Optical Cavity for Raman Laser

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Abstract

Our research seeks to employ magnetic and optical fields to form complex many-body quantum states of the spins of ultra-cold neutral atoms. This summer, I worked with an optical cavity as a part Raman laser system to control the quantum states of single cesium atoms. The purpose of this optical cavity research is to stabilize the frequency of light exiting the laser via laser locking and filtering out unwanted sidebands that are byproducts of a phase modulator that generates the Raman tones on the optical field.

Introduction

An optical cavity is an arrangement of two relatively flat mirrors that are a certain distance away from one another. Light enters the cavity and is reflected multiple times and produces standing waves at certain resonance frequencies. Those standing waves produce transverse modes, which differ in frequency and intensity pattern from one another. This optical cavity is set up for a Raman laser system. In our case, this is a two-photon stimulated Raman transition. This transition consists of two steps, with the first step consisting of a molecule originally in the ground state being excited to the virtual state, and the second state in which the molecule is deexcited to a different vibrational state in the ground state. This transition is used to drive fast single qubit rotations between the hyperfine ground states of cesium. Also in our case, this can be used as a matter wave beam splitter in light pulse atom interferometry.

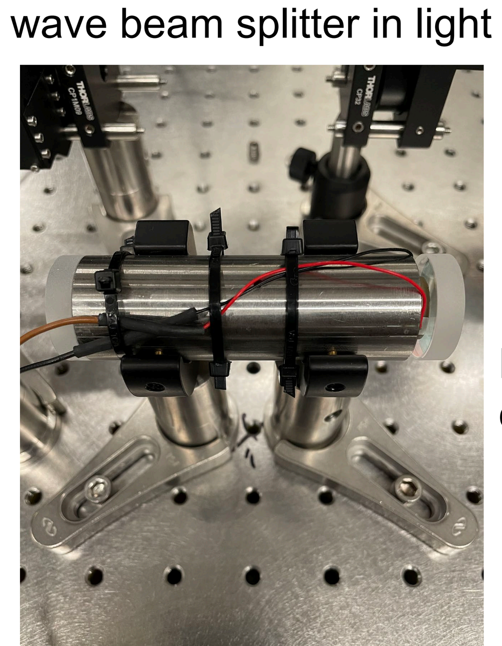

Figure 1: Image of the optical cavity

Methodology

Alignment is one of the most important things when dealing with optical cavities. The goal of alignment is to align the laser with the cavity in which the fundamental mode is visible. The fundamental mode, also known as the TEM_{00} mode, is where the laser light is at it's most intense.

