

Intrinsic decoherence mechanisms and formation of coexistent polariton condensates in CdTe semiconductor microcavities

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The recent observations¹ of polariton condensation in semiconductor microcavities have provided a new, solid state system for the study of non-equilibrium Bose-Einstein Condensate (BEC)-related phenomena. We show that the polariton BEC is able to reveal new physics of interacting BECs, not accessible so far for the case of atom condensates.

We investigate fundamental quantum properties of this coherent, matter-wave system by studying the temporal and spatial coherence of a CdTe polariton condensate using continuous wave excitation. Above threshold, the observed polariton emission consists of several

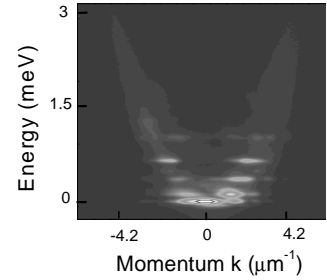


Fig 1 Image of polariton condensate emission above threshold in energy-momentum (E-k) space

(up to 6) narrow lines, separated by $\sim 0.1-0.4$ meV (Fig.1). The peaks exhibit superlinear behaviour with power. This indicates the formation of coexisting condensates with different energies. The polariton wavefunctions in real space corresponding to the narrow lines strongly overlap and have a size of $10-20 \mu\text{m}$. The spatial coherence lengths λ_c of $10-20 \mu\text{m}$ above threshold are also observed by Michelson interferometry. The multimode structure of the stimulated emission, and hence of the polariton condensates, arises from spatial fluctuations of the photonic potential ($\sim 0.5-0.7$ meV), which occur on a length scale of $3-4 \mu\text{m}$. This result in the formation of discrete localised polariton levels. Above threshold condensation into each localised level occurs, resulting in multimode stimulated polariton emission. Higher energy condensates ($E > 0.5$ meV) are delocalised, but their finite k-vectors (Fig.1) are also determined by the photonic potential.

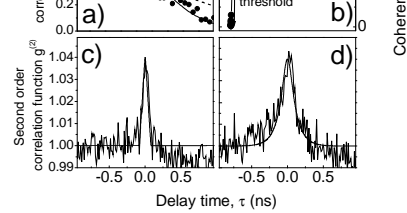


Fig.2 a) Decay of $g^{(1)}$ -function. b) Coherence time ($g^{(1)}$) vs emission intensity from condensate. c) and d) Decay of $g^{(2)}$ -function below (c) and above (d) threshold

We observe coherence times of the individual modes of $\sim 100-200$ ps for both the $g^{(1)}$ phase correlation function and the second order intensity correlation function, $g^{(2)}$. The $g^{(1)}$ function is found to have a Gaussian shape and a decay time which saturates with increasing numbers of particles in the condensate. The coherence times are nearly two orders of magnitude longer than the polariton lifetime (~ 1.5 ps). Such slowing occurs because stimulated scattering from the polariton reservoir into the condensate dominates over spontaneous processes. We explain quantitatively the slowing down of the decay of the $g^{(2)}$ function and show that the decay of $g^{(1)}$ with its Gaussian form are determined by the effects of interactions between polaritons in the coherent state. The interactions cause spontaneous number fluctuations in the coherent state which translate into random energy variations, leading to decoherence. These decoherence processes would occur in a true equilibrium system.

In conclusion, we report the observation of coexisting condensates with long temporal and spatial coherence in a non-equilibrium polariton system. The transverse photonic potential plays an essential role in the selection of k-vectors to which the condensation is triggered. We also show that a single polariton condensate can behave like an equilibrium BEC on timescales much longer than the cavity lifetime.

We will show finally that there is a very strong similarity between the coherence properties of the polariton BEC and the Optical Parametric Oscillator (OPO) in GaAs-microcavities. Long OPO temporal coherence is again observed with coherence times $200-500$ ps for both $g^{(1)}$ and $g^{(2)}$ -functions, where polariton interactions determine the $g^{(1)}$ decay. The OPO also exhibits long spatial coherence lengths $\sim 12-15 \mu\text{m}$ and spontaneous quantized vortices in its phase spatial profile, characteristic of the interacting polariton BEC subject to its transverse photonic potential².

¹ J.Kasprzak et al, Nature 443, 409-414 (2006)

² K.Lagoudakis et al, arXiv:0801.1916v1. Accepted for publication in Nature Physics