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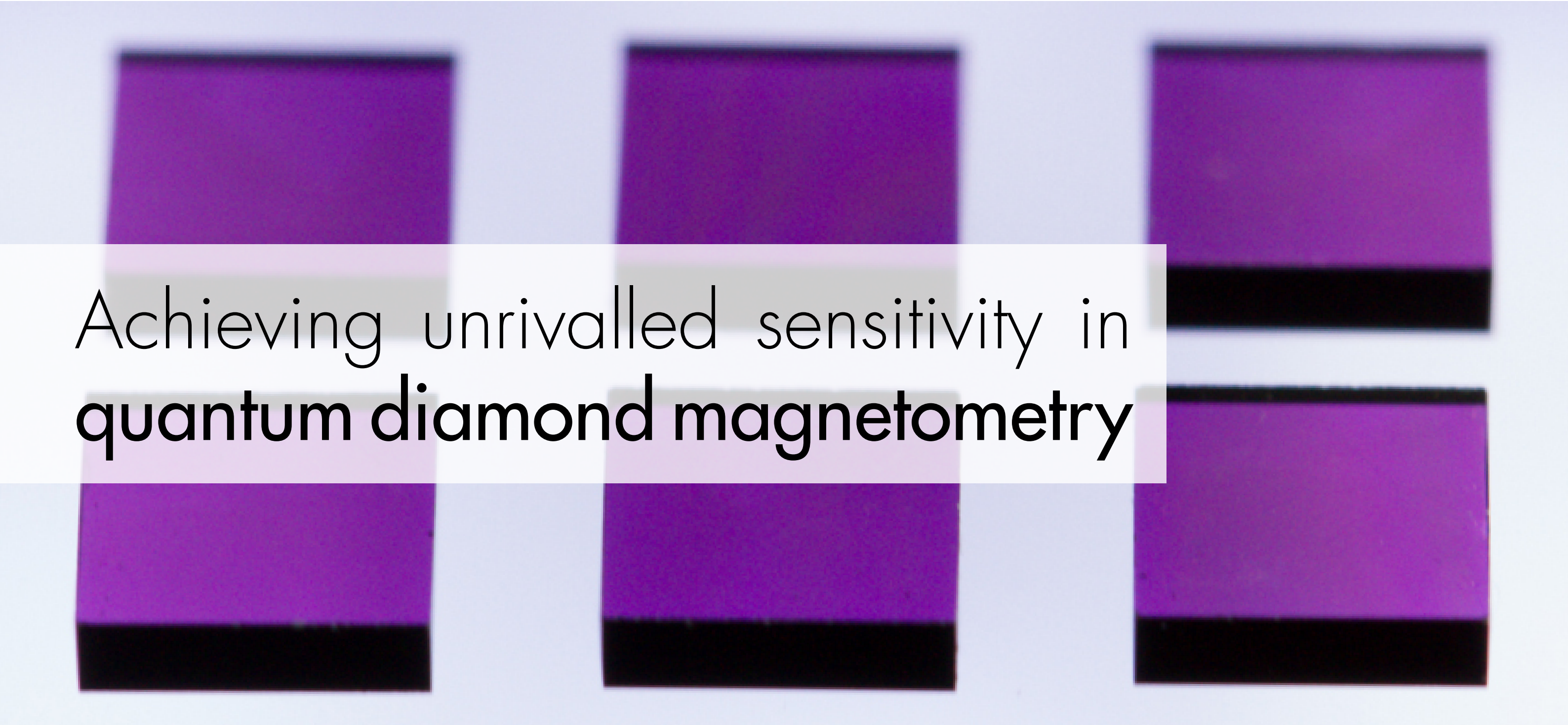


Achieving unrivalled sensitivity in quantum diamond magnetometry

Element Six's high purity CVD diamond has enabled a ground-breaking fibre-coupled diamond magnetometer which is set to improve medical diagnostics and structural materials aging

Collaborator: The University of Warwick
Coventry, UK

Leveraging a long-standing research collaboration with Element Six, a team of scientists from the University of Warwick have built the world's most sensitive fibre-coupled diamond magnetometer, powered by the properties of synthetic diamond. The device utilises the quantum technology of diamond nitrogen-vacancy (NV) centres to analyse objects or materials by measuring their magnetic fields.

