Single spin manipulation in a quantum dot microcavity

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We present a theoretical study of single electron spin manipulation and detection by short polarized optical pulses in a quantum dot placed into a microcavity. The strong coupling regime between the trion and cavity mode is considered. The electron spin can be efficiently polarized by a single short optical pump pulse in the presence of the weak transverse magnetic field. Spin-Faraday, Kerr and ellipticity effects for linearly polarized probe pulse are calculated and the Faraday rotation angle can reach tens of degrees.

The optical spin manipulation is intensively studied for the past decade [1]. It is of particular importance to achieve an ultra-fast nonmagnetic control of a single spin, especially, using short optical pulses. This can be done by placing a charged quantum dot into the microcavity, which strongly enhances light-matter interaction [2]. The single spin manipulation theory has been already developed in the weak coupling regime [3], while in the strong coupling regime the spin readout was studied considering *cw* radiation [4]. In the present work we present the theory of spin coherence generation, control and detection by short optical pulses in the strong coupling regime.

We consider an optical quantum microcavity with a singly negatively charged quantum dot embedded inside, as depicted in the inset in Fig. 1. The photon mode is assumed to be twofold degenerate in photon polarization. In the strong coupling regime the light-matter coupling leads to the formation of polariton modes. The energy separation between the modes is defined by the coupling constant, g. In addition we assume an external magnetic field to be applied in the Voigt geometry.

We focus on the case of moderate magnetic fields, such that the electron spin precession frequency, Ω, is small as compared with the coupling constant, $g/\hbar$, and inverse pump pulse duration, τ_p^{-1}. On the other hand, the magnetic field is assumed to be large enough so that Ω exceeds by far the damping rates of photon and trion. Due to the optical selection rules the light of the given helicity interacts differently with the spin-up and spin-down electron states. As a result after arrival of the circular polarized pump pulse the spin polarization in the ground state is induced. This polarization precesses around the magnetic field resulting in the spin beats. The amplitude of spin beats, S_z, is shown in Fig. 1 as a function of the effective pump pulse area, Θ. This mechanism of spin orientation is similar to that one realized in ensembles of charged quantum dots [1, 5, 6]. The difference is that in the latter case the induced spin polarization would show Rabi oscillation as a function of Θ as a result of finite number of involved excited states.

Manipulation of electron spin polarization can be realized by detuned circular control pulse. Our calculation shows that depending on the control pulse power and duration one can reach a 2π rotation of electron spin in the plane perpendicular to the light propagation direction.

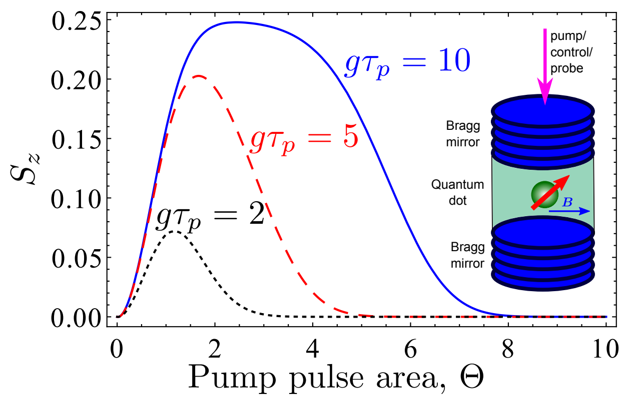

FIG. 1. Induced spin polarization as a function of the pump pulse effective area for in case of the resonant excitation for different pulse durations, τ_p. The inset illustrates the system under study.

The spin detection can be performed by linearly polarized probe beam. We show that even for the short probe pulses the Kerr and Faraday rotation angles of probe polarization plane can reach tens of degrees provided the strong coupling regime is achieved. The features of Kerr rotation spectral dependence correspond to the spectral positions of polariton modes and bare QD frequency. The spectrum is smoothed out with the a decrease of probe duration.

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