Team obtained high-level control of spin qubit lifetime based on silicon quantum dots

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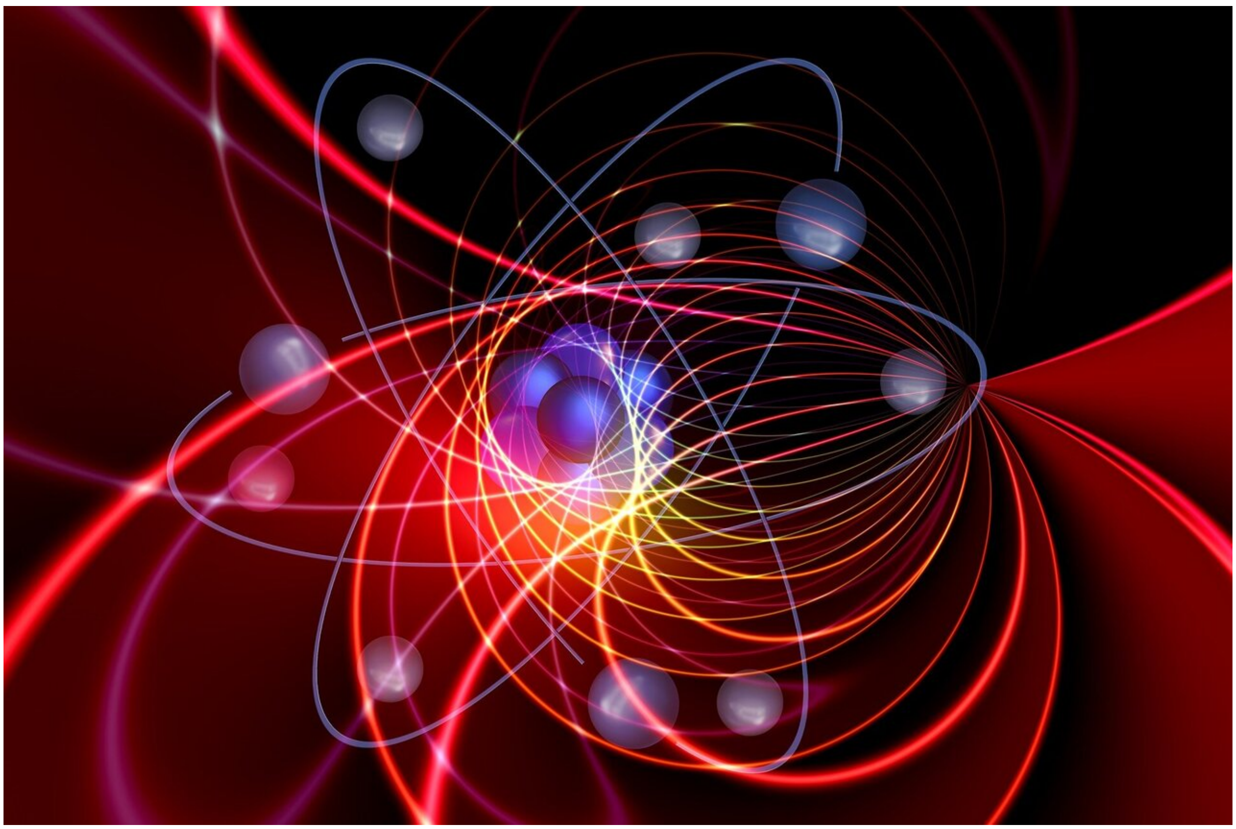

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By tuning the direction of the external magnetic field with respect to the crystallographic axis of the silicon wafer, an improvement of spin lifetime (relaxation time) by over two orders of magnitude was reported in silicon quantum dots. This breakthrough was carried out by a team led by academician Guo Guangcan from CAS Key Laboratory of Quantum Information, USTC, in which Prof. Guo Guoping, Prof. Li Hai-Ou with their colleagues and Origin Quantum Computing Company Limited. This work was published in *Physical Review Letters* on June 23, 2020.

Spin qubits based on silicon quantum dots have been a core issue in the development of large scale quantum computation due to its long coherence time and the compatibility with modern semiconductor technology. Recently, the relaxation time and dephasing time of spin qubits developed in Si MOS (Metal-Oxide-Semiconductor) and Si/SiGe heterostructure have surpassed hundreds of milliseconds and hundreds of microseconds, respectively, resulting in a single-qubit control fidelity over 99.9% and a two-qubit gate fidelity over 98%. With the success in college, labs and companies from the industry are starting to be involved in this field, such as Intel, CEA-Leti, and IMEC. However, the existence of valley states (a state associated with the dip in a particular electronic band) in silicon quantum dots could reduce spin relaxation time and dephasing time seriously via spin-valley mixing and limit the control fidelity of qubits. It was reported that at a certain magnetic field, spin-valley mixing could decrease the spin relaxation time to shorter than one millisecond (even one microsecond under certain conditions), called a spin relaxation "hot spot." When the number of qubits increase, this phenomenon will cause a great number of "bad" qubits and impedes further extension to more qubits.

A traditional method to suppress the adverse effects from spin-valley mixing is to increase the magnitude of valley splitting and push the qubit so far away that spin and valley states are no longer mixed. However, since the valley states are affected by multiple factors from the material, which is usually not uniform, the magnitude of valley splitting is hard to control (especially in Si/SiGe heterostructure). An alternative approach is to directly control the magnitude of spin-valley mixing. It was reported that in GaAs quantum dots, the strength of spin-orbit coupling could be tuned by the in-plane magnetic field orientation and the spin relaxation time is therefore extended. Nevertheless, so far, there is still no report on how the external magnetic field direction affects the strength of spin-valley mixing in silicon.

To resolve this problem, Prof. Li Hai-Ou, Prof. Guo Guoping and their colleagues fabricated high quality Si MOS quantum dot and achieved single-shot readout of spin qubits. Based on this reliable technique, they investigated the effect of both the strength and orientation of the external magnetic field on spin relaxation rates. They found when the in-plane external magnetic field is oriented at a certain angle, the spin relaxation "hot spot" could be "cooled down" by two orders of magnitude, increasing the relaxation time from below one millisecond to over one hundred milliseconds. This great variation indicates that spin-valley mixing is effectively suppressed, and it lays a foundation for future research on how to rid spin qubits of spin-valley mixing. Also, the researchers found that this anisotropy could still be over two orders of magnitude when the electric field is varied. This suggests that the anisotropy magnitude is electric-field independent in a certain range and it could be applied to an array of qubits that contain different local electric fields, which should offer new directions for optimizing readout, control and multi-qubit extension of silicon based spin qubits.

This work is highly regarded by anonymous referees, who said, "This work makes an important contribution to unraveling the underlying phenomena and solving the practical problem of finding the optimum operating conditions to exploit the spin degrees of freedom in silicon quantum dots," and "The study presented in this manuscript represents one of the few extensive studies realized for spin relaxation anisotropy in QDs and provides potential new ways to probe also the anisotropy properties of inter-valley and intra-valley spin mixing mechanisms," and "The physical understanding of the interplay of spin, valley and orbital degrees of freedom is taken to a next level with this work."

More information: Xin Zhang et al. Giant Anisotropy of Spin Relaxation and Spin-Valley Mixing in a Silicon Quantum Dot, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.257701

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