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ULTRA-STABLE EXTERNAL CAVITY DIODE LASERS FOR LASER COOLING

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ABSTRACT

Being able to manipulate and measure properties of atoms in optical lattices is a technique of growing importance throughout atomic physics. Creating a collision microscope in which we use many atoms in parallel to probe a many-atom system confined in an optical lattice will allow us to study fundamental aspects of quantum statistics and thermodynamics.

To achieve these aims, atoms must first be cooled to quantum degeneracy. In order to cool the atoms, we use a series of ultra-stable external cavity diode lasers (ECDLs) of a specific wavelength and frequency to create a magneto optical trap (MOT) inside high vacuum. The cooling and trapping effects of the MOT are induced by a magnetic field gradient and optical pumping. The lasers are detuned slightly below the transition frequency of the atoms so that if an atom is moving towards the incoming laser beam, it absorbs more photons as a result of the Doppler Effect. This laser cooling process is adequate to reach temperatures as low as a few hundred micro-Kelvin. By applying additional laser cooling methods of optical molasses and Raman sideband cooling, and finally using evaporative cooling, we can observe atoms at a few hundred nano-Kelvin. Once an optical lattice is setup, another set of lasers can be used in conjunction with a Potassium-40 atom to move it through the Cesium-133 lattice and observe how they interact. This collision microscope technique will allow us to further explore quantum entanglement and the Quantum Hall Effect.

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Chapter 1

Introduction

1.1 Overview

This chapter will outline the overarching goals of the project, and provide motivation for all of the designing and building of specific components necessary to perform such an experiment.

Studying quantum properties of particles is a very difficult science, not only because we have to deal with multiple lattices of atoms, but also because we must work at very low temperatures (~10^{-9} K) and sufficiently high density to achieve quantum degeneracy. These are the key aspects we must monitor in order to get away from the classical limit, which have been studied and are well understood today. The question then becomes, by what magnitude must we reduce temperature and increase density in order to observe quantum phenomenon, and how can we achieve these goals?

As we approach very low temperatures, atoms begin to drop into the lowest attainable energy levels. Because particles will all be moving to the lowest possible energy state, we begin to see quantum degeneracy, which refers to any energy level which is associated with multiple quantum states. It is important to note that different types of particles behave differently when degenerate. Bosons are able to occupy the same energy level in the same state, and therefore form what is known as a Bose Einstein Condensate at very low temperatures. Fermions differ due to the Pauli-Exclusion principle which states that no two fermions can be in the same quantum state. Because of this, Fermions behave in a way such that at ~0 Kelvin, all of the lowest possible levels are filled, starting with lowest and filling upwards. This is called a Fermi sea, and the highest energy state present in the Fermi sea is the Fermi energy.

1.2 The Fermion Experiment

In order to study thermodynamic properties at the quantum limit, we first needed to decide what types of atoms would be studied. For our experiment we chose to use Cesium-133 and Potassium-40, both of which were chosen based on several critical criteria. Cesium-133 is a boson. We chose a boson because we would like to study the properties of Bose condensates, which Cesium allows us to do. The reason we chose our other species, Potassium-40, is because it is a fermion. We plan to use Potassium as the collision microscope probe atom, so being a fermion is favorable since Fermi-exclusion will only allow a single probe atom at each lattice site in our collision microscope experiment. To enable ourselves to controllably collide the two atomic species, we take dilute gases of the atoms and used far-detuned laser light to create optical lattices of each species.

Another important factor we needed to consider when making the choice of what species of atoms to work with was the wavelengths required to create the optical lattices. If the wavelengths required to create the two separate lattices are too close, trying to move one species will interfere with the motion of the second lattice. As long as the wavelengths are far enough apart, the interference will be minimal and we can compensate for it.

In order to observe the atoms, we first need to have a way of manipulating atoms. This means we will need to be able to both move atoms and trap them in place on command. In order to achieve this we start with a dilute gas of atoms. To contain the gas, we place it inside of an ultra-high vacuum chamber, which has an internal pressure on the order of 10^{-12} Torr. This vacuum not only physically restricts the gas to a small volume, but it also limits interactions with molecules that would be encountered in our atmosphere. Any collisions with molecules in the atmosphere would cause a large disturbance and energy transfers to our gas of atoms, which would not allow for any sort of optical lattice to be created. To reach such an extremely low pressure, we must use a series of pumps to evacuate all of the air from the inside of the vacuum chamber. Starting from atmospheric pressure (~760 Torr), we first use a scroll pump which is an oil-free mechanical pump that uses spiral-shaped, rotating scrolls to pull air out of the vacuum, lowering our pressure to the order of 10^{-3} Torr. We next use a turbo pump, followed by an ion pump which finally brings us down to pressures around 10^{-12} Torr.

