Using Phonons to Populate the Bottom of the Polariton Dispersion Relation

M. D. Martín[1], D. Ballarini[1], A. Amo[1], L. Viña[1], R. André[2]

[1] *SEMICUAM, Depto. Física de Materiales, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*
[2] *Laboratoire Spectrométrie Physique (CNRS), Université Joseph Fourier 1, F-38402 Grenoble, France*

Abstract. We have studied the dynamics of polariton-LO phonon scattering in a CdTe microcavity at low temperatures under resonant excitation. We have set an exciton-cavity detuning such that the energy difference between the two polariton branches coincides with that of an LO phonon. Our experiments reveal a sub-linear dependence of the integrated emission with pump power. Simultaneously, we have observed that the rise time of the emission does not depend on excitation power. These two facts suggest that the relaxation dynamics after resonant excitation is not governed by polariton-polariton scattering.

Keywords: Microcavities, II-VI semiconductors, polaritons, relaxation dynamics.
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INTRODUCTION

In the last years, the possibility of achieving a polariton condensation in the bottom of the dispersion relation has elicited great interest [1]. In this paper we explore polariton-phonon scattering as a potential candidate to reach a macroscopic occupation of K ~ 0 states in the lower polariton branch (LPB). We have set an exciton-cavity detuning such that the energy difference between the upper polariton branch (UPB) and the LPB is close to that of an LO phonon. Then we have resonantly created K ~ 0 polaritons into the UPB. Previous reports in III-V microcavities indicate that direct scattering from K ~ 0 states in the UPB to K ~ 0 states in the LPB is inhibited [2] and show that UPB polaritons are more efficiently scattered to large-K LPB states. One could follow the argument and claim that, from those large-K states, polaritons relax to the bottom of the LPB through polariton-polariton scattering in a similar way as for non-resonant excitation. Our results show that this is not the case and that there are remarkable differences in the polariton relaxation after UPB resonant excitation.

SAMPLE AND EXPERIMENT

The sample under study is a $Cd_{0.4}Mg_{0.6}Te$ λ-microcavity with embedded CdTe quantum wells characterized by a Rabi splitting Ω = 10 meV. The measurements are performed at 5 K and at different points of the sample corresponding to negative detunings, such that the energy difference between UPB and LPB (Δ) is approximately that of an LO phonon ($\hbar\omega_{LO} = 21.2$ meV). The excitation laser pulse is tuned to the UPB and arrives to the sample almost perpendicular to its surface. We have time-resolved the photoluminescence (PL) originating from the bottom of the LPB at K ~ 0 by means of a spectrograph coupled to a streak camera.

RESULTS AND DISCUSSION

We have concentrated our analysis on the polariton relaxation dynamics, studying the rise and decay times of the emission and the excitation-power dependence of the integrated intensity of the PL from K ~ 0 LPB states. Figure 1 displays the time evolution of the LPB emission obtained for an excitation power of 1 mW. We observe a very fast rise of the PL ($\leq$ 15 ps), which is not modified by the increase of excitation power over two orders of magnitude. This short rise time is related to a fast, but inefficient, relaxation to the LPB [2]. The tuning of Δ to the LO-phonon energy does not increase the efficiency (one could expect a large increase if $\Omega = \hbar\omega_{LO}$ [3]). Only a small acceleration in the recombination dynamics is observed, with a reduction of the decay time from 125 to 110 ps with increasing excitation power (inset Fig. 1). This time is much longer than the photon lifetime inside the cavity (~ 10 ps) and is generally attributed to the relaxation of po-

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laritons along the LPB via the emission of acoustic phonons and/or polariton parametric scattering.

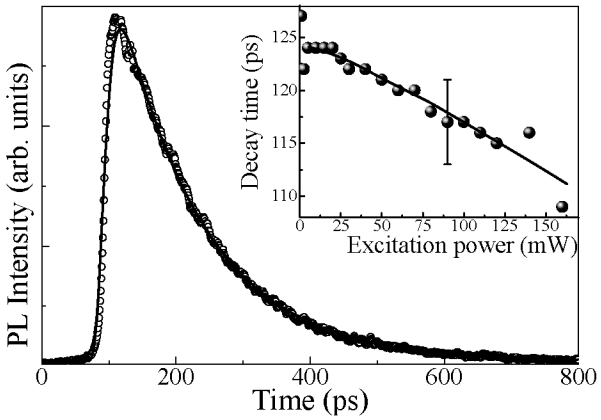

FIGURE 1. Time evolution trace of the emission from K ~ 0 LPB states for an excitation power of 1 mW and Δ = 21.2 meV. The line is a fit to $y = \frac{N_0}{t_r - t_d}(e^{-(x-x_0)/t_r} - e^{-(x-x_0)/t_d})$. Inset: excitation power dependence of the PL decay time. The line is a guide to the eye.

