Strain engineering enhances spin readout in quantum technologies, study shows

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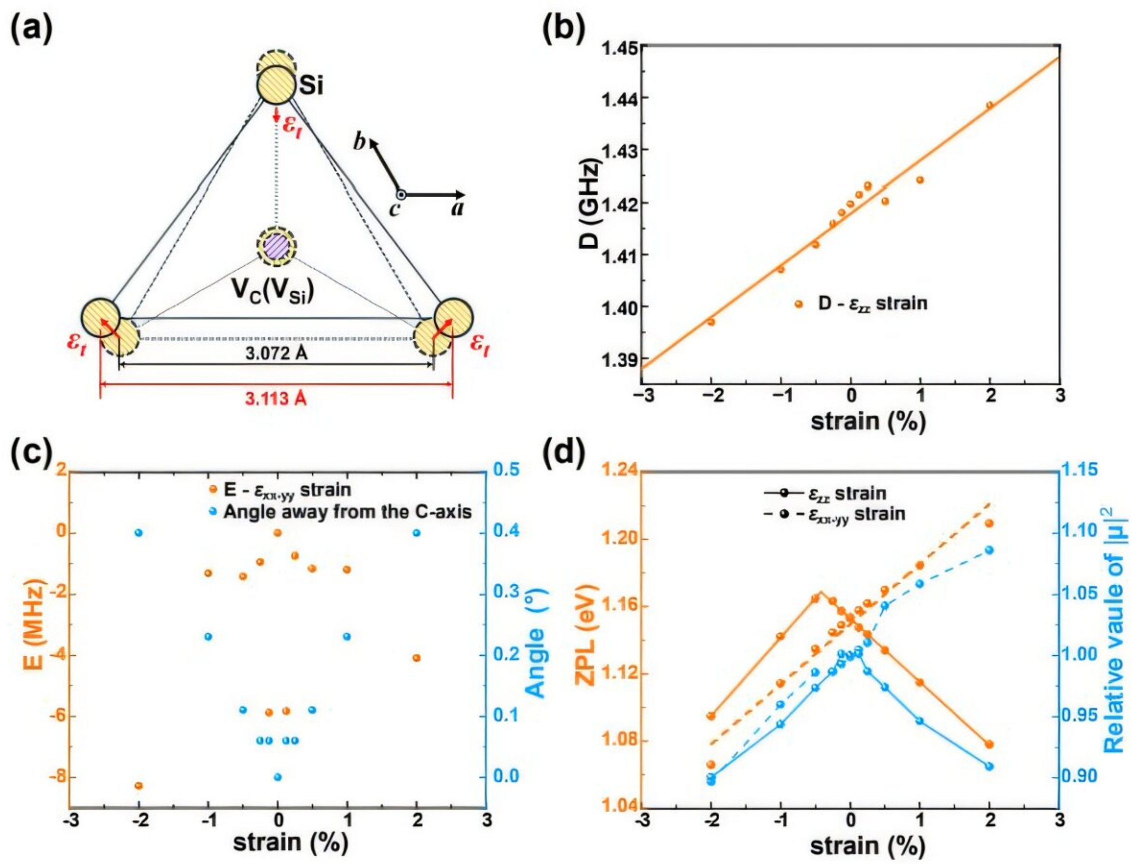


(a) Schematic diagram of the change of hh-divacancy due to the transverse strain ε_t of (xx−yy). The c-axis is perpendicular to the paper and extends outward. All yellow (purple) striped filled spheres represent Si (C) atoms. The dotted (solid) outline indicates the absence (presence) of strain. The black and red number with a unit of Angstrom shows the distance between the two Si atoms neighboring the divacancy before and after applying the 1% tensile transverse strain. (b)

Calculated D parameters under longitudinal strains. (c) Calculated E parameters (orange) and the angle away from the c-axis (blue) under transverse strains. (d) Calculated ZPL values (orange) and relative values of $|\mu|^2$ (blue) under both longitudinal and transverse strains. Credit: Haibo Hu et al

Quantum defects are tiny imperfections in solid crystal lattices that can trap individual electrons and their "spin" (i.e., the internal angular momentum of particles). These defects are central to the functioning of various quantum technologies, including quantum sensors, computers and communication systems.

