Correlations of axial and lateral emission of coupled quantum dot–micropillar cavity system in cQED regime

Anna Musiał[1,2], Caspar Hopfmann[1], Tobias Heindel[1], Christopher Gies[3], Matthias Florian[3], Alexander H. M. Leymann[4], Alexander Foerster[4], Christian Schneider[5], Frank Jahnke[3], Sven Höfling[5,6], Martin Kamp[5] and Stephan Reitzenstein[1]

[1] *Institut fuer Festkörperphysik, Technische Universität Berlin, Berlin, Germany*
[2] *Laboratory for Optical Spectroscopy of Nanostructure, Department of Experimental Physics, Wrocław University of Technology, Wrocław, Poland*
[3] *Institute for Theoretical Physics, University of Bremen, Bremen, Germany*
[4] *Institute for Theoretical Physics, University of Magdeburg, Magdeburg, Germany*
[5] *Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen-Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany*
[6] *SUPA, School of Physics and Astronomy, University of St. Andrews, St. Andrews, UK*

Quantum dot (QD)-microcavities are excellent candidates to study light-matter interaction-related phenomena in the framework of cavity quantum electrodynamics (cQED). Possible applications range from non-classical light sources to high-β microlasers. In a typical experimental configuration, the microcavity is accessed in axial direction through its top facet. Simultaneous access in the axial and lateral direction opens up appealing opportunities for a broad study of cQED effects. For instance, it enables direct access to the lateral losses, whereas lateral excitation allows very effective, cavity-independent excitation of QDs, minimizes excitation-induced dephasing and local heating.

We report on combined theoretical and optical studies of coupled QD-micropillars using a 90˚ excitation and detection scheme. Micropillars with diameters in the range of 1.6-4 µm were fabricated by electron-beam lithography and plasma etching of planar GaAs/AlAs epitaxially-grown cavity [1]. The active area comprises of single layer of self-assembled $In_{0.4}Ga_{0.6}As$ QDs with surface density of approx. $10^{10}/cm^2$. The experimental setup contains of two microscope objectives (numerical aperture: 0.4) and two independent 0.75 m-focal length spectrometers providing spectral resolution of approx. 25 µeV. This enables one/us to reveal correlations between coupling emission from a QD into the cavity mode of a micropillar and into leaky modes in the regime of cQED. Our experimental configuration is highly beneficial for (quasi)-resonant excitation schemes due to direct lateral excitation of the active medium and spatial separation of the excitation and optical signal. In the multi-emitter regime, this technique provides direct access to the cavity loss and reveals a strong increase of sidewall losses in the low diameter regime below 3 µm in agreement with the results of finite element numerical simulations. In the single emitter regime, we observe an anti-correlation between QD emission coupled into the cavity mode and into the leaky modes which is controlled by light-matter interaction in the weak coupling regime of cQED. This anti-correlation is absent in the strong coupling regime due to entangled light-matter eigenstates of the system. Moreover, excitation power-dependent study demonstrates that the intensity ratio between axial and lateral emission increases strongly above the lasing threshold due to increased directionality and contribution of stimulated emission relative to the spontaneous emission. Theoretical studies (within the microscopic laser model utilizing the cluster expansion method [2]) confirm that this intensity ratio constitutes a new and sensitive criteria to determine the threshold pump power of high-β microlasers.

[1] S. Reitzenstein et. al, *Appl. Phys. Lett.* **90**, 251109 (2007).
[2] M. Florian et. al, *Phys. Rev. B* **87**, 165306 (2013).