Observation of Quantum Hydrodynamic Effects in Microcavity Polaritons

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We study the hydrodynamics of a coherent polariton fluid lasting for hundreds of picoseconds and moving inside of a semiconductor microcavity. The momentum of the polariton droplets can be well controlled by selecting the angle and energy of two excitation laser beams. We observe unique behaviours due to the quantum nature of the polariton states, such as the linearization of the polariton dispersion around the energy of the signal states, and the propagation at constant speed of the polariton fluids. The experiments have been realized making use of a new technique for the detection of images simultaneously resolved in time, energy and real- or reciprocal- space.

Keywords: polariton, semiconductor microcavity, quantum fluids
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INTRODUCTION

Microcavity polaritons are quasi-particles obtained by strongly coupling photons, confined in an optical cavity, and excitons in quantum wells. The recent observation of Bose-Einstein condensates (BEC)[1, 2] for these particles has suggested the possibility to use them as a new test bed for phenomena related to BEC, which up to now have been only studied in diluted atomic gases. Theoretical studies predict the appearance of polariton phases with long range order even though polariton condensates are highly out-of-equilibrium systems due to the short polariton lifetime.[3, 4]. In fact, their out of equilibrium nature confers to polaritons very interesting properties hardly accessible in other bosonic systems.[5]

From the experimental point of view, due to their very short lifetime, polaritons dwell in the condensed state only a few picoseconds, hindering the observation of dynamical phenomena. In this communication we introduce a technique based in the final state stimulation of polaritons and the OPO physics to create and observe the real time movement of polariton droplets in a semiconductor microcavity, with a well defined momentum. The created polariton states show a linearized spectrum and constant velocity throughout its trajectory.

RESULTS AND DISCUSSION

We use a GaAs based $\lambda/2$ microcavity with a single QW placed at its centre.[6] Typical polariton lifetimes in such microcavity are on the order of ~4 ps. All the experiments are performed at the cavity-exciton resonance at a temperature of ~6 K. A CW Ti:Al_20_3 laser (*pump*) is focalized on the sample in a spot of 45 μm in diameter, at an angle of incidence close to the magic angle, resonant with the lower polariton branch (LPB). Within the pump spot, a pulsed Ti:Al_20_3 laser (2 ps pulses) is shone on a spot of 16 μm in diameter. The pulsed laser is incident with a higher angle and energy, also resonant with the LPB, such that the associated polariton momenta and energies follow $\boldsymbol{k}_P+\boldsymbol{k}_I=\boldsymbol{k}_S$ and $E_P+E_I=E_S$, respectively, where P, I and S indicate the pump, pulsed laser and signal fields. In this way, a signal polariton droplet with a

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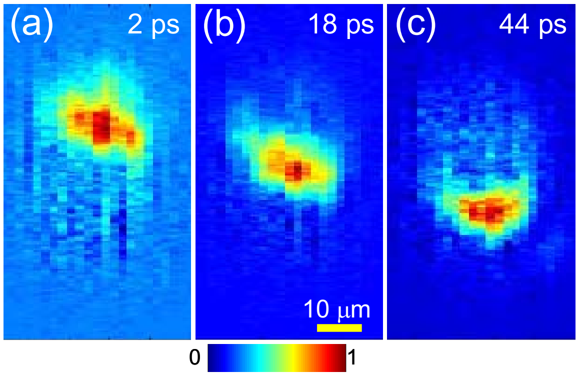

FIGURE 1. Real space images of the signal polariton droplet 2 ps (a) 18 ps (b) and 44 ps after the arrival of the laser pulse. All images are intensity normalized according to the scale shown on the bottom.

well defined momentum k_S can be triggered at the arrival of the laser pulse. Signal polaritons, which show occupations greater than 1 at the arrival of the pulse, continue to exist even after the pulse has disappeared due to the continuous replenishing of signal polaritons from the CW pump due to final state stimulation.[7] Real- and momentum-space images of the polariton fluids at the signal energy can be registered with a time resolution of about 8 ps with the use of spectrometer attached to a streak camera.[8]

Figure 1 shows real space images of the signal polariton droplet 2 ps (a),18 ps (b) and 44 ps (c) after the arrival of the laser pulse. In this case the polariton droplet traverses the pump spot at a constant velocity of 0.5 μm/ps. The signal polariton droplet keeps its size and shape throughout its trajectory.

Figure 2 shows the signal polariton dispersion (white dots) under the conditions of Fig. 1. A clear blueshift ΔE due to interactions is observed with respect to the case of non-resonant excitation (red dots). Note that the signal polaritons show a linearized spectrum, with no trace of backscattering.

The linearized spectrum of signal polaritons is compatible with the observed absence of expansion of the signal droplet, revealing its quantum nature. A coherent wavepacket moving on top of a linear dispersion should not expand.

In conclusion, we have presented a technique that enables the creation and observation of polariton droplets whose quantum nature is evidenced through their real and momentum space dynamics. With our experimental configuration the momentum of the signal polaritons can be changed by selecting the angle and energy of the incident laser pulse, as indicated by the aforementioned phase matching conditions. This versatility enables the detailed study of the fluid dynamics of quantum polariton fluids.

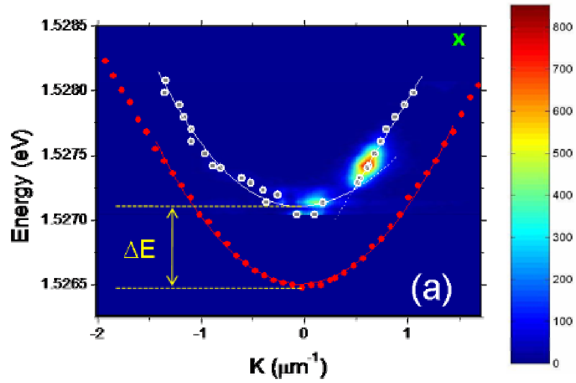

FIGURE 2. False color map of the polariton dispersion under the conditions of TOPO. The emission under cw pump excitation has been subtracted from the luminescence under cw-pump plus pulsed-probe excitation. The white open points show the maxima of the spectra. Solid white lines show a linear+parabolic fit to the data. Red points show the emission of the LPB under non-resonant excitation, the solid line showing a parabolic fit. ΔE indicates the polariton renormalization. The pump field is at the energy and momentum indicated by the green X.

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