Reliably predicting and controlling the behavior of quantum defects is thus very important, as it could pave the way for the development of better performing quantum systems tailored for specific applications. A property closely linked to the dependability of quantum technologies is the so-called spin readout contrast, which essentially determines how clear it is to distinguish between two different spin states in a system.

Researchers at the Harbin Institute of Technology (Shenzhen), the HUN-REN Wigner Research Center for Physics, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences and other institutes recently showed that strain engineering (i.e., stretching or compressing materials) could be used to control how quantum defects behave and enhance spin readout contrast in quantum systems.

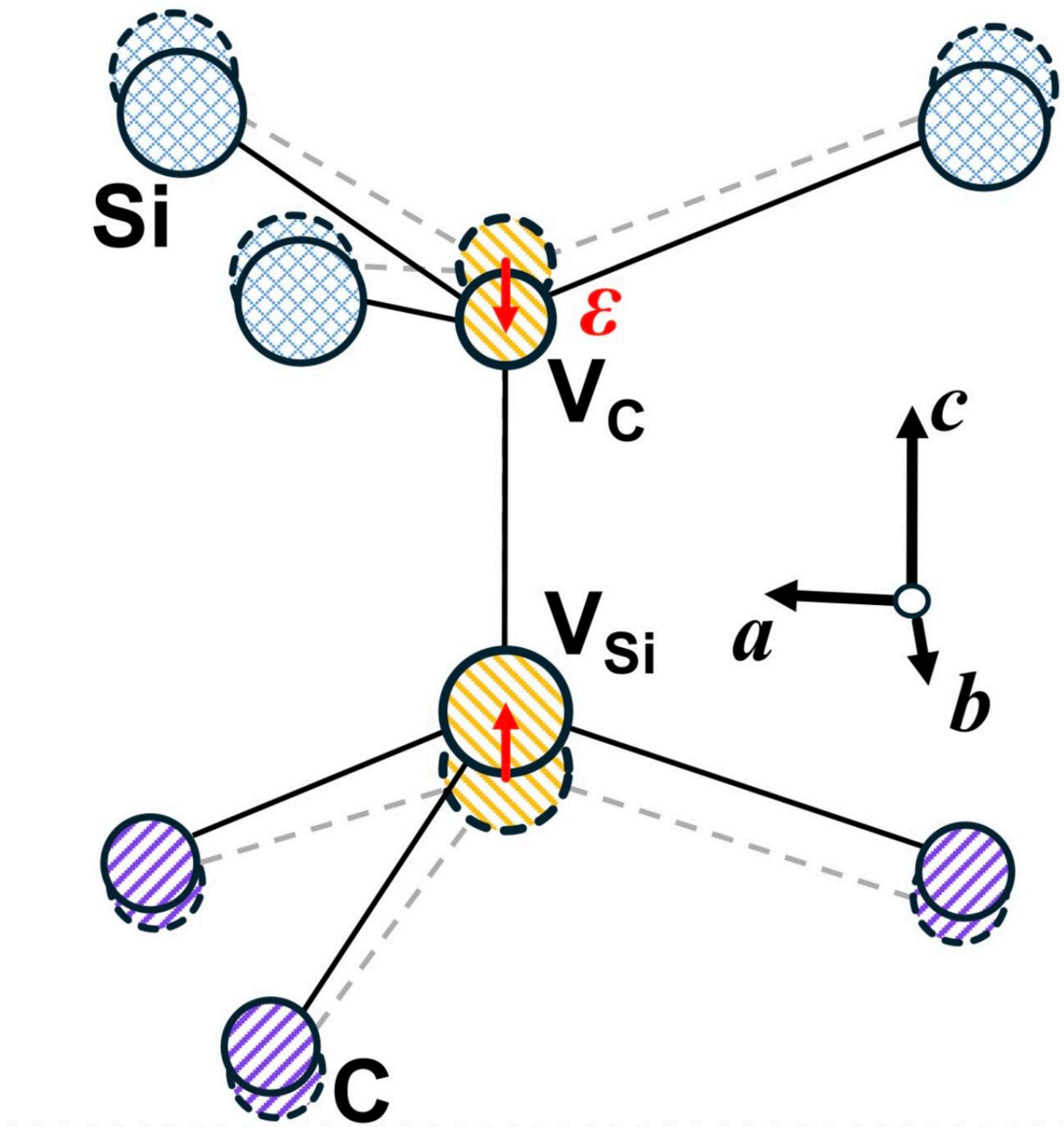
Their paper, published in *Physical Review Letters*, could open new possibilities for the realization of sophisticated quantum biosensing devices and other advanced quantum technologies.

