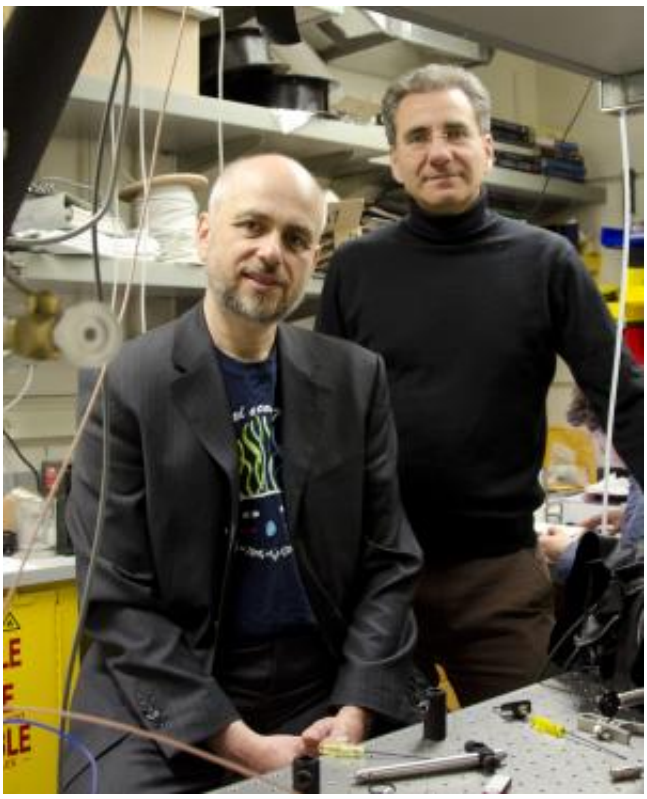
Colored diamonds are a superconductor's best friend

March 6 2014, by Robert Sanders



This is a photo of Dmitry Budker, professor of physics at University of California Berkeley, and Ron Folman, professor of physics at Be-Gurion University of the Negev, in their lab at University of California Berkeley. Folman builds 'atom chips' that he and Budker use to probe the minuscule magnetic properties of high-temperature superconductors. Credit: Robert Sanders/University of California Berkeley

(Phys.org) —Flawed but colorful diamonds are among the most sensitive detectors of magnetic fields known today, allowing physicists to explore the minuscule magnetic fields in metals, exotic materials and even human tissue.

University of California, Berkeley, physicist Dmitry Budker and his colleagues at Ben-Gurion University of the Negev in Israel and UCLA have now shown that these diamond sensors can measure the tiny magnetic fields in high-temperature superconductors, providing a new tool to probe these much ballyhooed but poorly understood materials.

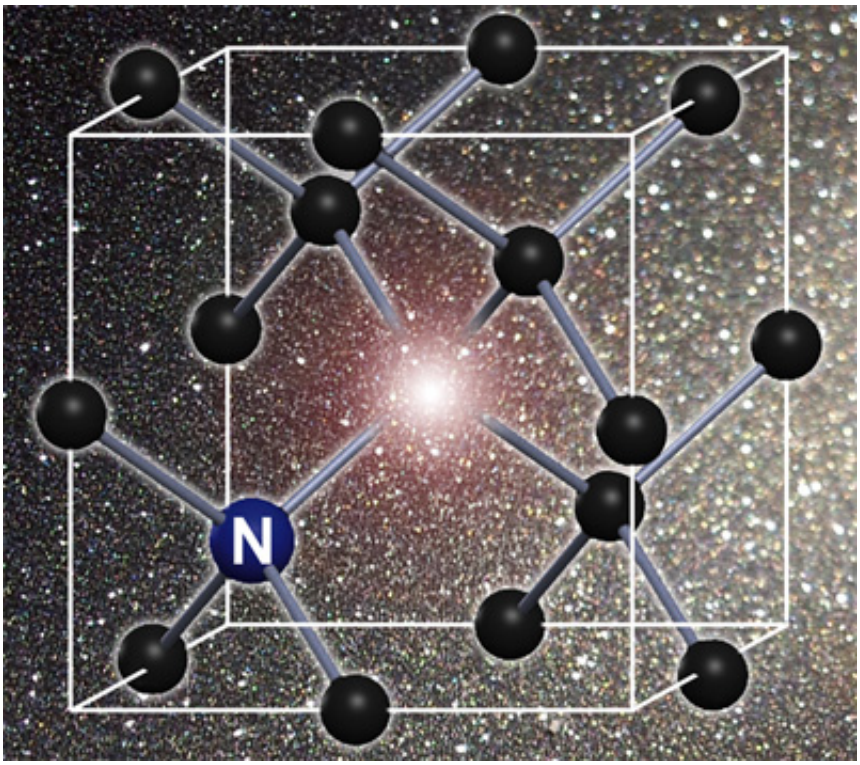
"Diamond sensors will give us measurements that will be useful in understanding the physics of high temperature superconductors, which, despite the fact that their discoverers won a 1987 Nobel Prize, are still not understood," said Budker, a professor of physics and faculty scientist at Lawrence Berkeley National Laboratory.