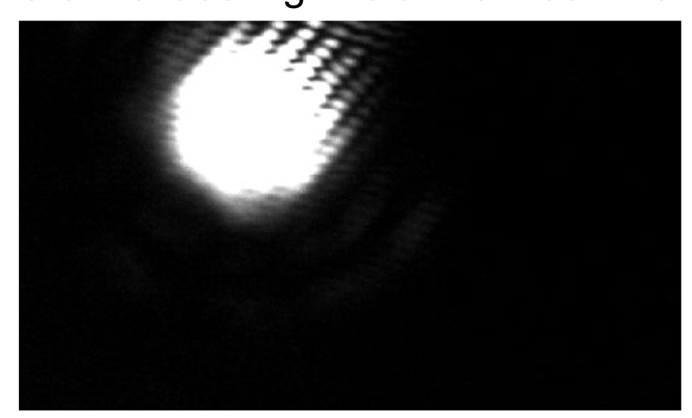

Figure 2: Image of the laser going through the cavity in the fundamental mode

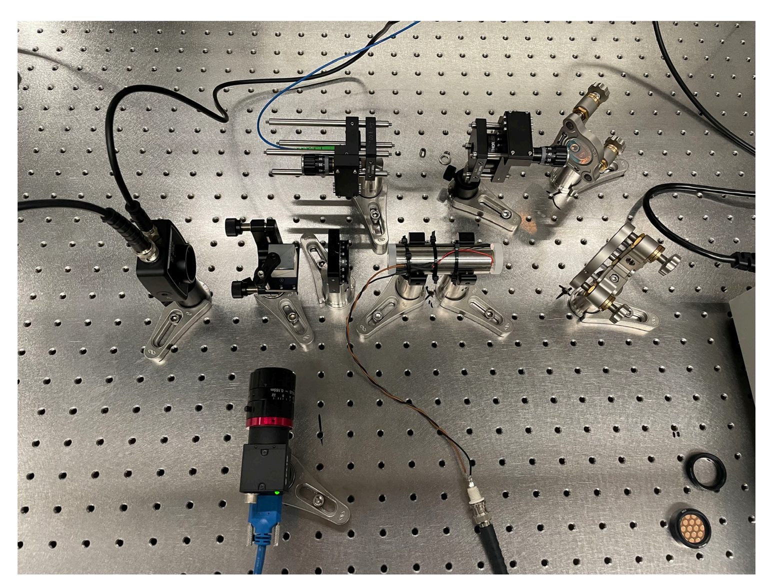

Figure 3: Image of the optical cavity experiment.

Finesse is one of the values that is important to quantify when dealing with optical cavities. Finesse is a unitless value that is defined as the free spectral range divided by the full width at half-maximum of the resonance peaks inside an optical cavity. The free spectral range(FSR) is the spacing in optical frequency between maximum peaks. The full width at half-maximum(FWHM) is the width of the peak measured between the points on the vertical axis when the peak is at half of its amplitude.

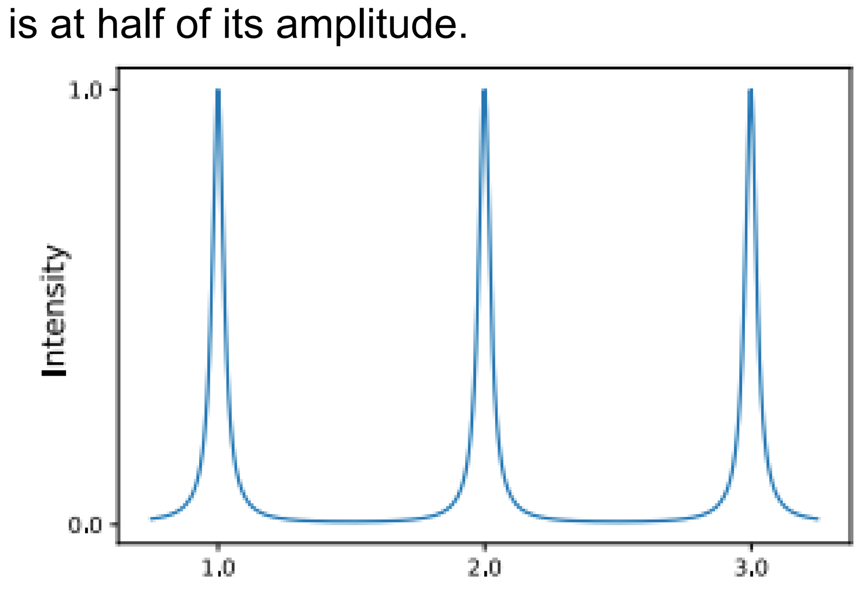

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Figure 4: Example plot of intensity inside an optical cavity

Results

Laser locking can be achieved by a process called the Pound-Drever-Hall(PDH) Method. The process works by having the frequency of the laser being modulated to match the frequency of the cavity, or by slightly changing the length of the cavity to the laser frequency. The length of the cavity can be changed by a Piezo-electric controller. In the setup, a frequency change can be recorded on a photodetector, like a photodiode. The signal being recorded will determine if the frequency is above or below resonance. This feedback is known as an error signal. The error signal can be sent back to the laser, converted into a voltage by a control loop, and used to keep the laser locked on resonance with the cavity. The feedback can also be sent to the Piezo to change the length of the cavity.

