Spatiotemporal properties of exciton-polariton dynamic wave-packets in periodic acoustic potentials II

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Purpose of the visit

This visit aimed further exploration of the properties of properties of exciton-polariton wavepackets in acoustically generated periodic potentials, as a continuation to the exploratory experiments realised in the first visit. In particular, we realised time-resolved experiments with pico- and nanosecond resolution in order to characterize the temporal evolution of the wavepacket and determine whether it shows soliton-like behavior.

Description of the work carried out during the visit

A GaAs-based microcavity similar to the one used in the last visit was studied. In this case, the detuning between the photonic and excitonic resonances was smaller (∼2 meV), so the polaritons have a larger excitonic component than that of the sample studied the last time. The surface acoustic waves (SAWs) of wavelength $l_{SAW} = 8$ μm are generated using metallic interdigitated transducers (IDTs) deposited at the surface of the sample. The

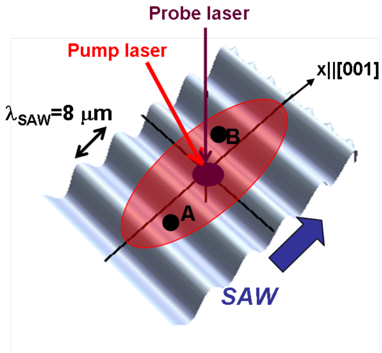

Figure 1: a) Scheme of the sample, where the IDT at the surface generates a SAW that propagates along a [100] direction. b) Polariton wavepacket excitation technique. The CW pump has a diameter of around 60 μm and the writing beam of 5 μm.

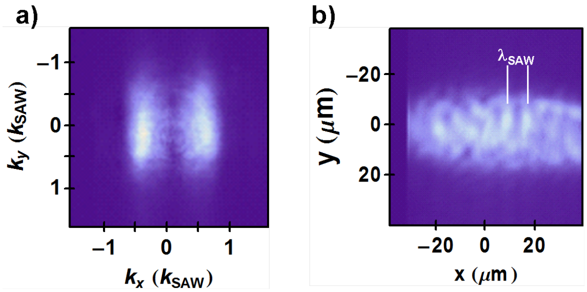

Figure 2: Condensate under a shallow potential. a) Recirpocal and b) real space patterns of the photoluminiscence of the condensate created under modulation of a shallow acoustic potential. The SAW propagates in this case along the x direction.

sample contains IDTs oriented along <100> directions perpendicular to each other. Real- and reciprocal-space resolved photoluminiscence (PL) experiments were carried out by excitation with a single mode CW pump laser focused in a ellipsoidal spot of 60×20 μm^2 with the larger axis oriented along the propagation direction of the SAW and impigning on the sample at an angle of approximately 14 degrees (Fig. 1). Temporally resolved experiments with nanosecond resolution were realised by measuring the classical temporal correlation function $g^{(2)}$ between two different points of the condensate (i.e. points A and B in Fig. 1, for example) using a Hanbury Brown and Twiss setup. This type of measurement gives information on the displacement of the confinement potentials, as described in detail in Ref. [1]. The wavepackets were generated using a resonant optical excitation technique with a pulsed probe laser. In this case, the pump is the same as above and the probe is a ultrafast laser pulse (5 ps) with a small diameter of 5 μm resonant with the energy of the condensate and normally incident to the sample. The photoluminescence (PL) emission was spatially resolved and captured by a Hamamatsu streak camera with temporal resolution of 2 ps. All the experiments were realised with the sample at a temperature of 2 kelvin.

Description of the main results obtained

Real and reciprocal space measurements.

The experiments focalised on the study of the condensation at the borders of the mini-Brillouin Zone that occurs in the presence of a weak SAW potential [1]. As shown in Fig. 2a), the reciprocal space emission shows two maxima located at $k = \pm\lambda_{\rm SAW}/2$. Interestingly, for very weak values of applied radio-frequency power $P_{\rm rf}$, which correspond to a very shallow periodic potential, a weak static pattern in real space forms. This is remarkable, as the measurement is integrated in time and no structure is expected to be observed since the SAW moves with a velocity of $v_{\rm SAW} = 2.6\mu m/ns$. The pattern could be explained by the spontaneous formation of a polariton standing wave on top of the moving potential. The mechanisms of formation are however not clear. The period of the pattern corresponds to $\lambda_{\rm SAW}$. The time-resolved experiments described below were realised under these conditions.

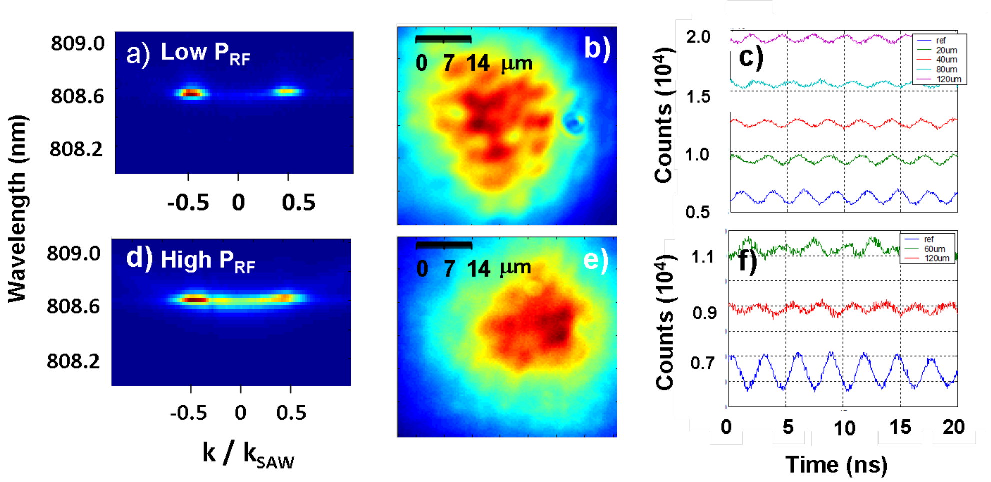

Figure 3: Spatio-temporal properties of a condensate in a shallow potential. Panels a) and d) show spectra resolved in reciprocal space where of condensation under a shallow and deep SAW potentials, respectively. Panels b) and e) show the corresponding real space images and panels c) and f) show the dependence of the $g^{(2)}$ function for each of the two cases.

