Ultrafast polarization switching in a CdTe microcavity

M. D. Martín[1], **H. Davies**[1,2], **L. Viña**[1], **and R. André**[3]

[1] Dpt. Física de Materiales, Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[2] Clarendon Laboratory, Dpt. of Physics, University of Oxford, Parks Road, OX1 3PU, UK
[3] Lab. Spectrométrie Physique (CNRS), Univ. Joseph Fourier I, F-38402 Grenoble, France

Abstract We have studied the spin polarization dynamics of II-VI microcavity polaritons. Under non-linear emission conditions, we have observed a very fast and efficient reversal of the polarization of the emission. This effect is accompanied by a splitting of the σ^+ and σ^- emission energies. These two effects become evident in the photon-like polariton branch, but the excitons and the cavity are still strongly coupled.

Introduction

The polarization of the light emitted by semiconductor heterostructures has been profusely studied in the last decade [1]. The development of fast spin-based optoelectronic devices has rekindled the interest in the manipulation of the spin in semiconductors and a new field known as spintronics has arisen. In microcavities, new aspects in the spin properties are expected because of the mixed radiation-matter character of the fundamental excitations of the system, namely cavity-polaritons [2]. Strong anomalies in the polarization of the photon-like polariton branch emission of III-V microcavities have been reported [3-5]. In this paper, we will give a detailed description of the time-resolved spin polarization in a II-VI microcavity as a function of the exciton-cavity detuning and the excitation density.

Experimental details

The sample consisted of 90 Å CdTe quantum wells (QWs) placed in the antinodes of a $\lambda/2$ $Cd_{0.40}Mg_{0.60}Te$ microcavity. The cavity is wedge-shaped and allows tuning the cavity resonance to the transition in the QWs. A Rabi splitting of 10.3 meV was found from cw reflectivity measurements. The sample was kept constant at 5 K. A constant difference of 90 meV was kept between the excitation energy and the photon-like branch. The photoluminescence (PL), after excitation with σ^+ polarized pulses, was polarization- and time-resolved in a conventional up-conversion spectrometer with a time resolution of ~ 2 ps. We will refer to the PL's polarization degree, defined as $\wp=(I^+-I^-)/(I^++I^-)$ -where $I^{+/-}$ denotes the $\sigma^{+/-}$ emission intensity-, simply as polarization.

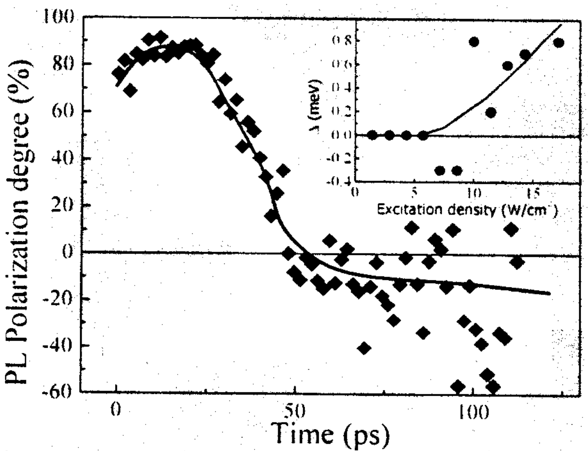

Fig. 1 Time evolution of the polarization degree of the PL of the UPB for $\delta>0$. Inset: σ^+/σ^- energy splitting as a function of excitation density for $\delta>0$. The line is a guide to the eye.

Experimental results and discussion

We have studied the recombination dynamics of microcavity polaritons as a function of excitation density and exciton-cavity detuning ($\delta = E_C - E_X$). We have found that the PL shows two peaks only at very short times (<50 ps). We have observed a Rabi splitting of 9.5 meV, slightly smaller than that extracted from cw reflectivity measurements. The time evolution of the PL of the upper/lower polariton branch (UPB/LPB) depends on the detuning. The characteristic decay times are: τ_d(LPB)~375/175 ps, τ_d(UPB)~15/100 ps for $\delta>0/\delta\sim0$, respectively. In the case of $\delta<0$, the decay time of the PL of both branches is approximately equal and amounts to τ_d~150 ps. An increase of the excitation density has several important consequences on the emission dynamics. The most important one is the exponential growth of the integrated intensity with increasing excitation power, for any detuning. A similar dependence has been reported recently [4] and it is characteristic of the final state population stimulated scattering processes in a gas of bosons. A second effect is a small blue shift (<2 meV) of the emission energies with increasing excitation density. It has been demonstrated that the strong coupling regime persists in spite of the appearance of this small blue shift [6]. We will now concentrate on the spin properties of microcavity polaritons for three different detunings and under non-linear emission conditions.

