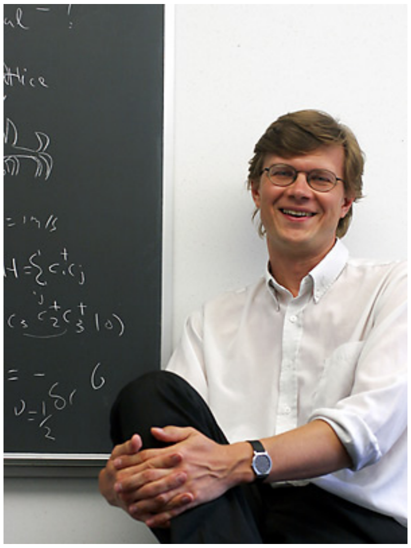
Harvard University Gazette Online

October 2, 2008



New research by Mikhail D. Lukin and colleagues will help make it possible to peer inside proteins.
File Rose Lincoln/Harvard News Office

Related links

Lukin illuminates quantum science

New research: Have light, will not travel

Researchers now able to stop, restart light

News Office Multimedia

Slide Shows

Videos

Special Presentations

Technique offers close-ups of electrons and nuclei

Diamond-based magnetic imaging could prove a boon in materials science, biology, medicine

By Steve Bradt
FAS Communications

Providing a glimpse into the infinitesimal, physicists have found a novel way to spy on some of the universe's tiniest building blocks.

Their "camera," described this week (Oct. 1) in the journal Nature, consists of a special "flaw" in diamonds that can be manipulated into sensitively monitoring magnetic signals from individual electrons and atomic nuclei placed nearby.

The new work represents a dramatic sharpening of the basic approach used in nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), which ascertain chemical structures and images inside human bodies by scanning the magnetic activity of billions of individual nuclei. The new diamond-based magnetic sensor could enable novel forms of imaging, marrying NMR's noninvasive nature with atomic-scale spatial resolution, potentially benefiting fields ranging from materials science, spintronics, and quantum information to structural biology, neuroscience, and biomedicine.

Among other applications, the new research could make it possible to peer inside proteins, map the structure of impossibly intricate molecules, closely observe the dynamics of microscopic biochemical processes, monitor the activity of neural circuits, or use single electrons and nuclei for storing and processing information. Some of these applications were recently described by the authors in a separate contribution published online Sept. 14 in the journal Nature Physics.

"Although some existing magnetic field sensors have higher sensitivity, they probe magnetic fields over large volumes of space," says Mikhail D. Lukin, professor of physics in Harvard University's Faculty of Arts and Sciences (FAS). "The combination of excellent sensitivity and nanoscale spatial resolution that we demonstrate is completely unique. Potentially, it may allow one to image single nuclei in individual molecules."

The collaborative research, led by Lukin and Harvard physicists Amir Yacoby and Ronald L. Walsworth, involved scientists from Harvard, the Smithsonian Institution, the Massachusetts Institute of Technology (MIT), and the University of Pittsburgh.

The work builds on a Science paper published last year by Lukin and colleagues. That paper reported that single atoms of carbon-13 — which make up some 1.1 percent of natural diamond — can be manipulated via a nearby single electron that can, in turn, be controlled by focusing laser light on a diamond lattice flaw where nitrogen replaces an atom of carbon. Such excitation using optical and microwave radiation causes the diamond flaw's electron spin to act as a very sensitive magnetic probe with extraordinary spatial resolution.

An electron's spin, or intrinsic angular momentum, acts like a tiny magnet, providing one of the few outwardly detectable signs of an atom's location. An atomic nucleus can also have a spin, but because a nucleus is much heavier than an electron, its magnetic field is a thousand times smaller, making it much harder to detect.

"Our magnetic sensor is based on a single electronic spin associated with an impurity or flaw in a small diamond crystal. We managed to turn our understanding of quantum information physics into an extraordinary measuring apparatus," says Yacoby, professor of physics at FAS. "A nanocrystal of diamond containing this specific type of impurity could be placed on the tip of a needle as a minuscule probe of extremely weak magnetic fields, such as those generated by the spin of an electron or even an atomic nucleus."

The 2007 work effectively brought the futuristic technology of quantum information systems into the realm of solid-state materials under ordinary conditions; the current research builds on that advance to develop new nanometer-scale magnetic sensors that could have important implications in imaging of a variety of materials, biological compounds, and tissues.

"Precision sensing of magnetic fields is at the forefront of a wide range of scientific fields — from nanoscience to bioimaging," says Walsworth, senior lecturer on physics at Harvard and senior physicist at the Smithsonian. "Potential nanoscale applications of the diamond magnetic sensor include detection of individual electron and nuclear spins in complex biological molecules, and serving as a universal 'quantum magnetic head' for addressing and readout of quantum bits of information encoded in an electron or nuclear spin memory."

Accompanying this work in the current issue of Nature is a report from scientists at the University of Stuttgart who have obtained the first scanning images using a diamond magnetic sensor.

"This is a case where the sum of two contributions is really greater than their parts," says Lukin. "Together, they really jump-start a new research field."

Lukin, Yacoby, and Walsworth's co-authors on the Nature paper are Jeronimo Maze, Sungkun Hong, Liang Jiang, Emre Togan, and Alexander Zibrov, all at Harvard; Paul Stanwix of the Smithsonian; Jonathan Hodges at Harvard and MIT; Jacob Taylor at MIT; and M.V. Gurudev Dutt at Pittsburgh. The work was supported by the National Science Foundation, the Defense Advanced Research Projects Agency, the Packard Foundation, and Harvard's Center for Nanoscale Systems.

steve_bradt@harvard.edu