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Storage of fiber-guided light in a nanofiber-trapped ensemble of cold cesium atoms

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Abstract:

To store a classical light pulse is an important capability for the realization of all-optical signal processing schemes. Optical buffers that allow storing optical pulses can be extended to work as optical quantum memories, in which quantum states of light can be stored. Those optical quantum memories are crucial elements of large-scale quantum optical networks.
The storage of light has been achieved with several systems, such as cold or ultracold atoms. Despite this, the realization of efficient and long-lived fiber-integrated optical memories is still subject to active research.

In this thesis, I report on the progress towards a novel implementation of an optical quantum memory. Here, a nanofiber-based experimental platform for trapping and optically interfacing laser-cooled Cesium atoms is used, where the nanofiber is realized as the waist of a tapered optical fiber. Despite the atoms being trapped close to the nanofiber surface, the system offers a long ground state coherence time. This, in combination with the good coupling of the trapped atoms to fiber-guided light fields, renders this system a promising candidate for the realization of a fiber-coupled quantum memory.

I demonstrate the realization of an optical memory for weak optical pulses, using the effect of electromagnetically induced transparency. This effect allows to drastically reduce the group velocity of a fiber-coupled light pulse when propagating through the medium. Eventually, the light pulse can be brought to a halt. In this context, I experimentally show storage and retrieval of fiber-guided light at the single-photon level, while featuring a competitive characteristic memory lifetime. The presented results are an important step towards realizing fully fiber-based quantum networks.

For further improvement of the lifetime of the presented optical memory, it is of advantage to gain better control over the trapped atom’s motional degree of freedom. One possibility to achieve this goal utilizes the trapping light field-induced fictitious magnetic fields. It allows the coupling between the external motional state and the internal hyperfine state of the atom.

As shown in this thesis, this coupling can be used to implement microwave sideband cooling, allowing the preparation of the majority of the nanofiber-coupled Cesium atoms in the motional ground state. Furthermore, the coupling can be utilized as a tool to probe specific parameters of the trapped atoms, such as the trap frequency, the mean motional excitation number or the heating rate.