics	Electric conductivity	[%I.A.C.S]							
	Volume resistivity	20°C [μΩ·cm]	7.0	1.7	2.7	10.0	72.0	1.6	
Magnetic characteristics	Permeability	[Km]							
	Susceptibility	[Xm]							
Chemical reactivity	Liquid	hydrochloric acid	Loss						
		hydrochloric acid	Loss						
		sulfuric acid	Loss						
		sulfuric acid	Loss						
		nitric acid	Loss						
		caustic soda (sodium hydroxide)	Loss						
		caustic soda (sodium hydroxide)	Loss						
	Gas	air or oxygen	Loss						
		air or oxygen	Loss						
		vapor	Loss						
		nitrogen	Loss						
		carbon monoxide	Loss						
		carbon dioxide	Loss						
		hydrogen	Loss						
		hydrofluoric acid	Loss						
		chlorine	Loss						
		bromine	Loss						
		iodine	Loss						
		ammonia	Loss						
	Solid body	hydrogen sulfide	Loss						
sulfur		Loss							
carbon, graphite		Loss							
Features & applications									
Remarks									

Ceramic Material Properties Table 1

Material			Fine ceramics										
			Alumina	Alumina	Alumina	Alumina	Zirconia	Silicon nitride	Aluminum nitride	Boron nitride	Silicon carbide	Boron carbide	
Data	Unit		Al ₂ O ₃ :99.5%	Al ₂ O ₃ :99.7%	Al ₂ O ₃ :99.8%	Al ₂ O ₃ :99.99%	ZrO ₂	Si ₃ N ₄	AlN:99.0% and above	BN:99.5% and above binderless	SiC	B ₄ C:98.5%	
Main component amount [%]													
Other component or binder													
General properties	Color	-	White	Beige	Light yellow	White	Milky white	Dark grey	Grey beige	White	Black		
	Density	[g/cm ³]	3.9	3.9	3.9 and above	3.9	6.0	3.2	3.3	1.8	3.1	2.5	
	Water absorption	[%]	0	0	0	0	0	0	0	0	0		
Machining properties	Hardness (HV)	[GPa]	18	15	16	18	13	16	13	0.8 12 (HS)	24	34	
	Flexural rigidity	20°C	[MPa] <small>(Impact bending 0.5-0.7)</small>	450	340	400	480	1000	750	350	30	500	550
		1000°C	[MPa]							330			
		1200°C	[MPa]	300			300	350	550	250		600	
	Compressive strength	[MPa]	2350	2900		2450							2000
	Fracture toughness	[MPa ^{m^{1/2}}]	4		4	4	6	6	3		3		
	Young's modulus	[GPa]	390	350	390	400	200	300	320	10	410	450	
Poisson's ratio	-	0.24	0.23		0.24	0.32	0.28	0.29		0.16			
Thermal properties	Max. use temp	Oxidizing atmosphere	[°C]	1300	1500		1500				950		2450 (melting point)
		Non-oxidizing atmosphere	[°C]								2200(inactive) 2000(in vacuo)		
	Thermal expansion coefficient	RT~200°C	[*10 ⁻⁶ /°C]	5.4	6.5	5.7	5.3	7.7	1.5	2.4		2.9	
		RT~400°C	[*10 ⁻⁶ /°C]		7.0					3.9(300°C)	-1.8		
		RT~600°C	[*10 ⁻⁶ /°C]	7.3(500°C)	7.5		7.5(500°C)	10.0(500°C)	3.1(500°C)	4.0(500°C)	-1.5	4.6(500°C)	
		RT~800°C	[*10 ⁻⁶ /°C]	8.5(1000°C)	7.9		8.6(1000°C)	11.0(1000°C)	3.7(1000°C)	5.2(1000°C)	-1.4(1000°C)	5.0(1000°C)	4.5
	Thermal conductivity	20°C	[W/(m·K)]	30		28	33	3	13	160	63	150	20
		400°C	[W/(m·K)]								45		
		800°C	[W/(m·K)]								30		
	Specific heat	RT	[J/(kg·K)]	800		920	800	470	680	740	800	660	960
400°C		[J/(kg·K)]								1500			
800°C		[J/(kg·K)]											
Impact resistance (ΔT)	[°C]	200		200	200	280	650	400	1500	450			
