Abstract

Active stabilisation of a microcavity to enable quantum operations on single ions

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In this thesis, the tilt locking scheme is applied to create an error signal that monitors length changes in a fibre-based microcavity. To find a robust and precise locking technique is an essential step towards quantum operations on single rare-earth ions doped in microcrystals as proposed in [1].

Quantum computing and information is a frontier of modern physics. Many scholars believe that Quantum technology will have a significant impact on future computation and communication [2]. It holds the potential to not only enable a whole new area of science by simulating highly relevant complex quantum systems like molecular structures but also to create the possibility of computer encryption for which safety is guaranteed by the laws of nature. The most recent publications demonstrating functioning quantum computers have shown that quantum computations are already in the realm of state of the art technology [3, 4]. However, there are currently multiple approaches to building quantum computers. At the moment, there is no clear picture of which approach for quantum operation is going to be the most applicable.

The quantum information group at Lund University focuses on rare-earth-ions doped into crystals to be used as qubits [5]. The long-lived energy levels of these ions can be used for quantum computations. It is necessary to make use of the Purcell effect to enable the interaction with single ions. This effect describes the emission probability for a photon by an atom in an optical resonator [6]. The reduction of the volume leads to an enhanced emission probability and therefore enables single ion readouts. By placing the substrate in an optical microcavity with a length of just a few micrometres, the phase volume is reduced. These planoconcave cavities consist of a coated concave fibre-tip on one side and a highly reflective mirror on the other [7].

The main limitation towards single ion readout is mechanical vibration which induces changes in the cavity length. There are well-known ways to actively stabilise the length of cavities, such as the Pound–Drever–Hall stabilisation, side-of-fringe locking, or the so-called tilt locking [8, 9]. In this work, the different locking techniques are compared and tested for their applicability to stabilise fibre-based microcavity.

In a short cavity, the resonant peaks are very far apart such that we can only use the resonant frequency, which is also used for the ion manipulations because the next resonance is no longer in the high reflectivity range of the coating. To avoid interfering with the main experiment, we base our locking scheme on the higher-order transverse modes of the cavity. These higher orders naturally occur in the cavity due to the asymmetric shape. This work derives the coupling coefficients of an incoming Gaussian beam into the higher-order transverse modes of the cavity to study the resulting error signal. The wavelength of the light which excites the higher orders does not disturb the fundamental quantum operations because the higher-order modes are resonant on a slightly shorter wavelength than the main resonance due to the Gouy-shift. Furthermore, a test setup to show the functionality of the tilt locking scheme for the microcavity was built and tested.

In this thesis, I theoretically and experimentally demonstrate the tilt locking error signal of a microcavity.

References

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