

# Germanium

Among other materials for IR applications Tydex uses Germanium showing good transmission in 2-15  $\mu\text{m}$  range. Due to high refractive index Ge lenses became very useful components of IR imaging systems operating in both "atmosphere windows": 3-5 and 8-12 microns.

Both monocrystalline and polycrystalline Ge may be used for manufacturing of optical components. We produce Germanium lenses and windows for infrared thermal imaging applications and pyrometry (see our brochure "Germanium windows and lenses for thermography"). Also such components for spectroscopy as ATR prisms, detector windows, and IR polarizers are available.

Ge is also good electromagnetic interference (EMI) shielding material. Its special grade called EMI for its ability to shield against electromagnetic interference has become increasingly important for modern military applications where other signals (within millimeter and centimeter range) can be strong enough to make nearby IR systems ineffective. Typical resistance for EMI grade Germanium is 4 Ohm\*cm but it depends on required level of spurious signal suppression. Using Ge window with such resistance these signals are effectively shorted out and the IR system shows good performance.

Below you can find list of main properties of Germanium as well as its transmission and absorption spectra.

## PHYSICAL PROPERTIES

Atom number	32	
Atom weight	72.6	
Crystal structure	diamond cubic	
Lattice constant at 25°C, Å	5.657	
Density, g/cm <sup>3</sup>	5.323	
Atomic density, atoms/cm <sup>3</sup>	4.42 x 10 <sup>22</sup>	
Surface tension, liquid at melting point, mN/m	650	
Modulus of rupture,	MPa	72.4
	PSI	1.05 x 10 <sup>4</sup>
Mohs hardness	6	
Vickers hardness, 25 gm load, kg/mm <sup>2</sup>	746	
Fracture toughness, MPa <sup>1/2</sup>	1.004 (110 fracture plane)	
Thermal shock resistance, °C	125	
Poisson's ratio, 125-375 K	0.278	
Elastic constants, 25°C, cm <sup>2</sup> /dyne	S11=9.685 x 10 <sup>-13</sup>	
	S12=-2.70 x 10 <sup>-13</sup>	
	S44=14.94 x 10 <sup>-13</sup>	
Elastic coefficients, 25°C, dynes/cm <sup>2</sup>	C11=13.16 x 10 <sup>11</sup>	
	C12=5.09 x 10 <sup>11</sup>	
	C44=6.69 x 10 <sup>11</sup>	
Young's moduli, 25°C, dynes/cm <sup>2</sup>	Y100=10.33 x 10 <sup>11</sup>	
	Y110=13.80 x 10 <sup>11</sup>	
	Y111=15.55 x 10 <sup>11</sup>	
Shear moduli, 25°C, dynes/cm <sup>2</sup>	M100=6.69 x 10 <sup>11</sup>	
	M110=4.1 x 10 <sup>11</sup>	
	M111=4.9 x 10 <sup>11</sup>	

## THERMAL PROPERTIES

Melting temperature, °C	937	
Boiling temperature, °C	2830	
Specific thermal capacity (0-100°C), kal/g x degree	0.074	
Latent heat of fusion	kal/mol	8100
	J/g	466.5
Latent heat of vaporization, J/g	4602	
Coefficient of linear thermal expansion (293 K), cm/degree	6.1 x 10 <sup>-6</sup>	
Heat capacity, 25°C, J/(kg x K)	322	

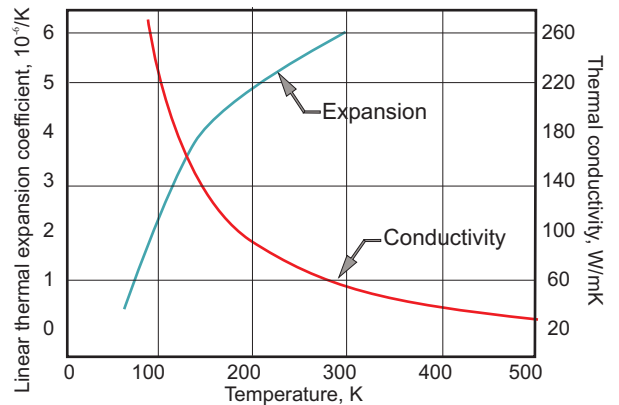


Fig. 1. Linear thermal expansion coefficient and thermal conductivity of Germanium vs temperature.

