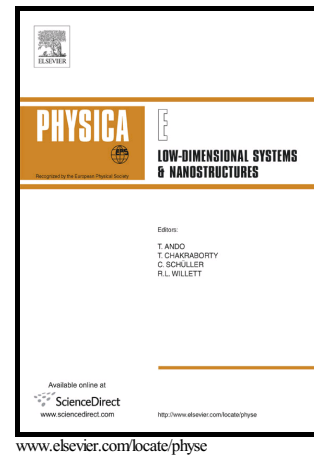


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Nuclear spin cooling by electric dipole spin resonance and coherent population trapping

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Nuclear spin fluctuation suppression is a key issue in preserving electron coherence for quantum information/computation. We propose an efficient way of nuclear spin cooling in semiconductor quantum dots (QDs) by the coherent population trapping (CPT) and the electric dipole spin resonance (EDSR) induced by optical fields and ac electric fields. The EDSR can enhance the spin flip-flop rate and may bring out bistability under certain conditions. By tuning the optical fields, we can avoid the EDSR induced bistability and obtain highly polarized nuclear spin state, which results in long electron coherence time. With the help of CPT and EDSR, an enhancement of 1500 times of the electron coherence time can be obtained after a 500 ns preparation time.

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I. INTRODUCTION

Single electron spin in artificial structures, such as semiconductor quantum dots (QDs), has become available and to a large extent controllable.^{1–7} Spin degrees of freedom are widely considered to be promising candidates for storing information. The interaction between localized electron spins and the environment is of particular interest both from a fundamental physics point of view and their potential use as quantum bits (qubits) for quantum information processing. Minimizing decoherence due to coupling of a quantum system to its fluctuating environment is a critical challenge in the quantum information and quantum computation.^{7–9}

A number of experimental and theoretical studies reveal that the predominant decoherence mechanism in QD is the hyperfine coupling between the electron spin and the nuclear spins in the host material^{1–6,10–12}. The electron-nuclear spin dynamics has been studied extensively.^{4–6,8–16} To suppress the decoherence effect due to the fluctuation of nuclear spins, one may either generate a state of highly polarized nuclear spins or squeeze the distribution of nuclear spin polarization.^{8–10} One basic approach to suppress the nuclear spin fluctuation is the feedback control by coupling the nuclear spins to a “background” of electron spin in specific configuration. One effective way of preparing such electron “background” for cooling the nuclear spins is to use coherent population trapping (CPT), which is at the heart of a number of key advances in quantum optics.^{16–20} Two circularly polarized laser fields/lights tuned to satisfy two-photon resonance could be used to deterministically

prepare a nuclear-spin environment with ultranarrow Overhauser-field (OF) distribution by using CPT.^{21–24} In turn, polarized nuclear spins, which can be described as an effective magnetic (Overhauser) field, induce an energy shift of the electron spin states. Under a large (effective) magnetic field, the direct electron-nuclear flip-flop processes are strongly suppressed due to the large mismatch in the electronic and nuclear Zeeman splitting, which reduces the “cooling” efficiency.

In this paper we propose to use two optical fields to realize CPT with highly polarized electron spin state, which leads to highly polarized nuclear spin. In addition, we add an ac electric field to realize electric dipole spin resonance (EDSR),^{25–29} which may increase the cooling efficiency by compensating the energy difference of electron states with different spins and enhancing electron-nuclear spin flip-flop rate. Compared with the electron-spin-resonance with magnetic field, the EDSR promises higher efficiency and strong local electric fields are easier to obtain than strong local magnetic fields. The EDSR enhanced feedback control of the nuclear spin bath (dynamical nuclear spin polarization) leads to interesting physics, such as bistable electronic states and the existence of an optimal ac electric field for nuclear spin fluctuation suppression. By the combination effects of the optical fields and the ac electric fields, we are able to greatly prolong the electron spin decoherence time of 1500 times.

II. THEORETICAL MODEL AND APPROACH

We explore the feedback control of the nuclear spin bath in a semiconductor QD, which includes the nuclear spin states, the Zeeman-split electron ground states and the negatively charged exciton (trion) $|t\rangle = |\uparrow\downarrow\uparrow\rangle$ ($|\uparrow\rangle, |\downarrow\rangle, |\uparrow\rangle$) the electron spin-up, down states and

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