Combined technique using diamond probes enables nanoscale imaging of magnetic vortex structures

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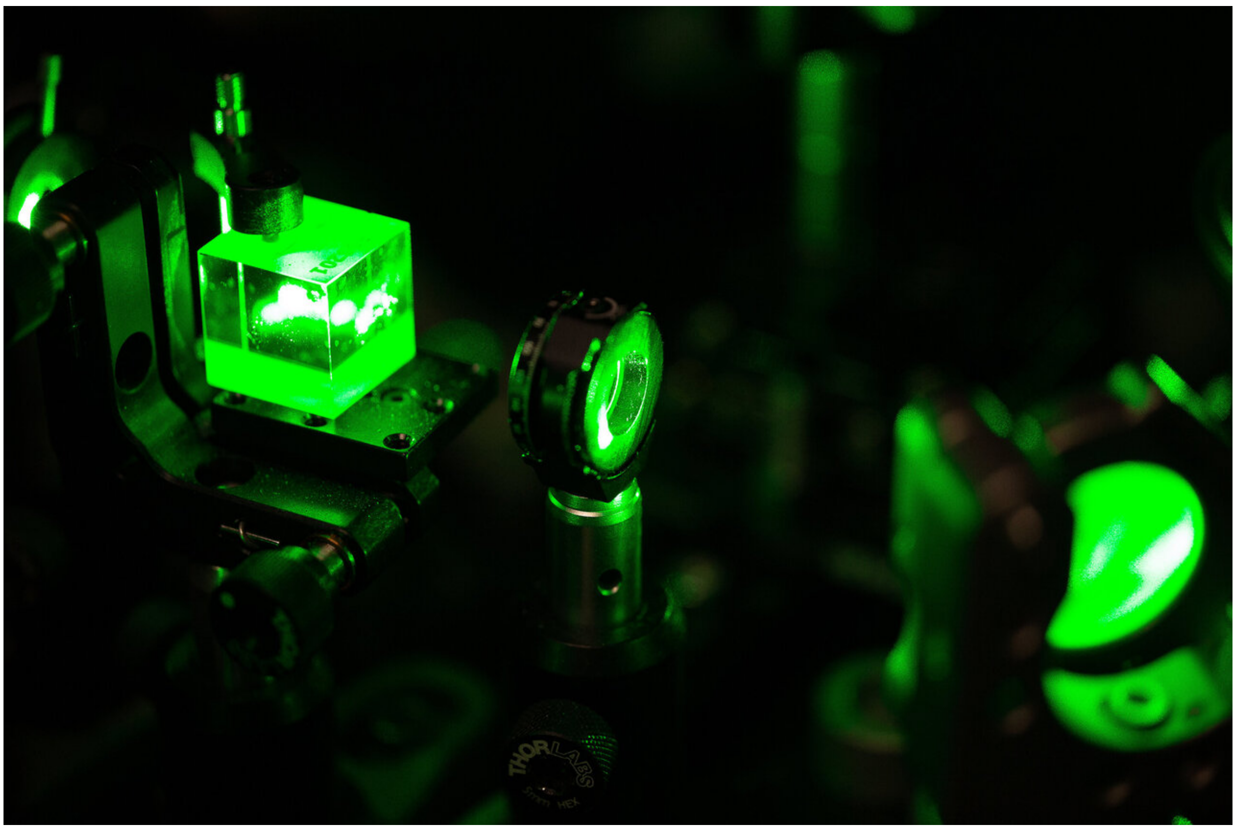


