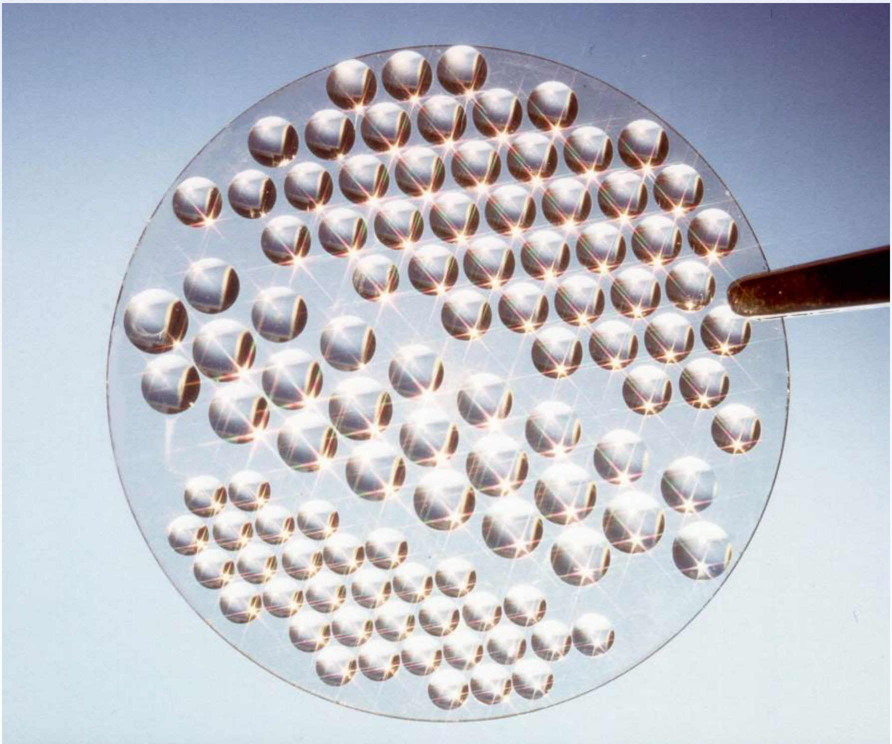
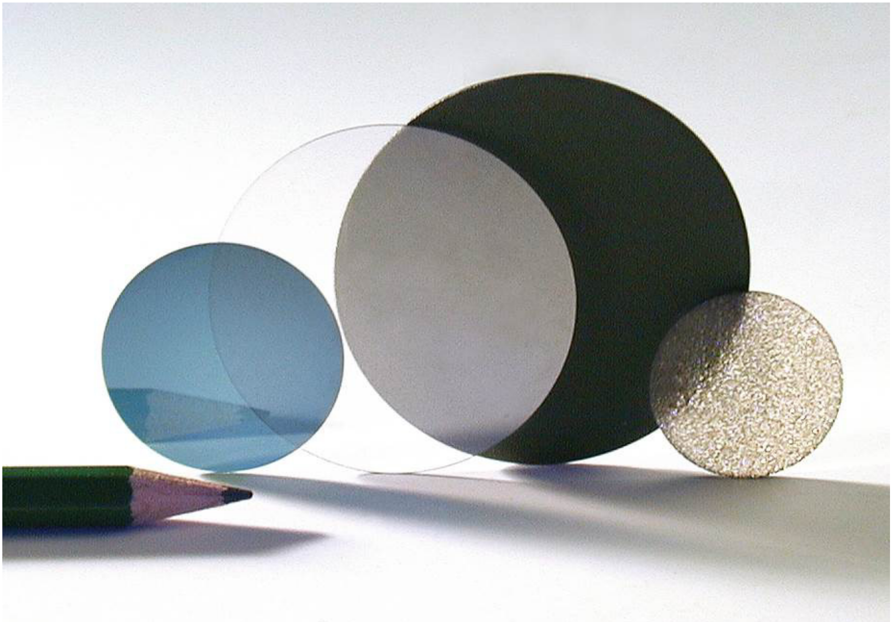
The CVD diamond booklet



available at: www.diamond-materials.com/download

Content



CVD Diamond wafers prepared by Microwave Plasma CVD: boron doped disk (blue), optical grade diamond, mechanical grade, unpolished disk

