elementsix™

DE BEERS GROUP

Optics

Enable extreme performance photonics

Our CVD diamond has an extremely broad transmission spectrum, exceptional thermal conductivity, it delivers vastly increased component lifetime and can be engineered to virtually any configuration, which is why industry leading photonics engineers choose Element Six.

CVD diamond for productivity and improved innovation

Durable, chemically resistant and virtually wear-free

The properties of optical (chemical vapour deposition) CVD diamond, which include durability, chemical resistance and freedom from wear, deliver three game-changing benefits:

- Engineers can create applications which have simply not been possible with conventional optical materials
- Existing photonics applications can achieve unprecedented levels of performance
- Combined with new levels of performance, the overall cost of ownership can be reduced

The properties of Element Six's CVD diamond transform component performance

Extremely broad transmission spectrum from 220 nm to >50 µm

The widest wavelength transmission spectrum known to material science, from 220 nm to >50 µm. One CVD diamond window can offer transparency normally only possible with a multitude of different windows, each spanning a small wavelength range. With CVD diamond, instead of many different components, only one is required.

The highest level of thermal conductivity of any material

The thermal conductivity of Element Six's CVD diamond optical components, at >2000 W m^{-1} K^{-1}, is up to 100x higher than competing optical materials. That means engineers can make use of much higher powered lasers and improve performance with consistent and undistorted beam quality during operation.

Low absorption

Extremely low absorption over the widest optical window enables CVD diamond optics to be used in a wide range of laser systems. It also allows higher power laser outputs to be transmitted through the window without suffering damage.

Unparalleled chemical inertness

Their chemical inertness allows CVD diamond components to operate in highly corrosive and hostile environments. In such applications diamond ATR prisms offer the longest lifetimes with consistent performance.

Ultimate scratch resistance

Diamond, the hardest material known to science, offers the ultimate scratch resistance. This means diamond optical components are mechanically robust and offer the longest lifetime under harsh conditions.

Sizes and shapes to suit your needs

Element Six's optical CVD diamond components are available with optical quality niches in sizes up to ∅ 135 mm in diameter and up to 3 mm thickness (polycrystalline optical grades) and as plates of up to 7 x 7 x 2 mm (single crystal CVD diamond). They can also be processed to virtually any shape.

Low birefringence

Element Six offers grades of CVD diamond where the birefringence loss of polarization (Δn) can be $\Delta n < 2 \times 10^{-5}$. This is ideal for applications where polarization is critical, including intra-cavity use.

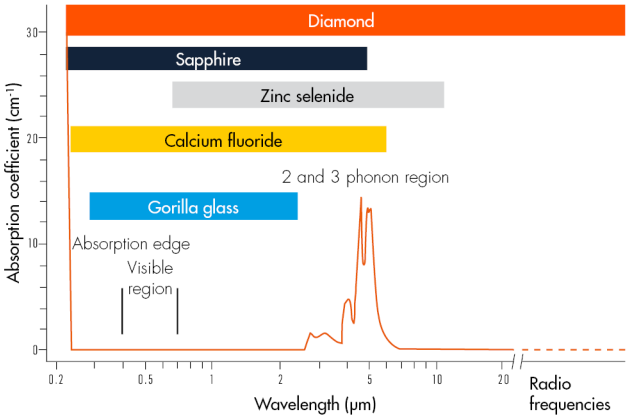
Transmission in the x-ray wavelengths

Element Six's CVD diamond also transmits in the X-ray wavelength range below 0.4 nm (above 3 keV). Therefore, CVD diamond can improve X-ray sensitivity and image detail in applications like structure analysis and medical radiology.

Biologically compatible

The biocompatibility of CVD diamond means it can be used directly in invasive surgical applications and as an optical substrate material for bio-analysis.

