ENABLE EXTREME PERFORMANCE PHOTONICS

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

elementsix™
a De Beers Group Company

CVD DIAMOND FOR PRODUCTIVITY AND IMPROVED INNOVATION

DURABLE, CHEMICALLY RESISTANT AND VIRTUALLY WEAR-FREE

The properties of optical CVD diamond, which include durability, chemical resistance and freedom from wear, deliver three transforming 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 MICROWAVE CVD DIAMOND THAT 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. So 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 CVD diamond optical components, at >2000 W/mK 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 RESISTANCE

Chemical resistance allows CVD diamond components to operate in highly corrosive and hostile environments. In such applications diamond ATR prisms offer the longest life times with constant performance.

ULTIMATE SCRATCH RESISTANCE

Diamond, the hardest material known to science, offers the ultimate in 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 optical CVD diamond components are available with optical quality finishes in sizes up to Ø 135 mm in diameter and up to 3 mm thickness (polycrystalline optical grades) and as plates of up to 8 x 8 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.

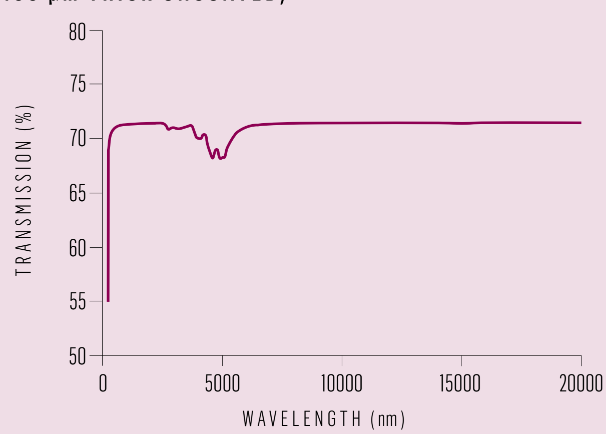
TRANSMISSION IN THE X-RAY WAVELENGTHS

Element Six CVD diamond also transmits in the X-ray wavelength range below 0.4 nm (above 3 keV). So 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
(100 µm THICK UNCOATED)

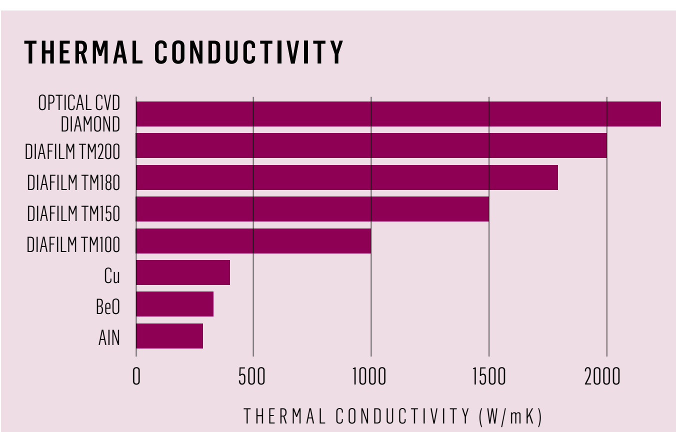


EXCITING TECHNICAL APPLICATIONS DRIVING BUSINESS ADVANTAGE

OPTICAL WINDOWS IN HIGH POWER LASERS

MICROWAVE GROWN CVD DIAMOND REDUCES OPERATING COSTS AND INCREASES PRODUCTIVITY

- Element Six CVD diamond windows allow much higher laser power densities than rival materials. That delivers faster cutting and welding resulting in shorter end-production timescales. This makes 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 being 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 (other windows need to be replaced regularly under high load)
    - Reduces maintenance requirements and machine down time