Element Six's engineered NV diamond solution is connected to the processing equipment by a fibre-optic cable, meaning the device can be precisely targeted at a range of applications. By leveraging diamond's room temperature properties, the solution doesn't require cryogenic cooling, which makes miniaturization possible, allowing the device to be portable. These unique properties are also ideal for medical diagnostic techniques, like Magnetocardiography (MCG), which measures the magnetic fields produced by electrical currents in the heart, paving the way towards advanced quantum-enabled healthcare solutions that could make early heart disease diagnosis a practical reality.

The opportunity
Revolutionising the ease of detection

Magnetometry is widely used in many applications, such as sensors in mobile phones and cars. However, for the best sensitivity, the sensors are typically large and expensive, often requiring cryogenic cooling, which negatively impacts usability.

The new diamond-enabled device is a relatively small and lightweight table-top solution. While also having the potential to considerably lower the cost per unit, this new technology delivers a much less invasive piece of equipment compared to some traditional magnetometers.

The fibre-optic cable also allows the user to target the diamond sensor at specific objects up to 10m away. Such flexibility and portability are crucial for the improved detection of heart diseases, the leading cause of death worldwide. If scaled for mass production, this magnetometer could enable health professionals to detect heart diseases quicker and more accurately at the point of care, leading to reduced discharge times for patients.

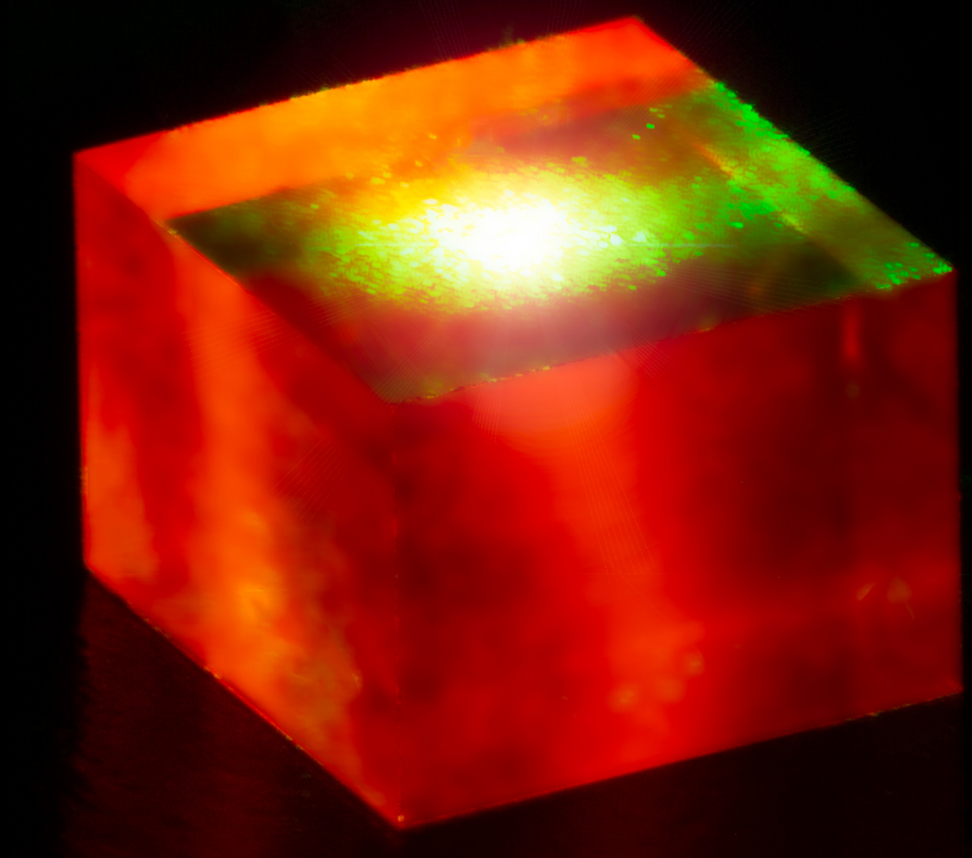
In addition to the biomedical applications, the facts that the device can be hand-held and is portable mean the range of detection can be easily moved and targeted. This makes it suitable for heavy industry applications, such as the analysis of large amounts of material for defects like corrosion.