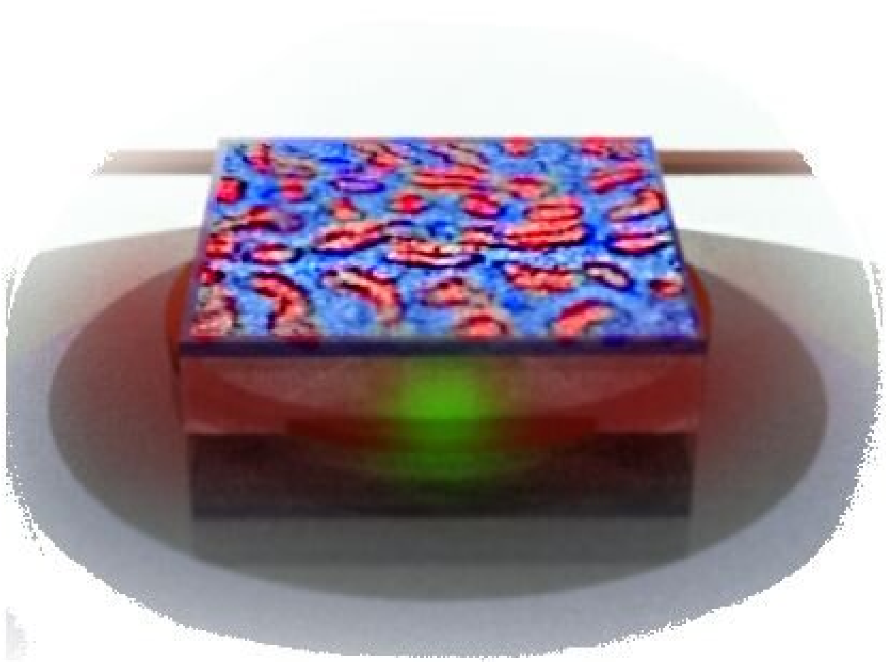
Diamond magnetometer with nitrogen-vacancy defects being optically initialized using green laser light. Credit: Arne Wickenbrock, JGU

Obtaining a precise understanding of magnetic structures is one of the main objectives of solid-state physics. Significant research is currently being undertaken in this field, the aim being to develop future data processing applications that use tiny magnetic structures as information carriers. Physicists at Johannes Gutenberg University Mainz (JGU) and the Helmholtz Institute Mainz (HIM) recently presented a new method for investigating magnetic structures combining two different techniques. This allows to measure and map the magnetization as well as the magnetic fields of the sample. Involved in the project were atomic physicists from the work group led by Professor Dmitry Budker and the team of experimental solid-state physicists led by Professor Mathias Kläui. The findings have been published in *Physical Review Applied*.

"In this project we combined two quantum sensing techniques which never before had been used together to analyze a sample," explained Till Lenz, first author of the article and a doctoral candidate in Budker's group. One well-known method employed in solid-state physics uses the magneto-optic Kerr effect (MOKE) in order to detect magnetic fields and magnetization. "But this gives us only a limited amount of information," said Lenz. For this reason, the researchers decided to combine the Kerr effect with magnetometry methods that utilize so-called diamond color centers in order to also enable the mapping of magnetic fields. "We hope that this will lead to new insights when it comes to solid-state physics and ferromagnetic structures," stated Georgios Chatzidrosos, also a doctoral student in the Budker group. Professor Mathias Kläui is excited about the new measuring capabilities: "The use of diamond probes provides a sensitivity that opens up entirely new options with regard to measurement potentials."

New combined measurement methods can be used in a wide range of different ambient conditions

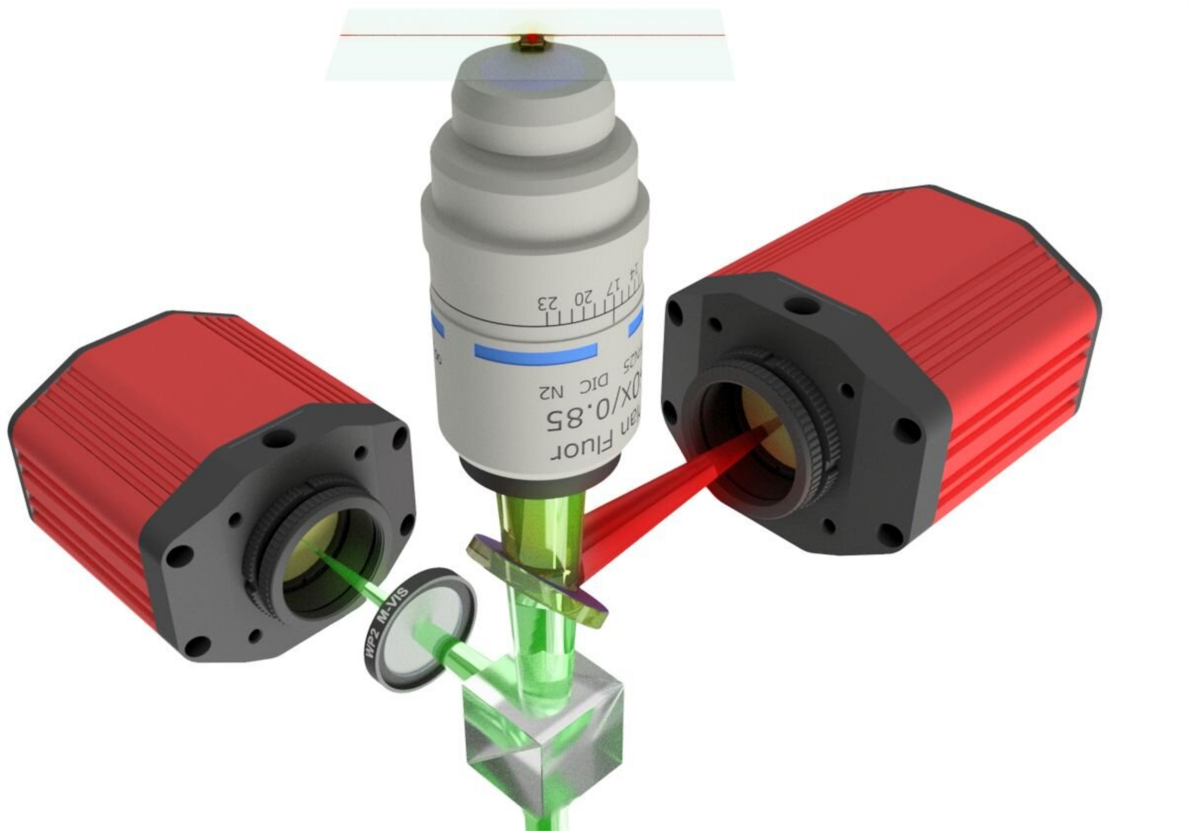
Diamond is not only a precious stone but is also used to make cutting and grinding tools. Specific defects in the diamond crystal lattice result in properties that can be used to examine magnetic structures. These color centers, also known as nitrogen-vacancy centers, are point defects in the carbon lattice structure of diamond. The research group led by Professor Dmitry Budker uses these color centers in diamond as probes to measure magnetic phenomena.



