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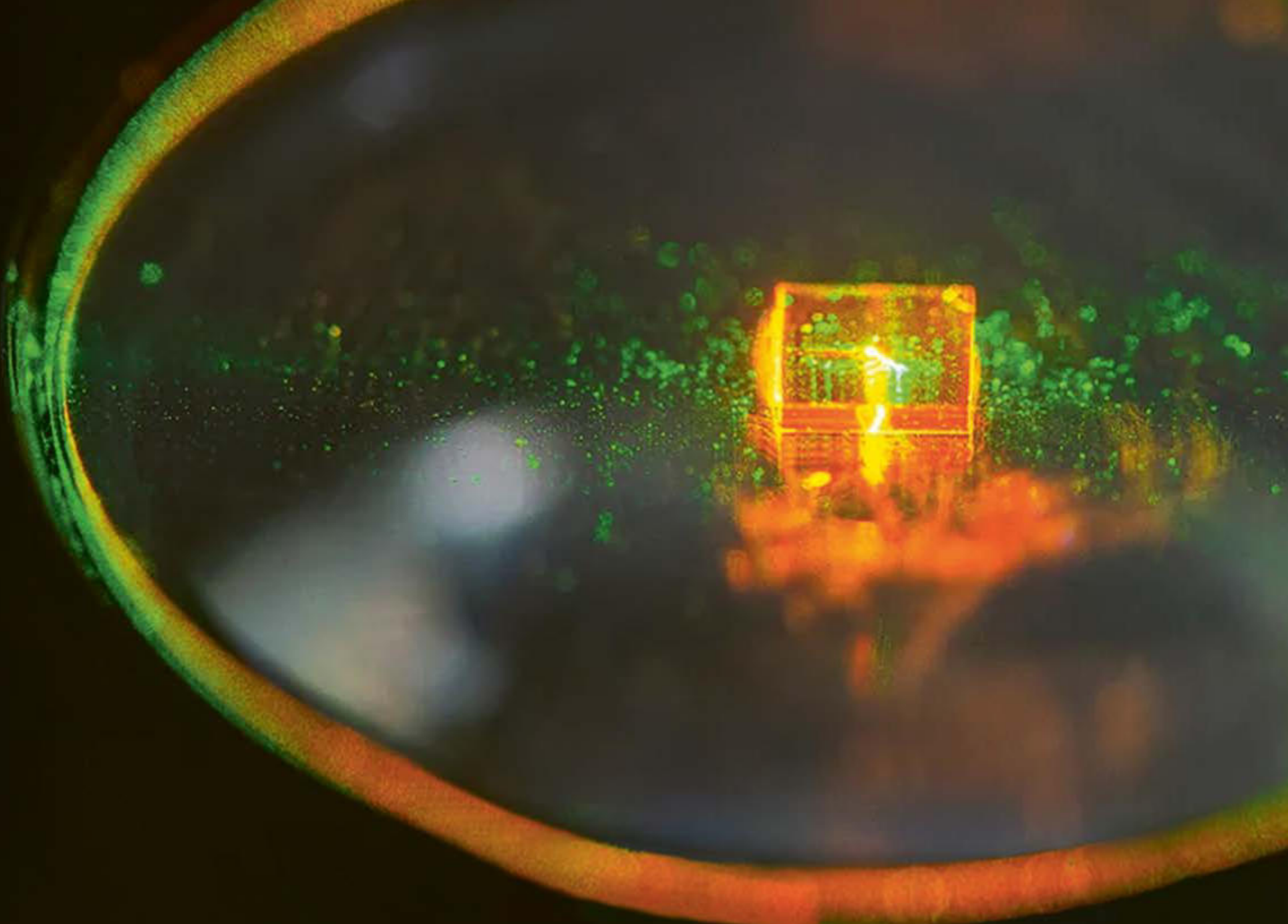
Quantum Sensors for Magnetic Resonance Imaging

A research team led by TUM has developed diamond quantum sensors that can be used to improve resolution in magnetic imaging.

Nuclear magnetic resonance (NMR) is an important imaging method in research that can be used to visualize tissue and structures without damaging them. The technique is better known from the medical field as magnetic resonance imaging (MRI), where the patient is moved into the bore of a large magnet on a table. The MRI device creates a very strong magnetic field that interacts with the tiny magnetic fields of the hydrogen nuclei in the body. Since the hydrogen atoms are distributed in a particular way among different types of tissues, it becomes possible to differentiate organs, joints, muscles and blood vessels.
NMR methods can also be used to visualize the diffusion of water and other elements. Research, for example, often involves observing the behavior of carbon or lithium in order to explore the structures of enzymes or processes in batteries. “Existing NMR methods provide good results, for example when it comes to recognizing abnormal processes in cell colonies,” says Dominik Bucher, Professor of Quantum Sensing at TUM. “But we need new approaches if we want to explain what happens in the microstructures within the single cells.”

Sensors made of diamond

The research team produced a quantum sensor made of synthetic diamond for this purpose. “We enrich the diamond layer, which we provide for the new NMR method, with special nitrogen and carbon atoms during its growth,” explains Dr. Peter Knittel of the Fraunhofer Institute for Applied Solid State Physics (IAF).
After growth, electron irradiation detaches individual car-



The research team creates defects in an artificial diamond. This creates special quantum mechanical properties that can be used for sensor technology.

Picture credit: A. Heddergott / TUM

bon atoms from the diamond's perfect crystal lattice. The resulting defects arrange themselves next to the nitrogen atoms – a so-called nitrogen-vacancy center has been created. Such vacancies have special quantum mechanical properties needed for sensing. "Our processing of the material optimizes the duration of the quantum states, which allows the sensors to measure for longer," adds Knittel.

Quantum sensors pass the first test

The quantum state of the nitrogen-vacancy centers interacts with magnetic fields. "The MRI signal from the sample is then converted into an optical signal, which we can detect with a high degree of spatial resolution," Bucher explains.
In order to test the method, the TUM scientists placed a microchip with microscopic water-filled channels on the diamond quantum sensor. "This allows us to simulate microstructures of a cell," says Bucher. The researchers were able to successfully analyze the diffusion of water molecules within the microstructure.
In the next step, the researchers want to develop the method further to enable the investigation of microstructures in single living cells, tissue sections or the ion mobility of thin-film materials for battery applications. "The ability of NMR and MRI techniques to directly detect the mobility of atoms and molecules makes them absolutely unique compared to other imaging methods," says Prof. Maxim Zaitsev of the University of Freiburg. "We now have found a way how their spatial resolution, which is currently often deemed insufficient, can be significantly improved in future." ■

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