Electrical characteristics	Dielectric strength	[kV/mm]	> 30	> 10	12	> 30	> 10	> 30	> 30	25			
	Volume resistivity	20°C	[Ω·cm]	> 10 ¹⁴	1*10 ¹⁵	> 10 ¹⁴	> 10 ¹⁴	> 10 ¹²	> 10 ¹⁴	> 10 ¹⁴	10*10 ¹⁵	> 10 ⁶	0.3~0.8
		500°C	[Ω·cm]		60*10 ⁹						10 ⁶ (1200°C)		
	Dielectric constant	1MHz	-	10	10.0	10.2	10	35	8	9	4.5		
		3GHz	-	10			10	40	8	8			
Dielectric loss	1MHz	[*10 ⁻¹]	30	4	82	7	20	30	10	9			
	3GHz	[*10 ⁻¹]	4				10	30	130				
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT loss (mg/cm ² /day)	-0.3μm (20%-72hr)			-0.3μm (20%-72hr)	0.0μm (20%-72hr)	-2.8μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
		hydrochloric acid	WT loss (mg/cm ² /day)	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	0.0μm (20%-24hr)	-0.6μm (20%-24hr)		0.0μm (20%-24hr)	
		sulfuric acid	WT loss (mg/cm ² /day)	-0.3μm (20%-72hr)			0.0μm (20%-72hr)	0.0μm (20%-72hr)	-5.3μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
		sulfuric acid	WT loss (mg/cm ² /day)	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	-0.3μm (20%-24hr)	-0.9μm (20%-24hr)		0.0μm (20%-24hr)	
		nitric acid	WT loss (mg/cm ² /day)	0.0μm (61%-72hr)			0.0μm (61%-72hr)	0.0μm (61%-72hr)	-1.9μm (61%-72hr)	erosion μm (61%-72hr)		0.0μm (61%-72hr)	
		nitric acid	WT loss (mg/cm ² /day)	0.0μm (61%-24hr)			0.0μm (61%-24hr)	0.0μm (61%-24hr)	0.0μm (61%-24hr)	-0.6μm (61%-24hr)		0.0μm (61%-24hr)	
		phosphoric acid	WT loss (mg/cm ² /day)	erosion μm (85%-72hr)			-0.3μm (85%-72hr)	-3.2μm (85%-72hr)	-1.3μm (85%-72hr)	erosion μm (85%-72hr)		0.0μm (85%-72hr)	
		phosphoric acid	WT loss (mg/cm ² /day)	0.0μm (85%-24hr)			0.0μm (85%-24hr)	0.0μm (85%-24hr)	0.0μm (85%-24hr)	-1.8μm (85%-24hr)		0.0μm (85%-24hr)	
		caustic soda (sodium hydroxide)	WT loss (mg/cm ² /day)	0.0μm (20%-72hr)			0.0μm (20%-72hr)	0.0μm (20%-72hr)	-0.3μm (20%-72hr)	erosion μm (20%-72hr)		0.0μm (20%-72hr)	
		caustic soda (sodium hydroxide)	WT loss (mg/cm ² /day)	0.0μm (20%-24hr)			0.0μm (20%-24hr)	0.0μm (20%-24hr)	-1.5μm (20%-24hr)	0.0μm (20%-24hr)		0.0μm (20%-24hr)	
		hydrogen fluoride	WT loss (mg/cm ² /day)	erosion μm (47%-72hr)			-0.5μm (47%-72hr)	erosion μm (47%-72hr)	-0.9μm (47%-72hr)	-3.6μm (47%-72hr)		0.0μm (47%-72hr)	
		Abrasiveness	Blast abrasion amount	[μm]	2.1			1.0	0.5	0.6			1.6
Features & applications			High intensity Wear resistance Thermal resistance Large shape possible Relatively low price			High intensity Wear resistance Thermal resistance Large shape possible Relatively low price	High tenacity High intensity Wear resistance	High intensity Wear resistance Thermal shock resistance	High thermal conductivity	High temperature insulator Sinter for firing ceramics Jig for semi-conductor manufacturing equipment Jig for glass casts Crucible for melting Heat exchanger	High hardness High stiffness High thermal conductivity	Wear resistance Light weight	
Remarks				CIP	mold								