By setting up magneto optical traps (MOTs) inside the chamber, one can collect and cool atoms of both species. This MOT requires the use of multiple laser beams in conjunction with a pair of current carrying coils. By using two separate species (Cs-133 and K-40), we can create two lattices – one in which we create interesting quantum states to study, and second used to probe the first.

Our goal is to observe how these atoms interact with each other. In order to make them interact, we use one species as a stationary lattice (Cesium), and the other as a probe lattice (Potassium). The optical lattice for Cesium will be created using a laser with a power that allows for a rapid rate of quantum tunneling, since we want to observe quantum entanglement of the

Cesium atoms with one another. The probe species should be controlled by a stronger lattice potential, so that it is held in position better, and not allowed to tunnel outside of its potential. Figure 1-1 shows a graph for the given wavelengths needed to create the lattices of Cesium-133 and Potassium-40 atoms. The blue and red lines represent the bounds for the laser power to operate while maintaining an optical lattice. The other lines all represent different rates of tunneling and scattering of the two species. Since Potassium is our probe lattice atom, we will want to select a power that limits the tunneling of this atom, while enabling a lot of tunneling for Cesium.

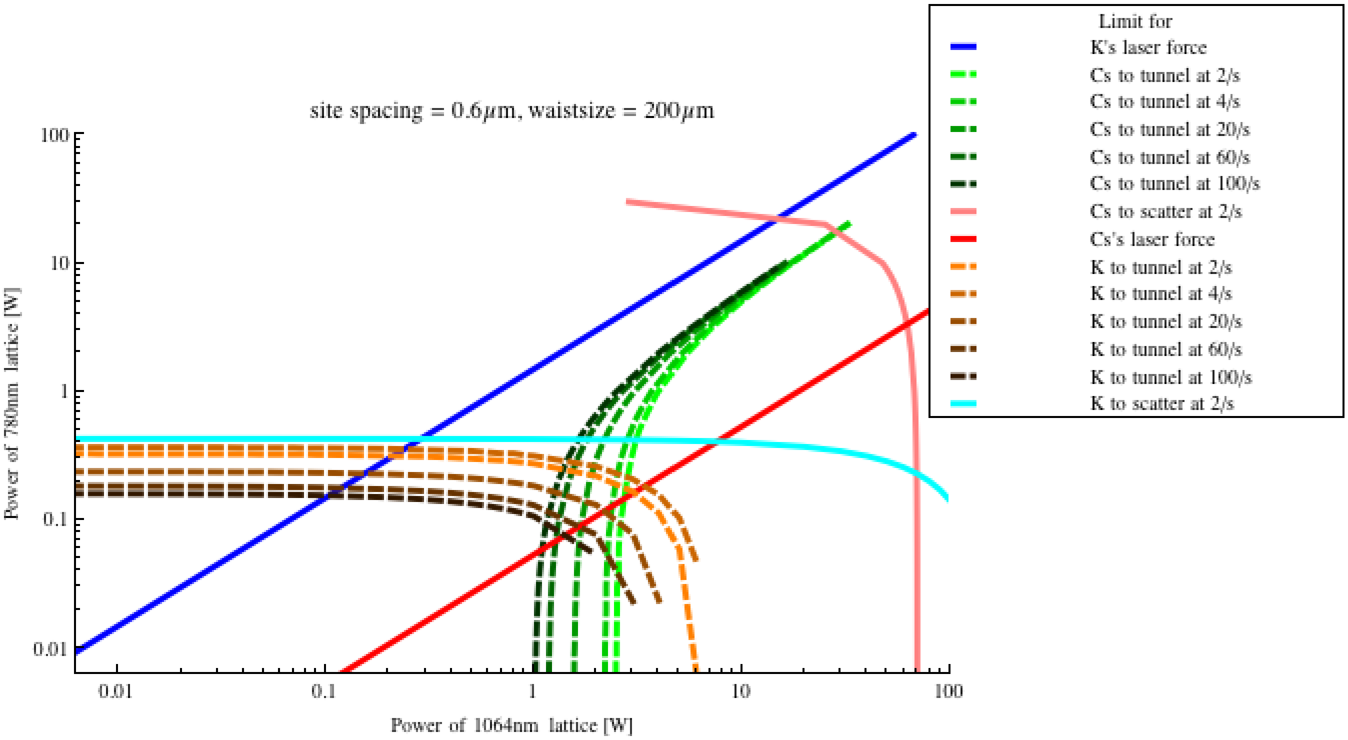

Figure 1-1: A graph of the laser powers used to create the optical lattices of K-40 and Cs-133 with the rates of tunneling and scattering for each included.

