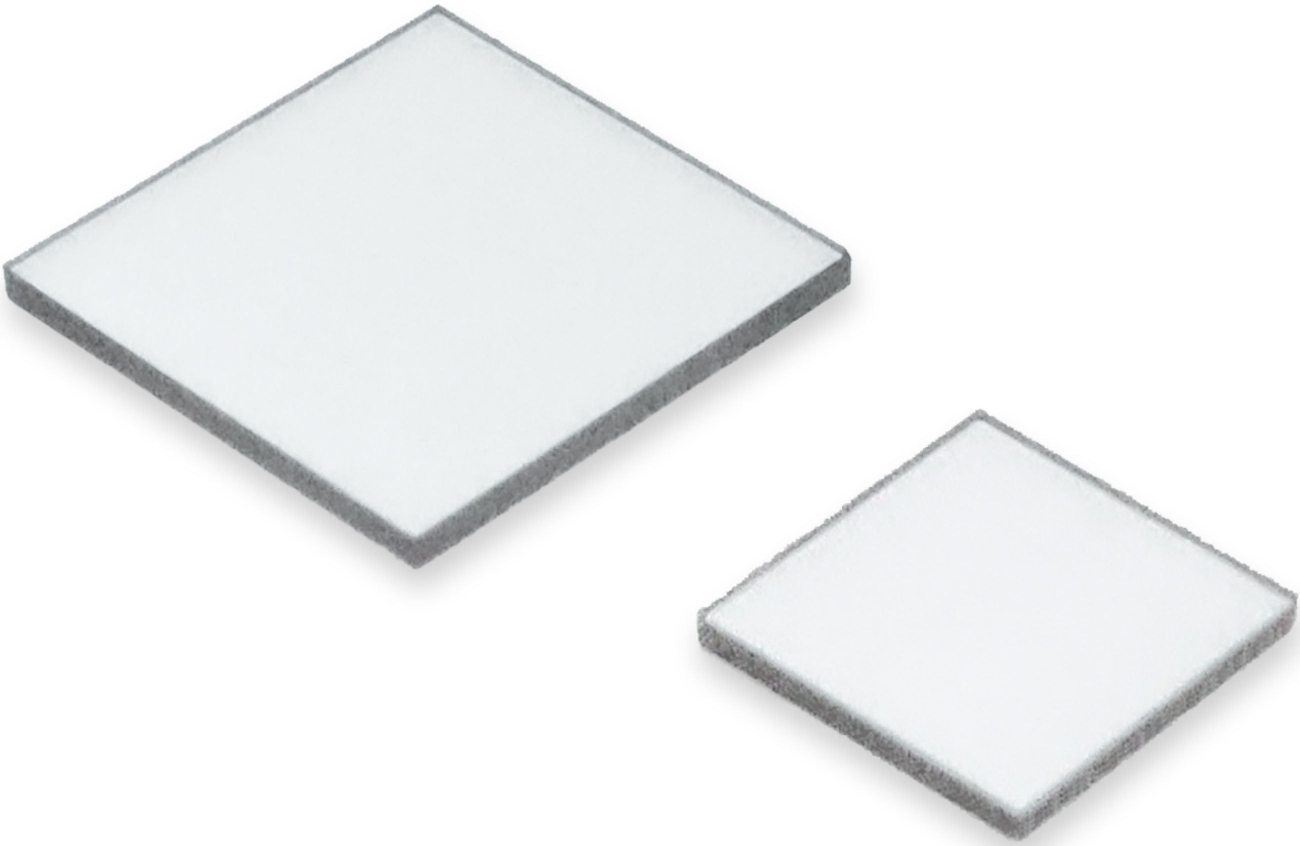
elementsix™

DE BEERS GROUP

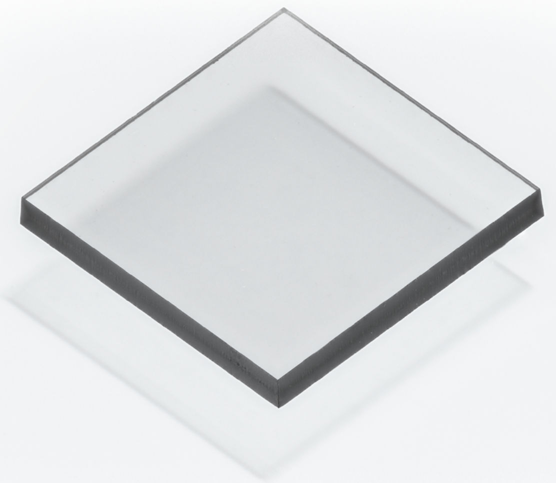


ELSC™ Series

First Generation and Next Generation

Element Six's electronic grade single crystal (ELSC™) is an exceptional platform material for synthetic diamond enabled detectors and quantum technologies. ELSC™ Series Next Generation delivers up to two times in area increase.