Ceramic Material Properties Table 3

※Published data is for reference only

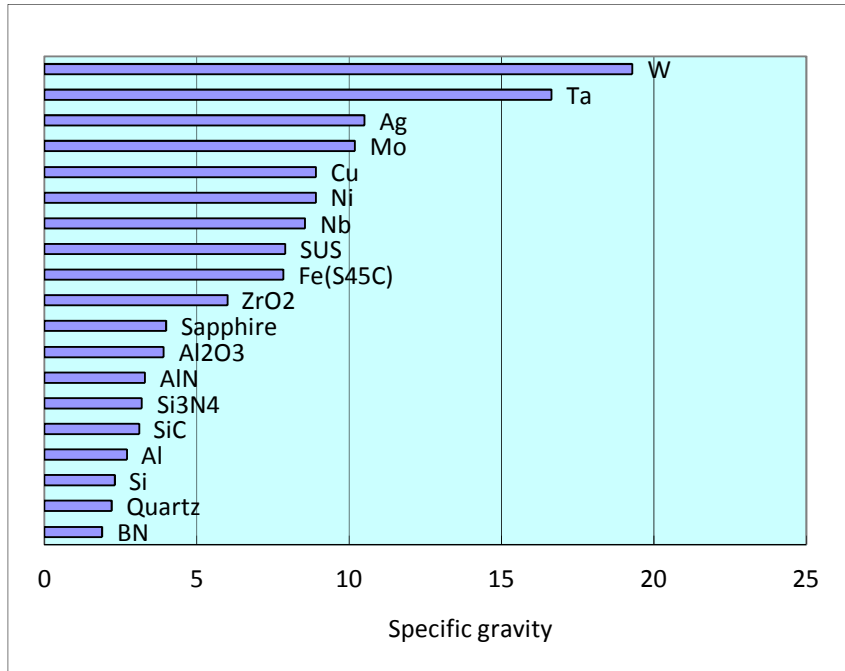
Material		Ceramic compound material (MMC)											
		Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based	Silicon carbide based		
Data	Unit	SiC:50%	SiC:65%	SiC:70%	SiC:80%	α-SiC:82%	SiC:85%	SiC:25%	SiC:30%	SiC:40%	SiC:70%		
Main component amount [%]		Si:50%	Si:35%	Si:30%	Si:20%	Si:18%	Si:15%	Al:75%	Al:70%	Al:60%	Al:30%		
Other component or binder													
General properties	Color	-											
	Density	[g/cm ³]	2.8	3.0	3.0	3.0	3.0	3.1	2.8	2.8	2.9	3.0	
	Water absorption	[%]											
Machining properties	Hardness (HV)	[GPa]				20			90(HRB)	93(HRB)	110(HRB) 35(HRC)		
	Flexural rigidity	20°C	[MPa]	300	300	300	250	250	300			380	
		1000°C	[MPa]					220(800°C)					
		1200°C	[MPa]				250(1300°C)	220(1200°C)					
	Compressive strength	[MPa]											
	Fracture toughness	[MPam ^{1/2}]	3	3	3			3		15	14	10	
	Young's modulus	[GPa]	280	310	330	350	370 (360-800°C, 340-1200°C)	380	115	125	150	260	
Poisson's ratio	-	0.20	0.20	0.20		0.18	0.20	0.29	0.29	0.29	0.10		
Thermal properties	Max. use temp	Oxidizing atmosphere	[°C]				1350	1350					
		Non-oxidizing atmosphere	[°C]										
	Thermal expansion coefficient	RT~200°C	[*10 ⁻⁶ /°C]	2.8	4.7	3.0			3.0	15.0	14.0	13.0	6.0
		RT~400°C	[*10 ⁻⁶ /°C]										
		RT~600°C	[*10 ⁻⁶ /°C]					3.4(700°C)					
		RT~800°C	[*10 ⁻⁶ /°C]				4.5	4.3(1200°C)					
	Thermal conductivity	20°C	[W/(m·K)]	175	210	190		220	210	145	150	155	170
		400°C	[W/(m·K)]				100(350°C)						
		800°C	[W/(m·K)]					60(700°C)					
	Specific heat	RT	[J/(kg·K)]	790	700	700	700	700	700		800	900	1000
400°C		[J/(kg·K)]											
800°C		[J/(kg·K)]				1000(1000°C)	1230(700°C)						
Impact resistance (ΔT)	[°C]												
Electrical characteristics	Dielectric strength	[kV/mm]											
	Volume resistivity	20°C	[Ω·cm]	2*10 ²	2*10 ¹	2*10 ²	10 ³		5*10 ²			1*10 ⁵	
		500°C	[Ω·cm]										
	Dielectric constant	1MHz	-										
		3GHz	-										
Dielectric loss	1MHz	[*10 ⁻⁴]											
	3GHz	[*10 ⁻⁴]											
Anti-corrosion properties	Chemical resistance	hydrochloric acid	WT Loss [mg/cm ² /day]										
		hydrochloric acid	WT Loss [mg/cm ² /day]										
		sulfuric acid	WT Loss [mg/cm ² /day]										
		sulfuric acid	WT Loss [mg/cm ² /day]										
		nitric acid	WT Loss [mg/cm ² /day]										
		nitric acid	WT Loss [mg/cm ² /day]										
		phosphoric acid	WT Loss [mg/cm ² /day]										
		phosphoric acid	WT Loss [mg/cm ² /day]										
		caustic soda (sodium hydroxide)	WT Loss [mg/cm ² /day]										
		caustic soda (sodium hydroxide)	WT Loss [mg/cm ² /day]										
hydrogen fluoride	WT Loss [mg/cm ² /day]												
Abrasiveness	Blast abrasion amount	[μm]											
Features & applications			Light weight High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish	Light weight High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish				High stiffness Low thermal expansion Vacuum support Pore-free Mirror finish					
Remarks			Pressureless Infiltration Technique	Pressureless Infiltration Technique	Pressureless Infiltration Technique			Pressureless Infiltration Technique	Casting process	Casting process	Pressureless Infiltration Technique		

Specific gravity

As a base point, the density of water is 1. The larger the bar, the heavier the material.

Compared to metals, ceramics tend to have less than half the density. Tungsten is heavier than lead and around the same weight as gold, making it an unusually dense element. As a result of this, tungsten is often used as radiation shielding.

Comparative specific gravity graph

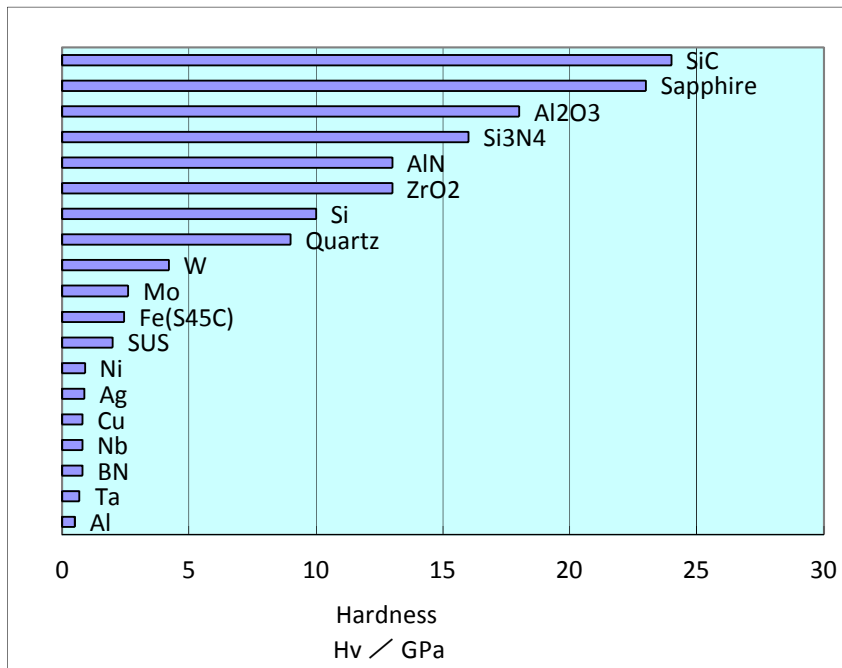


Hardness

This graph displays the hardness of various materials. The larger the bar, the harder the material.

