Optical control of spin textures in quasi-one-dimensional polariton condensates

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We investigate, through polarization-resolved spectroscopy, the spin transport by propagating polariton condensates in a quasi one-dimensional microcavity ridge along macroscopic distances. Under circularly polarized, continuous-wave, non-resonant excitation, a sinusoidal precession of the spin in real space is observed, whose phase depends on the emission energy. The experiments are compared with simulations of the spinor-polariton condensate dynamics based on a generalized Gross-Pitaevskii equation, modified to account for incoherent pumping, decay and energy relaxation within the condensate.

Keywords: microcavities, polaritons, condensation phenomena

I. INTRODUCTION

Semiconductor microcavities in the strong coupling regime are excellent candidates for designing novel “spinoptronic” devices due to their strong optical nonlinearities,1 polarization properties,2,3 and fast spin dynamics.4 The control of polariton condensates propagation and their polarization4 provide the necessary ingredients for future optical circuits. The first steps towards the fabrication of spin-based polariton condensate switches20, gates,10 and memories11,12 have been recently achieved. They fulfill the fundamental technological requirements for the operation with polarization-encoded signals: micrometric size, non-local action triggering and high-speeds (of the order of ∼1 μm/ps due to the ballistic polariton propagation). New schemes for the realization of spintronics devices13,14 and “polariton neurons” in circuits, the building blocks of all-optical integrated logic circuits15,16 have been recently proposed. One-dimensional (1D) and quasi-1D patterned high-finesse microcavities provide an ideal platform for all-optical manipulation17, ballistic propagation and amplification18 and gating of polariton condensates.20–22 The waveguide nature of these structures induces the channeling of polariton propagation, while the discretization of energy levels results in a rich relaxation dynamics20,27.

In this work, we investigate optically the collective spin dynamics of polariton condensates moving along macroscopic distances in a quasi-1D microcavity (MC) ridge. We adopt the pseudospin formalism in order to describe the polarization state of exciton-polaritons.23 Polaritons possess a spin with two possible projections on the structural growth axis of the MC. The polarization of the emitted light gives direct access to the pseudospin state, which is fully characterized by the four-component Stokes vector $\vec{S} = (s_0, s_x, s_y, s_z)$. Here, $s_0$ is the total photoluminescence (PL) intensity, and $s_{x,y,z} = (I_{H, D, \sigma^+} - I_{V, A, \sigma^-}) / (I_{H, D, \sigma^+} + I_{V, A, \sigma^-})$. $I_{H, D, \sigma^\pm}$ and $I_{V, A, \sigma^-}$ are the measured intensities in the horizontal ($H$) and vertical ($V$), diagonal ($D$) and antidiagonal ($A$), and the two circular polarization components $\sigma^+$ and $\sigma^-$. This paper is organized as follows. In Sec. II, we discuss the sample and the experimental setup. In Sec. II, we present and discuss our results; we first show, under continuous wave (cw) excitation, the optical spin Hall effect29 in a quasi-1D structure, discussing the $s_z$ oscillations in real space, for a $\sigma^+$-polarized pump. In Sec. III A, we investigate the distribution of the Stokes components as function of the PL energy and position along the ridge. In Sec. III B, we demonstrate that the $s_z$ precession is lost under linear excitation and/or high power excitation conditions. In Sec. IV, the experiments are compared with simulations of the spinor-polariton condensate dynamics based on a generalized Gross-Pitaevskii equation, modified to account for incoherent pumping, decay and energy relaxation within the condensate. Finally, in Sec. V, we provide the conclusions of this work.

