Optically trapped exciton-polariton and photon condensates in semiconductor microcavities

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Condensation of bosons gives rise to a coherent macroscopic quantum state of matter – the Bose-Einstein condensate (BEC). It has been demonstrated in an abundance of platforms. Notably, it was finally obtained for the most ubiquitous gas of bosons, photons, where it was achieved inside a high-quality optical microcavity filled with a dye solution as a thermalizing medium [1]. Since this observation, researchers have been searching for other photonic solutions that allow one to observe photon condensates in thermal equilibrium. The crucial property of this new direction is to find a system where the material nonlinearity is strong and fast enough, enabling the effective photon-photon interactions to attain the true superfluid light inside a microcavity.

In this contribution, we report on the study of photon thermalization and condensation in semiconductor optical microcavities, similar to the standard vertical-cavity surface-emitting lasers (VCSELs). Semiconductors, especially GaAs and AlGaAs, are widely known for their ultrafast and strong optical nonlinearities. Here, we employ a spatially structured optical excitation with a nonresonant laser to create an effective optical trap - a method widely celebrated in the exciton-polariton research field. We investigate the high-density regime of continuous-wave optical excitation of a strong coupling microcavity, where we observed a crossover from the polariton BEC to a photonic BEC [2]. Remarkably, both phases are trapped within our optically induced potential. In contrast, we have observed only transition to weak-coupling lasing (without polariton condensation) compared to quasi-homogeneous excitation. We study both excitation geometries in the context of efficient photon thermalization and find the optimal excitation conditions.

Moreover, to bring the photon densities to larger values, we employed a pulsed nonresonant excitation and studied the dynamical photon and polariton condensation in the optical trap. Interestingly, we have observed signatures of photon-photon interactions at the highest densities above the second threshold, manifested in the modified Bogoliubov-like dispersion of excitations. Our results might be an essential step towards investigating the quantum fluid of light in a semiconductor laser operating in the weak-coupling regime.

[1] Klaers, J., Vewinger, F. & Weitz, M. Nat. Phys. 6, 512–515 (2010).
[2] M. Pieczarka et al., arXiv:2112.05606 (2021)