Ceramics tend to be much harder than typical metals. By this, we mean that they resist abrasion and wear. These kinds of materials have many uses.

Comparative hardness graph

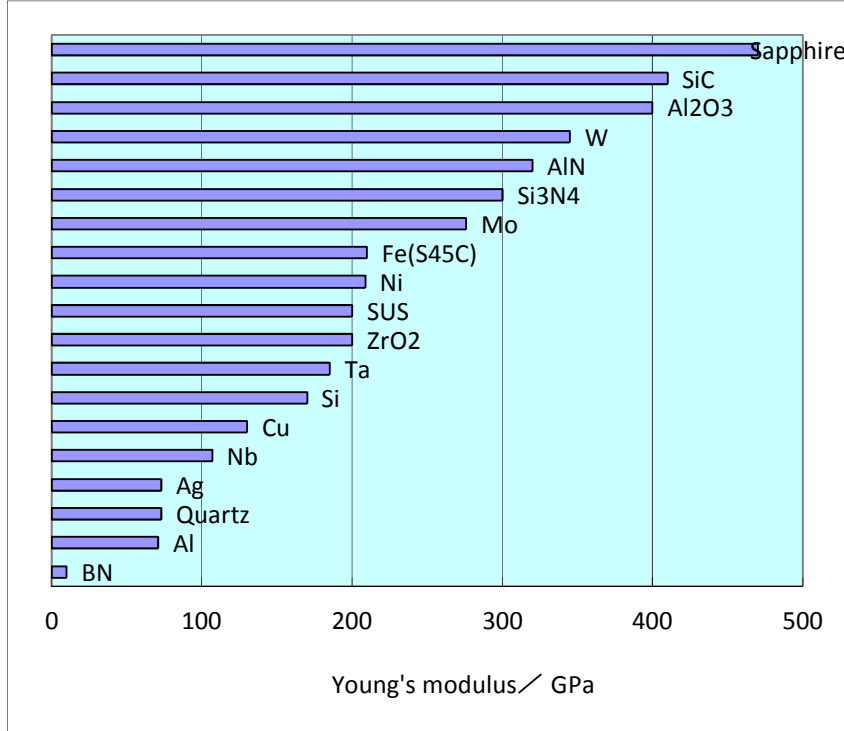


Young's modulus

Resilience to stress is an important commodity. The larger the bar, the stiffer the material.

Ceramics, tungsten and molybdenum, when compared to other metals, have a very high Young's modulus.

Young's modulus comparative graph



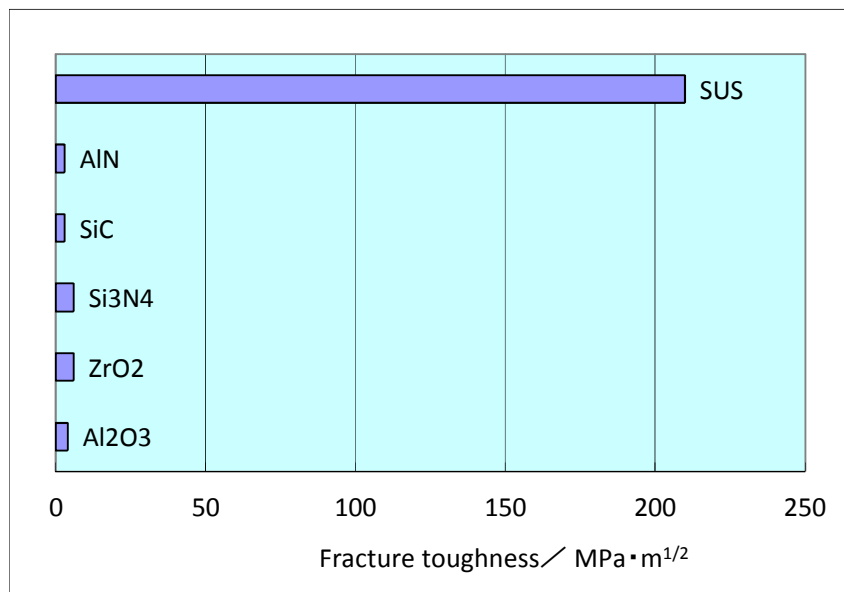
Fracture toughness

Fracture toughness can be defined as resistance to cracks. The larger the bar, the harder a material is to break.

Ceramics are extremely brittle.

As zirconia is especially resilient, it is often used in kitchen knives, scissors and wrecking balls.