II. SAMPLE AND EXPERIMENTAL SETUP

A high-quality 5λ/2 AlGaAs-based MC with 12 embedded quantum wells is investigated, whose Rabi splitting, $\Omega_R$, amounts to 9 meV. Ridges, with dimensions $20 \times 300 \ \mu m^2$, have been obtained by reactive ion etching (further information about this sample is given in Ref. 29). We study a ridge situated in a region of the sample corresponding to resonance (detuning between bare exciton and cavity modes is $\sim 0$). The sample is kept at 10 K in a cold-finger cryostat and it is excited with...
FIG. 1: (Color online) (a) Scanning electron microscopy image of a 20-µm wide ridge, including an angular scheme of the PL emitted from the center of the ridge (see cone of light as a guide to the eye). z direction is perpendicular to the plane of the paper. The bottom panels display, under non-resonant (1.612 eV), weak, circularly polarized-light excitation: (b) and (d) energy dispersions of the PL along \( k_x \) and \( k_y \), respectively; (c) and (e) linear degree of polarization \( (s_x) \) versus energy and \( k_x \) and \( k_y \), respectively. Dot-dot-dashed white and black lines in panels (d,e) mark the energy value (1.5407 eV) used for Fig. 2(b). Red and blue arrows in panels (a,b,d) mark the TM and TE character of the even subbands in the dispersion relations, respectively. Orange and black arrows in panels (b,e) mark the energy positions of weakly-polarized, consecutive higher subbands. The PL and \( s_x \) are coded in linear, normalized, false color scales.

In our experiments, polaritons propagate predominantly along the \( x \) axis of the ridge [see Fig. 1(a)]. Therefore in all the images presented in the manuscript, where the \( y \) direction is not shown, the spectral PL distribution is analyzed along the \( x \) axis from a \( \Delta y = 2 \) µm-wide, central region of the ridge. However, for the sake of completeness, the full two-dimensional polariton intensity and degree of circular polarization distributions are presented when appropriate.

We start by describing the dispersion relations of polaritons along two orthogonal directions in the ridge, \( k_x \) at \( k_y = 0 \) and \( k_y \) at \( k_x = 0 \). The confinement in the \( y \) axis of the ridge results in the discretization of the \( k_y \) in-plane momentum, splitting the lower polariton branch in many subbands, Fig. 1(b), whose antinodes along \( k_y \) are visible in Fig. 1(d). It is important to emphasize that only even subbands are visible in Fig. 1(b), since along \( k_x \) we spectrally resolve the PL at \( k_y = 0 \). Odd modes (with a node at \( k = 0 \)) are visible in Fig. 1(d), see for example the subband at 1.5405 eV. The scenery seen in these dispersion relations is very interesting because it reveals the possibility of parametric scattering processes among many different sub-branches. Recent works on 1D semiconductor microcavities exploit these extra-confinement effects to study new parametric phenomena (see, for example, Refs. 31,32 and references therein).

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Confined in a quasi 1D cavity enhances the splitting between the two light polarizations TM and TE, parallel and perpendicular to the \( x \) axis of the ridge, respectively. We identify TM (TE) as the H (V) direction used to define the linear degree of polarization \( (s_x) \). Considering the \( k_x \) direction, the lowest energy subband is TM\(_0\) polarized, see label in Fig. 1(b), and its corresponding \( s_x \) is shown in Fig. 1(c), where an intense, red subband appears, whose minimum is at \( E = 1.5397 \) eV and \( k_x = 0 \). The next TM\(_1\) mode is 0.2 meV blueshifted, lying very close to the TE\(_0\) mode [intense blue subband in Fig. 1(c)]. The splitting between TM\(_0\) and TE\(_0\) is 0.36 meV. Higher energy modes, with a weaker degree of polarization, are visible at 1.5407 and 1.5411 eV, marked by orange and black arrows in Figs. 1(b,d) and Figs. 1(c,e), respectively. Analyzing the dispersion relation \( k_y \), Figs. 1(d,e), a further, horizontal discretization of the energy levels is clearly observed. The separation in \( k_y \) between consecutive antinodes of a single state is \( \sim 0.4 \) µm\(^{-1}\).
FIG. 2: (Color online) (a) PL ($s_x$) as a function of energy at $k_x = 0$ in a gray, thick (purple, thin) line. (b) PL ($s_x$) as a function of $k_y$ at $E = 1.5407$ eV in a gray, thick (purple, thin) line. Red and blue arrows in panels (a,b) mark the TM and TE character of the even subbands in the dispersion relations, respectively. Orange arrows in panel (a) mark the energy positions of weakly-polarized, higher subbands.