1. General properties of diamond

The most important properties of CVD diamond are the

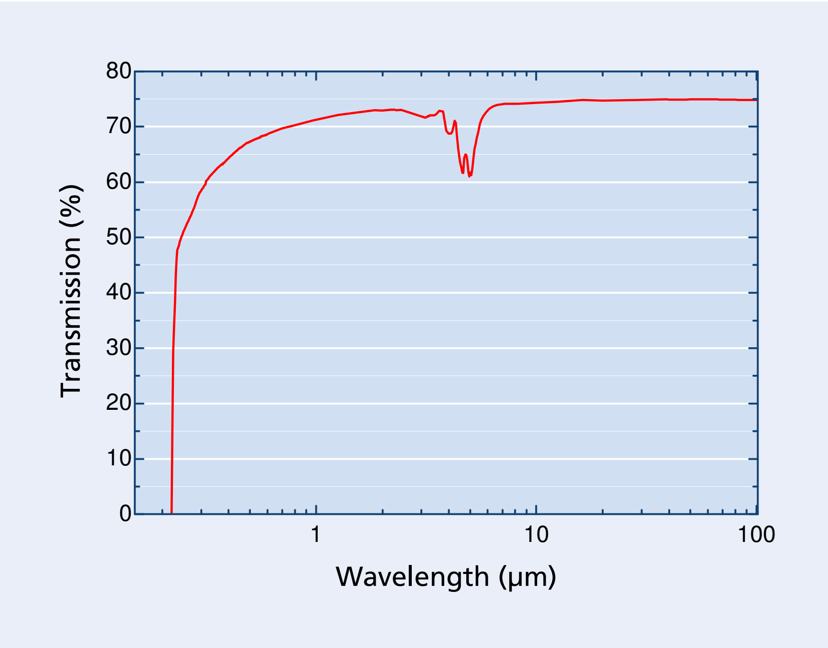
- unsurpassed hardness
- extremely high thermal conductivity
  (>1800 W/mK, five times that of copper)
- broad band optical transparency
- extremely chemically inert:
  Not affected by any acid or other chemicals
- Graphitization only at very high temperatures
  (T > 700°C in an oxygen containing
  and 1500°C in an inert atmosphere)

Property	Value
Vickers hardness*	10,000 kg/mm^2
Young's modulus*	1050 GPa
Poisson's ratio	0.1
Density	3.515 g/cm^3
Atom density*	1.77×10^{23} 1/cm^3
Thermal expansion coefficient	1.0×10^{-6}/K @300K
Sound velocity*	17,500 m/s
Friction coefficient	0.1
Specific heat @ 20°C	0.502 J/gK
Debye temperature*	1860±10K
Bandgap	5.45 eV
Resistivity	10^{13} - 10^{16} □cm

