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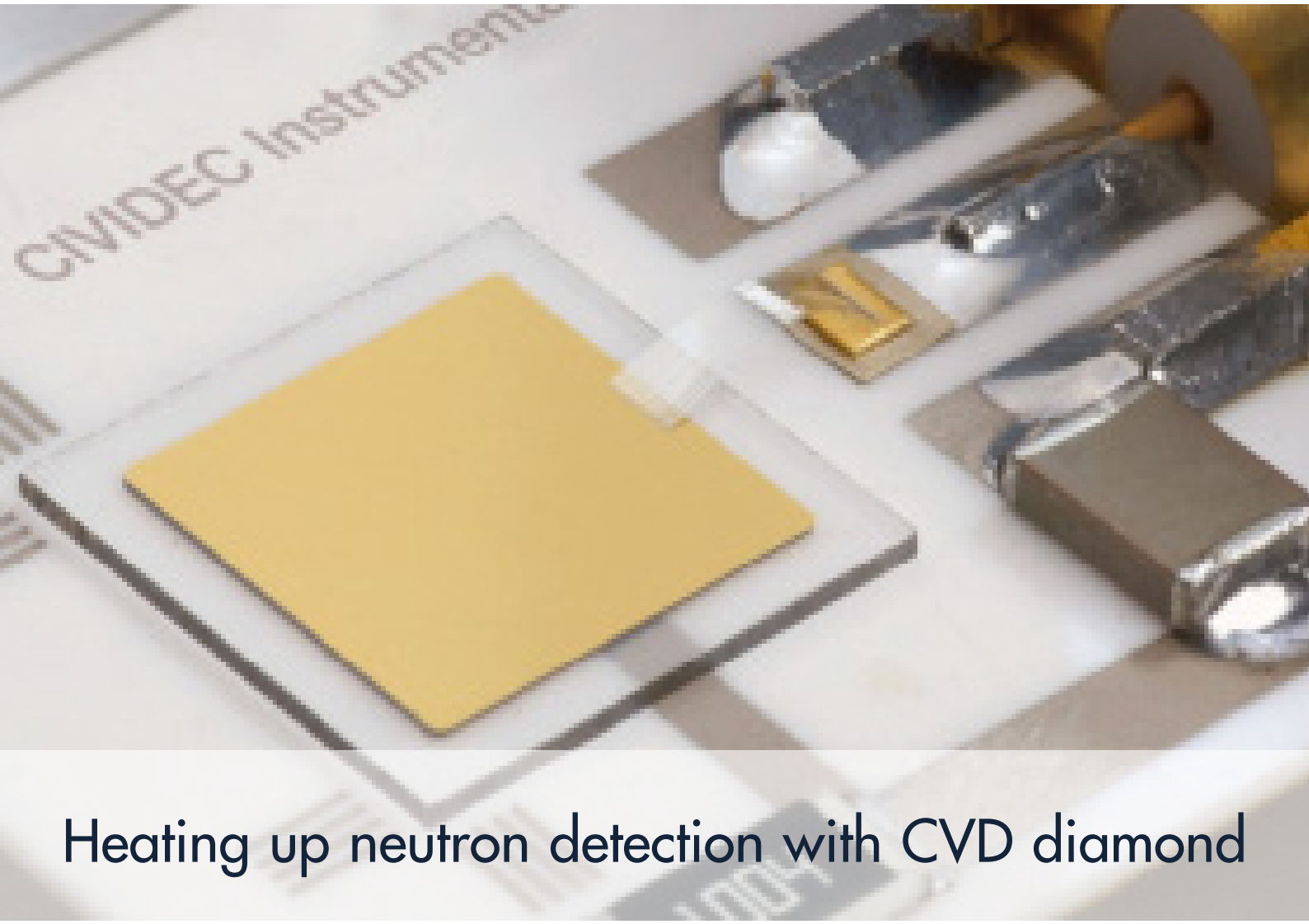
Instrumentation



Heating up neutron detection with CVD diamond

A long-standing development collaboration between CIVIDEC Instrumentation and Element Six has accelerated the use of CVD diamond in high energy particle physics, fusion experiments and neutron sources for essential diagnostic tools.

Customer: CIVIDEC Instrumentation
Vienna, Austria

CIVIDEC Instrumentation GmbH was founded in 2009 by Prof. Erich Griesmayer, to exploit the unique intrinsic electronic properties of electronic grade chemical vapour deposition (CVD) diamond to enable a series of versatile radiation diagnostic systems for neutrons, charged particles and X-rays. Innovations include real-time beam loss monitoring systems with 1 ns resolution for particle accelerators, Synchrotron beam positioning systems with ±1 nm resolution and neutron monitoring systems with 1 MHz sampling rates and energy resolution of 20 keV.