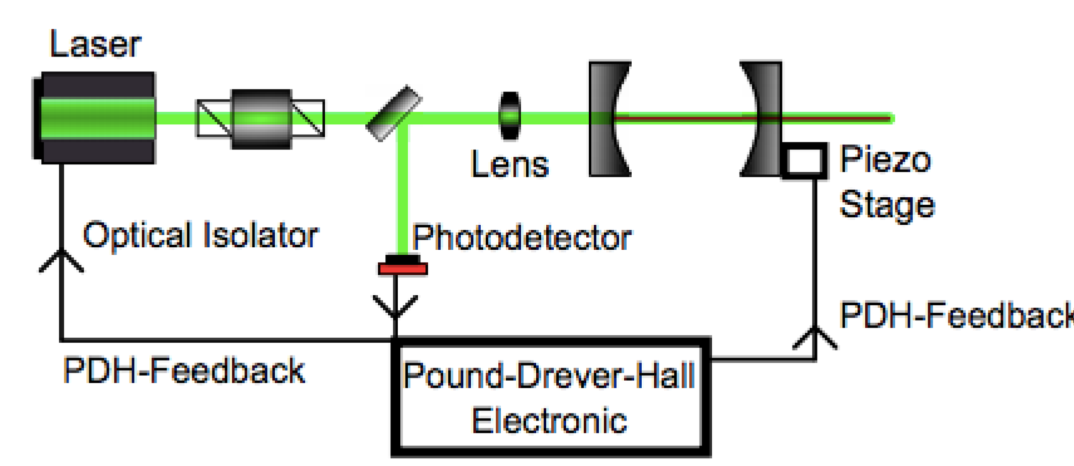

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Figure 5: Schematic example of the PDH Method

The other purpose of this optical cavity is to filter out unwanted sidebands by the process of phase modulation. Phase modulation is performed by phase modulators, or in our research, electro-optical modulators, or EOMs for short. During phase modulation, a set of sidebands are produced that are at certain frequencies above and below the carrier frequency. The optical cavity acts as a sideband filter by filtering out sidebands that are higher or lower than the carrier frequency. The cavity is useful for eliminating laser noise, because of the large number of sidebands that the EOM produces.

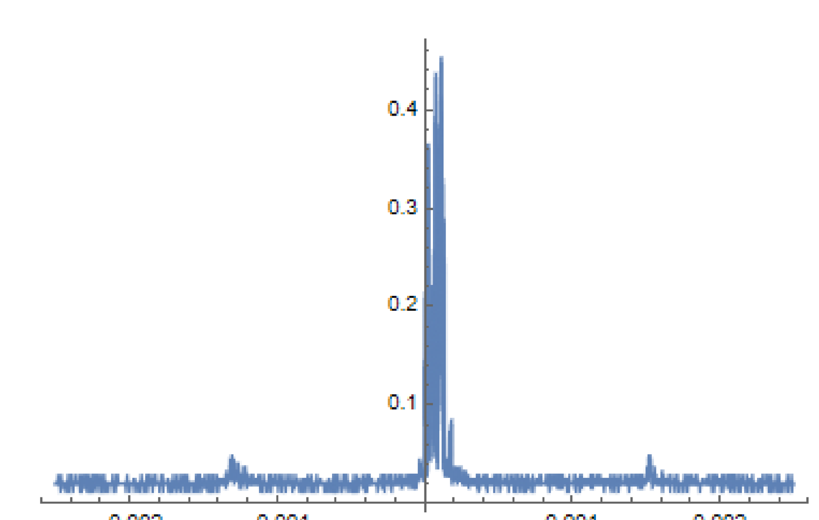

Figure 6: A Mathematica plot of the signal inside the cavity with sidebands equidistant apart from the carrier frequency

Conclusion

The future of this research is to continue developing an experiment to closely investigate new possibilities for high-fidelity quantum control and measurement. This research is working towards providing better methods for quantum entanglement. Quantum entanglement occurs when two systems share a common quantum state. In quantum entanglement, subatomic particles can share a relationship with one another regardless of their separation in space. Two-photon stimulated Raman transition is one of the multiple primitives that is required for quantum control of these systems and producing quantum entanglement. If subatomic particles, like electrons, can maintain a relationship, like vibrating when the other one vibrates, then quantum entanglement can be achieved. Better understanding of quantum entanglement and can lead to vast improvements of quantum computing. This Raman transition is used to drive single qubit manipulation. This process can be done without an optical cavity, but the cavity allows the laser frequency to be stable.

References

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