*highest value of all solid materials

2. Optical Properties

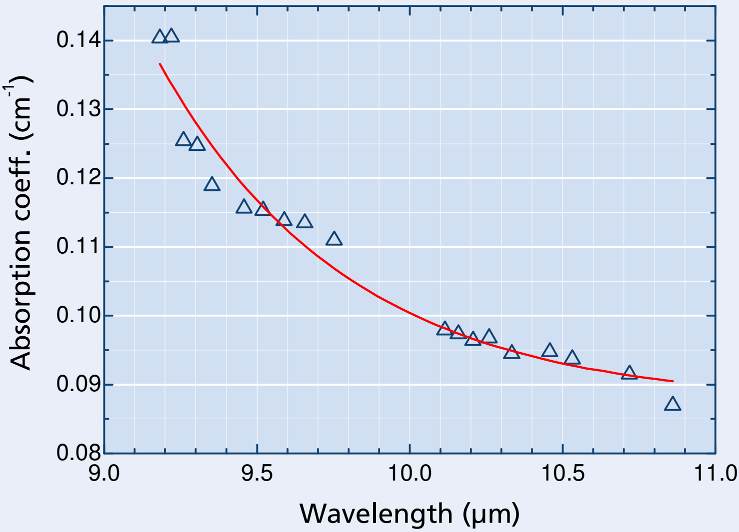
Optical transparency



Optical transparency of CVD diamond
In the UV, Visible, IR and far IR

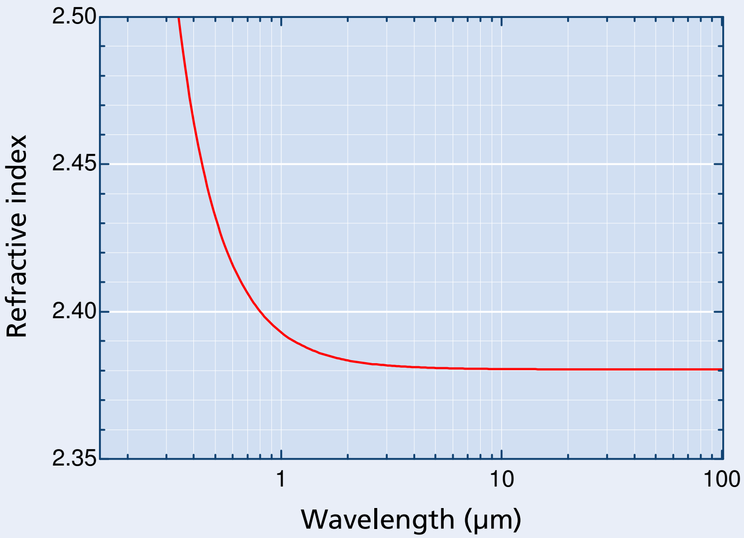
The spectrum has not been corrected for reflection losses

Absorption coefficient at 10.6 µm



Absorption coefficient of CVD diamond
as measured by laser calorimetry.

Refractive index: n vs. λ



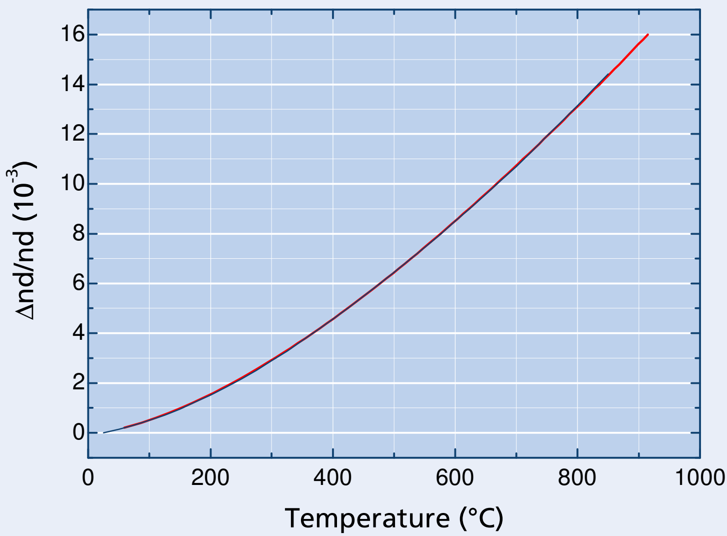
The spectral variation of n is described by the Sellmeier equation:[1]

$$n = \sqrt{\frac{0.3306x^2}{x^2 - 175^2 nm^2} + \frac{4.3356x^2}{x^2 - 106^2 nm^2} + 1}$$