Wide transmission spectrum of optical grade CVD diamond



Exciting technical applications driving competitive advantage

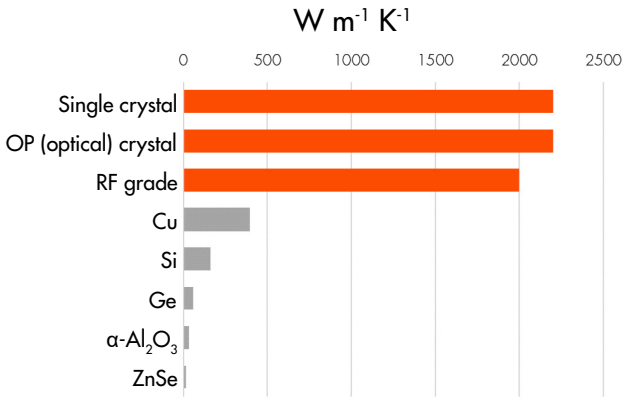
Optical windows in high power lasers

CVD diamond reduces operating costs and increases productivity

- Element Six's CVD diamond windows allow much higher laser power densities than other materials. That delivers faster cutting and welding, resulting in shorter end-production timescales and making a major contribution to your competitive advantage.
- High-quality CVD diamond can do this because of its unrivaled thermal conductivity. This prevents thermal lensing and hot spots from created. That yields two significant advantages:
  - Constant beam quality during operation
  - No need for thermal lensing compensation

CVD diamond windows will last as long as the laser

- No replacement is necessary, whereas other windows need to be replaced regularly under high load
- Maintenance requirements and machine down time are reduced



High power optical windows

Optical microwave CVD diamond at the frontiers of science

- CVD RF diamond windows are a crucial component in nuclear fusion experiments, used both in >2 MW gyrotrons and as containment windows in waveguides
- CVD diamond can be used for components in vacuum tube high power RF sources often found in satellites, aerospace and defence industries

Raman laser crystal

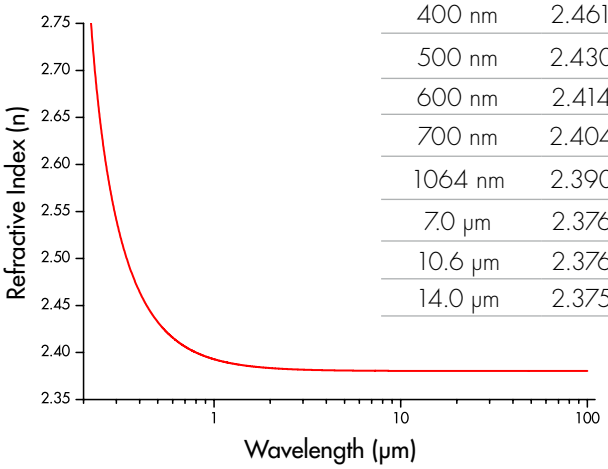
Windows, prisms and lenses for spectroscopy

One device for multiple transmission spectra

- The wide transmission spectrum of microwave CVD diamond greatly improves the efficiency of spectroscopy because only one device is required instead of several optical components, each with a narrow transmission spectrum
- Operating environments can be extremely hazardous. Here, the properties of chemical resistance, extreme hardness and durability permit CVD diamond spectroscopy instruments to operate where units with conventional windows, lenses and prisms will fail
- The robustness of CVD diamond components make them ideal for application in handheld spectroscopy devices such as those used in homeland security and forensic science

Refractive index of diamond

Wavelength	n
300 nm	2.534
400 nm	2.461
500 nm	2.430
600 nm	2.414
700 nm	2.404
1064 nm	2.390
7.0 µm	2.376
10.6 µm	2.376
14.0 µm	2.375



Collaboration in applications development

Our specialized team of application engineers and processing technologists will help you to design the right component for your application. This includes the windows, prisms and lenses, their processing and mounting, as well as partial or anti-reflective coatings. Windows, prisms and lenses can be engineered to any required size up to Ø 115 mm in diameter (Diafilm™ optical grades) and 7 x 7 x 2 mm (single crystal CVD diamond). Mounts can be of simple flange design or made to customer specifications, which facilitates special features such as water or air cooling if required.