Detailed spectra at $k_x = 0$, both for intensity (thick, gray line) and $s_x$ (thin, purple line), are given in Fig. 2(a), with different, labelled modes indicated by arrows. The aforementioned higher energy modes are marked by orange arrows. Figure 2(b) details a profile of the PL and $s_x$ versus $k_y$, at $E = 1.5407$ eV: the predominant structures at $|0.7| < k_y < |1.8| \mu m^{-1}$ in thick gray line are constituted by the modes (TM$_0$+TM$_1$) and (TE$_0$+TE$_1$) modes at high $k_y$ values, while the three central antinodes correspond to other confined modes at lower $k_y$ values. Only when a polarization analysis is performed, TE and TM distributions are resolved (thin purple line), as marked in the figure.

Assuming a square well type potential in the $y$ direction, the energies of the TM- and TE-polarized photonic modes can be approximated by:

$$E_{C;TM,TE}(n,k_x) = \frac{(n+1)^2 \hbar^2 \pi^2}{2m_C L_y^2} + \frac{\hbar^2 k_x^2}{2m_C} \pm \Delta_{TM,TE} \quad (1)$$

where $n = 0, 1, 2, ...$ is the subband index, $m_C$ is the photon effective mass, $L_y$ is the ridge width and $\Delta_{TM,TE}$ characterizes the splitting between the H and V polarizations. The dispersion of the upper (+) and lower (-) polariton modes is given by the standard two oscillator formula (up to a constant energy shift):

$$E_{TM,TE}^\pm(n,k_x) = \frac{1}{2} E_{C;TM,TE}(n,k_x) \pm \sqrt{E_{C;TM,TE}^2(n,k_x) + 4\Omega^2} \quad (2)$$

where $\Omega = \Omega_R/2$ is the exciton-photon coupling constant. Assuming a Lorentzian lineshape (corresponding to 18 ps lifetime) and an independent Boltzmann population of the TM and TE polarized energy levels ($T = 10$ K), we calculate the dispersions corresponding to lower polariton modes ($E^-$) shown in Fig. 3. As in the experiments, we show the $k_y = 0$ ($k_x = 0$) PL when resolving the dispersion along $k_x$ ($k_y$). The results show that the TM bands are hidden by the stronger populated TE bands at higher energies.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Recently, E. Kammann and coworkers reported an analogue of the optical spin Hall effect of an exciton-polariton condensate in a planar MC, under cw, non-resonant, circularly-polarized excitation. Circularly polarized condensates propagate over macroscopic distances, while the collective condensate spins coherently precess around an effective magnetic field. Here we study a similar phenomenon in our quasi-1D structure: we start focusing on the polariton distribution in real space and its degree of circular polarization, under cw, circular excitation, without resolving the PL energy.

Figure 3(a) shows the energy-integrated distribution of the polariton PL in real space, under $\sigma^+$-polarized, non-
resonant excitation at \((x, y) = (0, 0)\) with a pump power of \(3.75 \times P_{th}\). The pump creates outflowing polariton condensates due to the repulsive interactions with the excitonic reservoir.\(^{18,23}\) The propagation inside the ridge is not purely one dimensional since slanted traces of the polariton flow are visible (see white dashed arrows as a guide to the eyes), as a result of the reflection of the fluid against the lateral borders at \(y = \pm 10 \mu \text{m}\). Interference patterns in the PL, due to polariton-polariton scattering, are also observed (see, for example, the region enclosed by a dashed box). This effect has been also reported in the two-dimensional case.\(^{13}\) A Fourier transform of this enclosed region, shown in Fig. 4(c), obtains the frequencies corresponding to counter-propagating polariton wave packets, with a difference in momentum propagation of \(\Delta K_x \approx 3.4 \mu \text{m}^{-1}\) (see the area enclosed by a dot-dashed box). The corresponding value of \(k_x\) matches the typical speed of polariton wave packets in 1D systems \((\sim 1 \mu \text{m}/\text{ps})\).\(^{19,22}\)