where x is the wavelength in nm

[1] Peter, F. (1923), Z Phys, 15, pp 358–368

Refractive index: nd vs. T

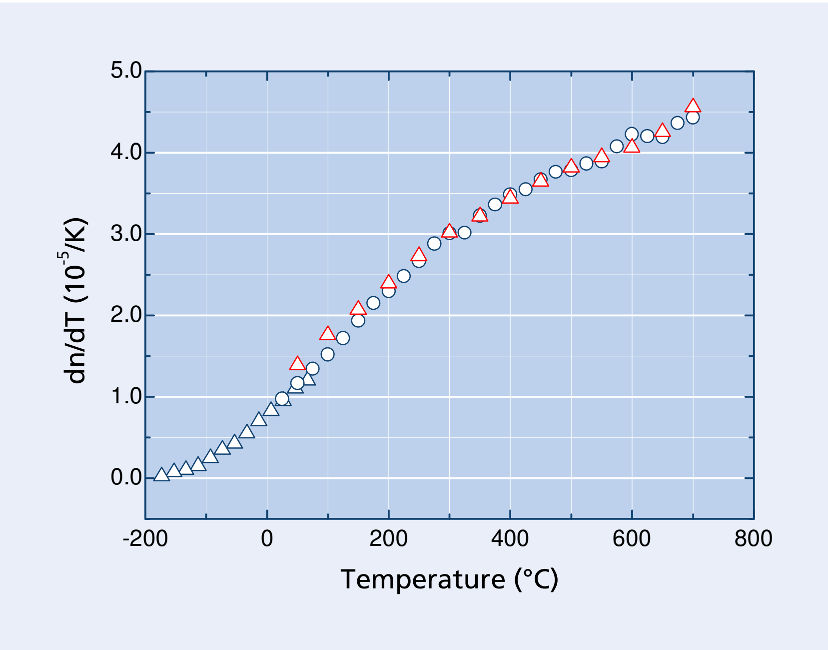


Variation of *nd* with temperature
Patterson et al.[2]
our data
measured at 633 nm wavelength

---

[2] M.J. Pattersonet et al., Electrochem. Soc. Proc. 95-4, 503 (1995)

Refractive index: Thermal coefficient



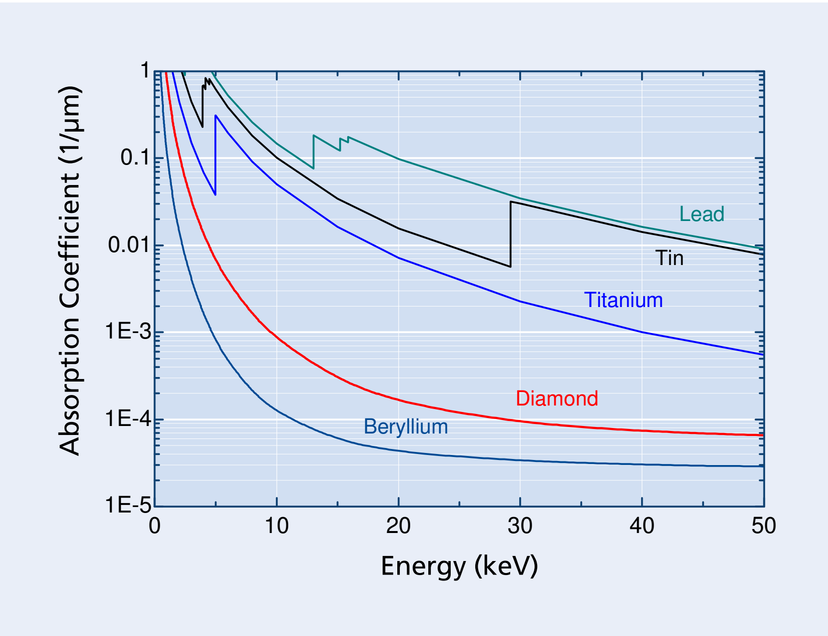
Thermal coefficient of the refractive index

△ Measured by laser refraction of a diamond prism
○ Measured with laser interferometry
△ Fontanella et al.[3]

---

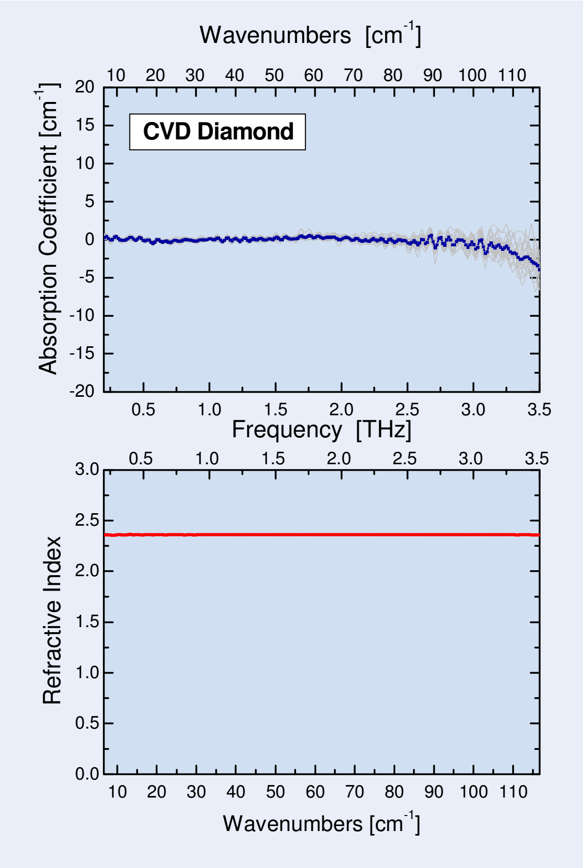
[3] J. Fontanella et al., Appl. Opt. **16**, 2949 (1977)

X-ray absorption



X-ray absorption coefficient of various materials.
Data from http://www.photcoef.com

THz dielectric properties



data from Peter Uhd Jepsen, University of Freiburg

Optical specifications of *Diamond Materials*

The core competences of *Diamond Materials* include the manufacturing of high purity CVD diamond disks with properties approaching those of perfect natural diamond crystals.