HIGH POWER RF GENERATORS

OPTICAL MICROWAVE CVD DIAMOND AT THE FRONTIERS OF SCIENCE

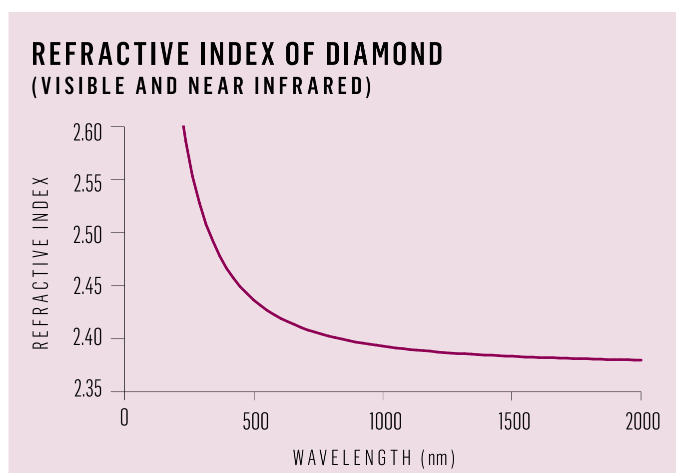
- CVD diamond windows are a crucial component in high power Gyrotrons (>2 MW) used to heat the plasma to initiate nuclear fusion
- There are a vast number of applications in the field of high power RF generators
- CVD diamond optical components play an important role in satellites and in the aerospace and defense industries

Single crystal CVD diamond prisms for use in spectroscopy applications.

WINDOWS, PRISMS AND LENSES FOR SPECTROSCOPY

ONE DEVICE FOR MULTIPLE TRANSMISSION SPECTRUMS

- The wide transmission spectrum of microwave CVD diamond greatly improves the efficiency of spectroscopy because only one device may be 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 use in handheld spectroscopy devices such as those used in homeland security and forensic science.



PARTNERSHIP IN APPLICATIONS DEVELOPMENT

Our specialized team of application engineers and processing technologists can 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 135 mm in diameter (Diafilm optical grades) and 8 x 8 x 2 mm (single crystal CVD diamond). Mounts can be of simple flange design or made to customer specifications which facilitate 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 on-line)	Optical windows, prisms and lenses
Semiconductor processing	Optical windows and beam splitters
Terahertz and Radar applications	Optical windows
(Bio)Medical optics	Optical windows, prisms and lenses
Defence and aerospace (directed energy/imaging)	Thermal mounting and optical windows

Other cutting edge technical applications for optical CVD diamond include: beam splitters, YAG cooling, particle detection.

ADVANTAGES OF CVD DIAMOND

- Extremely broad transmission spectrum from 220 nm up to >50 µm
- Highest thermal conductivity (>2000 W/mK)
- 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

MODELING AND ANALYZING PROPOSED SOLUTIONS

Our engineers and technologists use the latest computer modelling systems to analyze every aspect of the thermal and mechanical properties of a proposed application. In this way the ultimate performance of a component can be accurately predicted before prototyping.

