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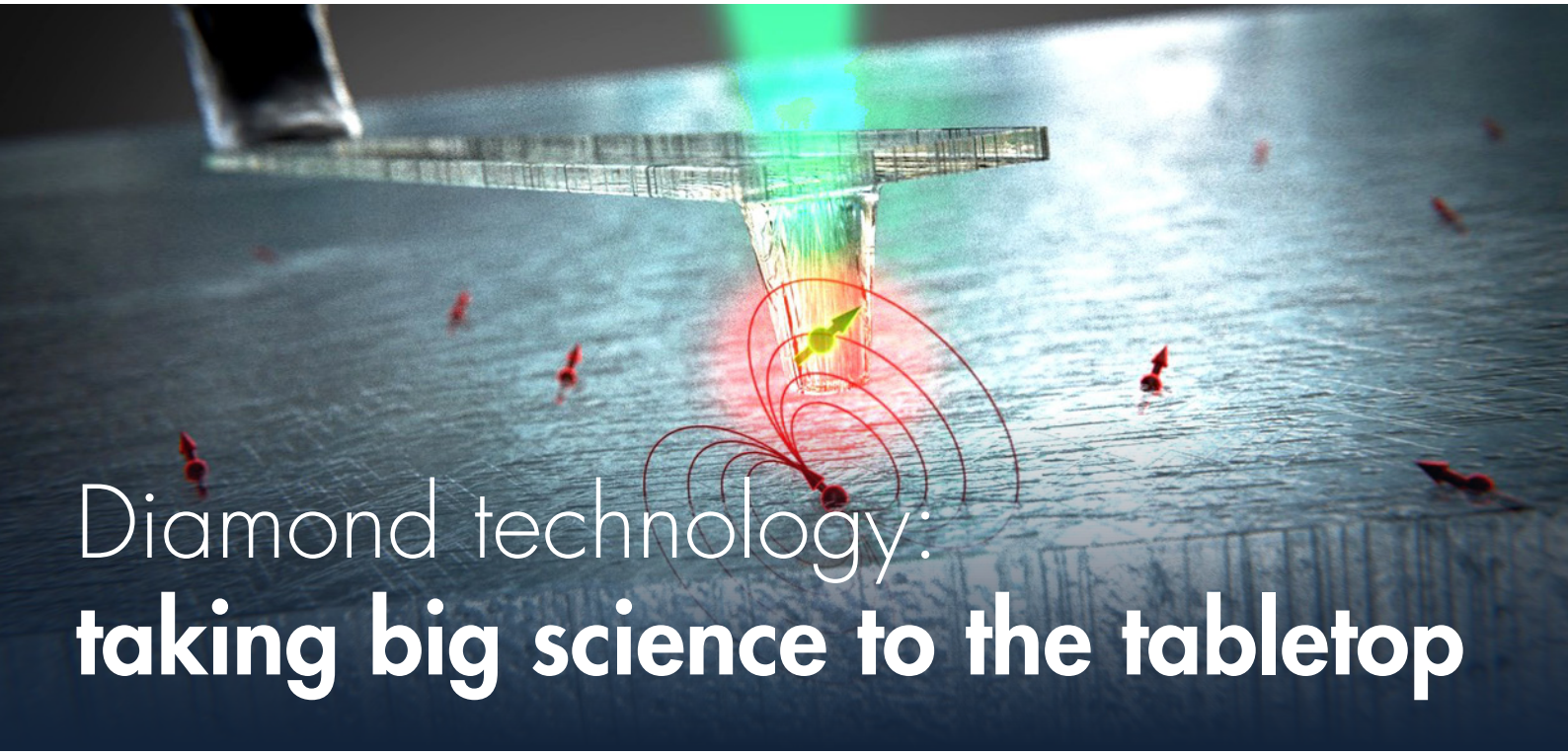
Qnami
the quantum wave



Diamond technology: **taking big science to the tabletop**

An innovative, diamond-enabled microscope is turning quantum metrology into a portable reality, opening up new opportunities in energy-efficient electronics.

Customer: Qnami
Muttenz, Switzerland

Qnami ProteusQ™ is the first commercially available microscope to use the quantum technology of diamond nitrogen-vacancy (NV) centres. Using a technique called Scanning NV Magnetometry, it enables table-top analysis of magnetic materials at the atomic scale. This new, diamond-enabled microscope offers an unprecedented miniaturised solution to processes which have previously relied on large-scale light sources, measuring many hundreds of metres in circumference. This accessible technology lowers the barriers of entry to nano-scale materials research and is expected to accelerate the development of advanced materials for energy efficient electronics.

"Element Six has been at the forefront of synthetic diamond innovation for decades. For Qnami, Element Six has been both a technical partner with whom we develop new applications and a reliable source of high quality diamond for our production needs."