By manipulating a probe atom, we can make it collide with one of the stationary atoms of the other species. Once the probe atom has collided with the stationary lattice, the atoms are said to be quantum-entangled. We can then take the probe atom and move it away. The goal is then to observe the effects that the collision had on the unprobed atoms of the optical lattice – if the sample atoms were entangled with one another before the collision process, then the probe is entangled not only with the atom it collided with, but with other sample atoms as well. Since the stationary lattice species is able to actively tunnel, we should be able to see interactions between the atom that was collided and the neighboring atoms in the lattice. We call this process an atomic collision microscope.

Chapter 2

The Laser Cooling Process

2.1 Overview

In order to cool atoms down to a temperature where we can contain them in an optical lattice, we must follow a precise process. Taking a sample of a dilute gas in high vacuum ($\approx 10^{-9}$ Torr), we first apply a process called laser cooling in a magneto optical trap. In order to laser cool an atom, we must use a diode laser with a very specific and stable frequency. The frequency of the laser needs to be slightly detuned (larger wavelength) then the resonant frequency of a particular hyperfine transition, which is specific to an element. We can then remove the magnetic field gradient and use an optical molasses to further cool the atoms. Finally, to get to the lowest attainable temperatures, we apply processes of Raman sideband cooling and evaporative cooling in order to so that we can study quantum interactions of the particles.

2.2 Atomic Structure and Transitions

In order to fully understand the nature of laser cooling, we must first understand the atomic structure and transition rules of an atom, which are explained simplest using quantum numbers. Using one of the easiest models of an atom to comprehend, called the Bohr model, we see a nucleus centered atom with an electron cloud around it. We observe the electron cloud to have different energy levels, which vary depending on the distance from the nucleus. The electrons are bound to the nucleus by an electro-static Coulomb force, due to the difference in charge between the positive nucleus and negatively charged electrons. We use the quantum number ‘n’ to represent the energy level of each electron. The closest orbit to the nucleus, referred to as the k-shell, is represented by n=1. Each electron shell of the atom may hold up to $2n^2$ electrons, so once a shell is full, all other electrons must be located in a higher n state.

The next two quantum numbers we introduce are the intrinsic angular momentum ‘S’ (also referred to as spin), and the orbital angular momentum ‘L’. These two quantum numbers sum to the total angular momentum of an electron ‘J’. Since electrons are spin ½ fermions, the value of the spin quantum number must be ½, which means $J=L\pm\frac{1}{2}$. We further denote the hyperfine structure of the atom by the letter ‘F’ which is referred to as the spin-spin interaction, which is defined as $F = J + I$, which means the magnitude of F must be $|J - I| \leq F \leq J+I$. Here ‘J’ is the total angular momentum and ‘I’ is the nuclear angular momentum. [1]

When we apply the laser cooling process to atoms, we use lasers that emit very specific frequencies of light that pertain to specific hyperfine transitions. For Cesium-133, we use a wavelength of ~852nm which corresponds to a frequency of ~352THz. This frequency is a good starting point, but we need it to have much more precision in order to satisfy the various aspects of laser cooling. For example, our laser that is used to laser cool in the MOT must use the F=4 ground state to the F=5 excited state transition, which corresponds to a frequency of 351.725 718 50 THz - 4.021 776 399 375 GHz + 263.8906(24) MHz, while our repumper beam needs to be from the F=3 ground state to the F=4 excited state which corresponds to a frequency of 351.725 718 50 THz + 5.170 855 370 625 GHz + 12.798 51(82) MHz. These small differences come from the hyperfine splitting of Cesium-133, seen in Figure 2-1, and the specific energy transitions we need to laser cool atoms.