Property	Value
Transmission	225nm to far IR , > 70% @ 10µm
Refractive index	2.38 @ 10µm, 2.41 @ 500nm
Absorption coefficient	$\leq 0.10\ cm^{-1}$ @ 10µm
Bandgap	5.45 eV
Tensile strength (0.5mm thick)	
Nucleation surface in tension	600 MPa
Growth surface in tension	400 MPa
Loss tangent (tanδ @140 GHz)	$< 2.0\times10^{-5}$
Dielectric constant	5.7

Properties of optical grade CVD-diamond
by Diamond Materials

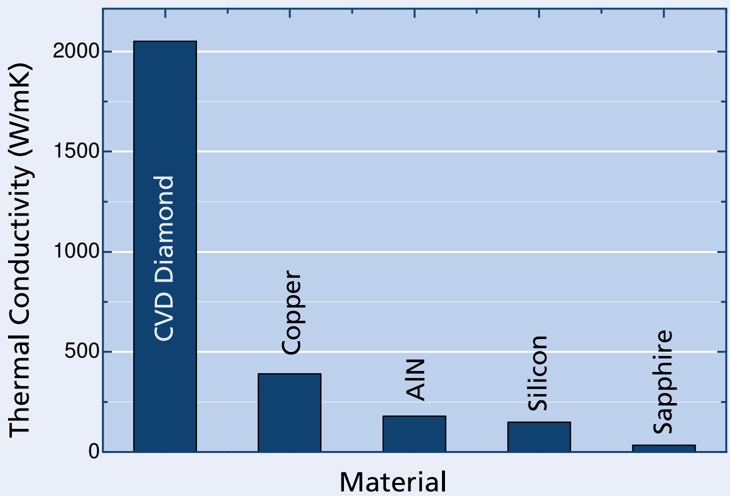
Surface finish, optical coatings and mounting

Property	Value
Dimensions	
Thickness	10 - 2000 µm
Diameter	up to 100 mm
Surface finish	
Shape	flat, spherical (convex & concave)
Roughness	< 5 nm*
Flatness	1 fringe/cm*
Wedge	0 – 1°*
Antireflection Coatings (visible and infrared)	
Spec. Transmission at 10.6 µm	>98.6 %
Wavefront distortion	
< 4 fringes at 633 nm over 30 mm*	
Mounting	
Diamond windows mounted e.g. in UHV flanges (bakeable at 250°C, vacuum tight < 10^{-10} mbar l/s)*	

*specifications available upon request

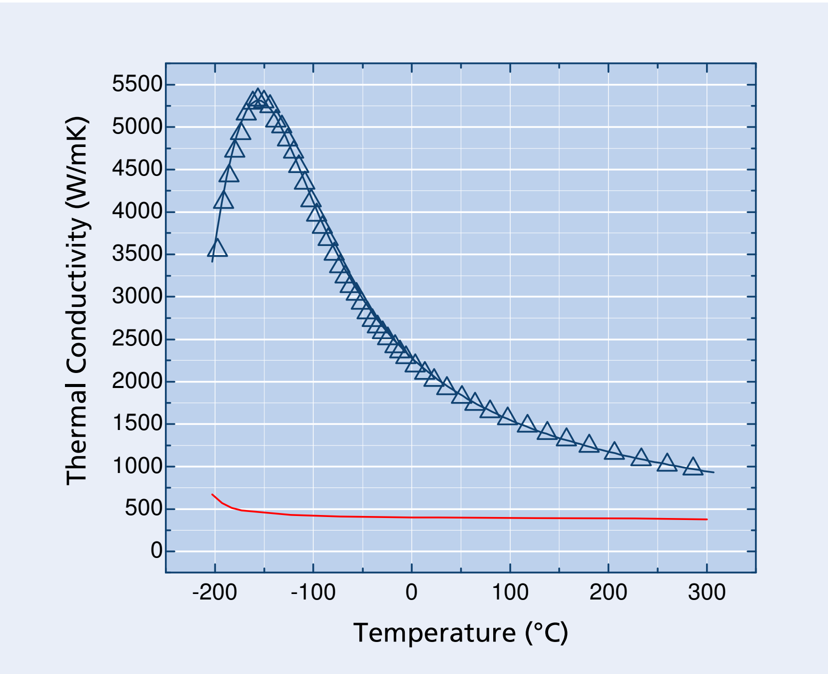
3. Thermal Properties

Thermal conductivity



The thermal conductivity of diamond in comparison to other materials.