Outside the pump spot, the potential energy is converted into kinetic energy. Polaritons also relax and lose energy through scattering with the excitonic reservoir and through intra-branch scattering,\(^{22,23,24}\) the energy of condensed polaritons spans \(\sim 1.5 \text{ meV}\) across the subbands (see below). Therefore, the description of the spin distribution in our quasi-1D structure, in the presence of polariton energy relaxation, becomes more complex than in 2D (where the ballistic spin precession occurs in a simpler dispersion relation). However, for the sake of simplicity, we show in Fig. 4(b) the energy-integrated distribution of the circularly-polarized component of the PL \((s_z)\). The large red area in the central region corresponds to the predominantly spin-up aligned polaritons at the excitation area. The spin of leftwards and rightwards propagating polaritons precesses with a periodicity of \(\sim 40 \mu \text{m}\) (see up- and down-arrows). The energy integration is responsible for the relatively low values of \(s_z\). In Fig. 4(d) we quantify both the total PL (thick gray line) and \(s_z\) (thin purple line) as function of \(x\) at the central cross-section of the ridge \((y = 0)\). The oscillations in the PL are caused by the fluid reflections against the borders of the ridge, obtaining large intensities when polaritons merge at the center [see arrows in Fig. 4(a)]. The spin oscillation and its damping along its propagation are clearly visible (thin purple line). Note that the periodicities of the PL and the spin oscillations do not match since they arise from different phenomena.

### A. PL spectroscopy on the spin Hall effect

Figure 5 shows the energy- and space-resolved Stokes components of the polarized PL under the same excitation conditions as those described in Fig. 4. The polariton condensates span an energy of 1.5 meV around \(\sim 1.540 \text{ eV}\). We present here a spatial analysis of \(s_x\), \(s_y\), and \(s_z\) at two different energies \(E_0 = 1.5396 \text{ eV}\) and \(E_1 = 1.5403 \text{ eV}\), which correspond to those of polaritons condensing into the TM's and the TE's subbands (see in Figs. 5(a-c) dashed and solid horizontal lines), respectively. Figure 5(a) shows a weak spatial oscillation of \(s_x\) at \(E_1\). Additionally, a small positive \(s_x\) from higher-energy excitons (from 1.5405 to 1.5415 eV) is present at \(x = 0\); this was already present in Fig. 4(c), under below-threshold excitation. At \(E_0\), \(s_x\) is large and positive, as expected from the TM-character of the lowest polariton subband [see Figs. 4(c) and 5(a)]. The diagonal component \(s_y\) displays a significant spatial oscillation with a period of \(\sim 40 \mu \text{m}\) at \(E_1\) [see Fig. 5(b)]. In contrast, \(s_y\) barely oscillates around a value of \(\sim -0.2\) at \(E_0\). Figure 5(c) shows a highly \(\sigma^{\pm}\)-polarized population at \(x = 0\) at \(E_1\) and above, set by the excitation laser. At \(E_1\) the condensed, spreading polaritons exhibit a precessing \(s_z\), again with the same period of \(\sim 40 \mu \text{m}\). This precession, although weaker, is also seen at \(E_0\). The phase of the spatial \(s_z\) oscillations shifts continuously with increasing energies, so that at \(E_0\) and \(E_1\) they are shifted with respect to each other by a \(\pi\) phase approximately. In Figs. 3(b) and 5(c) the slanted, dot-dashed (solid) lines highlight the minimal (maximal) points of the \(s_y\) and \(s_z\) oscillation across the PL energy, respectively. This phase shift arises from the different propagation speeds of polaritons at different energies: polaritons at higher energies move at higher speeds and therefore travel longer...
FIG. 5: (Color online) Stokes parameters of the polariton PL as function of energy and spatial position (x): (a) \(S_x\), (b) \(S_y\), and (c) \(S_z\), respectively, under non-resonant (1.612 eV), circular-polarized (\(\sigma^+\)) excitation. (d) Corresponding PL. The pump power is 3.75 \(\times P_{th}\). Slanted, dot-dashed (solid) lines in panels (b,c) sketch the continuous shift with energy of the minima (maxima) values of \(s_y\) and \(s_z\). The horizontal purple, solid (orange, dashed) line at \(E_1 = 1.5403\) eV (\(E_0 = 1.5396\) eV) marks the energy of interest used for the data depicted in Fig. 6. The PL (degree of polarization) is coded in a logarithmic (linear), false color scale.