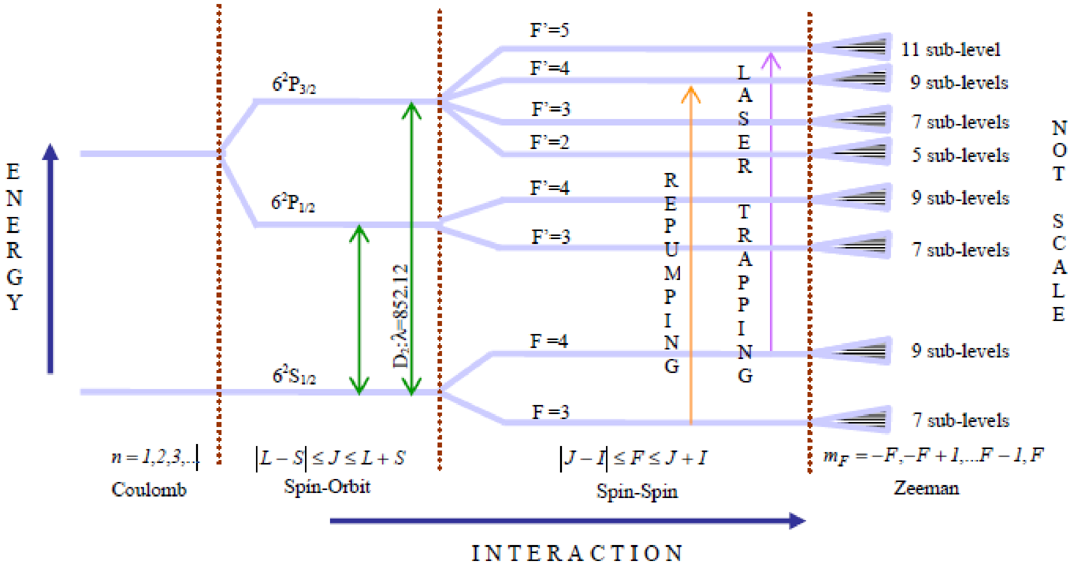

Figure 2-1: The hyperfine atomic transitions of Cesium-133 used for laser cooling. [1]

Although the lasers being built are for Cesium-133, since Potassium-40 will also be used in the experiment, we note that the laser cooling of the potassium atoms is similar in technique to Cesium-133. The hyperfine splitting of Potassium has levels that are much closer together than Cesium, so we plan to only use one physical laser diode for Potassium, which can be adjusted for all the aspects of cooling using acousto-optical modulators (AOMs). As seen in Figure 2-2 below, the transition associated with the MOT for Potassium is from the F=9/2 state to the F=11/2 in the top manifold. The repumping laser takes atoms from the F=7/2 to the F=9/2, also in the top manifold. [2] [3] The reference laser is not seen in this diagram, but has a frequency about 79MHz below the bottom of the top manifold of Figure 2-2.

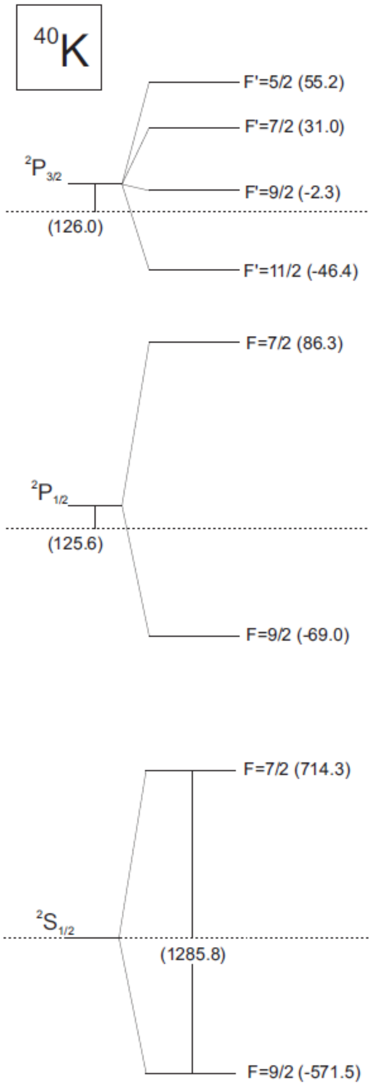

Figure 2-2: The hyperfine structure of Potassium-40. [2]

2.3 Creating an Optical Molasses

When a photon is incident upon an atom, the energy of the photon given by E=hν, can cause a deflection of the atom. Here, h is Plank’s constant and ν is the frequency. More specifically, in our case, when a laser beam is directed at a dilute gas of atoms, we can cause interactions between the photons and the atoms. By introducing three pairs of counter-propagating, orthogonal beams, we use these deflections of the atoms by the photons in a productive manner to slow the atoms down. This concept is referred to as radiation pressure because the lasers are, in a sense, pushing the atoms. Since the motion of a particle is directly related to its temperature, we can see that by using lasers in this manner, we can effectively cool atoms. To apply this method, the laser beam must be detuned just below a resonant transition frequency (the transition for Cs-133 is precisely the one we defined above when introducing the atomic structure and hyperfine transitions.) This way the atom will only absorb a photon if it is moving toward the laser beam, since doing this effectively increases the frequency of the beam due to a Doppler shift. When an atom tries to move in any given direction, the atom experiences a momentum kick from the photons being emitted from the laser. Using this process, we are able to effectively cool atoms down to a few hundred micro-Kelvin. Further, a process of Sisyphus cooling can achieve sub-Doppler temperatures, which for Cesium-133 can cool to 10uK or below.

