Quantum networking tools with single atoms and single photons

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Abstract

We develop interfaces between stationary and propagating quantum bits for quantum networks, using single trapped ions and single photons. We demonstrate high-fidelity atom-photon qubit interconversion, atom-photon entanglement, teleportation, as well as photonic qubit conversion to the telecom range.

In the context of quantum communication technologies, we are developing a comprehensive set of experimental tools, based on single photons and single atoms (trapped ions), that enable controlled generation, storage, transmission, and conversion of photonic qubits in quantum networks. Such tools are required, for example, in quantum repeater protocols for reliable intermediate storage of quantum information.

Specifically, we implemented a programmable atom-photon interface, employing controlled quantum interaction between a single trapped $^{40}\mathrm{Ca}^{+}$ ion and single photons [1, 2]. Depending on its mode of operation, the interface serves as an atom-to-photon or photon-to-atom quantum state converter, or as a source of entangled atom-photon states [3, 4]. We also use it for measuring atom-photon Bell states [5].

The interface lends itself particularly to integrating Ca^{+} ions with entangled photon pairs from a resonant, narrowband spontaneous parametric down-conversion (SPDC) source [6, 7]. As experimental applications, we demonstrate high-fidelity transfer of entanglement from an SPDC photon pair to atom-photon pairs, as well as atom-to-photon quantum bit teleportation [5]. We also extend our quantum network toolbox into the telecom regime by entanglement-conserving quantum frequency conversion [8] of photons that are generated by the interface in entangler mode [9], see Figure 1.

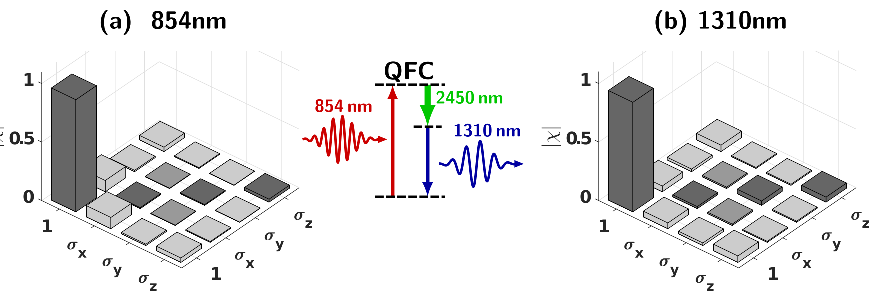

Figure 1: Process matrix reconstruction of the mapping process from an atomic qubit to (a) an 854-nm photon and (b) a 1310-nm photon, after quantum frequency conversion (QFC, center scheme).

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