High-temperature superconductors are exotic mixes of materials like yttrium or bismuth that, when chilled to around 180 degrees Fahrenheit above absolute zero (-280ºF), lose all resistance to electricity, whereas low-temperature superconductors must be chilled to several degrees above absolute zero. When discovered 28 years ago, scientists predicted we would soon have room-temperature superconductors for lossless electrical transmission or magnetically levitated trains.

It never happened.

"The new probe may shed light on high-temperature superconductors and help theoreticians crack this open question," said coauthor Ron Folman of Ben-Gurion University of the Negev, who is currently a Miller Visiting Professor at UC Berkeley. "With the help of this new sensor, we may be able to take a step forward."

Budker, Folman and their colleagues report their success in an article posted online Feb. 18 in the journal *Physical Review B*.



The crystal lattice of a pure diamond is pure carbon (black balls), but when a nitrogen atom replaces one carbon and an adjacent carbon is kicked out, the 'nitrogen-vacancy center' becomes a sensitive magnetic field sensor.

Flawed but colorful

Colorful diamonds, ranging from yellow and orange to purple, have been prized for millennia. Their color derives from flaws in the gem's carbon structure: some of the carbon atoms have been replaced by an element, such as boron, that emits or absorbs a specific color of light.

Once scientists learned how to create synthetic diamonds, they found

that they could selectively alter a diamond's optical properties by injecting impurities. In this experiment, Budker, Folman and their colleagues bombarded a synthetic diamond with nitrogen atoms to knock out carbon atoms, leaving holes in some places and nitrogen atoms in others. They then heated the crystal to force the holes, called vacancies, to move around and pair with nitrogen atoms, resulting in diamonds with so-called nitrogen-vacancy centers. For the negatively charged centers, the amount of light they re-emit when excited with light becomes very sensitive to magnetic fields, allowing them to be used as sensors that are read out by laser spectroscopy.

Folman noted that color centers in diamonds have the unique property of exhibiting quantum behavior, whereas most other solids at room temperature do not.

"This is quite surprising, and is part of the reason that these new sensors have such a high potential," Folman said.

Applications in homeland security?

Technology visionaries are thinking about using nitrogen-vacancy centers to probe for cracks in metals, such as bridge structures or jet engine blades, for homeland security applications, as sensitive rotation sensors, and perhaps even as building blocks for quantum computers. Budker, who works on sensitive magnetic field detectors, and Folman, who builds 'atom chips' to probe and manipulate atoms, focused in this work on using these magnetometers to study new materials.

"These diamond sensors combine high sensitivity with the potential for high spatial resolution, and since they operate at higher temperatures than their competitors – superconducting quantum interference device, or SQUID, magnetometers – they turn out to be good for studying high temperature superconductors," Budker said. "Although several

techniques already exist for magnetic probing of superconducting materials, there is a need for new methods which will offer better performance."

The team used their diamond sensor to measure properties of a thin layer of yttrium barium copper oxide (YBCO), one of the two most popular types of high-temperatures superconductor. The Ben-Gurion group integrated the diamond sensor with the superconductor on one chip and used it to detect the transition from normal conductivity to superconductivity, when the material expels all magnetic fields. The sensor also detected tiny magnetic vortices, which appear and disappear as the material becomes superconducting and may be a key to understanding how these materials become superconducting at high temperatures.

"Now that we have proved it is possible to probe high-temperatures superconductors, we plan to build more sensitive and higher-resolution sensors on a chip to study the structure of an individual magnetic vortex," Folman said. "We hope to discover something new that cannot be seen with other technologies."

Researchers, including Budker and Folman, are attempting to solve other mysteries through magnetic sensing. For example, they are investigating networks of nerve cells by detecting the magnetic field each nerve cell pulse emits. In another project, they aim at detecting strange never-before-observed entities called axions through their effect on magnetic sensors.

More information: Diamond magnetometry of superconducting thin films, *Physical Review B*: journals.aps.org/prb/abstract/ … 3/PhysRevB.89.054509