Observation of a Long-Lived Polariton State in Semiconductor Microcavities

D. Ballarini[1], A. Amo[1], D. Sanvitto[1], M. D. Martín[1], L. Viña[1], M. Wouters[2], I. Carusotto[3], A. Lemaitre[4], J. Bloch[4]

[1] *Semicuam, Departamento de Física de Materiales, Universidad Autónoma, E-28049.Madrid, Spain*
[2] *Institute of Theoretical Physics, Ecole Polytechnique Federale de Lausanne, CH-1015 Lausanne, Switzerland*
[3] *BEC-CNR-INFM and Dipartimento di Fisica. Universita di Trento. I-38050 Povo, Italy*
[4] *CNRS-Laboratoire de Photonique et Nanostructures, F-91460 Marcoussis, France*

Abstract. The spectrum of a polariton optical parametric oscillator (OPO) around the signal state is investigated by means of a novel experimental configuration, which allows for the observation of the imaginary part of the OPO elementary excitations. Using continuous-wave resonant excitation, around the inflection point of the lower polariton dispersion, with a pulsed-probe, resonant at the idler position, we obtain the long dynamics behavior around the signal state. This allows the study of the damping rate of the OPO's signal state as a function of pump intensity by means of time- and energy-resolved photoluminescence. At high pump intensities, the lifetime of the perturbed signal is observed to be orders of magnitude (nanoseconds) longer than the intrinsic cavity lifetime (picoseconds). These results are in agreement with calculations of the self-energy of the excitations around the signal state.

Keywords: Microcavities, Goldstone modes, OPO
PACS: 71.35.Lk**,** 71.36.+c

INTRODUCTION

Polaritons, boson-like particles, are coupled modes in semiconductor microcavities formed in the limit of low-carrier density. While its bosonic character is preserved, polariton-polariton scattering can be stimulated by final state occupation. Due to their strong Kerr-nonlinearities, and to their peculiar dispersion relation, polaritons show large gain values in parametric amplification [1] as well as parametric oscillations [2]. They are very promising objects to study phase transitions in non equilibrium systems, where the concept of quantum fluid is no longer determined by a thermodynamical equilibrium condition, but rather by a balance between external driving and dissipation. Their mixed excitonic/photonic nature allows for a number of notable properties, such as a very light mass, significant interactions, and the possibility of all-optical manipulation and diagnosis [3]. We propose a novel experimental configuration to study the excitations of the signal state of an OPO by analyzing its temporal response to a weak, pulsed perturbation set at resonance with the idler state. Good agreement between the experimental observations and a theoretical model based on the generalized polariton Gross-Pitaevskii equation is found, which supports the present theoretical understanding of the strongly modified dispersion of the elementary excitations of polaritons in the presence of a strong pump beam.

EXPERIMENTAL DETAILS

The studied microcavity is composed by a $\lambda/2$ AlAs cavity with a top (bottom) Bragg mirror of 15 (25) $Al_{0.1}Ga_{0.9}As$/AlAs pairs, grown on a GaAs substrate. A 20-nm wide GaAs quantum well is embedded at the antinode position of the cavity mode. The excitons are in strong coupling with the cavity mode with a Rabi splitting of 4.4 meV. The sample is kept at a temperature of 10 K. A *cw* Ti:Al_2O_3-laser pump, with an incident angle of 10º, at resonance with the lower polariton branch (LPB),

CP1199, 29th *International Conference on the Physics of Semiconductors,* edited by M. J. Caldas and N. Studart

excites polaritons with a well defined finite momentum and energy. Parametric processes convert pump polaritons into signal-idler ones via optical nonlinearities. Above a threshold intensity, the parametric process becomes stimulated and gives rise to a pair of signal-idler coherent beams. Signal emission originates at the bottom of the LPB, while the energy and momentum of the idler are fixed by the phase matching conditions (further details on the OPO configuration can be found in [4]). Additionally, a weak, pulsed Ti:Al_2O_3-laser probe (2 ps) is tuned at the energy and momentum of the idler state, allowing the detection and study of the response to the perturbation at the signal energy. Its spectral and temporal behavior is analyzed by means of a spectrograph coupled with a streak camera, both in real- and momentum-space.