Steel accounts for the vast majority of global metals production but suffers from corrosion. The new magnetometer could enable operators to more easily analyse steel in situ to detect corrosion before expensive and potentially lethal accidents happen, delivering improved safety and cost efficiencies.

The challenge
Obtaining sensitivity

For magnetocardiography or in high value operations, like the detection of corrosion in steel, sensitivity is key. The magnetometer's objective is to measure tiny magnetic fields emitted from the heart or emanating from the surfaces of potentially corroded materials.

Diamond magnetometry provides a great method to combine room temperature operation in a compact system. To ensure maximum sensitivity, Element Six's engineered diamond is optimised to contain the right concentration of NV centre defects, while minimising the presence of others. Achieving the perfect balance is not simple: impurities in the diamond cause magnetic noise, which reduces the accuracy of the device, too small a concentration of NV centres would render it not sensitive enough, while too large a concentration would accrue interference. As other factors, like size or surface finish, can also affect sensitivity, the Morley group relied on Element Six to deliver tailor-made, high-quality, synthetic diamond materials.



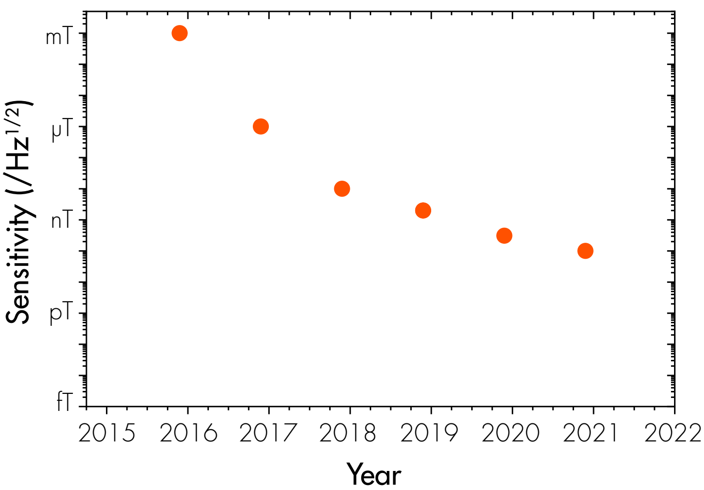
The University of Warwick and Element Six's solution

High quality diamond magnetometry

Throughout decades of collaboration and shared successes, Element Six has worked with the University of Warwick to make progressive steps towards increased sensitivity and accuracy. Over a five-year period of experiments, the magnetometer's sensitivity has improved by a factor of 10 million, starting from a threshold of milli-tesla to nano-tesla (as seen in the graph below), making the technology suitable for applications like the early diagnosis of heart disease and the detection steel corrosion.

"Witnessing the sensitivity gains achieved by the immensely talented team at Warwick in such a short period of time has been great. It's testament to their knowledge of the field and practical expertise. We're delighted to have made a significant contribution to this innovation and we look forward to seeing our diamond materials unlocking new milestones in the journey to commercializing quantum technology."

Dr Matthew Markham,
Principal Research Scientist, Element Six



The fibre-coupled diamond magnetometer at the University of Warwick has been improved in sensitivity by a factor of 10 million in five years.

The success of the project has also been dependent on support from the UK Quantum Programme, which has provided significant funding to improve the product's sensitivity to date. The Networked Quantum Information Technologies Hub (NQIT) and the Royal Society are also credited with support, while members of the team at the University of Warwick who have worked on the project have graduated through the Centre for Doctoral Training (CDT) in Diamond Sciences and Technology, which is supported by Element Six.

"There's no doubt that the quality of the diamond and the people I've been lucky enough to work with have been vital. They are the two most important factors in our success."