## ELECTRONIC PROPERTIES

Band gap, direct (300 K), eV	0.67	
Intrinsic carriers concentration (300 K), cm <sup>-6</sup>	p, n=5.5 x 10 <sup>26</sup>	
Intrinsic drift mobility (300 K), cm <sup>2</sup> /vs:	electrons	3800
	holes	1820
Diffusion coefficient (300 K), cm <sup>2</sup> /sec:	electrons	101
	holes	49
Intrinsic resistivity (300 K), Ohm x cm	52	
Number of intrinsic electrons, cm <sup>-3</sup>	2.12 x 10 <sup>13</sup>	
1 Ohm x cm (n-type) is equal to, 10 <sup>15</sup> /cm <sup>-3</sup>	1.1	
1 Ohm x cm (p-type) is equal to, 10 <sup>15</sup> /cm <sup>-3</sup>	2.3	

## CHEMICAL PROPERTIES

Solubility	
In water at 20 °C, g/100cm <sup>3</sup>	insoluble
In acids	soluble

Thickness of Germanium window required to withstand pressure differential at opposite sides may be calculated by the following equation:

$$\text{Thk} = \sqrt{(1.1 * P * r^2 * SF / MR)}$$

where P = Pressure difference (PSI), r = Unsupported radius (mm), SF = Safety factor (4 to 6) (suggested range, may use other factors), MR = Modulus of rupture (PSI).

For example window with diameter 100 mm and unsupported radius 45 mm used in environment with pressure differential of 1 atmosphere should have thickness of ~4.0 mm (safety factor 5).



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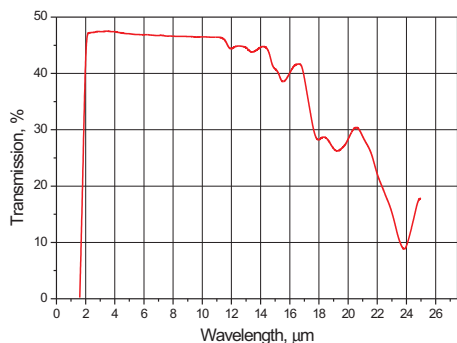


Fig. 2. Typical transmission of optical grade Ge (2 mm thick polished Ge sample).

Germanium exhibits low absorption of infrared radiation in wavelength range of 2 to 12  $\mu\text{m}$ . The band gap of 0.67 eV in Germanium is responsible for the increase in absorption in the short wavelength range.

The lattice (phonon) absorption bands are responsible for the long wavelength absorption.

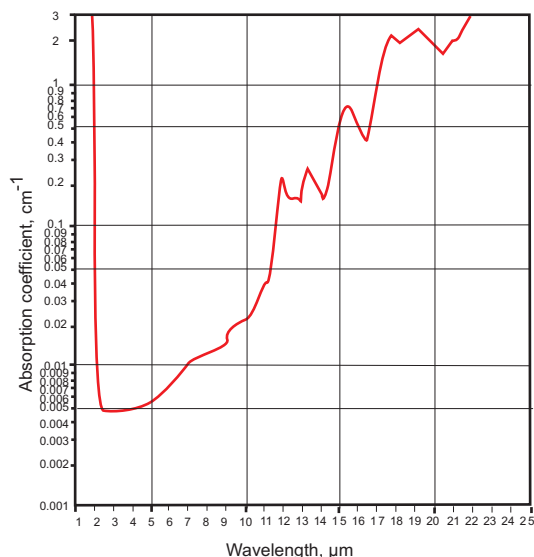


Fig. 3. Typical Germanium coefficient of absorption.

