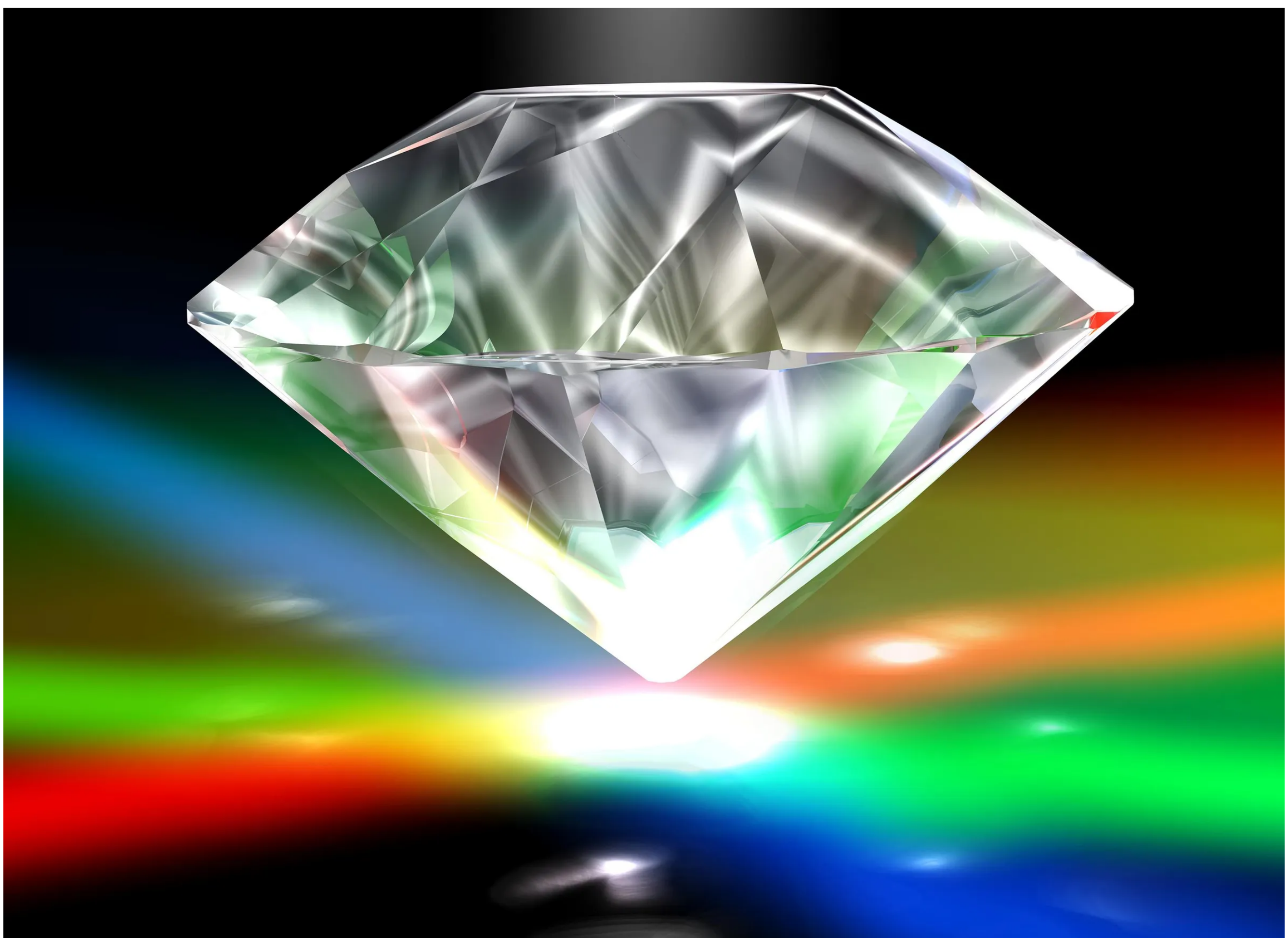
IEEE Spectrum

NEWS SENSORS

Photon Bursts Boost Quantum-Sensor Performance 100x › What was previously a nuisance may now greatly enhance diamond-based sensor sensitivity

BY CHARLES Q. CHOI

14 SEP 2022



QUANTUM SENSORS PROMISE unprecedented levels of sensitivity to empower a host of new applications, such as detecting the magnetic fields of thoughts or listening to radio waves from dark matter. However, many quantum sensors experience high levels of noise during measurements that severely degrade their performance. Now a new study reveals a technique for overcoming this noise to potentially boost the sensitivity of these devices up to a hundredfold.

Quantum technology depends on quantum effects that can arise because the universe can become quite ill-defined at its very smallest levels. For example, the quantum effect known as superposition enables atoms and other building blocks of the cosmos to essentially exist in two or more places or states at the same time.

These quantum effects are notoriously fragile to outside interference. However, quantum sensors capitalize on this vulnerability to achieve extraordinary sensitivity to the slightest disturbances in the environment. Scientists are hidden underground with unprecedented detail and noninvasively scan brain activity with exceptional performance and cost.

A common solid-state quantum-sensor platform consists of microscopic artificial diamonds with defects within them, in which a carbon atom is replaced with a nitrogen atom and the adjacent carbon atom is missing. These nitrogen-vacancy (NV) centers may each be thought of as a "quantum bit" existing in a superposition of two energy levels, 0 and 1.

"When you apply green laser light, you only get strong fluorescence of red light if the qubit was in the 1 state, and not the 0," says study senior author Aashish Clerk, a theoretical quantum physicist at the University of Chicago. Magnetic, electric, thermal, and other disturbances can alter this response, allowing NV centers to help serve as sensors.

However, typical solid-state quantum sensors, including those based on NV centers, often encounter a great deal of noise during the readout of their measurements. This detection noise can significantly limit their achievable sensitivity.

Now Clerk and his colleagues find that a quantum effect often seen as a nuisance may help dramatically improve the sensitivity of these quantum sensors. “We think sensitivity enhancements of one to two orders of magnitude might be possible,” he says.

A solid-state quantum sensor may often possess hundreds or thousands of qubits. These may collectively release their energy in a burst of photons. This effect, known as superradiant decay, can inject some noise into quantum sensing and so is often unwanted. However, the noise from this decay is much less than what solid-state quantum sensors experience during readout.

When the researchers explored the interactions that occurred between qubits during this decay, “we realized something potentially useful could be going on,” Clerk says. “As each single qubit decays from 1 to 0, it gives a little kick to all the other undecayed qubits, which remain in a superposition state.”

The scientists unexpectedly found this kick could magnify the detectability of the information encoded in the remaining qubits. If the researchers let the superradiant decay happen for only a limited time, they could end up with half the qubits staying intact while significantly amplifying the signals in them.

The researchers suggest that coupling a microwave or mechanical resonator with the qubits in a NV-center quantum sensor could help enable a superradiant amplification step before readout. This would in turn greatly augment the resulting sensitivity of the device.

The scientists add that this approach should also work with a number of other quantum-sensing platforms, such as those based on silicon-vacancy centers in diamonds. “We are actively working with experimental groups to implement our protocol,” Clerk says.

Physicists have known of superradiance since the 1950s. “It is surprising and exciting that there are aspects of superradiance physics that we are only just now starting to understand and exploit,” Clerk says.

Clerk, with theoretical quantum physicist Martin Koppenhöfer at the University of Chicago and colleagues, detailed these findings online 30 August in the journal *PRX Quantum*.