Measurement of temporal properties in the nanosecond range

In order to study the properties of the static pattern, we measured the classcial time correlation function $g^{(2)}(\delta y, \delta t) =< I_{PL}(0,0), I_{PL}(\delta y, \delta t) >$ of the PL two small regions whithin the condensate using a Hanbury Brown and Twiss setup. In order to do this, each of the regions A and B depicted in Fig. 1 were imaged into each of the two photodectectors of the setup. Since the SAW potential is moving, the $g^{(2)}$ function exhibits maxima at time intervals τ multiples of the SAW period when condensates cross the collection regions of both detectors. In the case when the condensation occurs at borders of the Brillouin Zone (Fig. 3a)), the pattern is present (panel b), notice that in this case the SAW is propagating vertically) and we observe weak oscillations of $g^{(2)}$ (panel c), which indicates that there is some transport of particle population even though there seems to be a part of the population that remains static forming the pattern. The transport effect is stronger in the well known case of a deep potential (panel d) where the condensate is extended all over the first MBZ due to the confinment. In this case, the pattern is not present (panel e) and the contrast of the in the $g^{(2)}$ (panel f) oscillations is larger. The different lines in panels c) and f) show the shift in the phase of the oscillations when the position of one of the imaged region is changed. The lowermost curve is a reference signal where both spots A and B are at the same position where at the top most curve they are separated by a distance equivalent to λ_{SAW}.

Measurement of temporal properties in the picoseconf range

In the former visit we observed that when the probe k-vector is below certain threshold level (approximately 5 degrees in our case), but is not 0, the probe propagates certain distance but in the meanwhile it breaks onto regions which seem to be defined by the potential minima induced by the SAW. This behavior could be related with the observations described in the former paragraphs regarding the existence of the static pattern and possibly to the

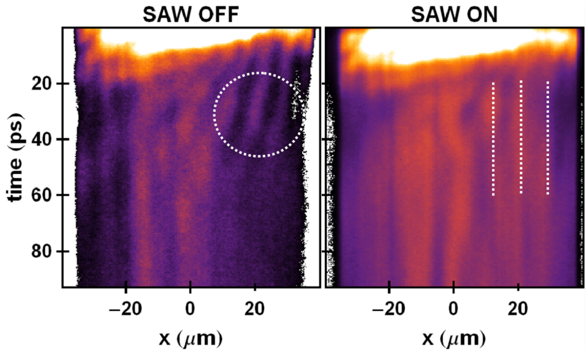

Figure 4: Raw streak camera image of the condensate excited by a small pump (bright spot at t=0) on top of the large pump spot, as depicted in Fig. in the a) absence and b) presence of the SAW.

formation of some kind of dissipative soliton. In order to assess this behavior, we carried out the experiment depicted in Fig. 1 where a small probe is injected with $k = 0$ to artificially create a self focused population within the larger spot. The experiment was unfortunately not easy, and no definitive data could be obtained. We believe that the difficulty lies in the fact that the bistable behavior of the polariton system necessary for the formation of a soliton [2] is strongly affected by the presence of the SAW. This results in a complex nonlinear behavior which makes difficult to find the right conditions for the stimulation of such a state. Further investigations are being carried on in order to asses this problem. In Fig. 4 we present an example of the measurements made. The image correponds to the excitation of a condensate excited with the small probe (bright emission around t=0) on top of the large pump spot. Some changes can be seen mostly on the right side of the image (region delimited by the white circle), where, in the absence of the SAW some wavepackets are generated and propagate slowly and for a short time (the probe is focalised and pulsed and thus contains a wide range of k vectors and energies). In the presence of the SAW under conditions when the standing pattern was observed (panel b)), the wavepackets do not propagate horizontally but remain for some time at positions which seem to be fixed by the SAW potential (white lines).

Conclusions

We carried out PL experiments on a polariton microcavity with negative detuning. Under a shallow potential, a static spatial pattern seems to form despite the fact that the SAW potential moves. We investigated this pattern by classical time correlation experiments where it was observe that, even in the presence of the spatial pattern, trasnsport of polariton population is present. We explored the possibility of the formation of a soliton-like polariton object by using a pump and probe experiment. The latter experiments were not conclusive due to the complex nonlinear behavior of the system under the presence of a SAW.

Future collaboration with host institution (if applicable)

The results in this report show that it is hard to draw a definite conclusion on the behavior of the system without further analysis of the data and realisation more experimens. We expect therefore to continue the close collaboration in the near future to gather more experimental data and provide an adequate model explaining our results.

Projected publications/articles resulting or to result from your grant

The physics of polariton wavepackets in periodic potentials is a novel field. The results regarding the formation of the static spatial pattern are being presently processed and more experiments realised to establish its origin. We expect that this highly remarkable feature results in the publication of an article. Further analysis and more experimental data are required in order to establish the possibility of a mechanism for the formation of polariton soliton-like objects in periodic potentials, which should result in publication in high impact journals.

Other comments (if any)

References

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