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Ultra-fast spinor switching in polariton condensates

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Abstract: We demonstrate a linear to circular polarization conversion mechanism of a confined polariton condensate created by an optical potential trap. This system features a high degree of circular polarization under linear polarization pumping and is favorable for the development of spin logic operations. The physical mechanism behind this process is explained by the spin precession in the exciton reservoir that results in a condensate of a preferred spin state. Application of a non-resonant below threshold femtosecond pulse on the spinor condensate results in an ultrafast reversal of the spin state.

OCIS codes: (240.5420) Polaritons; (320.7130) Ultrafast processes in condensed matter

Implementation of an all-optical spin switch has long been a significant objective in solid-state systems for the advancement of spintronics. Semiconductor microcavities, featuring inherent intensity non-linearities and spin multistabilities [1], have emerged as ideal systems for achieving this purpose. Exciton-polaritons which are the eigenstates of these systems are bosonic hybrid light-matter particles that inherit the spin properties from their exciton component and their small mass, which enables them to propagate over large distances ($\sim 100\mu\text{m}$), from their photonic component. The improvement of the microcavity structures in recent years has led to the predicted polariton Bose-Einstein Condensation (BEC) regime, and has led to the emergence of polariton spintronics [2]. The polariton spin state dictates the polarization of the emitted photon and can thus be readily recorded. Furthermore, it has been demonstrated that even under non-resonant optical pumping the polarization of the emission is correlated with the polarization of the excitation beam [3]. Polaritons also feature an extremely short lifetime (~ 10 ps) and although this was considered to be a hindrance for polariton BEC it is now seen as advantageous in creating ultrafast (ps) optical polariton spin switching devices.

Figure 1 Left panel: schematic of the condensate in the center of a ring-shaped reservoir and its spin precession in time. **a)** Real Space emission and **b), c), d)** circular, linear and diagonal polarization images of the optically confined polariton condensate. **e)** Profiles of the condensate intensity (black dots) and the degree of circular polarization of the emission (red dots) taken along the y-axis of (a) and (b) (white lines).

We initialize the optically confined condensate with a linearly polarized CW non-resonant excitation beam shaped into a ring with the use of a set of axicons and project it on the microcavity as in our previous work [4]. Remarkably the resultant condensate in the center of the optical trap has a well-defined degree of circular polarization of more than 60%. The exciton spin in the reservoir can precess under an effective magnetic field

$\Omega = \Delta\hat{\chi} / \hbar$, where Δ is the linear polarization splitting induced by the TE-TM splitting of the microcavity structure, as in eq. (1) and thus acquire a circular component (Fig.1 schematic).

$$s_z(t) = s_z(0)\cos(\Omega t)e^{-\Gamma t} + s_y(0)\sin(\Omega t)e^{-\Gamma t} \quad (1)$$

where Γ is the sum of the bare decay and the loss rate to the polariton condensate.

Particles with a non-zero circular component are injected into the trap from the reservoir and when the density of polaritons reaches the threshold for condensation, they give rise to a strongly polarized BEC by condensing preferentially in the spin state dictated by the reservoir. It is worth noting that the degree of circular polarization of the emission has a different spatial profile to that of the polariton condensate, as shown in Fig. 1e, reflecting the extent of the first order coherence in the condensate (not shown). The linear to circular polarization conversion mechanism is further verified by a parametric scan of the circular polarization of the condensate versus the angle of the linear polarization of the excitation beam (Fig2a). The amount of circular polarization of the reservoir depends on the angle between the injected pseudospin orientation and the orientation of the effective magnetic field Ω (Fig 2a).

We fix the linear polarization of the excitation beam so as to obtain a high degree of circular polarization of the polariton condensate. A non-resonant, cross-circular polarized, 180-femtosecond pulse is focused at the center of the trap, at a $5\mu\text{m}$ spot similar to the extent of the condensate, switches the circular polarization of the condensate. The excitation density of the pulse was below the threshold density for condensation ($\sim 0.5 P_{\text{th}}$). Time resolved photoluminescence in the picosecond domain demonstrates that the flip of the condensate's polarization transpires in just under 45ps after the arrival of the pulse (fig 2b). The condensate remains in the switched state for up to 80ps, orders of magnitude more than the duration of the pulse. As the pulse-injected carriers decay, the condensate returns to its prior state within 40ps.

Figure 2 a) Dependence of the circular degree of polarization of the condensate at $P=1.2P_{\text{th}}$ as a function of the angle of the linear polarization of the excitation beam. b) Polarization flip in the transient domain under perturbation using a non-resonant femtosecond pulse.

In conclusion we have presented a system with inherent spin anisotropies that lead to the emergence of a circularly polarized condensate under linear polarization of the optical excitation. Moreover the circular polarization of the condensate is tuned by the angle of the linear polarization of the pump making this a robust system for linear to circular polarization conversion. The fast response of the polarized condensate to an external probe pulse is a further advantage of this excitation scheme for the implementation of all-optical ultrafast switching devices. The fundamental advantage of this configuration over previous implementations and propositions of polariton spin switches lies in the fact that both the excitation and perturbation laser sources are under non-resonant excitation. This feature is of paramount importance in future implementation of realistic devices since the fine tuning of the excitation that previous resonant injection schemes feature would greatly increase the complexity of the device.

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