B. Spin precession collapse

A recent study shows that a transfer of the polarization of a non-resonant excitation laser to polariton condensates occurs for excitation powers slightly above the condensation threshold and that the transfer efficiency decays with increasing pump power. We also profit from the former fact to non-resonantly create polariton condensates with a predominant circular polarization. In this section, we investigate not only the latter fact, i.e. the influence of the pump power, but also that of its spin polarization (circular or linear) on the collective polariton spin state and on its propagation.

Two different pump powers are used for the experiments compiled in Fig. 7: 3.75 (4.75) \(\times P_{th}\) for the left (right) column. \(s_z\) maps as a function of energy and x under \(\sigma^+\) (linear excitation) are shown in Figs. 7 (a-1) and 7 (a-2) [Figs. 7 (b-1) and 7 (b-2)]. Finally, for the sake of completeness, Figs. 7 (c-1) and 7 (c-2) show the polariton PL. In Fig. 7 (a-1) \(s_z\) oscillations are clearly observed from 1.5395 to 1.5408 eV. The \(\sigma^+\)-polarized, non-resonant excitation induces a highly \(\sigma^+\)-polarized, blueshifted population at \(x = 0\), whose PL spans from 1.5400 to 1.5415 eV. A 25% increase of the pump power strongly reduces the amplitude of the spin precession, which becomes barely visible in Fig. 7 (a-2). These oscillations are also suppressed for linear excitation, as shown in Figs. 7 (b-1) and 7 (b-2). The PL map at high excitation power, 4.75 \(\times P_{th}\), reveals a non-emitting region around \(x = 0\) with an energy-width of 0.7 meV and a spatial extent FWHM of \(\sim 20\) \(\mu\)m, highlighted with a dashed line in Fig. 7 (c-2). This dark region is caused by the excitonic reservoir, which ejects polariton outwards from \(x = 0\).

IV. MODEL

To model the spatial structure of polariton condensates we use a mean-field description including incoherent pumping and decay as well as energy relaxation. This model was used previously to describe the dynamics of condensate transistors in microwire ridges. In the current experiment it is important to use a two-dimensional model that accounts for the subband structure reported in Fig. 4 as well as a two-component spinor wavefunction to account for the spin degree of freedom.
FIG. 7: (Color online) Polariton spin precession and PL as a function of pump power at $3.75 \times P_{th}$ (left column), and $4.75 \times P_{th}$ (right column). The non-resonant excitation (1.612 eV) at $x = 0$ is circularly- (linearly-) polarized in the first (second) row. Panels (a,b) depict the circular degree of polarization ($s_\pm$); panels (c) show the polariton PL. In panel (c-2) the local repulsive potential induced by photo-generated excitons at $x = 0$ is sketched by a dashed line. The PL ($s_\pm$) is coded in a logarithmic (linear), false color scale.

