Polarization of Light Emission in Semiconductor Microcavities: Dispersion Mapping

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Abstract. We study the polarization of the light emission from polaritons in semiconductor microcavities. We focus on the non-linear regime and negative detunings. The behavior of the linear and circular polarization dynamics is shown to be determined by the polariton longitudinal-transverse splitting.

Strong coupling between cavity photons and quantum well (QW) excitons leads to appearance of new quasi-particles - exciton polaritons (for a review see [1]). Polaritons have a well defined spin, which makes them potential candidates for applications in many optoelectronic and spintronic devices. This perspective have resulted recently in a number of interesting theoretical and experimental reports. In particular, Aichmayr *et al.* observed that, at negative detunings and in the non-linear regime, the circular polarization of the $k = 0$ lower polariton (LP) emission exhibited temporal oscillations and that the time-integrated circular polarization was opposite to that of the excitation pulse [2, 3]. The oscillatory behavior was subsequently explained by Kavokin *et al.* within a pseudospin model taking into account the longitudinal-transverse splitting (Δ_{LT}) of the lower polariton [4].

In this work we address two issues: (i) The existence of a linear polarization which can be inferred from the model in Ref [4]. (ii) The existence of emission with positive circular polarization from certain k-states to compensate the negative value of the integrated circular polarization observed at $k = 0$ and therefore to assure conservation of the total angular momentum.

The sample is a typical wedge-shaped λ $Cd_{0.4}Mg_{0.6}Te$ microcavity with four QWs placed at the antinodes of the confined electromagnetic field. The emission was excited by 2 ps pulses from a Al_2O_3:Ti laser pumped with an Ar^{2+} ion laser. The excitation energy was tuned to the first reflectivity minimum after the stop band. The signal was detected and time-resolved by a streak camera with an overall resolution of about 10 ps. We measured the signal at various angles with respect to the normal to the sample surface. The angular resolution was better than 1°, corresponding to a k-vector resolution of the about 10^3 cm^{-1}. Here, we present only the results obtained for negative detunings, where negative polarization and polarization oscillations were observed. The degree of circular/linear polarization (DCP/DLP) under circularly/linearly polarized excitation was evaluated as $P = \frac{I^{\mathrm{co}} - I^{\mathrm{cross}}}{I^{\mathrm{co}} + I^{\mathrm{cross}}}$, where I^{co} and I^{cross} are emission intensities of co- and cross-circular/linear signals. The linear polarization of the excitation pulse was horizontal.

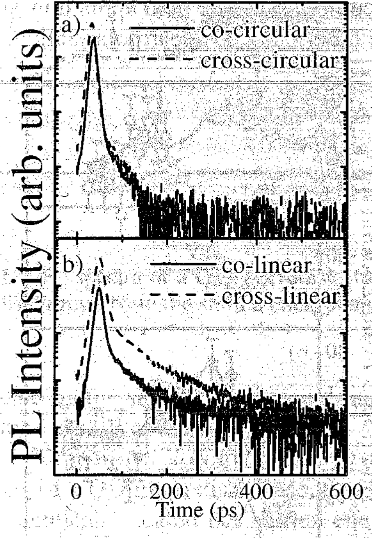

FIGURE 1. Time-resolved LP emission in two circular (a) and in two linear (b) polarizations under circularly σ^+ (a) and linearly (horizontal) (b) polarized excitation.

Figures 1a) and 1b) present temporal decays of LP emission at $k = 0$, in the nonlinear regime, for the circular and linear excitation, respectively. In the former case, in about 150 ps after the excitation, I^{co} and I^{cross} become equal. On the contrary, in the case of linear excitation, I^{cross} remains larger than and I^{co}, even 400 ps after excitation. These results are clearly evidenced in Fig 2,

