Multiphoton Coherent Manipulation in Large-spin Qubits

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Introduction

Large spin Mn$^{2+}$ ions (S = 1 = 5/2) diluted in a non-magnetic MgO matrix of high crystalline symmetry are used to realize a six level system that can be operated by multi-photon coherent Rabi oscillations. The spin system has a small anisotropy which can be reversibly tuned in-situ between harmonic and non-harmonic level configurations. Decoherence effects are strongly suppressed as a result of the quasi-isotropic electron interaction with the crystal field and with the $^{55}$Mn nuclear spins.

Results and Discussion

By means of pulsed ESR, we show that the 6 levels of the Mn$^{2+}$ spins can be manipulated by single or multi-photon Rabi oscillations for temperatures up to 300 K (Fig. 1). Moreover, by rotating the applied field, the 6-levels can be reversibly transformed into a harmonic system showing two-level characteristics. Multi-photon oscillations are shorter lived when compared to 1-photon ones due to the larger number of levels involved. For $h_{mw}=0.32$ mT (where $h_{mw}$ is the amplitude of the microwave field), the 1-photon Rabi oscillation decay time is ~0.5 μs, and 1 μs for $h_{mw}=0.11$ mT. It becomes ~0.05μs for $h_{mw}=1.4$ mT but the slow oscillation attributed to the 3-photon resonance remains coherent up to 0.4 μs. This shows that an important part of the noise spectrum is located in the high frequency range and affects nutations with Rabi frequency $> 20$ MHz. The large hyperfine field of the $^{55}$Mn has a very limited influence on the electron spin decoherence owing to an isotropic hyperfine coupling. Similarly, the host's cubic symmetry and Mn$^{2+}$'s zero orbital momentum ensure negligible spin-orbit coupling which reduces relaxation processes. Dipolar Mn$^{2+}$ - Mn$^{2+}$ couplings are estimated to be weak in this diluted system (~0.01 MHz) due to an average spin-spin distance of ~42 nm. The main source of decoherence involves superhyperfine coupling to the $^{25}$Mg nuclear spin bath (I = 5/2 with 10% natural abundance).

Conclusions

These first observations of spin states dressed by coherent photons show the leading role of a small anisotropy on the dynamics of a spin qubit. Our results apply to other spin qubit implementations with quasi-harmonic energy diagram and in quasi-isotropic environments. The present study shows that multi-level spin systems can be coherently manipulated via multi-photon Rabi oscillations and, therefore, be exploited for use in quantum algorithms.

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References