The spinor polariton wavefunction $\psi_\sigma(\vec{r}, t)$ obeys the dynamical equation

$$i\hbar \frac{d\psi_\sigma(\vec{r}, t)}{dt} = \left[ \hat{E}_{LP} + (\alpha_1 - i \Gamma_{NL}) |\psi_\sigma(\vec{r}, t)|^2 \right. \left. + \alpha_2 |\psi_{-\sigma}(\vec{r}, t)|^2 + V_0(\vec{r}) + V_\sigma(\vec{r}) + i \left( W_\sigma(\vec{r}) - \frac{\Gamma}{2} \right) \psi_\sigma(\vec{r}, t) \right] \psi_\sigma(\vec{r}, t)$$

$$+ \Delta_{XY} \psi_{-\sigma} + i \hbar \mathcal{R}[\psi(\vec{r}, t)].$$

(3)

where $\sigma = \pm$ denotes the two circular polarizations of polaritons. $\alpha_1$ and $\alpha_2$ represent the strengths of interactions between polaritons with parallel and antiparallel spins, respectively. The operator $\hat{E}_{LP} = -\hbar^2 \nabla^2 - \frac{\mu}{2m_e}$ represents the parabolic dispersion of the lower polariton branch (LP). Here, $\vec{r}$ is a two-component vector consisting of the real space coordinates lying on the ridge, the origin of this coordinate system being in the center of the ridge.

Polaritons enter the condensate at a rate determined by $W_\sigma(\vec{r})$, which is both polarization and space dependent. While the non-resonant laser used in the experiment is polarized, due to the presence of spin relaxation, one does not expect a full polarization of the photocreated hot excitons. Consequently we expect a partially polarized reservoir of excitons to drive the polariton condensates, eventually yielding both possible circular polarizations. The condensation rate for the $\sigma^+$-polarized polaritons from the excitonic reservoir is given by:

$$W_+(\vec{r}) = W_0 e^{-r^2/L^2}$$

(4)

where $W_0$ is the peak condensation rate and $L$ is the width, which is taken to be the same as the pump-spot diameter. The condensation rate for the $\sigma^-$-polarized polaritons is smaller and given by $W_- = \rho W_+$, where $\rho$ is a parameter that is fitted to the experimental results. In this form, the condensation rate is explicitly spin anisotropic.

The spin dependent effective potential experienced by polaritons can be described by:

$$V_\sigma(\vec{r}) = G_\sigma W_\sigma(\vec{r})$$

(5)

where $G_\sigma$ is a constant representing the strength of forward scattering processes between excitons in the reservoir and in the condensate.

The polaritons decay with a decay rate $\Gamma$. They also experience a nonlinear loss corresponding to scattering out of the condensate. According to estimates in Ref. [71], $\Gamma_{NL} \approx 0.3 \omega$. Once injected, different circular polarizations are also coupled by the linear polarization splitting $\Delta_{XY}$ in the system, which can give rise to oscillations between spin components. While in 2D MC the dominant polarization splitting is wavevector dependent, the dominant splitting in polariton channels is due to strain giving an anisotropic lattice constant. A splitting occurs between polarizations aligned parallel and perpendicular to the channel axis, which remains for zero in-plane wavevector [as can be seen in Figs. 1(c,e)], and takes larger values than the TE-TM splitting in 2D MCs.

The final term in Eq. (3) accounts for energy relaxation processes of condensed polaritons:

$$\mathcal{R}[\psi(\vec{r}, t)] = -\nu \left( \hat{E}_{LP} - \mu(\vec{r}, t) \right) \psi(\vec{r}, t),$$

(6)

where $\nu$ is a phenomenological parameter determining the strength of energy relaxation and $\mu(\vec{r}, t)$ is a local effective chemical potential that conserves the polariton population. These terms cause the relaxation of any kinetic energy of polaritons and allow the population of lower-energy states trapped between the pump-induced potentials. For the simulation that produce the results in Figs. 8 and 9, the following parameters are used: $\alpha_1 = 2.4 \times 10^{-3} \text{ meV} \mu \text{m}^2$, $\hbar \omega = 0.14$, $\Gamma = 0.0366 \text{ meV}$ (Ref. [27]), $\alpha_2 = -0.2 \omega$ (Ref. [11]). The LP dispersion is characterized by an effective mass $m = 7.3 \times 10^{-5} m_e$, fitted to Fig. 1, where $m_e$ is the free electron mass. $G_+ = 1.0$ and $G_- = 0.7$ are fitted to the measured space- and polarization-resolved energy distributions. $W_0 = 0.185$
meV, \( \rho = 0.5 \) and \( \Delta_{XY} = -0.15 \) meV. The width of the condensation rate profile is taken to be \( L = 10 \mu m \).