ELSC™ grown by chemical vapor deposition (CVD) is Element Six's highest purity synthetic diamond grade. This makes it the perfect material for radiation hard, stable, highly selective ionizing radiation detectors, or as a host for spin defects for a number of quantum technologies.



Element Six's ELSC™ CVD diamond

Detector applications

Using its proprietary CVD technology, Element Six produces synthetic diamond with background point defect densities around or below the parts per billion level (~10^{14} cm^{-3}). These ELSC™ diamonds have exceptional electronic properties and are suitable for a range of extreme radiation detector applications, where volume sensitivity, radiation hardness and/or temperature insensitivity are essential.

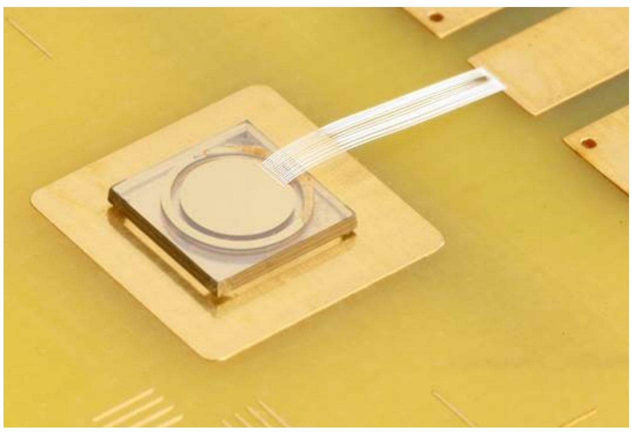
The high purity of ELSC™ allows charge carriers to move freely with minimal scattering and trapping, enabling diamond detectors to act as effective solid state ionization chambers, with charge collection efficiencies approaching 100%[1].

In comparison with other solid state detector materials, diamond is radiation hard thanks to its high atomic displacement energy (42 eV/atom) and low atomic number. Diamond's large bandgap (5.47 eV) leads to low leakage currents, even at room temperature, in contrast to detectors based on Si or Ge, which must be kept cool to limit thermally generated charge carriers. In addition, diamond's exceptional thermal conductivity allows it to be used in applications where high fluences produce heat loads which exceed the capabilities of conventional detector materials.

The wide array of CVD diamond-enabled detector applications includes:

- Counting and spectroscopy of fast neutrons produced in D-D and D-T nuclear fusion plasmas
- Fast response beam condition monitoring for protection of sensitive detectors
- High energy resolution spectroscopy of heavy ions
- Beam position monitors for particle accelerators

Diamond detectors enabled by ELSC™ have been used at the world's most prestigious research facilities, including CERN's Large Hadron Collider, the Stanford Linear Accelerator Center (SLAC), the Joint European Torus (JET), Experimental Advanced Superconducting Tokamak (EAST), and Gesellschaft für Schwerionenforschung (GSI). For those users wishing to develop their own diamond detector technology, Element Six supplies its highly-engineered ELSC™ materials directly, on a global scale. Alternatively, end users may source complete diamond detector solutions from specialists in the field, such as Cividec[2] and Micron Semiconductor[3].



ELSC™ diamond is used in high energy particle detectors

ELSC™ for quantum technologies

Certain defects in solids possess a quantum property called "spin". This is the attribute of particles, such as electrons, which is responsible for magnetism in materials. In most materials, the electronic spin of such defects rapidly loses its phase due to interactions with phonons (lattice vibrations) and other electronic and nuclear spins. However, with diamond's strong carbon-carbon bonds comes a high Debye temperature (~2200 K). This can result in exceptionally long-lived spin states, even at room temperature, enabling their use in a number of quantum technologies, including:

- Secure communications
- Quantum computation/simulation
- Next generation magnetic sensors

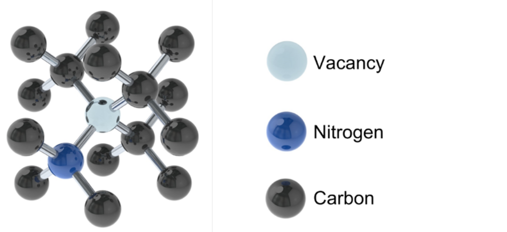


Figure 1: The atomic structure of the nitrogen-vacancy (NV) defect in diamond

One particular spin defect in diamond, which has been the subject of extensive research, is the negatively charged nitrogen-vacancy center or NV. The nitrogen-vacancy defect occupies two adjacent sites in the diamond lattice, whereby one carbon atom has been replaced by a nitrogen atom, and the other by a lattice vacancy (Figure 1). By virtue of the electronic energy levels associated with the NV center, as shown in Figure 2, the spin state of this defect can be initialized, manipulated, and read out at room temperature, using light and microwave radiation.

Element Six's ELSC™ typically contains less than 1 ppb of single nitrogen and less than 0.01 ppb of NV defects. This low defect background makes it the perfect platform material for studying isolated, single NV centres. Figure 3 shows a typical confocal microscope image of a sample of ELSC™ diamond, illustrating a sufficiently low background NV level to allow individual NV centers to be located.

