Photonic platform for investigations and functionalization of novel quantum emitters

Progress in nanotechnology and photonics enables interfacing single quantum objects, such as electrons spin with single-photons that can be sent over macroscopic distances while keeping their encoded quantum information intact. The progress has already led to fascinating demonstrations, such as the one achieved in recent years by a group of researchers in Delft. Using an atomic defect in diamond interfaced by a conceptually simple mean, a microscopic diamond lens, they performed an experiment [1] that allowed rejection of a fundamental scientific assumption called local realism conflicting previously with specific quantum mechanics predictions. The same approach used for this experiment can be used to implement quantum-information protocols that enable secure communication, even when the devices used are not trusted by the users. Building such a quantum network fuels many researchers' motivation to work on the defects in diamond and other quantum emitters.

Single photons can also be used in circuits and perform quantum computation called boson sampling. In a very specialized application, similar principles were recently applied by a group of researchers in China to demonstrate quantum computational supremacy by using gaussian boson sampling [2], which used yet another quantum state of light called squeezed state.

However, significant advancements must be made to go beyond the proof of principle experiments and demonstrate real applications. Two fundamental factors inhibit progress. Firstly, a solid-state environment is a magnetic and electric noise source that destroys the relevant quantum properties. Secondly, efficient extraction of single photons into the desired direction remains a challenge. In short, despite the exciting potential, so far, there is neither a single-photon nor spin-photon interface operating in the single-photon regime that shows immediate potential for widespread practical implementation. Moreover, although there are platforms with sufficient spin coherence, as the color centers in diamond, or featuring very high brightness as semiconductor quantum dots, there is no ideal platform combining the two aspects.

This project aims to realize an efficient light-matter interface at the single quantum level on newly established, very promising emitters. One of those emitters classes has been recently discovered in the monolayers of semiconducting transition metal dichalcogenides, a class of materials with interesting optical end electronic properties. These materials feature a spectrum of exciting properties that are already intensively investigated in numerous laboratories worldwide. Still, the interactions governing coherence and population decay of the emitters need to be understood at a single quantum particle limit to assess their suitability for quantum technologies. We expect that coupling to the cavity will provide a new tool for investigating the emitters, allowing us to get new insight into their interesting physical properties. Furthermore, we will employ and further develop the open Fabry-Perot microcavities, which have generic characters and offer open access for various samples. Finally, we aim to address issues preventing scaling up the open cavity platform.

In parallel, based on prescreening criteria regarding the desired electric and magnetic properties that impact the spins desired properties, we will actively seek emitters in new potential platforms and further explore them. The targeted platforms include, for example, diamond hosting group-IV atomic defects. Furthermore, we will use the developed cavity platform to investigate the novel emitters in the next stage.

We expect this project's results to give definite answers regarding the proposed emitters' suitability for quantum technologies. Furthermore, upon identifying desired properties, such as long spin coherence time, efficient photon emission, and extraction, we expect the obtained system to outperform existing single-photon emitters, yielding exciting prospects for applications and studying various physical phenomena resulting from these the enhanced light-matter interaction.

[1] B. Hensen *et al.*, *Loophole-Free Bell Inequality Violation Using Electron Spins Separated by 1.3 Kilometres*, Nature **526**, (2015).

[2] H. Sen Zhong *et al. Quantum Computational Advantage Using Photons*, Science (80-.). **370**, 1460 (2020).