"Element Six's breakthroughs in electronic grade diamond engineering and production have been critical to CIVIDEC's success, working together in partnership to determine the critical material and device parameters to offer our customers the perfect tailored solution"

Prof. Erich Griesmayer
CEO, CIVIDEC

Target applications

Neutron-based measurements are important diagnostic tools across a range of industrial, security and research applications and the emergence of diamond-based neutron detectors has delivered significant capabilities as more sophisticated diagnostic tools develop.

Neutron diagnostics for fusion reactors

For deuterium-tritium (DT) plasma diagnostics in fusion reactors, such as ITER, diamond is an ideal sensor material. Its radiation hardness, combined with fast response, allow diamond detectors to directly identify fast neutrons and distinguish them from the background.

Temperature stability

Neutron generators often operate at high temperatures. Being insensitive to these conditions is critical for effective neutron diagnostic tools. Based on this requirement, diamond is an ideal material solution as it is proven to operate with constant performance up to 500 K.

Gamma ray rejection

Rejecting gamma radiation background is the key to effective neutron diagnostics as neutron environments are inherently characterised by significant levels of gamma radiation. Thanks to its low atomic number and, hence, intrinsic gamma insensitivity, diamond is the ideal sensor material for gamma ray rejection.

D-D plasma: the special case

In particular for D-D plasma diagnostics, with intrinsically low neutron energy deposition, the gamma insensitivity and high spectroscopic performance of single crystalline diamond sensors are crucial. Commercially available high-quality material allows the sensors to be configured in the most suitable way for these applications.

Diamond detectors are a compact, temperature insensitive, radiation hard and mechanically robust platform neutron diagnostic technology and can be tailored to meet the requirements of a wide range of experiments and industrial applications.

About Element Six CVD diamond

- Synthetic CVD diamond engineered for optical, thermal, acoustic, quantum and sensing applications
- Element Six launched Electronic Grade Single Crystal range as an ideal high energy particle detector semiconductor, leveraging over 30 years of innovation leadership and a wide patent portfolio in single crystal CVD diamond
- The **ELSC™ Series** combines 100% charge collection efficiency, energy resolution, fast response, high temperature stability and outstanding radiation hardness

"Plasma diagnostics and control are an immense technical challenge for the next generation of fusion energy reactors currently being constructed. Element Six is proud to be a solutions provider for cutting-edge, high temperature neutron detectors, which represent a critical part of these fusion experiments"

Dr Tim Mollart
Principal Application Engineer, Element Six

Why single crystal diamond?

Intrinsic diamond possesses remarkable semiconductor properties that enable high performance solid state detector devices, which can be operated in high radiation environments for many years. The control over bulk and surface defects that the CVD diamond synthesis process provides has enabled production of diamond crystals with unparalleled performance in detector applications.

- Diamond detectors operate with high bias voltages, very low leakage currents and low power consumption in high radiation environments
- Compared to silicon-based devices, diamond solutions are temperature independent and insensitive to visible light
- The high mobilities and a charge lifetime of 1 μs enable energy selective detectors and spectroscopic applications with a resolution of 20 keV
- The large atom displacement energy of 42 eV enables unparalleled radiation tolerance and lifetimes in extreme fluence $>10^{15}$ particles cm^{-2} applications
- Diamond detectors have low absorption cross section and extreme dynamic range, making them ideal as insertion monitoring devices, such as instrumented collimators