Dr Gavin Morley,
Associate Professor, University of Warwick

Next steps

The Morley group's device can find damage in steel and could soon measure a signal from a person's heart. The next challenge will be to engineer this ground-breaking solution into a commercialized reality. Dr Morley expects to be able to scale the product down in order to ultimately become more portable and small enough to fit into a rucksack.

Looking forward to further applications, the Warwick team are also considering magnetoencephalography (MEG), the detection of signals from the brain. The magnetic fields from the brain are smaller than those from the heart, making MEG more challenging, but diamond MEG could eventually be used to diagnose illnesses such as schizophrenia and early-stage Alzheimer disease.

> "For our device to work, we need the diamond to be just right. Element Six has been the ideal development partner as the team have encouraged the kind of close co-operation that gets us to the position that we're currently in. They have manufactured exactly what we were looking for: a diamond that has the right shape, size and spin properties."
>
> Dr Gavin Morley,
> Associate Professor, University of Warwick

Why diamond?

The extreme fragility of quantum states offers great potential for highly sensitive sensors to measure magnetism and electric fields. The diamond crystal lattice makes a perfect host material for solid-state qubits as it provides a low noise background. However, this fragility also creates process development challenges. Ideally, quantum states would be isolated from the surrounding environment, but measurement requires a degree of 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. Element Six provides its global network, including the University of Warwick, with unrivalled diamond expertise and advanced materials, and works closely with them to scale this advanced technology to workable, real-life solutions.

What is a diamond nitrogen vacancy (NV) centre?

A series of pioneering studies in the 1990s and early 2000s demonstrated that a defect in diamond, called the nitrogen vacancy centre, has a quantum spin that can be manipulated and read out at room temperature using simple optical techniques. Synthetic diamond, manufactured through the chemical vapour deposition (CVD) method, allows for these quantum defects to be introduced into the material with a high degree of precision.

NV centres are created by removing two adjacent carbon atoms from the diamond lattice and replacing one of them with a nitrogen atom, leaving the other one empty, thus forming a vacancy. The NV has an electronic spin that is highly sensitive to magnetic fields, providing the perfect solution for highly accurate magnetometry. This platform is so powerful because the electronic spin can be manipulated simply by shining a green laser onto the material, then measuring the spin through the intensity of the red florescence emitted. It has been demonstrated that NV electron spins can store quantum information for over 1ms at room temperature. While groups of multiple NV centres are required for some applications, this method of detection and alignment can also work for single NV centres, opening up new possibilities for unprecedented spatial resolution and nanoscale sensitivity.

About Element Six

Part of De Beers Group, Element Six is a pioneering manufacturer and supplier of diamond, synthesised to contain NV centres using the chemical vapour deposition (CVD) method. In collaboration with researchers and commercial groups around the world, Element Six has developed, manufactured and supplied the quantum grade diamond used in many of the most exciting recent breakthroughs in quantum technology.

About the University of Warwick

The University of Warwick builds quantum science and technology using diamond with support from UKRI, The Royal Society and The Royal Academy of Engineering. Key partners have been the NQIT Hub (Networked Quantum Information Technologies), the Hub in Quantum Computing and Simulation (QCS), and the Quantum Sensors Hub, which are part of the UK National Quantum Technologies Programme.

The University of Warwick is one of the world's leading research institutions, ranked in the UK's top 10 and world top 100 universities. Since its foundation in 1965, Warwick has established a reputation of scientific excellence, through the Faculty of Science, Engineering and Medicine (which includes WMG and the Warwick Medical School). A global university, Warwick was named in the top 25 of the Times Higher Education's Most International University rankings and has been in the top 30 for employability in the world by the QS World University Rankings.

Further reading

1. The diamond quantum revolution - M Markham & DJ Twitchen, 2020, PhysicsWorld
2. Characterisation of CVD diamond with high concentrations of nitrogen for magnetic-field sensing applications - AM Edmonds et al, 2021, Materials for Quantum Technology 1, 025001
3. Imaging damage in steel using a diamond magnetometer - LQ Zhou et al, 2021, Physical Review Applied 15, 024015
4. Sub-nanotesla magnetometry with a fibre-coupled diamond sensor - RL Patel et al, 2020 Physical Review Applied 14, 044058

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

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

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e6.com