Coherence of the Microcavity Polariton Condensate

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The demonstration of coherent polariton emission from a CdTe microcavity structure [1] has provided a new system for the study of condensate physics. Unlike atomic condensates, the microcavity system is not in equilibrium; the polariton life-time in the cavity is only $\sim$ 2ps, so the population has to be maintained by pumping. This raises interesting questions about how the properties of such a non-equilibrium condensate differ from those of an equilibrium system.

Recent experimental measurements of the first ($g^{(1)}$) and second ($g^{(2)}$) order correlation functions of the emitted light have shown that the decay times of both are $\sim 100-200$ps, much longer than the cavity life-time. In this work, we present a theroetical treatment which provides a quantitative explanation of these results, and shows that the ultimate cause of the coherence decay is interactions between polaritons in the condensate.

The microcavity polariton condensate is a mesoscopic quantum system, consisting of $N \sim 10^2$ polaritons within the finite size excitation spot. As a result, number fluctuations of $\sim N^{\frac{1}{2}}$ are expected. For a finite equilibrium condensate of interacting particles, it is straight forward to show that the decay of $g^{(1)}(t)$ has a Gaussian form [2]. The physics behind this is the effect of self phase modulation: the interactions translates number fluctuations in the condensate into random changes to its energy, and so the coherence is lost. The calculated time for this decay turns out to be $\tau_c \sim$ 200ps, in good agreement with the measured values.

The problem with this picture is that the decay time, τ_c, is much longer than polariton life-time, due to emission from the cavity. These losses, and the corresponding gain processes which maintain the population, interrupt the unitary evolution of the system under the interaction Hamiltonian. We argue that the coherence decay should then have an exponential form, with a much longer time constant τ_c^2/τ_r, where τ_r is the effective time-scale of the gain and loss. To explain the observed Gaussian decay, it is thus necessary for the τ_r to be much greater than the empty cavity life-time, τ_0, so the self-phase-modulation decay is completed before it is interrupted.

The explanation for this slowing comes from laser physics. The gain process, which replaces the polariton losses, involves stimulated scattering, which does not interrupt the unitary evolution. This means that the effective time-scale, τ_r, can be much longer than τ_0. As the same physics determines the decay of the second order intensity correlation function, we can deduce $\tau_r \sim$ 150ps directly from the experimental data. This provides sufficient slowing to see the Gaussian decay of the first order correlation function.

To put these ideas on a more quantitative footing, we have developed a simple model of the polariton condensate which correctly predicts the time decay of both correlation functions. The coherent mode is treated as a harmonic oscillator with a Kerr non-linearity representing their interactions. The mode is coupled to a reservoir, using the master equation formalism. Reservoir losses are offset by a laser-like saturable pump term and we assume the system is well below saturation, so the mode population $N \ll N_s$, its saturation value. We find that the decay of the second order function is slowed, to $\tau_r \sim \tau_0 N_s/N \sim$ 50ps, comparable to the experimental value. Furthermore, when we solve our model for $g^{(1)}(t)$, we find that there are indeed two limiting regimes, with behaviour predicted by the arguments given above; for short timescales, compared to this slowed τ_r, we get the Gaussian decay of the isolated condensate, with decay time τ_c, while for long time scales the decay is exponential with time constant τ_c^2/τ_r.

References

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