It is important to note that in order to achieve this optical molasses, we must use a laser source that is ultra-stable monochromatic so that the frequency of light being emitted is constant and unchanging. Even small fluctuations of a line width in the frequency will ruin the molasses, and the atoms will not be cooled. Another problem with working with single atoms is that any atomic collisions will cause a large disturbance and temperature jump. Because of this, we must isolate our gas of atoms from all other atoms, including air. We accomplish this by restricting our gas to an ultra-high vacuum chamber where the pressure is kept on the order of 10^{-12} Torr.

2.4 Magneto Optical Trap

By setting up an optical molasses as defined above, the atoms can be cooled down, but they are not restricted spatially by the molasses. This is because the laser beams are only taking into account the relative motion of the atoms, with a disregard to their spatial location. Because of this, the atoms are cooled, but not confined to a specific volume within the vacuum. In order to trap the atoms, another method is usually applied first to constrain and cool them. A common method of trapping the atoms is comprised of using current carrying coils, which induce a magnetic field in the vacuum chamber. To trap the atoms in some central location at the intersection of the three sets of counter-propagating beams, the applied magnetic field must be spatially dependent.

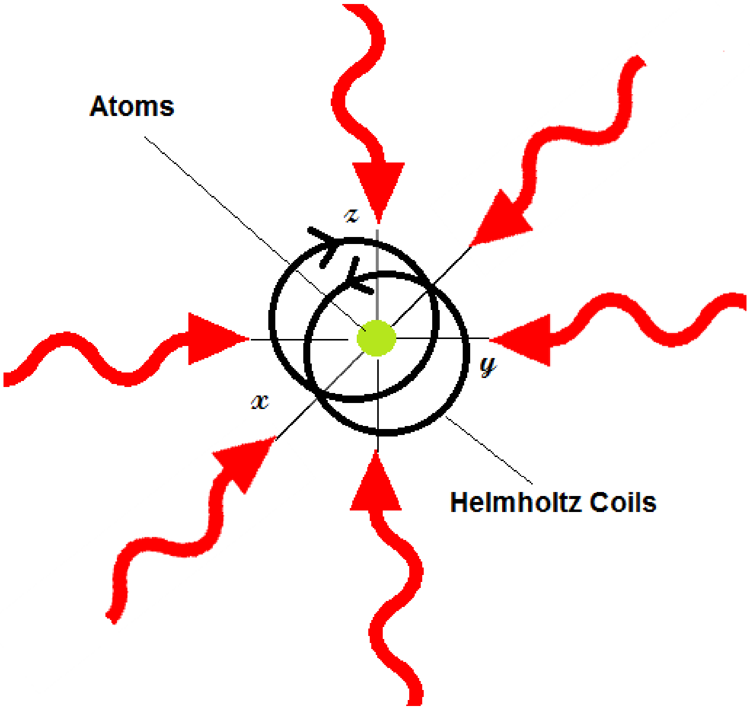

Figure 2-3: A basic MOT setup with three sets of counter-propagating, circularly polarized beams and a pair of Helmholtz magnetic field coils used to cool and trap atoms.

At the center, where we want to trap the atoms, the magnetic field should be near 0, increasing linearly in the positive x-direction, and linearly decreasing in the negative x-direction. This field effects the energy sublevels so that the Δm_f=+1 shifts to lower frequency when an atom is to the left of the center of the trap, and the Δm_f=-1 shifts to higher frequency. [1] When the atom is not at the center, the laser beam that it is closer to will have a large number of photons scattering off of the atom compared to the respective counter-propagating beam, which will cause the atom to be pushed back to the center of the MOT. This is the basic premise of a magneto optical trap, which is the primary method used today in laser cooling and trapping of atoms.

2.5 Repumping

As we laser cool atoms and they jump to an excited state, nearly all of the atoms will relax back into the proper hyperfine F state in the laser cooling cycle. When the atoms relax, they do not always return to the correct F state to continue the laser cooling process. Because of this, we need to use another laser beam to ‘repump’ the atoms out of this lower state, and back into the laser cooling cycle. This laser beam is called a repumper, and the energy transition associated with it depends on the atom. For Cesium-133, we can see this transition in Figure 2-1 as discussed above from the F=3 ground state to the F=4 excited state. The Potassium-40 repumping laser operates using the F=7/2 to F=9/2 transition in the top manifold of Figure 2-2. After being excited by the repumping beam, the atoms will more than likely fall back into the correct state to be cooled again, and if not, the repumper will act on the atom again.

2.6 Further Cooling

Using this process of laser cooling, we are able to cool the dilute gas of atoms down to a temperature on the order of micro-Kelvin in a brief time of ~100 ms. For Cesium-133, this laser cooling also involves an additional method called Raman Sideband cooling in which we use a laser to take advantage of Raman transitions to further cool the atoms. In order to achieve even lower temperatures, we need to apply an additional method.