The collaboration

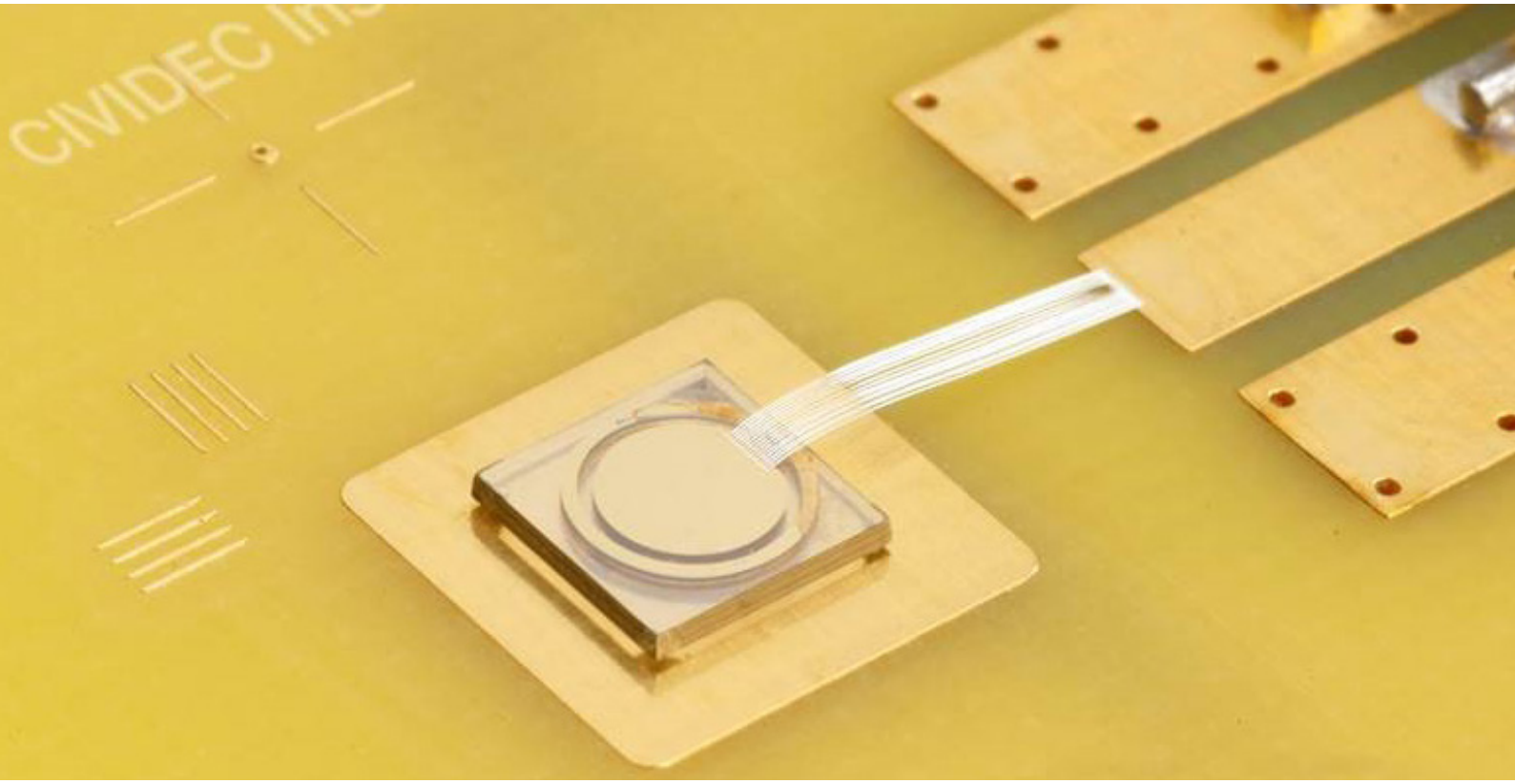
Having a long-standing and close relationship in CVD Diamond Radiation Detector Development at CERN, Prof. Erich Griesmayer chose to launch CIVIDEC in 2009, two years after Element Six introduced its Electronic Single Crystal (ELSC) Grade diamond. With an initial focus on Large Hadron Collider (LHC) beam line diagnostics, work on developing neutron detectors began with experiments in the neutron time-of-flight (n_TOF) facility at CERN in 2010. Since then, Element Six has provided CIVIDEC with:

- Developed and improved ELSC grades
- Expert support on diamond material solutions
- Access to early-stage prototype devices
- New solutions for targeted applications and markets

A leading diagnostic instrumentation supplier to the high energy particle detector community, CIVIDEC has been a natural collaborator for Element Six's unique diamond capabilities. As each generation of particle accelerators, fusion experiments and synchrotron light sources reaches ever higher energy levels, diamond solid state solutions have emerged to supplant silicon in critical applications.

"Electronic grade diamond neutron detectors are gaining importance in various neutron applications. The combination of excellent detector characteristics, background selectivity, thermal robustness and radiation hardness make it uniquely suited for harsh environments"

Dr Christina Weiss
Scientist, CIVIDEC



Further reading

1. Charge carrier properties of single-crystal CVD diamond up to 473 K - B. Kraus et al., NIMA 989, 164947, (2021)
2. Particle interactions with diamond detectors - C. Weiss et al., IBIC2019-MOPP016 (2019)
3. B7-HT high-temperature fast-neutron diamond detector - C. Weiss et al., Eur. Phys. J. A 52:269 (2016)
4. Charge-carrier properties in synthetic single-crystal diamond measured with the transient-current technique - H. Pernegger et al., Journal of Applied Physics 97, 1, (2005)
5. Advanced neutron spectroscopy in fusion research - G. Ericsson, Journal of Fusion Energy 38 330-355 (2019)

About Element Six

Element Six (E6), part of the De Beers Group, is a world-leader in the design, development and production of synthetic diamond and tungsten carbide solutions. The company operates worldwide with primary manufacturing facilities in Germany, Ireland, South Africa, the UK and US. Element Six leverages the extreme properties of synthetic diamond to open up new possibilities in areas such as quantum optics, acoustics, power transmission, water treatment, thermal management and sensors.

CIVIDEC Instrumentation

By exploiting the intrinsic electronic properties of detector-grade CVD diamond, CIVIDEC has established a series of immaculately manufactured products, suitable for extreme environmental conditions. CIVIDEC offers versatile radiation diagnostic systems for neutrons, charged particles and X-rays. Its products are available off-the-shelf and as customised solutions.

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