Dr. Mathieu Munsch, Qnami CEO

The opportunity: a new generation of energy efficient electronics

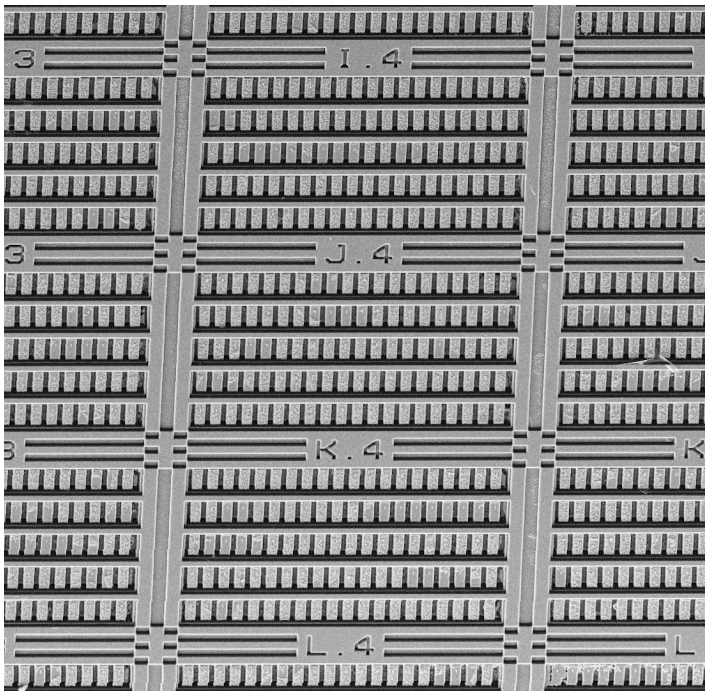
Until recently, the magnetic properties of materials for electronic devices had been largely overlooked. However, a new type of electronics – spintronics – has emerged and promises to combine high performance with a low energy footprint. In spintronics, information is encoded in magnetic bits, just as it is in traditional hard-disk drives. Spin is a quantum property of electrons which can be used instead of an electron's charge to carry information and allow it to travel on spin-waves instead of electrical current.

The challenge: big science with atomic precision

Spintronics requires sophisticated thin film structures or multi-layers, whose thickness must be controllable down to one atomic layer. These films are further engineered into complex nano-structures whose lateral size can be as small as a few nanometres. To understand the root cause of any system failures, it is necessary to measure the effects of microscopic changes in the design or fabrication process. However, traditional diagnostic tools provide no direct information on the magnetic properties of such devices, slowing down the development process.

Existing technology: x-ray magnetic circular dichroism

The current method of precision metrology for spintronics, X-ray magnetic circular dichroism (XMCD), requires equipment of a vast scale, synchrotrons, which can measure several hundreds of meters across, managed by large teams of operators. Accessing such a facility can be costly, time-consuming and impractical in a fast-moving research or production environment.



10µm Diamond wafer during the manufacturing process of Qnami Quantilevers™

Why diamond?

The extreme fragility of quantum states offers great potential for highly sensitive sensors to measure magnetism and electric fields. However, this fragility also creates a fundamental challenge. Ideally quantum states would be isolated from the surrounding environment, but measurement requires external interaction. This balance between control and interaction is the fine line quantum engineers are increasingly determined to traverse in order to take full advantage of this exciting technology. The ease of qubit initialisation and readout, combined with diamond' stability, make it a perfect host material for spin qubits.

Element Six CVD single crystal diamond

- Element Six engineers a range of CVD diamond grades for applications which include machining, optics, thermal management and sensing
- Single crystal CVD diamond is an ideal spin qubit host material with high sensitivity and long decoherence times and wide dynamic range (and vector functionality)
- Leveraging its innovation capabilities for over 10 years, Element Six has secured established multiple patents in quantum technologies

Qnami and Element Six's solution: scanning NV Magnetometry

With the quantum power of NV diamond, faster and more accurate atomic-scale material analysis can now be achieved in a standard lab environment, with just one operator using the table-top Qnami ProteusQ™.

Through the Scanning NV Magnetometry technique, quantum sensors made of sharp, microscopic NV diamond tips can be precisely maneuvered over tiny magnetic structures to map and visualise magnetic properties. This delivers improved nano-scale spatial resolution, performing ten times better than large scale XMCD.

Offering real time feedback and the potential for industrial scaling, this breakthrough device has the potential to accelerate R&D and commercialisation of new technology that relies on nano-structures and the manipulation of electrons.

What is a nitrogen vacancy (NV) centre?

A series of pioneering studies from the University of Stuttgart and Harvard University demonstrated that carbon atoms with nitrogen vacancy centres, the same defect found in some rare pink diamonds, have a quantum spin that can be manipulated and read out at room temperature using simple optical techniques. Synthetic diamond, manufactured by chemical vapour deposition (CVD) method, allows for these quantum defects to be engineered into the material with an unprecedented degree of precision.

NV centres are colour centres in which a carbon atom is replaced by a nitrogen atom with a nearest neighbour carbon atom missing (referred to as a vacancy)". The NV has an electron spin that is highly sensitive to magnetic fields, forming the basis for sensing and magnetometry technology. This platform is so powerful because the electron spin can be detected and aligned simply by shining a green LED onto the material and measuring the intensity of red florescence emitted. It has been demonstrated that NV electron spins can store quantum information for over 1 ms at room temperature. While groups of multiple NV centres are required for specific applications, this method of detection and alignment can also work for single NV centres, opening up new possibilities for unprecedented spatial resolution and nano-scale sensitivity.

