Project: Research assistant for Development of Deterministic Quantum Light Sources based on TMDC Monolayers

On-demand sources of single photons with high indistinguishability are key building blocks of photonic quantum systems such as large-scale quantum networks for secure data communication. Defect centers in TMDC monolayers are prime candidates to realize such non-classical light sources in a scalable and inexpensive manner [1]. While single-photon emission of such centers has been proven [2], despite major efforts world-wide the demonstration of photon indistinguishability is still elusive and is considered as holy grail in the field. In fact, high photon indistinguishability is a key requirement for advanced quantum photonic applications such as quantum repeater networks based on entanglement swapping via Bell-state measurements [3].

This project aims at fabricating and studying bright, cavity-enhanced single-photon emitters in TMDC monolayer which feature high coherence properties to demonstrate for the first time the emission of highly indistinguishable photons of such devices. The technological and experimental work is accompanied by theoretical studies to develop advanced theoretical concepts which will provide a understanding of the underlying physics to design and optimize the properties of the emitters in their complex solid-state environment.

To meet the goals of the project the work is subdivided into four tasks as described in the following:

Task 1 - Numerical modelling and device design: Numerical optimization will be performed to maximize the light-matter interaction of TMDC single-photon emitters integrated into circular Bragg gratings. Such nanocavities provide high Purcell factors which lead to increased photon indistinguishability due to shortened spontaneous emission lifetime. Also, nanobeam cavities shall be considered which promise even higher Purcell factors.

Task 2 – Device nanofabrication: High quality TMDC (WSe_2) samples will be realized by exfoliation and transfer of monolayers on patterned substrates. Here, metal particles or nanopillars will induce local strain to induce single emitters in the monolayers. Nanocavities will be aligned to the created quantum emitters using in-situ electron beam lithography.

Task 3 – Optical and quantum optical studies: Before device integration single quantum emitters will be identified in locally strained TMDC monolayers by micro-photoluminescence mapping. Moreover, the spontaneous lifetime, the coherence time, single-photon emission, and the indistinguishability of emission will be tested. After device integrated comparative studies will be performed to determine the Purcell factor and to evaluate the cavity enhance indistinguishability.

Task 4 – Theoretical description: The limits for the emission of ideal indistinguishable photons result from the interplay of strain, providing the localization for the excitonic way function and exciton-phonon interaction as a counteracting factor for pure cavity quantum optical effects as observed in non-interacting atomic emitters. The modelling will be done in a density matrix formalism including the respective interactions and using the input of the luminescence measurements to extract parameters which cannot be provided by a pure microscopic approach. The goal is a mostly parameter free calculation of the indistinguishability studies done in the experimental part.

The research will be performed at the Technische Universität Berlin, jointly in the research group "Optoelectronics and Quantum Devices" lead by Prof. Stephan Reitzenstein in the group "Nonlinear Optics and Quantum Electronics" of Professor Andreas Knorr.

[1] I. Aharonovich et al., Nature Photon 10, 631–641 (2016)
[2] P. Tonndorf et al., Optica 4, 347 (2015)
[3] H.-J. Briegel et al., Physical Review Letters 81, 5932 (1998)
[4] A. Carmele et al,, Physical Review B 81 (19), 195319 (2010)