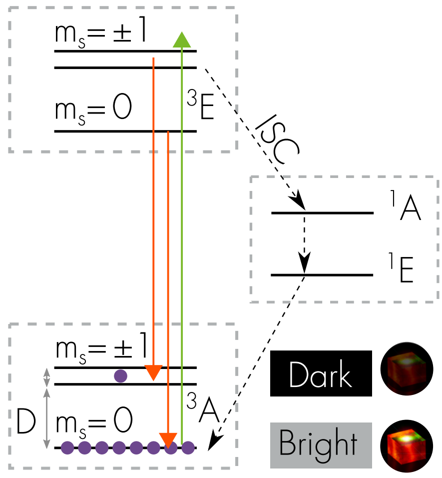


Figure 2: The energy levels of the NV defect

The magnetic spin properties (T_2) of NV defects in this material have been measured to be up to 600 μs, using a Hahn echo measurement on single isolated defects[4], although the spin life-time does vary from defect to defect, due to the variation in the local environment at the nanoscale level.

Due to its low background defect level, ELSC™ can also be used as a substrate for the controlled implantation of NV or other spin defects, or for growth of CVD diamond epilayers containing controlled concentrations of spin defects or color centers of interest.

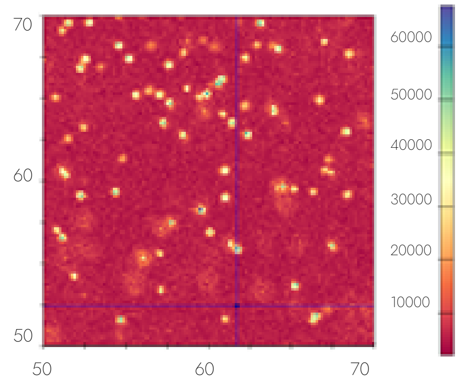


Figure 3: Typical confocal microscope image of ELSC™ diamond. High count regions (yellow) are mostly single NV centres. Data courtesy of the University of Ulm.

Further reading

1. Pernegger H 2006 Phys. Status Solidi a 203 3299
2. cividec.at
3. micronsemiconductor.co.uk/core-departments/#diamond
4. Phys. Rev. B 80, 041201 (2009)

Properties	ELSC™	Notes
Hole mobility ($cm^2 V^{-1} s^{-1}$)	>2000	Measured by time of flight technique
Electronic mobility ($cm^2 V^{-1} s^{-1}$)	>2000	
Carrier lifetime (ns)	~2000	
Charge collection distance (µm)	*Typically > 475	*At 0.5 V $µm^{-1}$ applied field, for 500 µm plate
Charge collection efficiency	Typically >95 %	for 500 µm plate
Bandgap (eV)	5.47	
Electron saturation velocity (cms^{-1})	20	
Breakdown voltage ($MV\ cm^{-1}$)	1 - 2	Experimental value. Threshold current 10 µA 4 x 4 mm x 20 µm contact area 0.71 mm^2
^{13}C Fraction	1.1 %	Natural abundance
$[N_S^0]$ (ppb)	<5 (typically 0.1 - 1)	Measured by EPR
[B] (ppb)	<1	Measured by SIMS
[NV] (ppb)	<0.03	Calculated value†
Thermal conductivity ($W\ m^{-1} K^{-1}$)	>2000	
Expansion coefficient ($ppm\ K^{-1}$) at 300 K	1.0 ± 0.1	
Expansion coefficient ($ppm\ K^{-1}$) at 1000 K	4.4 ± 0.1	
First Generation (mm)	2 x 2, 4 x 4, 4.5 x 4.5	Tolerance +0.2 - 0 mm Thickness 0.5 ± 0.05 mm
Next Generation (mm)	5.5 x 5.5, 6 x 6, 6.5 x 6.5	
Thin Plate (mm)	4.3 x 4.3	Tolerance +0.2 - 0 mm Thickness 0.05 ± 0.05 mm
Laser kerf	<5 °	
Edge features (mm)	<0.2	
Crystallographic orientation (face/edge)	{100} ±3 ° <110>	
Surface finish side 1 Ra (nm)	<5	Over 1 mm^2
Surface finish side 2 Ra (nm)	<5	Over 1 mm^2

† Orientated NV Centres: Edmonds A M et al. Phys. Rev. B 86, 035201 (2012)

About us

Element Six (E6), part of the De Beers Group, designs, develops and produces synthetic diamond and other supermaterials, and operates worldwide with primary manufacturing facilities in the US, UK, Germany, Ireland and South Africa.

E6 solutions are used in applications such as cutting, grinding, drilling, shearing and polishing, while the extreme properties of synthetic diamond beyond hardness are opening up new applications in a wide array of industries such as optics, power transmission, water treatment, semiconductors and sensors.

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