NQIT Networked Quantum Information Technologies

BRUKER

Diamonds for Medical Applications

NQIT Industry Partnership Case Study

Key Points:

- The Networked Quantum Information Technologies (NQIT) Hub is a £38M collaborative programme funded by the UK government to develop a quantum computer demonstrator and its related technologies.
- Diamonds have properties that could be used as quantum bits (called 'qubits') for computation, and also as magnetic field sensors for medical applications.
- For this project, we partnered with Bruker GmbH, a manufacturer of scientific instruments for molecular and materials research and for industrial and applied analysis.
- Together, we investigated the commercial viability of diamond-based sensing technology and evaluated the potential market opportunity.

Diamonds for Medical Applications

Properties of Diamond


A diamond containing nitrogen vacancy centres glows red under green excitation

Diamond is a crystal lattice of carbon atoms that are held together by strong chemical bonds, which make diamond one of the hardest known materials. Diamonds are transparent to visible light, but the presence of impurities changes the absorption characteristics giving rise to diamonds of various colours. Since the impurities create coloured diamonds, they are known as "colour centres".

We are able to use diamond for quantum applications because of a particular colour centre called the nitrogen-vacancy (NV) centre. An NV centre is formed by a nitrogen atom replacing a carbon atom, adjacent to a missing carbon atom (the 'vacancy'). The NV centre emits red light when we shine green light on it and we can detect this red florescence from a single centre.

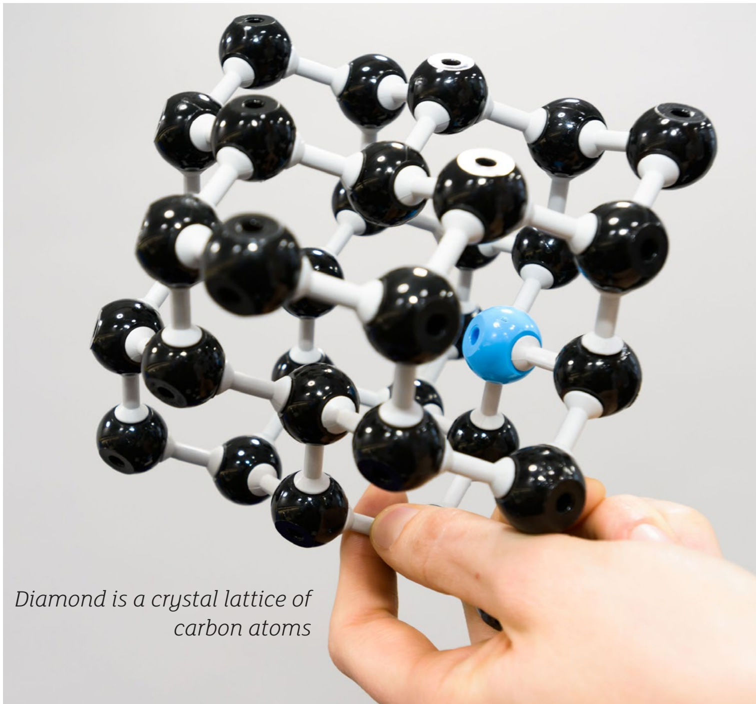
These colour centres have an electron spin which is like a tiny compass needle. The amount of florescence reveals the strength of the surrounding magnetic field and its direction, which means it can be used as a sensitive sensor.

State of the Art for NV Centres in Diamond

The challenge is to measure the magnetic field emitted by the heart, which is one million times smaller than the Earth's magnetic field. For **magnetocardiography (MCG)** and magnetic imaging of the brain (**magnetoencephalography or MEG**) this will require over a trillion NV centres in each diamond sensor to reach the required sensitivity. We are at an early stage in the research but the results are promising.

MAGNETOCARDIOGRAPHY EXPLAINED

Magnetocardiography (MCG) is a very sensitive, non-invasive method of detecting the magnetic fields produced by electrical activity in the heart. It is used for research on the normal human heart and for clinical diagnosis of conditions such as abnormal rhythms or arrhythmia. MCG provides similar information to electrocardiography (ECG), which is widely used in hospitals.


Diamond is a crystal lattice of carbon atoms

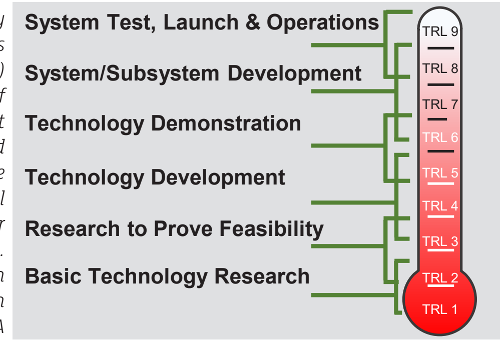
Contending Technologies

There are currently two contending technologies for MCG and MEG applications:

Superconducting quantum interference devices (SQUIDs) are a well-established technology but expensive as it requires a cryogenic system and costs around US$1M. It also limits how close the sensor can be to the patient, reducing the overall quality of the measurement.

Alkali metal atomic vapour cell magnetometers detect the Faraday rotation or absorption of light through a spin-polarised vapour of potassium, rubidium or caesium. The cells have high sensitivity and do not need cryogenic cooling, thereby reducing complexity and costs. However, the most sensitive type of these devices needs to be operated in a very low magnetic field environment, which requires expensive magnetically shielded rooms.

Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. This diagram is taken from NASA

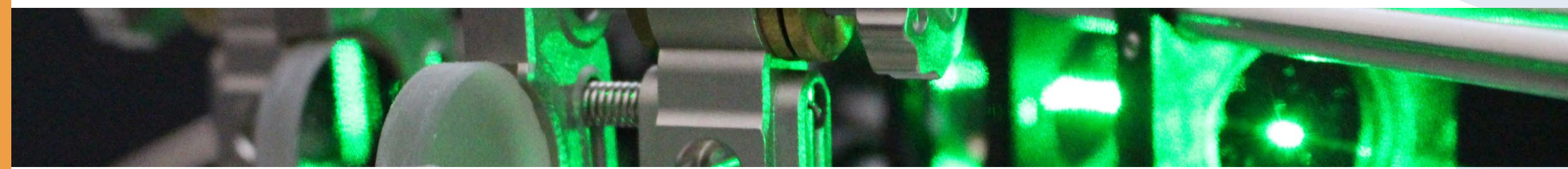


Market and Technology Readiness Level (TRL)

There are around 100 SQUID MEG systems installed worldwide and even fewer MCG systems, at a cost of over US$1M each. The MCG market would be much larger if the instrumentation were affordable and portable. MCG has been shown to be superior to ECG and is preferable to other non-invasive approaches for the diagnosis of coronary artery disease (CAD) [1, 2, 3], a major cause of death both in the UK and worldwide. Several companies have tried to commercialise SQUID-based MCG, but have been held back by the high cost of cryogenic systems.

There are over 100,000 hospitals in China, India, the EU, Japan and the USA. If an MCG system were available with the same functionality as the existing SQUID systems, but at a tenth of the cost, we estimate a market worth over US$10 billion [4].

Diamond magnetometers are at TRL 7, meaning that the technology has been demonstrated and is moving towards commercialisation. However, MCG systems require higher sensitivities and so this area is under active research. An MCG system based on diamond is at TRL 4-5 (the technology development stage).



Bruker and NQIT

This industry partnership project teamed up diamond researchers from NQIT, based at the University of Warwick, with Bruker GmBH, a manufacturer of scientific instruments, to design and develop a prototype magnetometer using four diamonds. We also assessed its commercial competitiveness over vapour cell magnetometers.

We were fortunate to have Bruker as our project partner, as they have the infrastructure and resources to carry out subsequent product development and a route to market for commercial exploitation.

This project has allowed Bruker to evaluate the commercial potential of this approach, and decide on the next steps in its commercialisation strategy.

Outlook

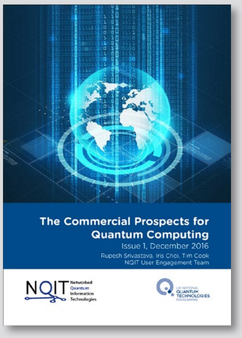
Diamond magnetometers offer the benefits of robustness, significantly lower costs and can be placed in close proximity to the patient. A mobile magnetometer which is brought to a patient's bedside does not require magnetically shielded rooms. However, the sensitivity of diamond magnetometers cannot currently compete with that of the more mature SQUID and atomic vapour cell magnetometers, which have been in development for much longer. Nevertheless, the future for diamond sensors holds great promise, and orders of magnitude improvements will be achieved over the next few years through optimisation of the diamond material, sensor configuration and detection technology.

"Bruker has committed staff time and resources in this NQIT collaboration to ensure that the magnetometry with NV centres project heads in the most practical direction towards a product that Bruker could commercialise, and to evaluate the market for such a technology."

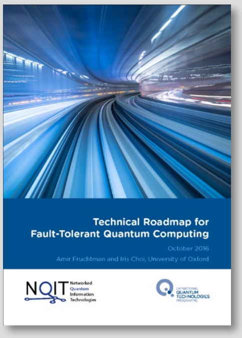
Other NQIT Reports

Networked Quantum Information Technologies

Annual Report 2017



The Commercial Prospects for Quantum Computing



Technical Roadmap for Fault-Tolerant Quantum Computing

All of these reports are available from our website:

http://www.nqit.ox.ac.uk/content/publications

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References

[1] Joey S W Kwong at al., Diagnostic value of magnetocardiography in coronary artery disease and cardiac arrhythmias: a review of clinical data. International Journal of Cardiology, 167, 1835 (2013).

[2] R. Fenici at al., Thirty years of clinical magnetocardiography at the Catholic University of Rome: Diagnostic value and new perspectives for the treatment of cardiac arrhythmias. International Journal of Cardiology, 168, 5113 (2013).

[3] Riccardo Fenici et al., Clinical application of magnetocardiography. Expert Review of Molecular Diagnostics, 5, 291 (2005).

[4] Matthew W. Dale, Gavin W. Morley, Medical applications of diamond magnetometry: commercial viability, https://arxiv.org/abs/1705.01994

Image Credits

Inside left: Red diamond, Jon Newland Photography; Diamond model, Dan Tsantilis / EPSRC

Inside right: Optical table, Gavin Morley; TRL diagram, NASA

About NQIT

The Networked Quantum Information Technologies (NQIT) Hub is part of the UK National Quantum Technologies Programme. It is led by the University of Oxford and involves 9 UK universities and over 30 companies all working together to develop a quantum computer demonstrator and, in the process, realise an entirely new technology sector.

NQIT User Engagement

The aim of the NQIT User Engagement team is to ensure uptake of early spin-out technologies and to identify new opportunities for user-driven applications.

We have set aside substantial funding to support promising quantum technology projects that have early commercialisation potential. These are divided into User Projects, which have immediate applications, and Partnership Projects, which have a longer technology maturity timeline but substantial industrial interest.

If you have an idea for a project that aligns with the aims of the NQIT Hub, would help speed up NQIT deliverables and uses NQIT scientists with commercial partners to advance quantum technology, please do get in touch with our User Engagement team: engage@nqit.ox.ac.uk

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