

Coupled high-Q micro-cavities

Cavity quantum electro dynamics (CQED) involving (visible) light has attracted quite some attention since the fabrication of optical cavities with ultra-high quality factors (Q-factors) enabled the strong coupling between cavity photons and single optical emitters. The latter are typically established in form of optical transitions in cold atoms or excitonic transitions in molecules or quantum dots. The resulting mixed state of optical excitation and photon (polariton) leads e.g. to correlation effects between emitted photons (non-classical light). A wide field of new types of photon states opens up, when a coupling of various cavities in chains or arrays is achieved. First results have e.g. been demonstrated for micro-wave photons coupled to superconducting qubits. A most interesting task would be to demonstrate similar CQED effect in the visible or near-IR spectral range. A prerequisite for such experiments are high-Q optical resonators. A high Q leads to long dwelling times of the photons in the cavity and in combination with a small modal volume one can achieve strong coupling to attached or incorporated quantum dots or dye molecules. This has been shown e.g. for single quantum dots in Bragg-type semiconductor micro-cavities. The highest Q-factors have been demonstrated for whispering-gallery-mode (WGM) micro-resonators like glass spheres and glass toroids. Just recently our group lead by Prof. Dr. H.Kalt (Institute of Applied Physics at KIT) and group lead by T.Mappes (Institute of Microstructure Technology at KIT) have introduced a novel type of WGM resonator based on polymers. These goblet resonators achieve Q-factors of ten millions and are thus most promising for applications like micro-lasers and bio-molecule sensors integrated into lab-on-chip devices.

Currently we are developing processing techniques that should allow to position polymer cavities within respective distances of about 100nm. We further test the attachment of quantum dots and dye molecules to the cavities using e.g. dip-pen nanolithography to achieve strong light-matter coupling. The task as a PhD candidate is to investigate strong coupling between quantum dots and the cavities as well as the coupling between different cavities. The later can be achieved either via optical (glass or polymer) wave guides or direct coupling of adjacent cavities in chains or arrays. If successful, one will be able to address phenomena like polariton tunnelling between cavities or slowing down and localization of light in cavity arrays. The work is embedded at Karlsruhe Institute of Technology (KIT) in a cooperation of the Institute of Applied Physics, the Institute of Microstructure Technology, the Light Technology Institute and the Institute of Theoretical Solid State Physics. This collaboration provides a solid background in nano- and microstructure technologies, advanced spectroscopy and photonics theory. The second European partner in this project is the European Laboratory for Non-Linear Spectroscopy (LENS) in Florence. The LENS team has excellent facilities for imaging the near and far field contribution of the electro magnetic field, using SNOM and confocal microscopy. This allows resolving the spectral and spatial distribution of the modes, as well as their polarization. In addition, at LENS a unique combination of techniques has been developed to tune the modes of photonic structures by locally addressing them with fluids (local micro-infiltration) and by thermal oxidation via illumination by the SNOM tip. This will allow to bring individual resonators in and out of resonances with their neighbours and allows to study, for instance, the avoided crossing that you obtain when two resonators couple. The technique can also be used to bring a high Q resonator in exact resonance with a local emitter, thereby allowing to study the weak, and possibly strong, coupling regime between source and cavity.