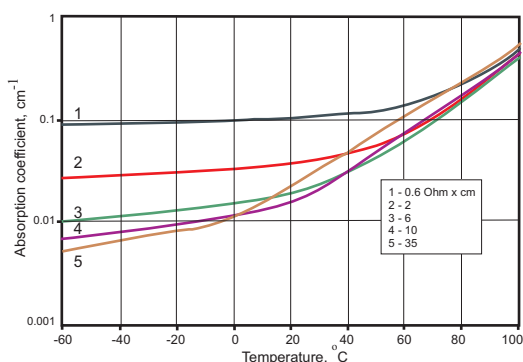


Fig. 4. Absorption vs temperature at 10.6  $\mu\text{m}$ .

At high temperature optical grade Germanium is subject to excessive absorption due to increased number of thermally generated holes.

As it can be seen from spectra absorption growth becomes important at temperatures over about 45°C.

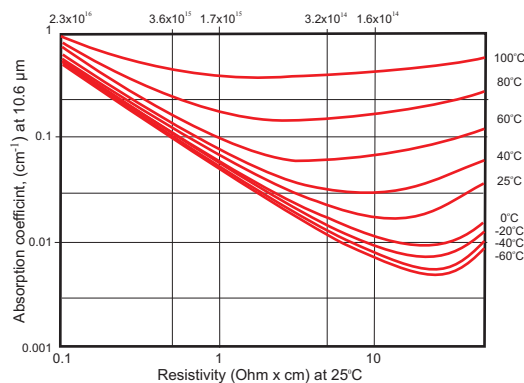


Fig 5. Dopant density (Sb atom s/cm<sup>3</sup>).

Refractive index:

$\lambda$ , $\mu\text{m}$	$n(\lambda)$	$\lambda$ , $\mu\text{m}$	$n(\lambda)$	$\lambda$ , $\mu\text{m}$	$n(\lambda)$	$\lambda$ , $\mu\text{m}$	$n(\lambda)$
2.0	4.1079	8.0	4.0074	11.3	4.0043	13.0	4.0035
2.5	4.0653	8.5	4.0067	11.5	4.0042	13.3	4.0034
3.0	4.0446	9.0	4.0061	11.7	4.0041	14.0	4.0032
4.0	4.0255	9.5	4.0056	11.9	4.0040	14.1	4.0031
5.0	4.0170	10.0	4.0052	12.0	4.0039	15.0	4.0029
6.0	4.0122	10.6	4.0048	12.3	4.0038	15.6	4.0027
7.0	4.0092	11.0	4.0045	12.7	4.0036	16.0	4.0026

Free carrier (electron and hole) absorption and lattice (phonon) absorption account for the IR absorption in the optical range. Holes in Ge absorb more energy than electrons in this range.

For nearly electrically neutral Ge, number of holes times number of electrons is constant. The number of holes present can be reduced by increasing the number of electrons by the addition of group V atoms (donors) to the Ge. This lowers resistivity. Excessive addition of donors leads to excessive electron concentration and increased absorption.

Usually material with the following properties is used for optical component manufacturing:

Orientation	111
Orientation deviation, arc. deg	$\leq 2$
Conductivity type	n
Specific resistance, Ohm x cm	5-40
Refractive index inhomogeneity, ? n	$\leq 2 \times 10^{-4}$
Dislocations density, $\text{cm}^{-2}$	$\leq 1 \times 10^4$
Transmission of 1 mm thick sample, %	at 10.6 $\mu\text{m}$ $\geq 46.8$
Internal scattering coefficient at 2.5 $\mu\text{m}$ , %	from 2.5 to 11 $\mu\text{m}$ $> 46$
	$\leq 5$

Different shapes of optical components are available: spherical, elliptical, rectangular, plano-plano, plano-convex/concave, meniscus, wedges, rods. Overall dimensions are available from 2 mm to 250 mm for monocrystal and to 300 mm for polycrystal.

Please pay attention that this article is only for your information. We do not supply Germanium in blanks or as raw material. Our standard products are finished (polished, coated) parts.



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