Demonstration of diamond nuclear spin gyroscope
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A diamond sensor
Nuclear spin gyroscopes are based on nitrogen-vacancy (NV) color centers in diamond and are analogs of vapor-based NMR devices capable of functioning across a broad range of environmental conditions. A diamond sensor can function as a multi-sensor to report on magnetic field, temperature and strain, while serving as a frequency reference, suited for challenging environments. Jarmola et al. showed how a diamond NMR gyroscope directly provided information about the nuclear spin states without requiring precise knowledge of electron spin transition frequencies that are susceptible to environmental influences. With further improvements to the device, the team expect practical applications of miniature diamond gyroscopes during navigation.

Experimental setup
In a new report now published in Science Advances, Andrey Jarmola and an international research team in physics and materials in the U.S. and Germany demonstrated the function of a rotation sensor based on nitrogen-14 (14N) nuclear spins intrinsic to nitrogen-vacancy color centers in diamond. Nitrogen vacancy color centers are formed by nitrogen impurities that sit next to a missing carbon in diamond. The sensor used optical polarization and readout of the nuclei and a radiofrequency double-quantum pulse protocol to monitor the 14N nuclear spin precession. Rotation sensors or gyroscopes are typically used for navigation and automotive guidance. Among commercial sensors including mechanical gyroscopes and microelectromechanical systems, emerging techniques include nuclear magnetic resonance (NMR) gyroscopes. These sensors can surpass commercial devices within the next decade relative to accuracy, robustness and miniaturization.
DQ measurement protocol using 14N nuclear spins in diamond. (A) Energy-level diagram of the NV center ground state with and without a magnetic field B applied along the NV axis. The inset depicts the 14N nuclear spin levels, where the splitting between the $\Delta m_I = \pm 1$ sublevels depends on the applied field and on the rotation of the sample around the NV axis. Rotation sensing is based on the measurement of this interval. (B) DQ nuclear Ramsey pulse sequence. Inset: 4-Ramsey phase cycling measurement scheme. (C) DQ nuclear Ramsey fringes (R1, R2, R3, and R4) obtained by sequentially alternating phases of the last double quantum pulse as depicted in the inset of (B). The frequency-domain spectrum shows the square of the absolute value of the Fourier transform, which reveals DQ signal at IDQ frequency and residual single-quantum (SQ) signals at f1 and f2 frequencies. Bottom left: DQ nuclear 4-Ramsey fringes obtained by combining four DQ sequential Ramsey measurements $R_1 \equiv R_2 + R_3 \equiv R_4$ to cancel residual SQ signals. (D) DQ nuclear 4-Ramsey fringes. Symbols represent experimental data, while the solid line is an exponentially decaying sine wave fit. The oscillation frequency of the signal corresponds to the IDQ, while an exponential decay time corresponds to the nuclear DQ spin coherence time $T_2 = 1.95(5)$ ms. Inset: Zoomed plot of DQ 4-Ramsey fringes near the working point; rotation measurements were performed at a fixed free precession time $\tau = 1.4$ ms by monitoring changes in the fluorescence signal. Credit: Science Advances, doi: 10.1126/sciadv.abl3840

Diamond gyroscope: Rotation sensing. (A) Diamond gyroscope fluorescence signal $R$ measured as a function of the rotation rate of the platform (average of 15 traces; 200 s per trace). The calibration coefficient $\alpha$ is determined from the linear fit. Inset: Time stability of $\alpha$. Fractional change in $\alpha$ is measured over several hours. (B) The rotation rates both measured by the diamond gyroscope and reported by the rate table are averaged over each second and then plotted together as a function of time. The time dependence is programmed to trace “NV.” Credit: Science Advances, doi: 10.1126/sciadv.abl3840

Rotation detection principle and practical applications of the gyroscope

To detect rotation, the team measured the shift in the precession state of $^{14}$N nuclear spins intrinsic to nitrogen vacancy centers in diamond. The scientists prepared the $^{14}$N nuclear spins in a superposition state. They then achieved the rotation detection presented in the work by measuring the frequency shifts with a Ramsey interferometry technique. To demonstrate the practical implications of the diamond gyroscope across a range of rotation rates, the scientists performed a series of test experiments on a rate
To begin with, they calibrated the gyroscope and then converted the fluorescence signal into a calibration rotation signal.


**Outlook**

In this way, Andrey Jarmola and colleagues developed a solid-state NMR gyroscope based on $^{14}$N nuclear spins intrinsic to nitrogen vacancy (NV) centers in diamond. Jarmola et al. noted the key features of the technique including optical polarization and readouts of the nuclear spins without using microwave transitions. By using temperature-compensated magnets, magnetic shielding and robust pulse protocols, the team reduced the influence of temperature and magnetic field drift to extend the long-term stability of the gyroscope to hundreds of seconds. The team intend to improve the sensitivity of the diamond gyroscope by extending the $^{14}$N nuclear spin coherence time. To improve the long-term stability, they also propose to reduce the ambient magnetic field drifts with better magnetic shielding.

**More information:** Andrey Jarmola et al, Demonstration of diamond nuclear spin gyroscope,