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

CVD DIAMOND OUTPERFORMS SAPPHIRE AND ZINC SELENIDE

PROPERTY	CVD DIAMOND		SAPPHIRE	ZINC SELENIDE
	POLYCRYSTALLINE	SINGLE CRYSTAL		
Hardness (GPa)	81 ± 18[1]	81 ± 18[1]	16[1]	1.05[1]
Fracture toughness ($MPam^{0.5}$)	5.3 – 7.0 [1]	5.3 – 7.0 [1]	2[1]	0.5[1]
Young's modulus (GPa)	1000 – 1100[1]	1000 – 1100[1]	344[1]	70.3 ± 2.8[1]
Poisson's ratio	0.1 [1]	0.1 [1]	0.27[1]	0.28[1]
Tensile strength (MPa) [Weibull Modulus] Polycrystalline strength at 0.4 mm thick	Nucleation surface 800 [10][4] Growth surface 400 [15][4]	2000[2.5][9]	400[7]	50[1]
Rain impact DTV (m/s) 2 mm drop size	525[2]	–	457–533[2]	137[2]
Sand erosion (mg/kg) at 100 m/s C300/600 sand	2.1 ± 0.6[1]	–	92 ± 2[1]	>30 000[1]
Thermal conductivity at 300 K (W/mK)	1900 – 2200[4]	1900 – 2200[4]	34[1]	16[1]–18[3]
Thermal conductivity at 500 K (W/mK)	1100[4]	1100[4]	6[3]	–
Thermal expansion coefficient (ppm/K)	1.0 at 300 K[4] 4.4 at 1000 K[4]	1.0 at 300 K[4] 4.4 at 1000 K[4]	5.3[1]	7.1 at 300 K[1] 10.9 at 800 K
Thermal shock FOM ($\times 10^3$ W/m)*	~1000[4]	~4000[4]	5.4[1]	1.1[1]
Refractive index	2.375 (at 10 µm)[1]	2.375 (at 10 µm)[1]	1.77 (633 nm)[1]	2.4 (10 µm)[1]
dn/dT (1/K)	9.6×10^{-6}[1]	9.6×10^{-6}[1]	12×10^{-6}[1]	57×10^{-6}[1]
Dielectric constant D (35 GHz)	5.68 ± 0.15[5]	–	9.4 – 11.6[1]	8.98[1]
% increase in D at 773 K	4.3%[5]	–	6.5%[5]	–
Loss tangent 145 GHz (10^{-6})	8 – 20[8]	–	200[8]	–
8–12 µm absorption coefficient (1/cm)	<0.07[4]	<0.05[9]	>1000[1]	0.0005[1]
3–5 µm absorption coefficient (1/cm)	min 0.8 at 3.7 µm[5]	min 0.8 at 3.7 µm[5]	0.01– 0.04[1]	0.015[3]
1 µm absorption coefficient (1/cm)	Typical 0.12[9]	Down to <0.005[9]	–	0.001
Emissivity at 10 µm (1 mm thick)	0.02 at 573 K 0.03 at 773 K [5]	0.02 at 573 K 0.03 at 773 K [5]	N/A	–
Integrated forward scatter 8–12 µm (%)	0.1 – 0.7%[5]	–	N/A	–
Integrated forward scatter visible (%)	<4%[5]	<0.7%[9]	0.1%[1]	–
Density ($\times 10^3$ kg/m^3)	3.52[7]	3.52[7]	3.98[7]	5.27[7]
Specific heat capacity (J/kgK) 300 K	520[1]	520[1]	750[1]	340[1]
Transmission 8–200 µm (1 mm thick)	71.4%#[4]	71.4%#[4]	N/A	–
Transmission 633 nm (1 mm thick)	>64%#[4]	>70%#	84.5%[6]	60.8%[6]

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#	= Reflection and scattering loss limited
–	= Not known
N/A	= Not applicable

*THERMAL SHOCK FIGURE OF MERIT

FOM	$= S(1 - \upsilon)\, k / \alpha E$
α	= Expansion coefficient
E	= Young's modulus
υ	= Poisson's ratio
S	= Strength
k	= Thermal conductivity

ELEMENT SIX TECHNOLOGIES

Element Six Technologies is a division of Element Six, the world's market leader in the manufacture and development of synthetic diamond, established in the 1940s.

Today Element Six is a $500 million company operating production facilities in 7 countries and serving over 5,000 customers worldwide.

Element Six Technologies operates two production and technical facilities around the globe; Santa Clara in California, and Ascot in the United Kingdom. The new Santa Clara facility offers US based customers a state-of-the-art facility for producing CVD diamond solutions for use in a wide array of advanced industry applications including optics, power transmission, sanitization and water treatment, semiconductors and sensors.

In 2013, Element Six opened the world's largest and most sophisticated synthetic diamond supermaterials research and development facility in Oxford, UK.

If you would like to know about Element Six please visit our website at www.e6.com/optical, or contact us at any of the addresses below.

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