Magnetizing Diamonds with Light

By tuning the magnetic properties of a tiny levitating diamond, researchers control its orientation in a magnetic field.

By **Michael Schirber**

New experiments reveal that a tiny levitating diamond can become magnetized in a strong magnetic field and orient itself in the field like a compass needle [1]. This induced magnetization relies on magnetic spins inside atomic scale defects. The ability to fix the orientation of these defect-filled diamonds could improve magnetic field sensing and NMR imaging. Aligned diamonds could also be used to explore the limits of quantum behavior in macroscopic objects.

Flawless diamonds may attract rich clients in jewelry shops, but physicists have an eye for diamonds bearing defects called nitrogen-vacancy (NV) centers. An NV center is made of a single nitrogen atom and a single neighboring vacancy—an empty atomic site in the crystal structure. These defects behave like individual atoms with their own bound electrons. Researchers can directly manipulate an NV center's electronic states using light tuned to specific wavelengths.

A cut above. Researchers have shown that the crystalline axes of a micrometer-sized diamond can be aligned with a magnetic field by optically exciting defects in the crystal.
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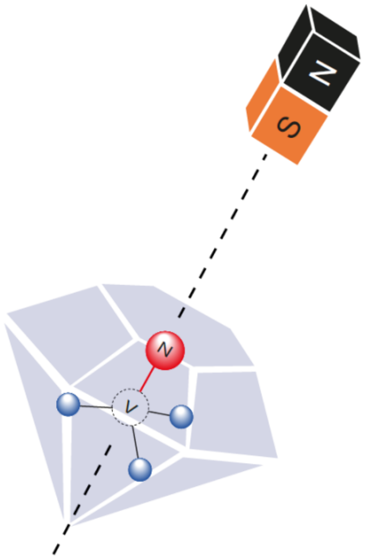
Many researchers are studying diamond NV centers for uses such as quantum computing and magnetic-field sensing (see Focus: Hooking a Magnet to an Electron). In some of these applications, the diamond is suspended in a fluid or is made to levitate in an electric field. The challenge is that these "floating" diamonds tend to wobble, which makes them less useful. "There are plenty of situations where the diamonds do not naturally stay pointing in the direction that you'd like," says Gabriel Hétet of the École Normale Supérieure (ENS) in Paris.

Hétet and his colleagues have found a way to lock the direction of a levitating diamond in a magnetic field. The method builds on recent experiments in which the team induced magnetization of a diamond by exciting its NV centers with microwave pulses [2]. The researchers have now shown that they can produce a similar effect by replacing the microwaves with a strong magnetic field.

Many types of materials become magnetized when placed in a magnetic field. For paramagnets such as aluminum, the induced field points in the same direction as the applied field, whereas for diamagnets such as water, the induced field points in the opposite direction. Usually, the induced magnetization is small and depends on the electron motion within the material. Hétet and his colleagues were able to create a relatively large diamagnetic effect in diamond by manipulating the electron spin states of the NV centers.

The team first levitated a 15-micrometer-wide, NV-doped diamond crystal using an electric field trap. They shined a green



Crystal compass. When the applied magnetic field is greater than 0.1 tesla, an NV-filled diamond becomes diamagnetic. In this diamagnetic phase, the diamond rotates so as to align the axes of the NV centers with the magnetic field.
Credit: G. Hétet/ENS Paris

laser on the diamond, forcing its NV electrons into their zero-spin ground state. They then applied a magnetic field, which lowered the energy of the NV excited state that corresponds to a spin of negative one. In calculations, the researchers showed that—when the field is strong enough—electrons will transfer from the zero-spin state into the negative-one-spin state, creating an alignment of spins and a net magnetization in the diamond. The team verified these predictions using a microwave-based probe that measures the magnetic response of the diamond.

The type of magnetization depended on the strength of the magnetic field. Below 0.1 tesla, the diamond was paramagnetic; above this threshold, it was diamagnetic. In the diamagnetic phase, the diamond experienced torques that rotated it into a particular orientation in which the NV axis (defined by the positions of the nitrogen atom and its corresponding vacancy) aligned with the magnetic field. This orientation was stable—if the diamond was perturbed, the magnetization-based torques brought it back into alignment. Such a stable orientation could prove useful. “It’s a good starting point for doing all kinds of manipulations to the NV spins,” Hétet says. One application is to use NV-doped nanodiamonds to enhance the contrast in an NMR image or to sense the magnetic field in a living cell. A more long-term goal is to explore quantum effects, such as superposition, in a macroscopic diamond. One could try to take advantage of the coupling between NV spins and diamond orientation to see whether some of the spins’ quantumness transfers to the diamond motion, Hétet explains.

“The paper advances the control of NV centers coupled to mechanical degrees of freedom in a levitated diamond,” says quantum scientist Oriol Romero-Isart from the Institute for Quantum Optics and Quantum Information in Austria. The long-term goal, he says, is to perform quantum experiments with a single NV center coupled to the diamond’s orientation. “While that level of control is still a formidably challenging goal, results such as the one by the Hétet team show progress in that direction,” Romero-Isart says.

Michael Schirber is a Corresponding Editor for ***Physics*** based in Lyon, France.

REFERENCES

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