Nonlinear Rabi frequency of Electric Dipole Spin Resonance

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Coherent control of a single spin confined in a quantum dot (QD) by the microwave electric field, which is called as the electric dipole spin resonance (EDSR), is an active field of recent research. One of the required mechanisms to couple the orbital motion to the spin degree of freedom is to utilize the slanting magnetic field[1]. This approach had enabled recent experimental studies, including fast Rabi oscillation[2], coupling with microwave photons[3], and fast QD electron spin manipulation[4]. Another dominating mechanism uses intrinsic or extrinsic spin-orbit interactions (SOIs)[5], which are particularly strong in hole spin systems[6].

Higher Rabi frequency is required for a given spin decoherence time to accomplish high-fidelity spin control. In a standard analysis of EDSR, the Rabi frequency at resonant condition is proportional to the strength of SOI and the amplitude of the applied electric field. This relation holds in the lowest (linear) order in the linear magnetic field gradient or in linear-to-momentum SOI system, for example for electron spins with Rashba and linear Dresselhaus SOI in GaAs/AlGaAs heterostructures. In contrast, the behavior of the EDSR Rabi frequency for non-linear field gradient, non-parabolicity of the confinement, or cubic-to-momentum SOI is not yet well understood. In this report, we have studied various mechanisms of non-linear electric field amplitude dependence of the EDSR.

We applied Schrieffer-Wolff transformation to obtain an effective Hamiltonian for the spin. For linear gradient in parabolic confinement or linear SOI, this provides genuine Rabi Hamiltonian for the spin. In contrast,, for the non-ideal cases, the obtained effective Hamiltonian includes both the orbital and spin degrees of freedom. Extrinsic non-linearity is provided for non-linear field gradient or non-parablic potential, where the sign of the non-linearity is not universal. For the cubic SOI case, the orbital state of the electron in QD is assumed to be in the ground state in the preceding work[7] and similar results as linear SOI were obtained. However, with increasing the amplitude of the electric field, the orbital state becomes a coherent state[8], which is a superposition state of the ground and excited states. Assuming the separation of the fast orbital motion and slow spin dynamics, we obtain that the Rabi frequency non-linearly depends on the electric field amplitude.

Recently, SOI Hamiltonian for hole spins in strained germanium QD is analyzed[**?**] and the dominating Rashba SOI for the EDSR is found to be cubic-in-momentum. We present the results of the Rabi frequency in this system assuming cyclotron frequency is much smaller than the angular frequency characterizing the confinement. Part of this work is supported by JSPS Kakenhi (23H05455) and JST ' s Moonshot R&D (Grant No. JP-MJMS2061).

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