"Our paper was inspired by the challenge of achieving reliable spin readout in solid-state quantum defect systems, especially at room temperature," Adam Gali, Qinghai Song, and Yu Zhou, co-senior authors of the paper, told Phys.org.

"We aimed to show that strain could be a potential control parameter to significantly enhance the readout contrast of high-spin solid-state defects, which is crucial for advancing quantum technologies, e.g., developing efficient quantum sensors operating under ambient conditions."

As a first step, a team of theoretical physicists led by Prof. Adam Gali at HUN-REN Wigner Research Center developed a new framework. This framework describes the relationship between a system's spin readout contrast and the electronic structure of high-spin defects.

"We then used ab initio wave functions to compute the relevant quantities and quantify the contrast," explained Gali.



Schematic of a silicon carbide divacancy under mechanical strain. The distorted lattice (solid) compared with the unstrained case (dashed) modifies spin-dependent energy levels, enabling a better room-temperature optical readout contrast. Credit: Hu et al. (*Physical Review Letters*, 2025).

"We hypothesized that specific strain fields can tune these quantities, thereby enabling control over the readout contrast. Building on our previous theoretical work, we tested this hypothesis and found a significant strain-induced effect."

Building on the theoretical work by Gali and his colleagues, another research group at Harbin Institute of Technology, led by Prof. Qinghai Song, performed experiments aimed at assessing the potential of strain engineering for controlling spin readout contrast.

As part of these experiments, the team used the existing strain within silicon carbide membranes and measured the spin properties of individual defects.

"Our experiments confirmed the simulations, demonstrating a significantly enhanced readout contrast, which means we can distinguish between different spin states more effectively," said Song.

"Our most significant finding is that strain engineering is a powerful and practical way to boost the spin readout contrast of quantum defects, achieving over 60% at room temperature."

This work by Gali, Song and their colleagues demonstrates that the careful engineering of the strain applied to quantum systems can significantly improve the ability to distinguish between distinct spin states within them. As part of their study, the researchers showed that strain engineering can significantly enhance the sensitivity of quantum sensors.

Other research teams could soon draw inspiration from this paper and set out to devise other strain engineering-based strategies to precisely control quantum defects. Meanwhile, Gali, Song and their colleagues plan to continue improving their approach and assess its potential for enhancing the performance of other quantum devices.

"Our future plans include seeking more precise methods for controlling strain and achieving a more accurate characterization of the underlying physics of strain-spin interactions," added Song.

"We also aim to extend strain engineering to other quantum defect systems and integrate these strained materials into advanced quantum circuits."

More information: Haibo Hu et al, Strain-Enhanced Spin Readout Contrast in Silicon Carbide Membranes, *Physical Review Letters* (2025). DOI: 10.1103/tdb3-tqfv. On *arXiv*: DOI: 10.48550/arxiv.2506.00345