The last technique used is slightly different than the previous ones we have discussed, in that it does not require the use of any lasers or optics. This process is analogous to the concept of using a harmonic trap. The idea is that we are holding our cooled (micro-Kelvin) atoms in an optical trap created by a magnetic field using magnetic coils. The atoms that are in this trap have varying temperatures, some hotter and colder than others. Since temperature is directly related to energy, we know that we need a higher potential to hold in atoms with higher energy. Using this idea, we observe that by lowering the potential of the optical trap, we will lose any atoms that have an energy that are higher than the potential energy of the trap. By doing this, we effectively let the higher energy, higher temperature atoms, escape and keep the colder ones that are still held by the potential. This process of evaporative cooling results in allowing us to keep atoms trapped that are on the order of only a few hundred nano-Kelvin over a time span of roughly 5-10 seconds.

2.7 Laser Tables

In order to physically set up these optical systems for laser cooling, a plan for a laser table has been created for both the Cesium-133 and Potassium-40 lasers. For the laser system that we have been developing in our lab for Cesium-133, we will need a separate beam for the MOT, repumper, Raman sideband cooling, and reference beams. The reference beam passes through a separate cell of Cesium-133,outside of the experiment, and is used to provide an absolute frequency for the other lasers. By taking advantage of a trick using an electro-optical modulator, we have eliminated the need for one of these diodes, as the repumping laser and the reference laser can come from a single diode. Figure 2-4 below shows the laser table for Cesium-133 in which we plan to use for laser cooling.

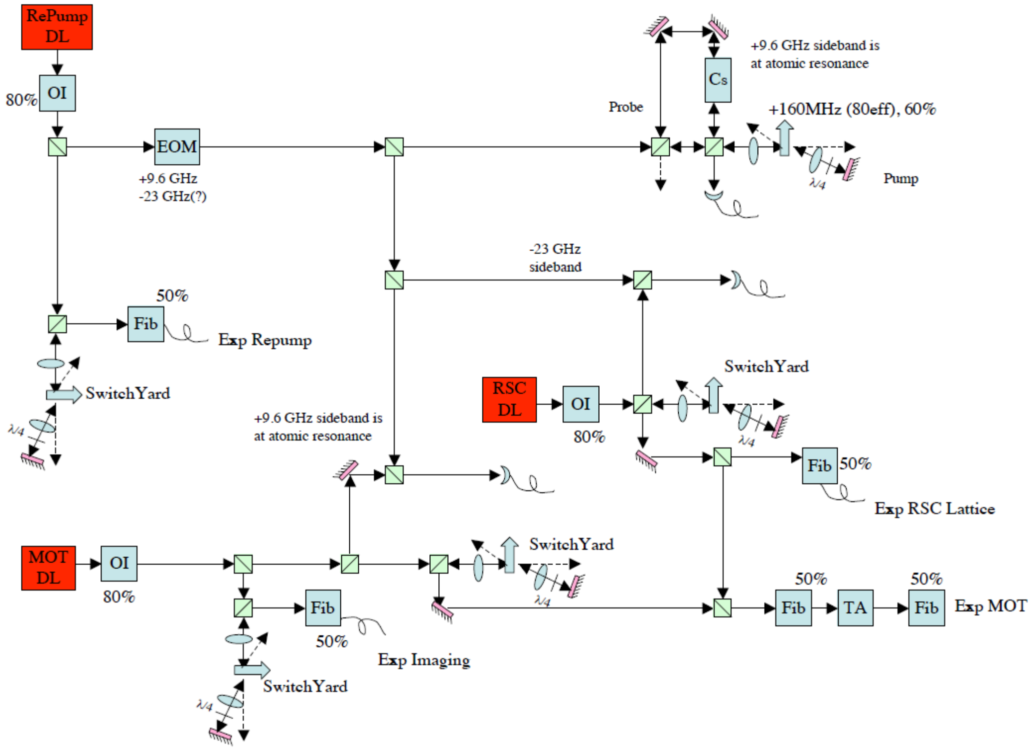

Figure 2-4: The Laser table diagram for Cesium-133. The Laser diodes used are defined in red according to their primary function in the cooling and trapping process.

As previously discussed, for Potassium, the hyperfine levels are much closer together than for Cesium-133, so we are able to set up our laser table for Potassium using a single laser diode. We use the same diode for setting up the MOT, repumping, and our reference beam. This set up is shown in Figure 2-5 below. Note that the additions of the Potassium-41 and Potassium-39 configurations are also shown in the table, and are not for use in cooling Potassium-40, but rather for future ambitions.