Comparative fracture toughness graph

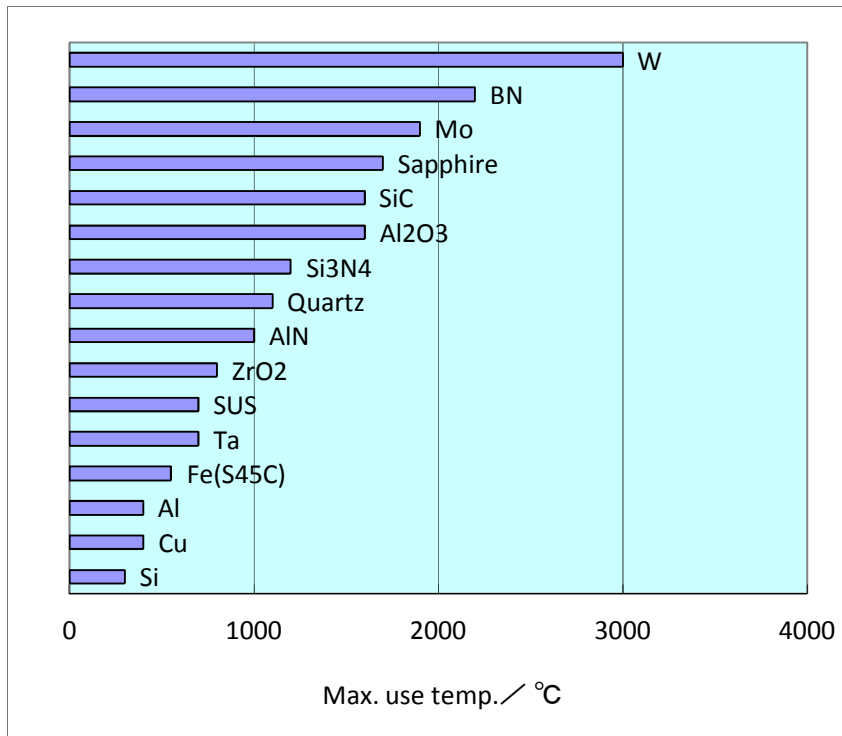


Max. use temp.

A temperature range in which material possible to use (it varies depending on atmosphere).

High melting point metals such as tungsten and molybdenum, as well as ceramic, have many uses, for example furnace materials, crucible, and heat shielding.

Comparative maximum use temperature graph



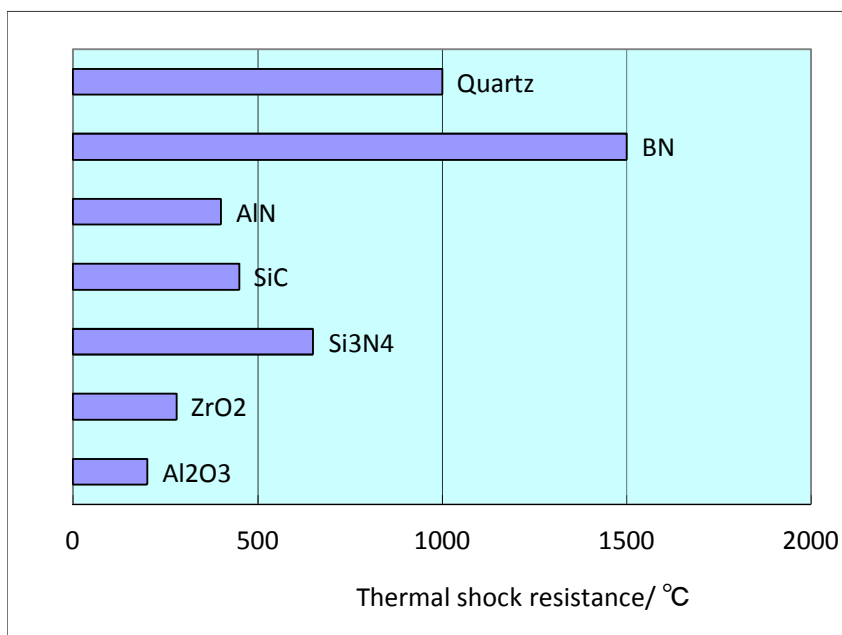
Thermal shock resistance

Temperature range that can withstand rapid changes in temperature.

The higher the temperature, the harder a material is to brake.

Glass and ceramics are easy to break with abrupt temperature change but boron nitride, quartz, and silicon nitride have a very high thermal shock resistance. These materials tend to be used in parts that experience extreme swings in temperature.

Comparative thermal shock resistance graph

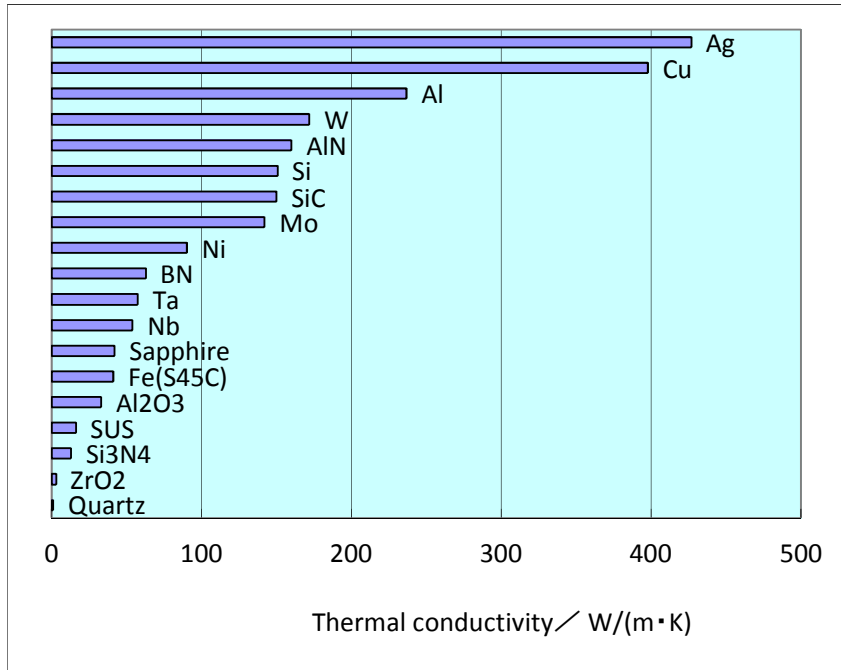


Thermal conductivity

This graph displays the heat conduction rate for different materials. A larger bar indicates that heat travels easily through the material.

