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Active stabilisation of a micro-sized fibre cavity using tilt locking to enable quantum operations on single ions

Quantum mechanics is one of the most well-established theories in modern physics. But in our day-to-day life, we barely observe any quantum effects. This is because quantum states need to be kept isolated from the environment to stay in a quantum state. To uncouple the quantum states from the environment is one of the main challenges that need to be overcome when building a quantum computer. In Lund, we want to build a quantum computer prototype that uses ions in crystals as quantum states. With laser light, we can interact with the single ions and measure their internal state. But single ions can always only emit and absorb a single photon. To make it more likely for the ions to interact with the light, we put them into a cavity. A cavity, in this case, is two mirrors in between which the light bounces back and forth.

When a peak of the light wave in the cavity perfectly lines up with the peak of the wave from the previous round-trip, so-called constructive interference occurs. This means the light could bounce up to thousands of times before escaping the cavity. This leads to a large enhancement of the emission from the ions. For the peaks from all round-trips to line up perfectly, however, the distance between the mirrors must be exactly an integer number of wavelengths and very stable.

The biggest problem we face at the moment is that these mirrors are vibrating, which disturbs the perfect line-up, and reduces the emission enhancement. There are tricks on using the light that bounces back and forth in the cavity to detect these vibrations. When we make the laser light enter the cavity with a slight angle, the light takes a different path inside the cavity compared to the light without an angle. This different path means that the vibrations of the mirrors affect them differently.

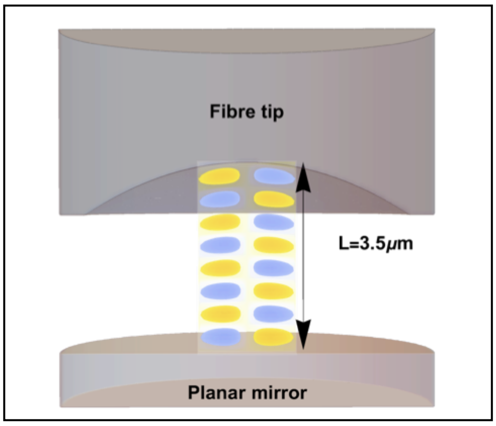

Figure: The standing wave pattern inside of the fibre based microcavity of the first order resonant mode.

We place a detector behind the cavity to detect the two light beams. In this signal, we can see the vibration of mirrors and correct them. Several techniques to do this are well known and have been very successfully used, for example, to detect gravitational waves. The difficulty for the cavity we use in Lund is that we have to work with an extremely short cavity to interact with the single ions. The distance between the two mirrors in our setup is less than the thickness of a human hair. This short length makes it difficult to find a suitable scheme to measure the vibration in our cavity.

In this work, we find a method of using a tilted incoming beam to measure the vibrations sufficiently well. This technique, known as tilt locking, promises to enable the interaction with single ions in the next-generation experiment.

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