One of our most remarkable findings is a complete absence of non-linear emission from K ~ 0 LPB states, which has been observed in an identical system under non-resonant excitation [4, 5]. In fact we find a sub-linear dependence of the integrated intensity increasing the pump power by more than two orders of magnitude (Figure 2). This fact reveals an inhibition of polariton-polariton final-state stimulated scattering for these energy settings. We have also studied different values of Δ in the vicinity of the LO phonon. We have found that even for an energy difference (Δ = 23.1 meV), which would involve acoustic phonon- and polariton-polariton scattering in the relaxation towards K ~ 0 LPB states, the power dependence of the integrated emission is unaffected (inset Fig. 2). Only after a large reduction of the exciton-cavity detuning (Δ = 17. 6 meV) does the integrated PL approach a linear dependence, recovering the non-linear behaviour of Ref. 5 for even smaller detunings (not shown).

The behaviour described above could be related to two very different causes. The first one is the large reflectivity of the microcavity at the UPB energy for large negative detunings, such as these. This implies that the effective excitation that gets inside the cavity is much smaller than in the non-resonant case and therefore it is not possible to achieve polariton populations large enough to drive the system into the non-linear regime. Yet it would not explain why the dependence is so clearly sub-linear. The second possibility is the fact that K ~ 0 UPB polariton scattering to large-K states in the LPB occurs to a particular region, further from the bottleneck than in the case of non-resonant excitation, from which polariton-polariton scattering is strongly inhibited, resulting in a weaker emission from K ~ 0 LPB states [6].

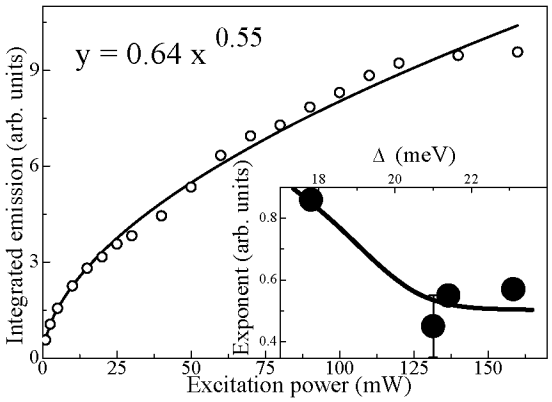

FIGURE 2. Integrated PL from K ~ 0 LPB states as a function of the excitation power. The solid line represents a fit with the equation that appears on the graph. Inset: dependence of the fit's exponent on the energy difference between UPB and LPB. The line is a guide to the eye.

CONCLUSIONS

We have investigated polariton-LO phonon scattering after resonant excitation in the UPB. We have found that the efficiency of the fast relaxation from K ~ 0 UPB to LPB states is not strongly modified by tuning Δ to $\hbar\omega_{LO}$. We have also found a sub-linear dependence of the integrated PL from K ~ 0 LPB states as a consequence of the inhibition of polariton-polariton final-state stimulated scattering. This inhibition could be due to a large reflectivity at the UPB energy or a narrow polariton distribution at large-K LPB states that will result in a very weak emission/small population at K ~ 0.

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REFERENCES

1. Special Issue on Microcavities, *Semic. Sci. & Tech.* **18** (2003) Ed. by J. J. Baumberg and L. Viña.
2. J. Bloch and J. Y. Marzin, *Phys. Rev.* B **56**, 2103-2108 (1997); A. I. Tartakovskii et al, *ibid.* **60**, R11293-11296 (1999).
3. A. Fainstein et al, *Phys. Rev.* B **57**, R9439-9442 (1998).
4. M. D. Martín et al. *Phys. Rev. Lett.* **89**, 077402 (2002).
5. L. Viña et al., *Semic. Sci. & Tech.* **19**, S333-335 (2004).
6. A. I. Tartakovskii et al, *Phys. Rev.* B **67**, 165302 (2003).