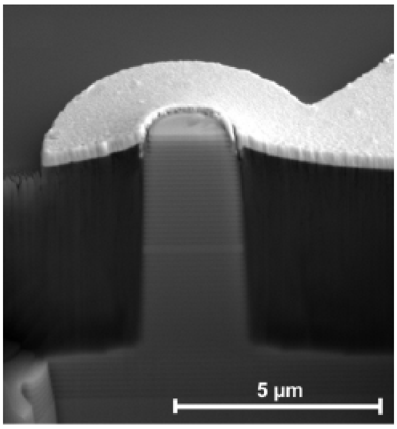
Micropillar cavity lasers in the cavity quantum electrodynamics regime

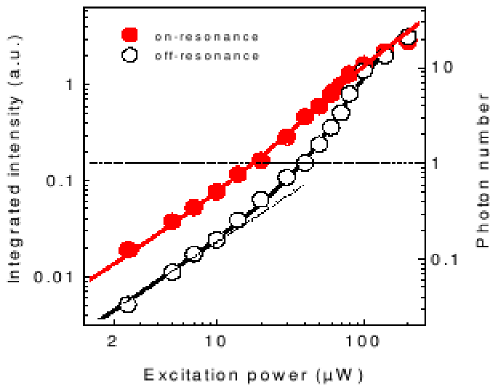
S. Reitzenstein, C. Kistner, S. Münch, T. Heindel, C. Schneider,
M. Strauβ, A. Rahimi Iman, M. Kamp, S. Höfling, A. Forchel

Technische Physik, Roentgen Research Center for Complex Material Systems, Würzburg University, Am Hubland, D-97074 Würzburg, Germany

High quality factor and low mode volume quantum dot microcavity lasers are attracting considerable scientific attention. On the way towards the realization of an ultimate nanolaser [1], microresonators based on cavity designs such as microdisks [2], photonic crystal structures [3, 4] and micropillars [5, 6] have been extensively investigated. As a result, low-threshold operation with a few quantum dots (QDs) as gain material has been reported and considerable advances have been achieved in this field by the development of microresonators with unprecedented quality factors. Consequently, these lasers are characterized by spontaneous emission factors approaching unity, thus allowing for the observation of pronounced cavity quantum electrodynamical (cQED) effects. Furthermore, the threshold region is reflected by a rather smooth non-linear increase in output power and a continuous change in photon statistics. By utilizing a specific ring-shaped contact scheme as presented in the scanning electron micrograph in figure 1, these low mode volume micropillar cavities can also be electrically driven.



(a) Cross sectional scanning electron microscope (SEM) image of an electrically contacted micropillar laser



(b) Output intensities and average photon number in the lasing mode versus the pump power for on-resonance (full circles) and off-resonance (open circles) conditions of the cavity mode and a single quantum dot exciton

This contribution focuses on QD-micropillar cavities with ultra-high quality factors up to 165.000 [7] and 16.000 [8] for optically and electrically pumped structures, respectively. As a result, the threshold characteristic of a corresponding micropillar cavity laser can be widely dominated by the spectral detuning between the cavity mode and a single QD transition. This is demonstrated by the results presented in figure 2, which reveal that laser operation takes place deep in the cQED regime, where on- and off-resonance of even a single QD controls the threshold behaviour notably. This work was financially supported by the Deutsche Forschungsgemeinschaft (DFG) within the Research Group "Quantum Optics in Semiconductor Nanostructures" and the State of Bavaria

References

[1] S. Noda, *Science*, vol. 314, 260, 2006.
[2] Z. G. Xie et al, *Phys. Rev. Lett.*, vol. 98, 117401, 2007.
[3] S. Strauf et al, *Phys. Rev. Lett.*, vol. 96, 127404, 2006.
[4] M. Nomura, *Phys. Rev. B*, vol. 75, 195313, 2007.
[5] S. Reitzenstein et al, *Appl. Phys. Lett.*, vol. 93, 061104, 2008.
[6] S. Reitzenstein et al, *Optics Express*, vol. 16, 4848, 2008.
[7] S. Reitzenstein et al, *Appl. Phys. Lett.*, vol. 90, 251109, 2007.
[8] C. Böckler et al, *Appl. Phys. Lett.*, vol. 92, 091197, 2008.