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Photon and Polariton Condensates in Microcavities

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Abstract: In this work we study thermalisation-, coherence- and spin dynamics of photon and polariton Bose-Einstein condensates (BECs). We witness carrier distributions following the Bose Einstein distribution, buildup of long-range order and spontaneous symmetry breaking.

Microcavities offer interesting opportunities for the generation of BECs as cavity photons and exciton-polaritons possess large de Broglie wavelengths that allow for condensation from temperatures achievable by cryogenic means up to the room temperature, where atoms need to be cooled to the sub milli-Kelvin range. Condensation of exciton polaritons in the strong coupling regime has been under intense investigation for a few years [1,2,3], whilst thermalization [4] and subsequent condensation of photons, which are weakly coupled to electronic excitations in a dye filled microcavity has only been shown very recently [5]. In a semiconductor microcavity switching between strong and weak coupling can be achieved by tuning the width of the quantum-well resonance. We tune the width of this resonance by changing exciton population created by optical pumping. We witness all features of BECs both in the weak and the strong coupling regime [6]: a) massive occupation of the ground state, b) long-range spatial coherence and c) spontaneous symmetry breaking and buildup of order parameter.

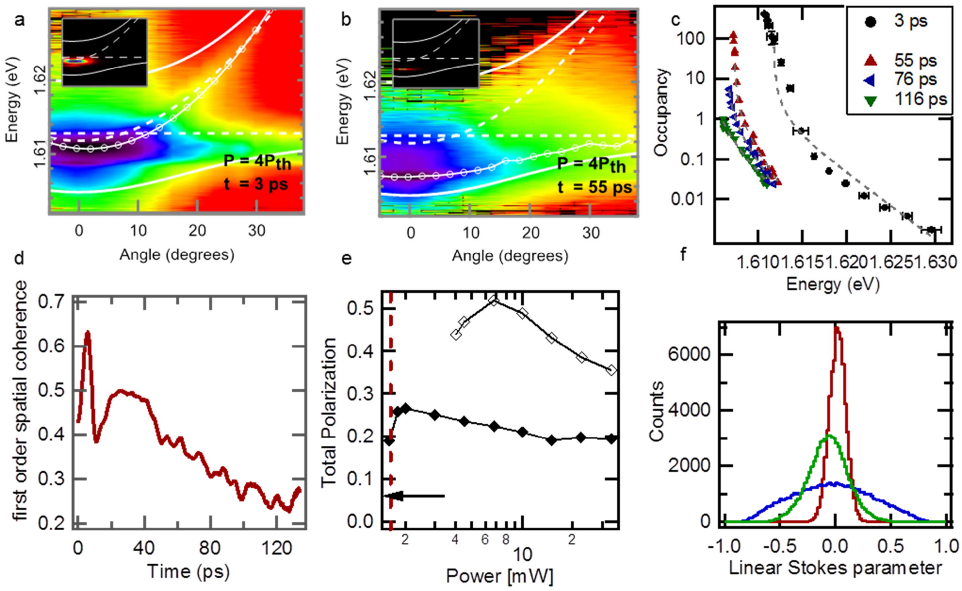

Figure 1. Properties of Photon and Polariton BECs: Dispersion relation in the weak (a) and strong coupling regime (b) at different times after optical excitation, 4 times above threshold (P_{th}) in a logarithmic (inset linear) color scale. c) Carrier distributions at different times after optical excitation. d) Long range order or first order spatial coherence as a function of time reveals a clear dip, when photon and polariton coexist in real space. e) Total degree of polarization as a function of power for photon (open diamonds) and polariton BEC (filled diamonds). The red dashed line marks the threshold power and the arrow indicates the total polarization degree measured below threshold. f) Distributions of the linear Stokes Parameter for a photon condensate (blue), a polariton condensate (green) and below condensation threshold (red). High degrees of polarization are observed in single shot measurements, without significant average polarization.

Ultrafast Thermalization

We map the angular dispersion after a short excitation pulse with picosecond resolution. This measurement provides access to two types of information: whether the system is in the strong or weak coupling regime as well as the distribution of carriers. We map the transition from the weak to the strong coupling (measured dispersions in Figure 1 a,b) as the exciton reservoir depletes with time and find that photons and polaritons are distributed according to the Bose-Einstein distribution in both regimes (Figure 1c). This is a direct evidence of a dynamic phase transition between two equilibrium phases in a bosonic system.

Dynamics of long-range coherence

Time resolved interferometry reveals interesting coherence dynamics during the transition from a photon to a polariton BEC. We observe a buildup of long-range coherence for photon and polariton BEC. In the transitory regime these mutually incoherent phases coexist, which manifests as a drop in the long-range order (Figure 1d).

Spontaneous symmetry breaking

In the last part of our study we investigate single-shot polarization of photon and polariton condensates. We show that individual condensates possess a high degree of polarization, in contrast to the averaged measurement which show almost zero polarization. The photon BEC exhibits an overall higher degree of total polarization than the polariton BEC (Figure 1e). Here, a lower exciton content reduces the interactions between the condensed quasiparticles. Histogram of the linear Stokes Parameter $S_{lin} = \frac{I_H - I_V}{I_H + I_V}$, where I_H and I_V are the intensities of horizontally and vertically polarized light are displayed in Figure 1f).

Conclusions

A dynamical phase transition between photon and polariton BEC states is observed in a monolithic resonator using time resolved dispersion mapping technique. Long range spatial coherence measurements reveal a reduced long range order in the transitory regime, while single shot polarization measurements demonstrate spontaneous symmetry breaking both in the photon and polariton BEC states. Our results signify the similarities and difference between photon and polariton BEC states while witnessing for the first time the transition between two condensed states.

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