Thermal conductivity vs. T



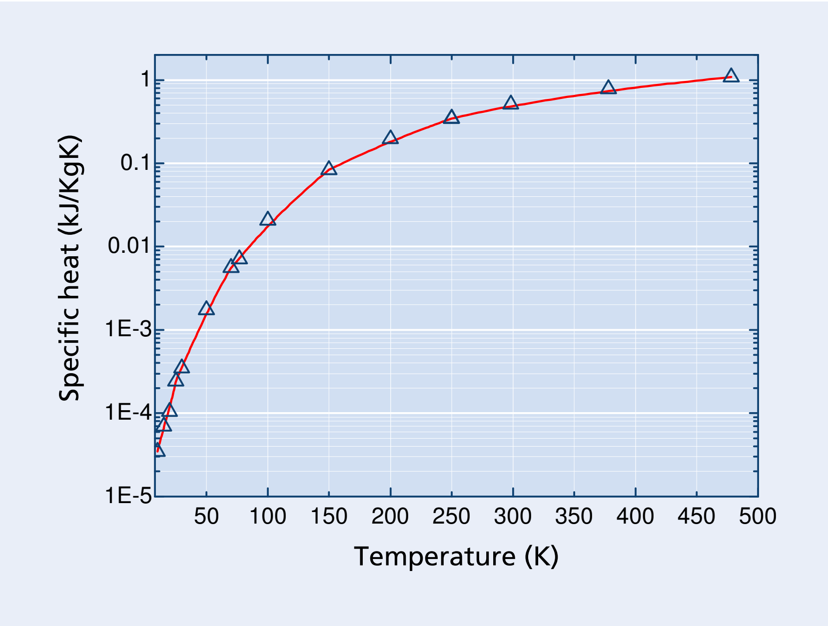
Thermal conductivity of CVD diamond vs. temperature

CVD diamond

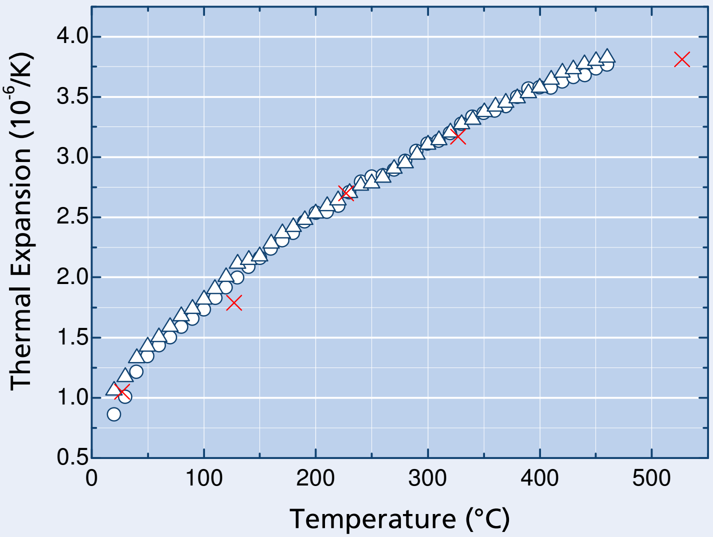
Theory

Copper

Specific heat vs. T



Thermal expansion



Thermal expansion vs. temperature

○ High quality CVD diamond
△ Medium quality CVD diamond
× Values recommended by Slack[4]

---

[4] G.A. Slack and S.F. Bartram, J. Appl. Phys. **46**, 89 (1975)