Positive detuning

The time evolution of the polarization of the UPB for an excitation density of ~10 W/cm^2 is presented in Fig. 1. The PL is co-polarized with the excitation, the maximum is attained at ~20 ps and it is followed by a fast decay, in contrast with the behavior of excitons in bare

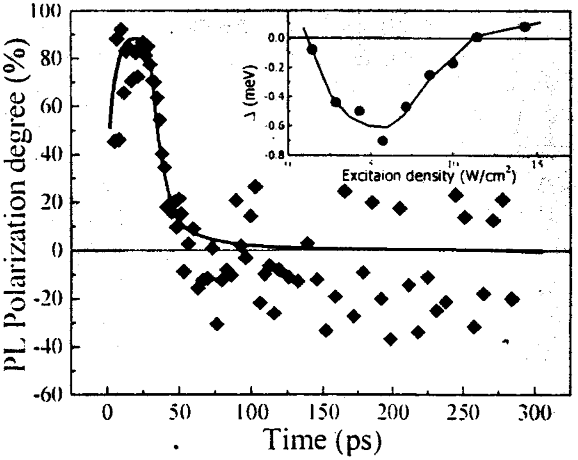

Fig. 2 Time evolution of the polarization degree of the PL of the LPB for $\delta\sim0$. Inset: σ^+/σ^- energy splitting as a function of excitation density for $\delta\sim0$. The line is a guide to the eye.

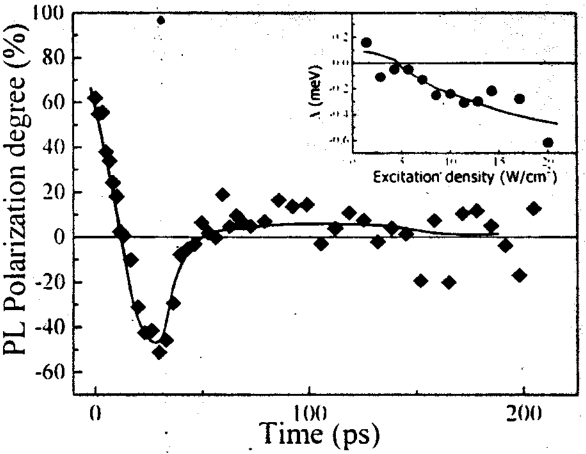

Fig. 3 Time evolution of the polarization degree of the LPB PL for $\delta<0$. Inset: σ^+/σ^- energy splitting as a function of excitation density for $\delta<0$. The line is a guide to the eye.

QWs [7], which do not show any initial rise. An increase of the excitation density leads to a splitting ($\Delta=E^+-E^-\sim1$ meV) between the σ^+ and the σ^- polarized components of the PL of the UPB at short times (inset of Fig. 1, @ 20ps). The initial pulse populates mainly the +1 spin level at K>0. The observed splitting, which still needs theoretical clarification, is responsible for the initial increase of the polarization under conditions of final-state stimulated scattering. A positive splitting means that the +1 spin state is the lower state and if the relaxation towards K~0 states is faster than the spin relaxation process then the population of the +1 spin state will be favored, giving rise to an increase of $\wp$. The fast decay of $\wp$ is due to the stimulated recombination of +1 spin states [5].

Zero detuning

The PL of the LPB is co-polarized with the excitation light and a similar behavior of the polarization has been reported recently [3-5]. The maximum polarization is attained in ~25 ps and is followed by a very fast decay, as shown in Fig. 2 for an excitation density of ~6 W/cm^2. The splitting Δ at ~13 ps is depicted in the inset. For small densities Δ is negative, and increases with increasing excitation density up to ~5 W/cm^2. At larger excitation densities, it decreases and reaches positive values. At $\delta\sim0$, the emission spectra show a complex behavior, which is still under investigation.

Negative detuning

The behavior observed in this case is markedly different to those reported in the two previous sections: excitation with σ^+ polarized light yields to a σ^- polarized PL (Fig. 3, ~14 W/cm^2). It can be seen that the initial polarization of ~60% switches very quickly to negative values (-60%) in ~30 ps. As depicted in the inset of Fig. 3 for 20 ps delay, the spin splitting is negative for $\delta<0$. This means that the -1 spin level (E^+) is the energetically lowest one. As in the previous sections, the nonresonant excitation pulse mainly populates the +1 spin state of K>0. However, for $\delta<0$, the final state stimulated scattering populates the -1 spin level (E^-) at K~0, leading to a larger σ^- emission intensity and thus to a negative polarization. Although the origin, and even more, the sign reversal of this spin splitting, is still to be understood it accounts for the observed polarization reversal.

Conclusions

We have presented the polarization-resolved emission dynamics of a II-VI microcavity under non-linear emission conditions. We have observed a large positive polarization for positive exciton-cavity detuning and a large negative polarization for negative detuning. The origin of these large polarizations is a splitting observed between the σ^+ and the σ^- components of the PL. This spin splitting is positive for $\delta>0$ and negative for $\delta<0$, revealing the reversal of the spin alignment with changing the detuning. The origin of this spin splitting is still under study.

Acknowledgments

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