Certain ceramics like aluminum nitride and silicon carbide have high conductivity rates but others such as zirconia have very low conduction. Tungsten and molybdenum have a comparatively high conductivity rate.

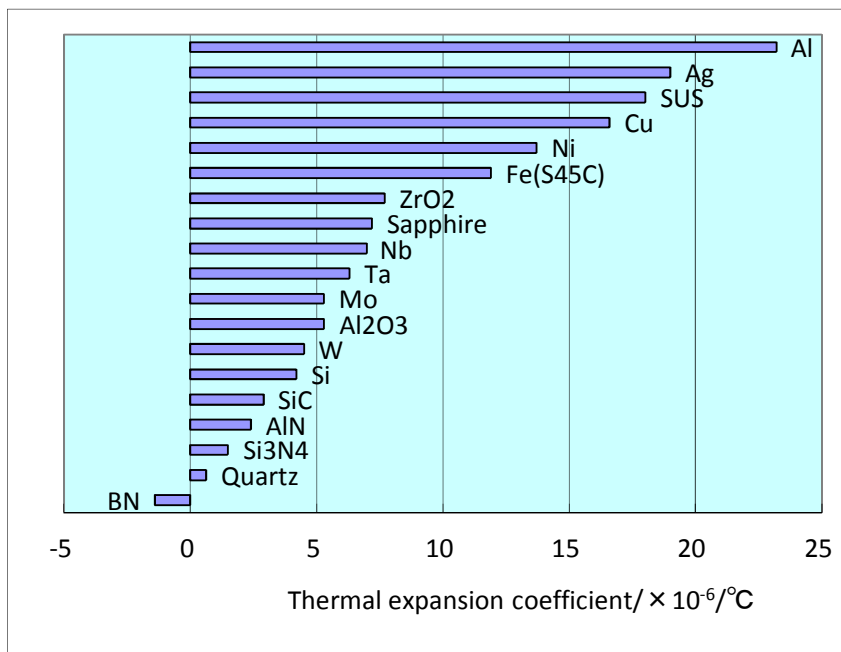
Thermal conductivity comparison graph



Thermal expansion coefficient

Rate of expansion of the materials in response to change of temperature. The larger the bar the greater the rate of expansion. Ceramics, tungsten and molybdenum, having a low rate of thermal expansion, undergo for little change of shape in response to changes in temperature.

Thermal expansion comparative graph

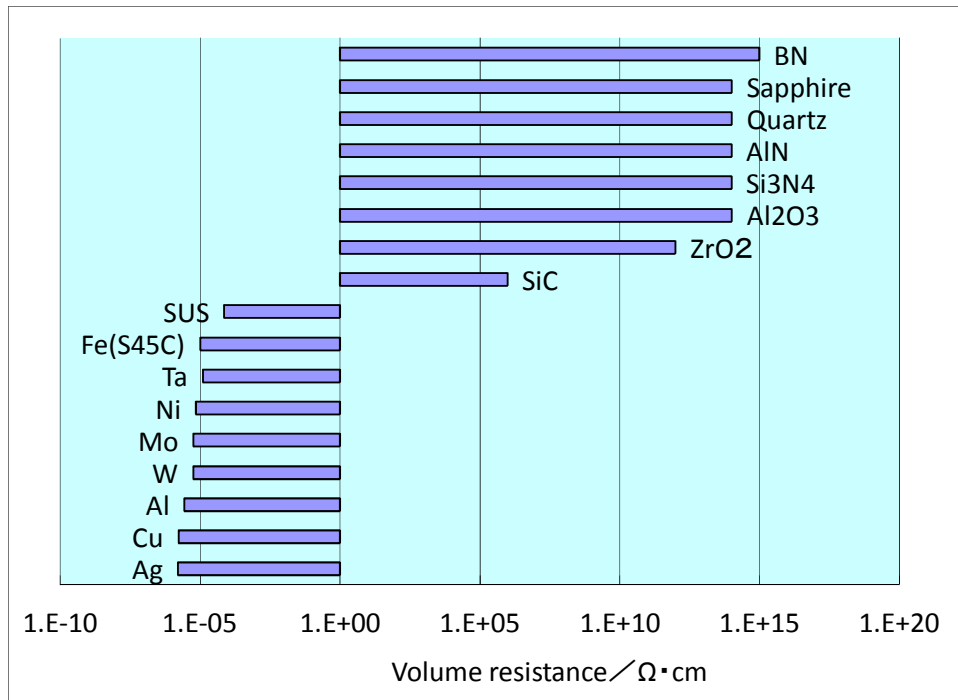


Volume resistance

This property explains how easy or not it is for electricity to pass through a material. The larger the bar, the greater resistance to electricity.

Ceramics in general are poor conductors of electricity and as a result have a variety of uses as insulators. Some of ceramics have electro conductive properties.

Volume resistance graph



Dielectric constant

According to the electrical charge of a material, the amount of energy it can emit is expressed as a coefficient.

Ceramics resist electricity so they are often used as insulators in electrical parts.

Corrosion resistance

The appearance or function of a material not being harmed by chemical or biological effects is known as corrosion resistance.

Ceramics excel in this, and as such they are often used in prosthetic limbs. As corrosion resistive parts they have many different uses. Tungsten resists acid and alkali in a similar manner.

Electric conductivity

In general, fine ceramics are insulators that do not conduct electricity. Depending on voltage or temperature, some of them can become semiconductors.

Piezoelectricity

Piezoelectric are materials, which after applying stress and distortion to their crystals, generate electric charge. It is called piezoelectric effect. When an electric field is applied, stress and distortion are generated and inverse piezoelectric effect occurs.