Thermal specifications of *Diamond Materials*

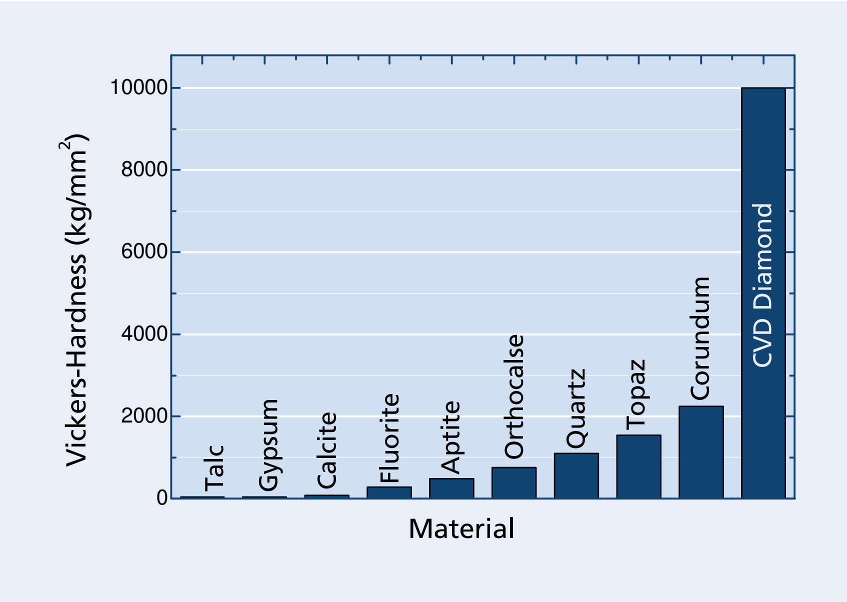
Optimized CVD-diamond as provided by *Diamond Materials* reaches a thermal conductivity of up to 2000 W/mK e.g. it exceeds that of copper by a factor of five. In contrast to metals, where heat is conducted by electrons, lattice vibrations are responsible for the high thermal conductivity of diamond.

Property	Value
Thermal conductivity	
@300 K	> 1200 W/mK* > 1500 W/mK* > 1800 W/mK*
Thermal expansion coefficient	
@300 K	1.0 +/- 0.1 $\times$ 10^{-6}/K
@700 K	4.4 +/- 0.1 $\times$ 10^{-6}/K
Specific heat @ 20°C	0.502 J/gK
Debye temperature	1860±10K

* various thermal grades are available upon request

4. Mechanical Properties

Vickers-Hardness

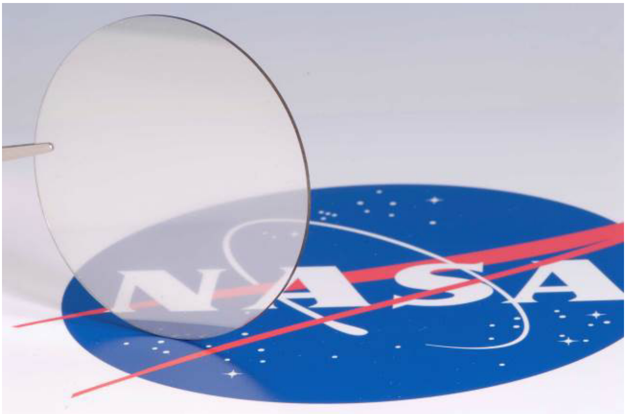


Mechanical specifications of *Diamond Materials*

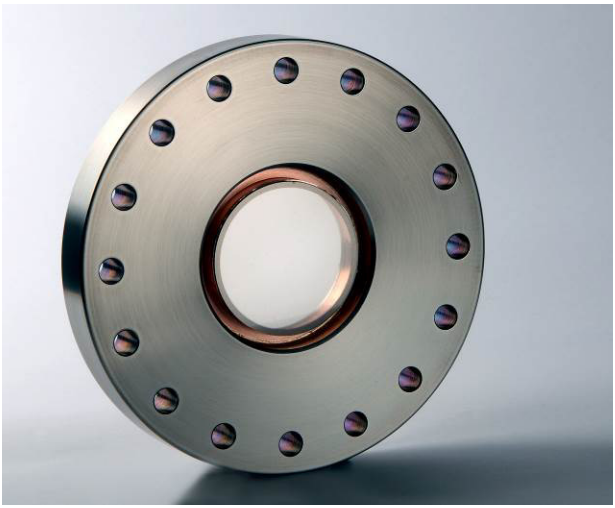
CVD diamond manufactured by Diamond Materials exhibits an exceptional wear resistance and a low coefficient of friction. Highly demanding applications such as cutting tools, surgical knives and wear resistant components have been demonstrated.

