Description

Image

Caption

1. Photovoltaic solar panels. © NASA - Public domain 2. Polycristalline silicon wafer in photovoltaic panel. © Georg Slickers at en.wikipedia - (CC BY-SA 2.5) 3. Solar array of the MAVEN spacecraft inspected by a technician. © NASA - Public domain

The material

Silicon is the second most abundant element, exceeded only by oxygen and making up 26% of the earth's crust by weight. It is found largely as silicon oxides such as sand (silica), quartz, rock crystal, amethyst, agate, flint, jasper and opal, and as silicates asbestos, feldspar, clay and mica. It is a reactive element, important as an alloying element in steels, cast irons, and certain copper and aluminum alloys where it gives both corrosion resistance and strength. Silicon is transparent to infrared and is used a windows and lenses for IR lasers. Its most important application, of course, is as a semiconductor, the mainstay of the electronics industry. Silicon is present in the sun and stars and is a principal component of a class of meteorites known as aerolites. Silicon is important in plant and animal life. Diatoms in both fresh and salt water extract silica from the water to use as a component of their cell walls. Silicon is an important ingredient in steel. Silicon carbide is one of the most important abrasives. Workers in environments where silica-containing dust is breathed may develop a serious lung disease known as silicosis. Hydrolysis and condensation of substituted chlorosilanes can be used to produce a very great number of polymeric products, or silicones. These range from liquids to hard, glasslike solids with many useful properties. Elemental silicon transmits more than 95% of all wavelengths of infrared and has been used in lasers to produce coherent light at 456 nm.

Composition (summary)

100% Si

General properties

Density	144	-	147	lb/ft^3
Price	* 4.14	-	6.87	USD/lb
Date first used	1823			

Mechanical properties

Young's modulus	20.3	-	22.5	10^6 psi
Shear modulus	8.99	-	9.43	10^6 psi
Bulk modulus	13.8	-	15.2	10^6 psi

Poisson's ratio		0.21	-	0.22	
Yield strength (elastic limit)		23.2	-	26.1	ksi
Tensile strength		23.2	-	26.1	ksi
Compressive strength		464	-	502	ksi
Elongation		0.1	-	0.15	% strain
Hardness - Vickers		900	-	1.12e3	HV
Fatigue strength at 10^7 cycles	*	18.9	-	21.8	ksi
Fracture toughness		0.755	-	0.855	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	7e-5	-	1e-4	

Thermal properties

Melting point		2.58e3	-	2.61e3	°F
Maximum service temperature	*	980	-	1.07e3	°F
Minimum service temperature		-458	-	-456	°F
Thermal conductor or insulator?		Good conductor			
Thermal conductivity		80.9	-	86.7	BTU.ft/h.ft^2.F
Specific heat capacity		0.16	-	0.171	BTU/lb.°F
Thermal expansion coefficient		1.11	-	1.78	µstrain/°F

Electrical properties

Electrical conductor or insulator?		Semiconductor			
Electrical resistivity		1e6	-	1e12	µohm.cm
Dielectric constant (relative permittivity)		11	-	12	
Dissipation factor (dielectric loss tangent)	*	0.001	-	0.005	
Dielectric strength (dielectric breakdown)	*	127	-	305	V/mil

Optical properties

Transparency		Opaque			
Refractive index		3.6	-	3.8	

Critical Materials Risk

High critical material risk?		Yes			

Processability

Castability		1	-	2	
Machinability		1	-	2	

Durability: water and aqueous solutions

Water (fresh)		Excellent			
Water (salt)		Excellent			
Soils, acidic (peat)		Excellent			

Soils, alkaline (clay)	Excellent
Wine	Excellent

Durability: acids

Acetic acid (10%)	Excellent
Acetic acid (glacial)	Excellent
Citric acid (10%)	Excellent
Hydrochloric acid (10%)	Excellent
Hydrochloric acid (36%)	Excellent
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Excellent
Nitric acid (70%)	Excellent
Phosphoric acid (10%)	Acceptable
Phosphoric acid (85%)	Acceptable
Sulfuric acid (10%)	Excellent
Sulfuric acid (70%)	Acceptable

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Excellent
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Excellent
Ethyl alcohol (ethanol)	Excellent

Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Excellent
Fluorine (gas)	Unacceptable
O2 (oxygen gas)	Excellent
Sulfur dioxide (gas)	Excellent

Durability: built environments

Industrial atmosphere	Acceptable
Rural atmosphere	Excellent
Marine atmosphere	Acceptable
UV radiation (sunlight)	Excellent

Durability: flammability

Flammability	Non-flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Excellent
Tolerance up to 150 C (302 F)	Excellent
Tolerance up to 250 C (482 F)	Excellent
Tolerance up to 450 C (842 F)	Excellent
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Geo-economic data for principal component

Annual world production, principal component		4.63e6	-	4.72e6	ton/yr
Reserves, principal component	*	9.84e8	-	1.08e9	l. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production		6.15e3	-	6.8e3	kcal/lb
CO2 footprint, primary production		3.78	-	4.18	lb/lb
Water usage	*	2.78	-	3.08	gal(US)/lb
Eco-indicator 99		447			millipoints/kg

Material processing: energy

Grinding energy (per unit wt removed)	*	2.95e4	-	3.25e4	kcal/lb

Material processing: CO2 footprint

Grinding CO2 (per unit wt removed)	* 20.4	-	22.5	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✗			
Recycle fraction in current supply	0.5	-	1	%
Downcycle	✓			
Combust for energy recovery	✗			
Landfill	✓			
Biodegrade	✗			
Toxicity rating	Non-toxic			
A renewable resource?	✗			

Environmental notes

The extraction and refinement of silicon is very energy intensive, but the value added is very great: the functionality per gram achieved by the use of silicon exceeds that of any other element. Micro machining and fabrication with silicon involves extremely aggressive and toxic chemicals requiring elaborate safety precautions.

Supporting information

Design guidelines

Silicon has a high strength, a high thermal conductivity and a low thermal expansion coefficient. This recommends it for the mechanical components of small precision instruments. A highly developed technology exists for machining silicon chemically and with particle beams - an outgrowth of the semiconductor industry - that is now being deployed to make MEMS (micro electro-mechanical systems) that perform mechanical and other functions at the micron scale.

Technical notes

To function well as a semiconductor silicon must be prepared in a super-pure, single-crystal form. A sophisticated technology has grown up to provide this: single crystals 200 mm in diameter and 1 meter long can be grown, and techniques for precision cutting and machining have been developed. Its availability opens up possibilities for using silicon for other devices, particularly those exploiting its thermal and mechanical properties as well as its electrical attributes.

Typical uses

Microcircuits, precision instruments, IR lenses and windows, MEMS

Links

Reference

ProcessUniverse

Producers