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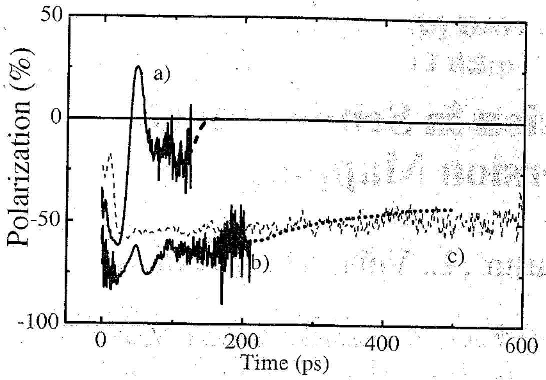

FIGURE 2. Temporal traces of DCP (a) and DLP (b) of LP emission. (c) DLP of LP emission in the linear regime. Dashed lines represent a mean value where the experimental data becomes very noisy.

where temporal traces of DCP (a) and DLP (b) are plotted. Oscillations of DCP, resulting in an ultrafast change from -60% to $+25$ % in just 27 ps are clearly resolved. According to Ref. [4], these oscillations occur due to beating between linear, longitudinal and transverse, polarization states separated by Δ_{LT}. This process is analogous to DCP oscillations of a bulk semiconductor photoluminescence in a magnetic field applied in Voigt geometry. On the other hand, a linear polarization, as high as -50%, persists as long as there is an observable signal (Fig. 2). Negative DLP value indicates that the majority of polaritons occupies the lower energy state, as expected for a thermalized population. Since $\Delta_{LT} > 0$, the vertical polarization state has lower energy and thus we observe a negative polarization. This effect, in turn, is analogous to thermalization of linear excitons on the states split by a magnetic field in Voigt geometry. Moreover, even in DLP, we resolve an oscillatory behavior at short delays after the excitation. These oscillations are only present in the non-linear regime (absence of oscillations in Fig 2c). Oscillations in DLP suggest the that linear states are not the eigenstates of the system. The proper eigenstates therefore must have an admixture of circular ones, i.e. they are elliptical. In other words, the proper "bulk" analog is a magnetic field applied in an oblique direction. However, since we do not observe a significant, constant, equilibrium DCP, we conclude that the circular admixture (the deviance from Voigt configuration in the "bulk" analog") is small.

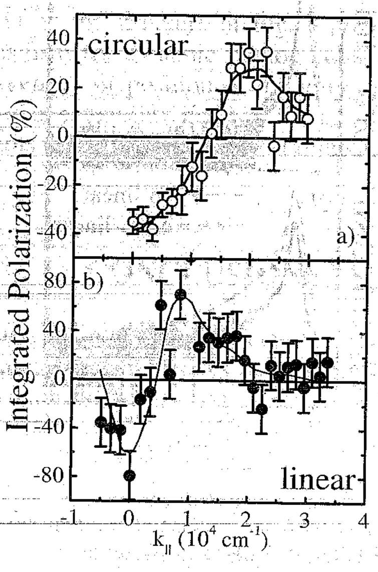

FIGURE 3. Time-integrated DCP (a,○) and DLP (b,●) polarization as a function of LP in-plane wave vector. Lines are guides to eye.

Figure 3 presents time-integrated DCP (a) and DLP (b) as a function of k. DCP increases from about -35% at $k = 0$ to $+35\%$ at $k = 2 \times 10^4 \text{cm}^{-1}$. With a further increase of k, DCP vanishes. This result proves the total angular momentum conservation in our system. Moreover, it points out that the stimulated scattering prefers the cross-circular polariton state. This effect can be related to a spin splitting of LP observed in emission excited non-resonantly with a circularly polarized laser pulse [2]. Due to a spin-dependent interaction between the excitonic parts of the polariton, the minority spin population state is shifted to lower energies [5]. Consequently, the stimulation to the cross-circular state occurs and a negative DCP at $k = 0$ is observed. Similar result is obtained for DLP. At $k = 0$ DLP is negative due to scattering to a lower, vertical linear polarization state. As k is increased, DLP becomes positive. In summary, we have shown that the polariton longitudinal-transverse splitting strongly affects the LP polarization dynamics. In particular, circular polarization exhibits oscillations and linear polarization reaches an equilibrium value. The dispersion mapping of the time-integrated polarization allowed us to demonstrate that the emission stimulation occurs in the spin subband of lowest energy.

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