Example applications

Application	Component
High power CO_2 lasers	Optical windows, lenses and output couplers
High power solid state lasers	Optical windows and lenses
Spectroscopy (both laboratory and in-line)	Optical windows, prisms and lenses
Semiconductor processing	Optical windows and beam splitters
Terahertz and radar applications	RF windows
(Bio)Medical optics	Optical windows, prisms and lenses
Defence and aerospace (high-power/multi-spectral imaging)	Thermal mounting and optical windows
Other cutting edge technical applications for optical CVD diamond include: beam splitters, YAG cooling, particle detection and quantum sensing	

Advantages of CVD diamond

- Extremely broad transmission spectrum from 220 nm up to >50 µm
- Highest thermal conductivity (>2000 W m^{-1} K^{-1})
- Thicknesses available up to 3 mm
- Low absorption
- Wide range of sizes available
- Single crystal path length >10 mm possible
- Chemically inert and operates in corrosive environments
- Biocompatiblity
- Scratch resistant
- Low birefringence
- Highest Raman gain coefficient

Modelling and analysing proposed solutions

Our engineers and technologists use the latest computer modelling systems to analyse every aspect of the thermal and mechanical properties of a proposed application. By doing so, the ultimate performance of a component can be accurately predicted before prototyping.

Microwave CVD diamond components have a transmission spectrum from 220 nm up to >50 µm. They also conduct heat better than any other material.

CVD diamond properties

Property	Polycrystalline		Single crystal	
	Optical grade	RF grade	Optical grade	Optical plus
Absorption coefficient cm^{-1}				
10.6 µm	<0.07	<0.1	<0.05	<0.05
1064 nm	0.12		<0.1	<0.005
Transmittance (1 mm thick)				
8-200 µm	71.4%	68 - 70%	71.4%	71.4%
633 µm	>64%		>69%	70.6%
Integrated forward scatter				
8-12 µm	0.1 – 0.7%		<0.1%	
220 – 800 nm	< 4%		<0.7%	<0.1%
Dielectric constant D (35 GHz)	5.68 ± 0.15			
% Increase in D at 773 K	4.3%			
Loss tangent 145 GHz ($\times 10^{-6}$)	8 - 20	10 - 100		
Refractive index				
10.6 µm	2.376		2.376	
1550 nm	2.386		2.386	
1064 nm	2.392		2.392	
dn/dT (K^{-1})	9.6×10^{-6}		9.6×10^{-6}	
Birefringence($n_e - n_0$)			1×10^{-4}	$<5 \times 10^{-5}$
Emittance at 10 µm				
573 K	0.02		0.02	
773 K	0.03		0.03	
Thermal expansion coefficient ($ppm\ K^{-1}$)				
300 K	1.0		1.0	
1000 K	4.4		4.4	
Thermal conductivity ($W\ m^{-1}\ K^{-1}$)				
300 K	>2200	>2000	>2200	
425 K	>1600	>1500	>1600	
Specific heat capacity at 500 K ($J\ Kg^{-1}\ K^{-1}$)	520		520	
Density ($\times 10^3\ kg\ m^{-3}$)	3.52		3.52	
Hardness (GPa)	81 ± 18		70 - 120	
Young's modulus	1050		1050	
Fracture stress (MPa) [Weibull modulus]			3500 [2.5]	3500 [2.5]
Nucleation	800 [10]	800 [10]		
Growth	400 [15]	300 [15]		
Rain impact DTV ($m\ s^{-1}$)	525		457 - 533	
Sand erosion ($mg\ kg^{-1}$) at 100 ms^{-1} C300/600 sand	2.1 ± 0.6			

For references and further information on these properties please download the Diamond Handbook.

Element Six is a global leader in the design, development and production of synthetic diamond and tungsten carbide supermaterials. Part of the De Beers Group, our primary manufacturing sites are located in the UK, Ireland, Germany, South Africa, and the US.

Since 1959, our focus has been on developing the diamond synthesis process to enable innovative synthetic diamond and tungsten carbide solutions. As well as being the planet's hardest material, diamond's extreme and diverse properties give it high tensile strength, chemical inertness, broad optical transmission and very high thermal conductivity.

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