Property	Value
Vickers hardness	10,000 kg/mm^2
Young's modulus	1050 GPa
Poisson's ratio	0.1
Thermal expansion coefficient	1.0×10^{-6}/K @300K
Tensile strength (0.5mm thick)	
Nucleation surface in tension	1100 MPa
Growth surface in tension	500 MPa
Density	3.515 g/cm^3

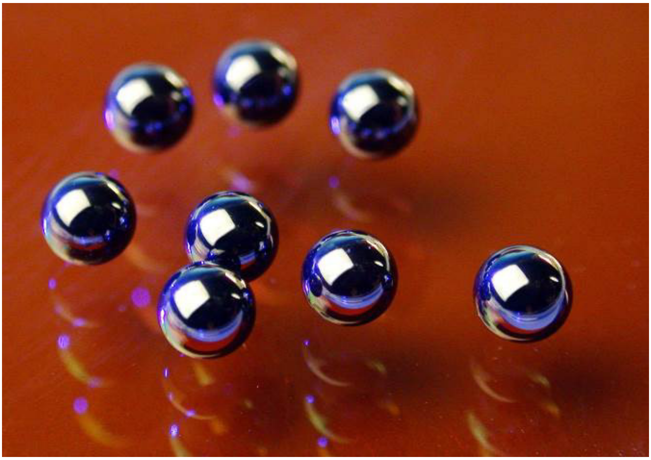
5. Examples of CVD diamond applications



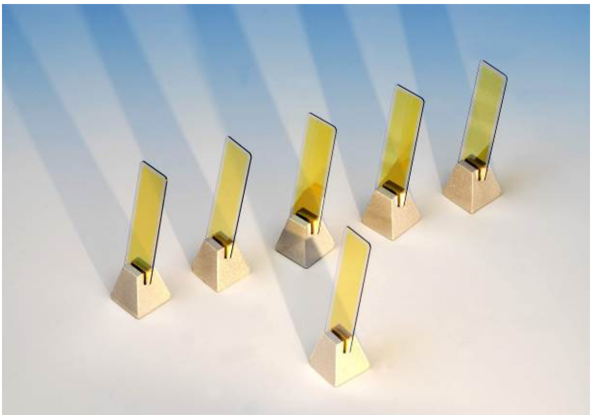
CVD diamond window beam splitter for space application



CVD diamond UHV window



Ultra-high precision diamond balls



CVD diamond laser windows
for high-power CO_2 lasers

CVD diamond wafers (80 mm Ø)

High-power X-ray window

6. Useful formula

Bowing of a circular disk under pressure[5]

$$w_{ss} = \mathrm{Pr}^4 \frac{5+\nu}{64S(1+\nu)} \quad w_{cl} = \mathrm{Pr}^4 \frac{1}{64S} \quad S = \frac{El^3}{12(1-\nu^2)}$$

where w = central deflection (ss = simply supported, cl = clamped), E = Young's modulus, L = thickness, P = pressure, ν = Poisson ratio, r = radius

Thickness requirements[6]

For flat windows, the minimum thickness as determined by pressure-induced fracture is given by

$$L = 0.554D\sqrt{\Delta p S_{sf} / \sigma_f}$$

where L = minimum thickness, σ_f = mechanical strength, Δp = pressure difference, D = diameter, S_{sf} = safety factor

Typically mechanical strength values are in the 2000-400 MPa range depending on thickness. As a rule of thumb the minimum thickness is 1.7 % of the free diameter (one bar pressure difference, S_{sf} = 4).

---

[5] Warren C. Young, "Roark's Formulas for Stress & Strain", McGraw-Hill, New York (1989)
[6] C.A. Klein, SPIE 1624, 475 (1992)

Diamond Materials
Advanced Diamond Technology

Contact Diamond Materials

Contact persons:	Dr. Christoph Wild Dr. Eckhard Wörner
Internet:	www.diamond-materials.com
E-mail:	contact@diamond-materials.com
Telefon:	+49 (0)761 600 6554
Fax:	+49 (0)761 600 6553
Address:	Diamond Materials GmbH Hans-Bunte-Str. 19 79108 Freiburg Germany