Piezoelectric ceramics have polycrystalline substance. An example of piezoelectric material is lead zirconate titanate (PTZ in short).

Unit conversion charts

◇Stress

GPa	MPa or N/mm ²	kgf/mm ²	kgf/cm ²	10 ³ lb/in ²
1	1X10 ³	1.0197X10 ²	1.0197X10 ⁴	1.45X10 ²
1X10 ⁻³	1	1.0197X10 ⁻¹	1.0197X10	1.45X10 ⁻¹
9.807X10 ⁻³	9.807	1	1X10 ²	1.422
9.807X10 ⁻⁵	9.807X10 ⁻²	1X10 ⁻²	1	1.422X10 ⁻²
6.895X10 ⁻³	6.895	7.03X10 ⁻¹	7.03X10	1

◇Thermal conductivity

W/(m·K)	kcal/(h·m·°C)	cal/(sec·cm·°C)
1	0.86	2.39X10 ⁻³
1.163	1	2.78X10 ⁻³
4.187X10 ²	3.6X10 ²	1

◇Specific heat

J/(kg·K)	kcal/(kgf·K)	Btu/(lb·°R)	kgf·m/(kgf·K)	ft-lbf/(lb·°R)
1	2.39X10 ⁻⁴	2.39X10 ⁻⁴	1.0197X10 ⁻¹	1.8586X10 ⁻¹
4.1868X10 ³	1	1	4.26935X10 ²	7.78169X10 ²
9.80665	2.342X10 ⁻³	2.342X10 ⁻³	1	1.82269
5.38032	1.285X10 ⁻³	1.285X10 ⁻³	5.4864X10 ⁻¹	1

◇Density

g/cm ³	kg/m ³
1	1X10 ³
1X10 ⁻³	1

◇Volume resistance

Ω·cm	μΩ·cm
1	1X10 ⁶
1X10 ⁻⁶	1

Hardness conversion tables

Rockwell hardness	Vickers hardness	Brinell hardness 10mm ball 3000kgf force		Shore hardness	Tensile strength (approx.)	Rockwell hardness	Vickers hardness	Brinell hardness 10mm ball 3000kgf force		Shore hardness	Tensile strength (approx.)
		HB						HB			
		Bogey tube	Tungsten carbide ball					Bogey tube	Tungsten carbide ball		
C scale HRC	Hv			HS	MPa	C scale HRC	Hv			HS	MPa
68	940	—	—	97	—	34	336	319	319	47	1055
67	900	—	—	95	—	33	327	311	311	46	1025
66	865	—	—	92	—	32	318	301	301	44	1000
65	832	—	(739)	91	—	31	310	294	294	43	980
64	800	—	(722)	88	—	30	302	286	286	42	950
63	772	—	(705)	87	—	29	294	279	279	41	930
62	746	—	(688)	85	—	28	286	271	271	41	910
61	720	—	(670)	83	—	27	279	264	264	40	880
60	697	—	(654)	81	—	26	272	258	258	38	860
59	674	—	(634)	80	—	25	266	253	253	38	840
58	653	—	615	78	—	24	260	247	247	37	825
57	633	—	595	76	—	23	254	243	243	36	805
56	613	—	577	75	—	22	248	237	237	35	785
55	595	—	560	74	2075	21	243	231	231	35	770
54	577	—	543	72	2015	20	238	226	226	34	760
53	560	—	525	71	1950	(18)	230	219	219	33	730
52	544	(500)	512	69	1880	(16)	222	212	212	32	705
51	528	(487)	496	68	1820	(14)	213	203	203	31	675
50	513	(475)	481	67	1760	(12)	204	194	194	29	650
49	489	(464)	469	66	1695	(10)	196	187	187	28	620
48	484	451	455	64	1635	(8)	188	179	179	27	600
47	471	442	443	63	1580	(6)	180	171	171	26	580
46	458	432	432	62	1530	(4)	173	165	165	25	550
45	446	421	421	60	1480	(2)	166	158	158	24	530
44	434	409	409	58	1435	0	160	152	152	24	515
43	423	400	400	57	1385	-	150	143	143	22	490
42	412	390	390	56	1340	-	140	133	133	21	455
41	402	381	381	55	1295	-	130	124	124	20	425
40	392	371	371	54	1250	-	120	114	114	-	390
39	382	362	362	52	1215	-	110	105	105	-	-
38	372	353	353	51	1180	-	100	95	95	-	-
37	363	344	344	50	1160	-	95	90	90	-	-
36	354	336	336	49	1115	-	90	86	86	-	-
35	345	327	327	48	1080	-	85	81	81	-	-

Note: Above numbers are for reference only.

Dielectric strength/resistivity

			dielectric strength	resistivity
			kv/mm	Ωcm
Ceramics	Fine ceramics	Alumina	>10	$>10^{14}$
		Zirconia	>10	$>10^{12}$
		Silicon nitride	>14	$>10^{14}$
		Aluminum nitride	>15	$>10^{14}$
		Silicon carbide	—	$>10^6$
		Cordierite	7	10^{13}
		Mullite	>10	10^{14}
		Steatite	18	10^{14}
		Calcia	—	—
		Magnesia (compact)	—	$>10^{14}$
		Sialon	>15	$>10^{15}$
	Machinable ceramics	Macerite S	>10	1×10^{15}
		Macerite SP	>10	2×10^{15}
		Macerite HSP	>10	5×10^{15}
		Photoveel II	35	2.2×10^{15}
		Photoveel II -S	30	10^{14}
		M-soft	40	10^{12}
		BN HC	25	10^{15}
		BN N-1	25	10^{15}
		BN NB-1000	22	10^{15}
		BA	21	10^{14}
		SBN	27	10^{14}
	Pottery	—	—	
	Porcelain	—	3×10^{14}	
	Glass	Universal glass	—	—
		Toughened glass	—	—
		Pyrex, Tempax	—	$>10^{15}$
		Neoceram	—	$>10^{13}$
		Quartz	>10	$>10^{14}$
		Baycol	—	10^{17}
	Brick	Sapphire glass	>10	$>10^{14}$
		Ordinary brick	—	—
		General purpose furnace material (ceiling use)	—	—
Cement	General purpose furnace material (insulation brick)	—	—	
	Universal cement	—	—	
	Fireproof cement	—	—	