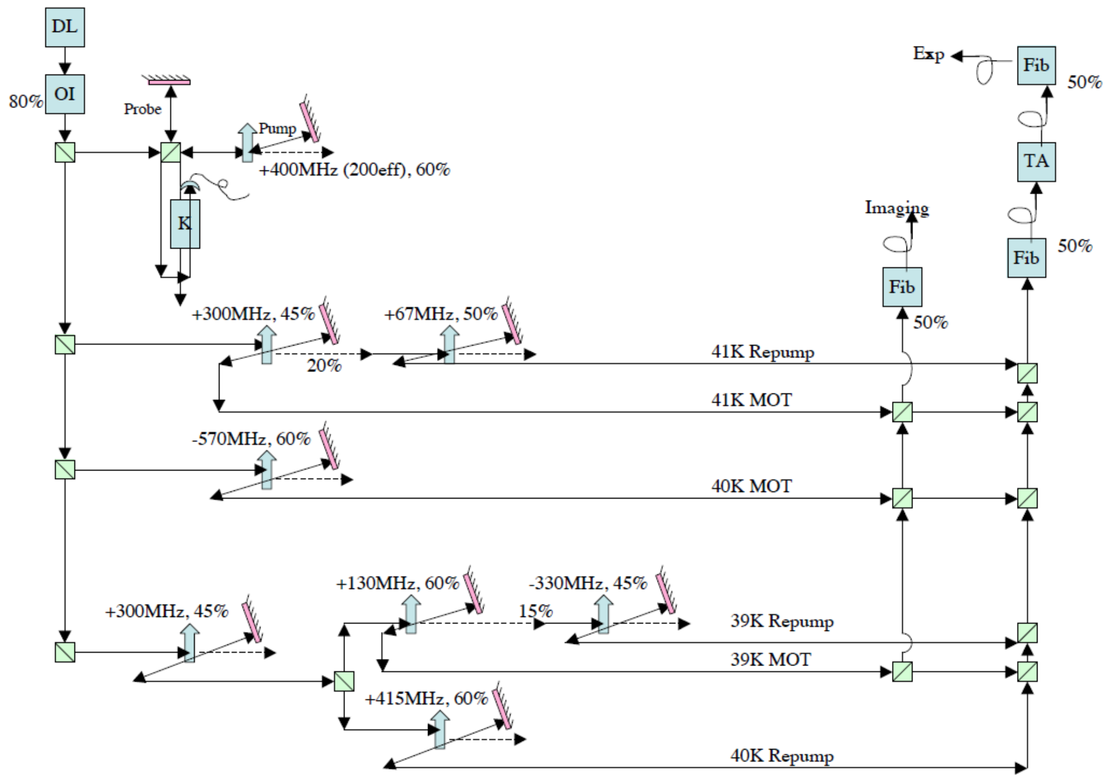

Figure 2-5: The Potassium laser table setup. The single laser diode in the upper left is used for all the various aspects of laser cooling using AOMs (represented by vertical arrows) to regulate the frequency of the beam.

Within each of the two laser tables, the beams of the lasers are denoted by the black arrows. Transmitted intensities are given by percentages after going through the various optics. All of the vertical arrows represent acousto-optical modulators, which use sound waves in a crystal to alter the frequency of the laser beam. Optical fibers are represented in the tables by the label FIB, and also the curly lines, and the label TA stand for tapered amplifier, which increases the intensity of the outgoing beam.

Chapter 3

Ultra-Stable External Cavity Diode Lasers Design

3.1 Grating Laser Concept

The basic concept of a grating laser must be understood in order to properly motivate its use in the laser cooling process. In a grating laser, a laser diode emits a beam of light with a frequency that is too variable for use in atomic physics. In order to fine tune this to a near monochromatic source, we collimate the beam and direct it at a diffraction grating. The angle of the grating can be changed by turning a differential adjuster, which for now can be thought of as a fine threaded screw, which bends the flexure arm that the grating is attached to. This allows us to alter the frequency and wavelength of the beam that is emitted by the laser. A schematic of the basic components of a grating laser can be seen in Figure 3.1.

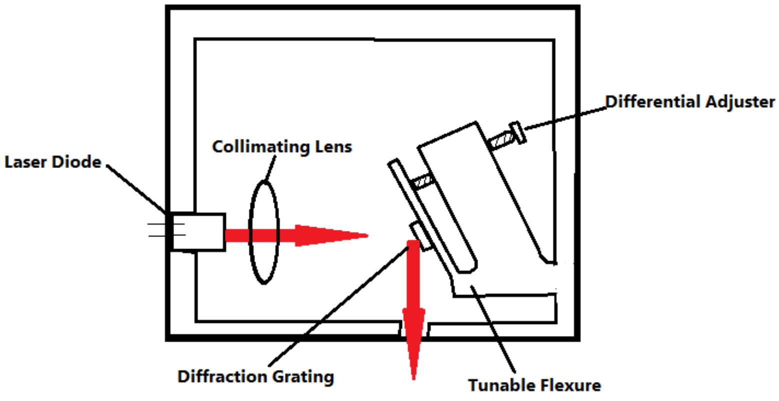

Figure 3-1: A conceptual sketch of a grating laser, with the path of the laser beam indicated by red arrows.