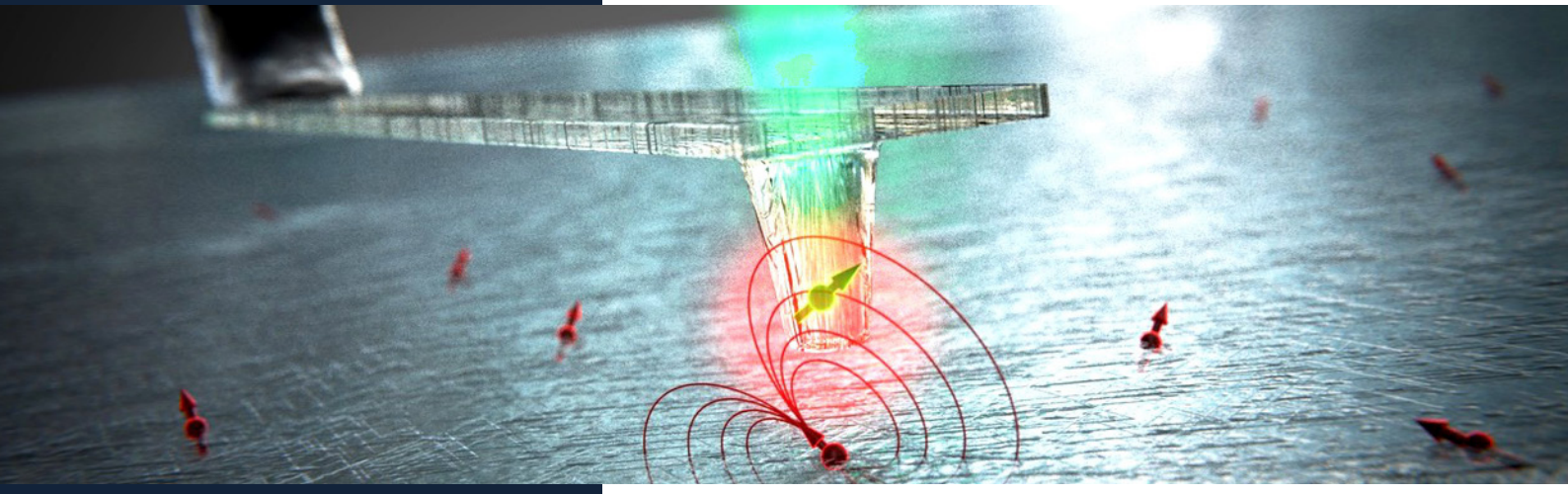
Next steps: commercial spintronics

With the advent of Magnetic RAM (MRAM) technology, spintronics is now moving out of the lab and into commercial product development. The competitive advantage delivered by Scanning NV Magnetometry is expected to unlock an increasing number of opportunities based on a new generation of advanced semiconductor materials - including ultra-thin ferromagnets, antiferromagnets, multiferroics and 2D materials.

The next challenge will be to scale down further, for the measurement of increasingly smaller solutions, and improve materials diversification to measure a range of physical properties in different conditions.

"Element Six has worked with this technology back when it was still basic science in Harvard over ten years ago. Today it is incredibly exciting to see this ground-breaking science coming to fruition and we are proud to collaborate with Qnami in the commercialisation of a new solution that will enable crucial breakthroughs in spintronics materials."

Dr. Daniel Twitchen,
Chief Technologist, Element Six



Artists rendering of a diamond Quantilever™ containing a single NV centre for high resolution quantum imaging

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Element Six's DNV-B1™ – the first commercially-available, general-purpose quantum grade diamond

About Element Six

Part of De Beers Group, Element Six is a world-leading provider of advanced material solutions, including diamond synthesised to contain NV centres using the chemical vapour deposition (CVD) method. In collaboration with global businesses, start-ups and academia, Element Six has developed, manufactured and supplied the quantum grade diamond used to accelerate the delivery of key breakthroughs in quantum technology. Element Six has been a commercial partner for Qnami since 2017, when the company span out from the EU 2020 Horizon-funded DIADEMS project.

About Qnami

Qnami is a quantum start-up based in Switzerland with operating offices in Germany. Launched to the market in 2020, the Qnami ProteusQ™ is powered by HORIBA Atomic Force Microscopy technology and NV diamond that has been developed, manufactured and supplied by Element Six. With quantum sensing, Qnami unlocks the ability to reach what had never been achieved before– the control and measurement of the state of a single electron. The idea behind Qnami's disruptive market presence started with the work of Prof. Dr. Patrick Maletinsky at the University of Basel, a partner in the EU Horizon 2020 funded DIADEMS project. The start-up was then founded as a result of the program in 2017.

For more information about Element Six CVD single crystal diamond solutions please contact:

E technologies@e6.com
T +44 1344 638 200

e6.com

For more information about Qnami please contact:

E contact@qnami.ch
T +41 61 207 37 40

qnami.ch