A thin layer of nitrogen-vacancy defects in diamond allows to measure magnetic structures of samples. Credit: Arne Wickenbrock, JGU

Diamond-based magnetometers can function at very low temperatures as well at temperatures above room temperature, while the distances required between sample and probe can be miniscule, in the range of just a few nanometers. "We have a thin layer of nitrogen defects in a diamond crystal and with this we can map magnetic structures and take photos of magnetic fields," explained Dr. Arne Wickenbrock from the Budker group. And co-author Dr. Lykourgos Bougas added: "By mapping all the components of a magnetic field, we can complement and extend the possibilities offered by magneto-optic measurements."

"The probe that functions with the help of diamond color centers is much more sensitive than conventional tools and provides us with extremely good results. We are able to access some fascinating samples, which results in unique opportunities for cooperation," emphasized Professor Mathias Kläui, describing the advantage of the collaboration between the two research groups. "Combining our complementary measurement techniques enables the complete reconstruction of the magnetic properties of our samples." The recently published article is the product of teamwork within the Dynamics and Topology (TopDyn) Top-level Research Area at JGU, which is funded by the state of Rhineland-Palatinate. In addition, the work was also undertaken under the umbrella of the 3D MAGiC project, which was launched in collaboration with Forschungszentrum Jülich and Radboud University Nijmegen in the Netherlands and has been awarded an ERC Synergy Grant.



Experimental setup for the imaging of magnetic structures using simultaneous magneto-optic Kerr effect (MOKE) microscopy and wide-field diamond magnetometry. Credit: Arne Wickenbrock, JGU

To quote the paper published in Physical Review Applied: "Our concept represents a novel platform for wide-field imaging of the magnetization and resultant magnetic fields of magnetic structures using engineered diamond magnetic sensors and an optical setup that allows for both measurement modalities." In addition to the two JGU and HIM work groups, also involved was Professor Yannick Dumeige of Université de Rennes 1 in France, who as a recipient of a Friedrich Wilhelm Bessel Research Award of the Alexander von Humboldt Foundation in 2018 also worked with the Budker group. Professor Kai-Mei Fu, physicist at the University of Washington, also participated in the project as a HIM Distinguished Visitor.

Looking to the future, the cooperation partners plan to employ the new technique to analyze various multidisciplinary aspects that are of particular interest to the respective groups. These include investigating two-dimensional magnetic materials, the magnetic effects of molecular chirality, and high-temperature superconductivity.

More information: Till Lenz et al. Imaging Topological Spin Structures Using Light-Polarization and Magnetic Microscopy, *Physical Review Applied* (2021). DOI: 10.1103/PhysRevApplied.15.024040

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