RESULTS AND DISCUSSION

The evolution of the system in response to the probe pulse is studied by analyzing the time- and momentum-resolved signal emission and its decay time. Figure 1 shows the time-evolution of the difference $\Delta I_s=I_s(pump+probe)-I_s(pump)$ between the signal emission intensity in the presence and in the absence of the probe, respectively, for three different pump intensities. The inset depicts an image from the streak camera for 11.25 mW, from which the energy-integrated time evolutions are obtained.

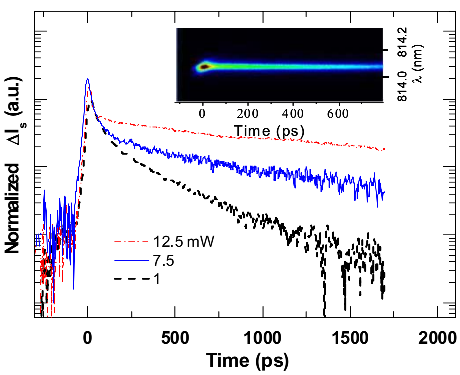

FIGURE 1. Time evolution of the energy-integrated signal emission ΔI_s for three different pump powers. The inset depicts the false color image from the streak camera for 11.25 mW.

After the arrival of the probe pulse, parametric scattering of pump polaritons into the k_s state is stimulated by the small population of the idler polaritons: a fast rise of ΔI_s at t=0 (probe arrival time) is obtained, followed by a fast decay on a 30 ps scale and by a much slower exponential decay on a time scale of the order of a few hundreds of picoseconds. The response of the system strongly depends on the intensity I_p of the *cw* pump. The fast decay- time of the transient decreases for increasing pump powers while the slow one, τ, significantly increases with I_p. τ, shows a divergent behavior for pump powers approaching I_p^{th}=12.5 mW. This is seen in Fig. 2(a), where the dependence on k of the increase of τ with respect to its value at |k| > 1 is shown (k=0 corresponds to k_s).

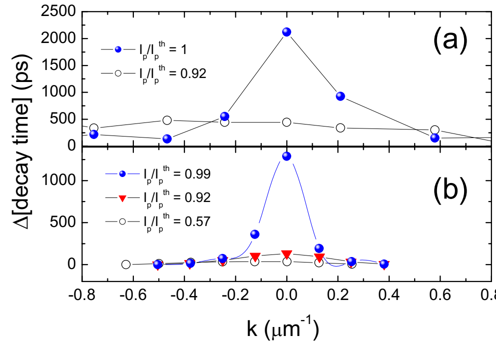

FIGURE 2. (a) Experimental dependence on k of the increase of decay time for 2 different powers. (b) Calculated dependence for 3 different powers.

The behavior is well reproduced by calculations based on a pair of coupled Gross-Pitaevskii-like nonlinear wave equations for the photon and exciton fields [5], as demonstrated in Fig. 2(b) for three different powers approaching threshold. In summary, we have found a critical slowing down of the elementary excitation dynamics at the threshold of an OPO in semiconductor microcavities, which can be interpreted as a precursor of a Goldstone mode.

ACKNOWLEDGMENTS

This work was partially supported by the Spanish MEC (MAT2005-01388, NAN2004-09109-C04-04 & QOIT-CSD2006-00019), the CAM (S-0505/ESP-0200). D.B. acknowledges a FPU scholarship of the Spanish MEC and D.S. thanks the RyC Program. I.C. thanks C. Ciuti for continuous discussions and the support from the Italian MIUR, the French CNRS and the EuroQUAM-FerMix program.

REFERENCES

1. P. G. Savvidis et al. Phys. Rev. Lett. **84**, 1547 (2000).
2. R. M. Stevenson et el. Phys Rev. Lett. **85**, 3680 (2000).
3. Special issue on Microcavities edited by J.J. Baumberg and L. Viña, Semicond.Sci.Technol.,**18** (10) (2003).
4. M. S. Skolnick et al. Phys. Stat. Sol. (b) **243**, 3741 (2006).
5. C. Ciuti *et al.*, reference 3, p. S279; C. Ciuti and I. Carusotto, Phys. Stat. Sol. (b) **242**, 2224 (2005).