The simulated images shown in Figs. 8 and 9 can be compared to the experimental results in Figs. 4(a,b) and 5(a-c), respectively. The localized, polarized, incoherent pumping generates two distributions of polaritons separated both in polarization and in energy at \( x = 0 \): while the majority of polaritons are \( \sigma^\pm \)-polarized, a significant number of polaritons also condense into a \( \sigma^\mp \)-polarized state, which has lower energy due to the spin-dependent blueshifts in the system \( V_\sigma(\vec{r},t) \). A very good agreement between the experimental and theoretical \((x,y)\) maps is obtained.

The potential \( V_\sigma(\vec{r}) \), which is mostly induced by hot excitons with the same spatial distribution as the pump, represents a strongly repulsive potential in the system that accelerates polaritons outwards. The simulated energy- and space-resolved map of the \( s_x \) Stokes parameter, shown in Fig. 9(a) is also in reasonable agreement with the experimental results depicted in Fig. 5(a). As the accelerated polaritons move outward, their spins precess, due to the polarization splitting, giving rise to oscillations in \( s_y \) and \( s_z \) [see Fig. 9(b,c)] as in the experiments [Fig. 5(b,c)]. Note that the theoretical model does not reproduce directly oscillations in the spatial distribution of \( s_z \). Theoretically, any polarization splitting in the system can always be represented by an effective magnetic field about which the Stokes’ vector rotates. It is impossible to find a effective magnetic field that causes oscillations between both negative and positive values in all three components of the Stokes’ vector simultaneously (even if multiple forms of splitting are present, the total effective magnetic field cannot make an angle greater than \( 45^\circ \) with the \( s_x, s_y \) and \( s_z \) axes simultaneously). We thus conclude that the experimentally observed oscillation in \( s_x \) is not directly due to spin precession caused by the polarization splitting. Instead, we expect that the oscillations in \( s_x \) are linked to the oscillations in the total PL intensity, which competes with a background of incoherent polaritons that are linearly polarized due to the TE-TM splitting. Where the condensate intensity is high, \( s_x \) is given by the mean-field theoretical value, while when the condensate intensity is low there may well be incoherent polaritons, not accounted for in the mean-field theory, that give a different polarization. Consequently, oscillations in intensity give the impression of oscillations in the linear polarization degree represented by \( s_x \). The oscillations in intensity are due to the two-dimensional nature of the propagation, where both theory and experiment show that polaritons tend to travel at an angle to the \( x \) axis, being guided by reflections from the ridge edges. The intensity viewed along the \( x \) axis is then greatest when polaritons propagating off-axis cross the \( x \) axis.

**V. CONCLUSIONS**

In summary, we have studied the optical spin Hall effect in a quasi-1D MC, where the lateral confinement yields a suitable scenario for the intra-branch polariton energy relaxation, enriching the phenomenology of the polariton spin patterns. Thanks to a spectroscopic analysis of the optical spin Hall effect, we have shown that a phase-shift in the oscillations of the \( s_y \) and \( s_z \) Stokes parameters results from the different speeds of propagation of polaritons. These oscillations collapse either when linear-polarized excitation is used or when the pump power of the circular-polarized excitation exceeds a certain level. Our results are interpreted within the framework of a mean-field model for polariton dynamics, which includes incoherent gain from a polarized exciton.
reservoir, the energy shift due to the reservoir, TE-TM splitting and energy relaxation. The demonstration of the inversion of the polariton spin as it propagates or relaxes in energy is an important ingredient for realizing polaritonic circuits based on the spin degree of freedom.

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