			dielectric strength	resistivity
			kv/mm	Ωcm
Metals	Metal with high melting point	Tungsten	—	5.5×10^{-6}
		Molybdenum	—	5.7×10^{-6}
		Tantalum	—	12.4×10^{-6}
		Niobium	—	—
	Heat-resistant steel	SUS310S	—	90×10^{-6}
		SUH445	—	60×10^{-6}
		Inconel 600	—	103×10^{-6}
	Universal metal (alloy)	SUS316	—	74×10^{-6}
		SUS304	—	71×10^{-6}
		Iron	—	19.5×10^{-6}
		Aluminum	—	2.7×10^{-6}
		Copper	—	1.7×10^{-6}

			dielectric strength	resistivity
			kv/mm	Ωcm
Plastic	Engineering plastic	Polyimide (PI)	23	$>10^{14}$
		Poly Benz Imidazol (PBI)	23	2×10^{15}
		Polymide-imide (PAI)	23	2×10^{15}
		Poly Ether Imide (PEI)	24	10^{17}
		Polyacetal (POM)	20	1×10^{14}
		Poly Phenylene Sulfide (PPS)	15	1.6×10^{16}
		Poly Ether Ether Ketone (PEEK)	19	10^{16}
		Poly Tetra Fluoro Ethylene (PTFE)	19	$<10^{18}$
		Polymide 6 (PA6)	31	10^{14}
		Ultra-high-molecular-weight polyethylene (UHMWPE)	—	$>10^{13}$
		General purpose plastic	Polyethylene	40~50
	Polypropylene		31	$>10^{16}$
	Vinyl chloride resin		37.5	$>10^{16}$
	Polystyrene		20~28	—
	Polyethylene-telephthalate		22	$>10^{16}$
	Acrylonitrile butadiene		14~20	$1 \sim 4.8 \times 10^{14}$

Heat-resistant material

		Max. use temp. atmosphere/°C	Normal temp. atmosphere/°C	
Ceramics	Fine ceramics	Alumina	1300~1600	—
		Zirconia	1000	—
		Silicon nitride	1200	—
		Aluminum nitride	900	—
		Silicon carbide	1500	—
		Cordierite	1200	—
		Mullite	1200	—
		Steatite	1000	—
		Calcia	1800	—
		Magnesia (compact)	1700	—
		Sialon	1300	—
		Machinable ceramics	Macerite HSP	700
	Photoveel II		1000	—
	Photoveel II-S		1000	—
	M-soft		1000	—
	BN HC		950	—
	BN N-1		950	—
	NB		950	—
	BA		950	—
	SBN	950	—	
	Pottery	140~450	—	
	Porcelain	110~390	—	
	Glass	Universal glass	380	110
		Toughened glass	250	230
		Pyrex, Tempax	500	230
		Neoceram	800	750
		Quartz	1200	900
		Baycol	1200	900
		Sapphire glass	1850	—
	Brick	Ordinary brick	500	—
		General purpose furnace material (ceiling use)	1300~1500	—
		General purpose furnace material (insulation brick)	900~1400	—
	Cement	Universal cement	<500	—
Fireproof cement		1100	—	

		Max. use temp. non-volatile gas/°C	Normal temp. non-volatile gas/°C	melting temp. °C	recrystallization temp. °C	
Metals	Metal with high melting point	Tungsten	—	—	3387	1100~1300
		Molybdenum	—	—	2623	800~1200
		Tantalum	—	—	2990	900~1450
		Niobium	—	—	2415	850~1300
	Heat-resistant steel	SUS310S	1150	900	—	—
		SUH445	1200	1000	—	—
		Inconel 600	1050	1050	—	—
	Universal metal (alloy)	SUS316	1000	700	—	—
		SUS304	1000	700	—	—
		Iron	550	—	—	—
Aluminum		400	—	—	—	
Copper	400	—	—	—		

		Max. use temp. atmosphere/°C	Normal temp. atmosphere/°C	
Plastic	Engineering plastic	Polyimide (PI)	—	300
		Poly Benz Imidazol (PBI)	—	310
		Polyimide-imide (PAI)	—	250
		Poly Ether Imide (PEI)	—	170
		Polyacetal (POM)	—	80
		Poly Phenylene Sulfide (PPS)	—	220
		Poly Ether Ether Ketone (PEEK)	—	250
		Poly Tetra Fluoro Ethylene (PTFE)	—	260
		Polymide 6 (PA6)	—	110~120
		Ultra-high-molecular-weight polyethylene (UHMWPE)	—	80
	General purpose plastic	Polyethylene	—	80~90
		Polypropylene	—	100~140
		Vinyl chloride resin	—	60~80
		Polystyrene	—	80~90
		Polyethylene-telephthalate	—	85~100
		Acrylonitrile butadiene	—	70~100

