Theory on the Effective g-Factor of a Hole-Spin Qubit in Semiconductor Quantum Dot Systems

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Hole spin qubits in germanium quantum dots (QDs) have emerged as a promising platform for scalable semiconductor qubit devices. One of the main advantages of the hole qubits over the electron spin qubits is the strong spin-orbit (SO) coupling, which allows the implementation of electric dipole spin resonance (EDSR) without microstructures to create local magnetic field gradients for single-qubit gate operations. However, the SO coupling makes the hole qubits vulnerable to charge noises and makes the analysis of the hole spin qubit device more complicated. One of the key characteristics of the hole spin qubit is its effective g-factor. Many experiments and theoretical work have shown that the effective g-factor changes significantly depending on the detailed device conditions. Understanding the physics of this phenomenon would be essential for developing hole-spin qubits in semiconductor QD systems.

In this talk, we present a theoretical analysis of the effects of the SO coupling on the hole spin qubits in a realistic QD confinement with anisotropy. Using the simple effective-mass formulation and the Rashba SO interaction, we show that the interplay between the asymmetry of the confining potential and the SO interaction leads to an angle-dependent effective g-factor. We compare our analytical results with numerical results from full Luttinger-Kohn Hamiltonian. We also show that the effectiveness of the EDSR driving for single-qubit gate operations also depends on the directions of the fields and the asymmetry of the QD.