3.2 The Diode and Optics

Since this set of lasers being created are going to be used to create the MOT for Cesium-133, the diode we have chosen is an 852 nm single mode diode. The error on this purchased diode is ±10nm, which is not accurate enough for our laser to be useful. We can however, use this diode as a starting point and make some optical adjustments to make it more accurate and stable for laser cooling. We need our laser light to be stable to one atomic line width which is about 5MHz. The diode is wired to a current controller which provides power to the laser diode. We also installed a safety switch to prevent current from passing the wrong direction through the diode, which would destroy it. The diode is placed in a diode mount, which was machined from a block of stainless steel, and is clamped to the mount using several screws and a clamp plate. As the diode emits light, the light radiates outward and is next focused by a collimating lens.

The collimating lens has a working distance of 1.91 mm working distance and a focal length of 2.5mm. The lens sits in a small, M8-0.5mm threaded case. Using a stainless steel optical post, we machined a lens tube with inner threading on the back half to securely hold the lens in place. Using a micro stage, the lens must be collimated so that the diode sits on the focal point of the lens within ~1 mil of error. The lens tube has a diameter that allows it to fit tightly into the diode mount to help with alignment and structure. After the beam passes through the lens and lens tube, it is next incident upon a diffraction grating.

We chose to use a holographic diffraction grating which produces a better single mode as compared to a ruler grating. This allows us to create a beam that is closer to monochromatic, which is crucial to laser cooling, since the differences in frequencies between hyperfine state transitions are only ~5MHz. The grating can be adjusted using the flexures so that the 1^{st} order light is reflected back to the diode, and the 0^{th} order light is reflected off the grating, and out of the laser through a small opening on the side of the middle layer. Once the laser leaves through this opening, it will be incident on the dilute gas of atoms and used for the laser cooling process. Figure 3-2 shows the CAD drawing for the internal components of the laser as described here.

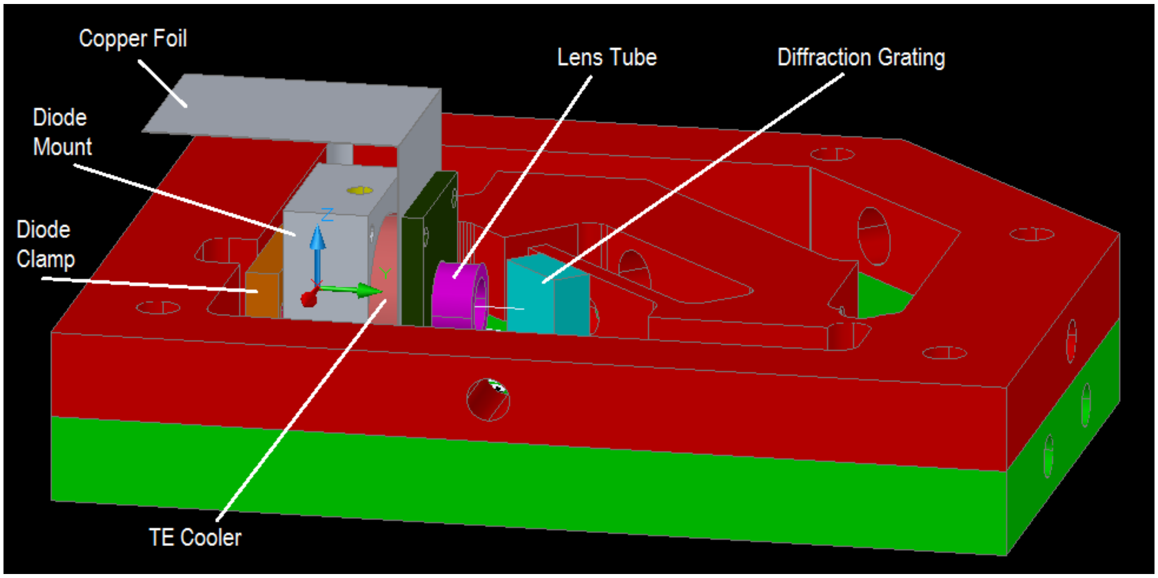

Figure 3-2: A CAD image of the internal structures of the EDCL with the top layer and heat sink removed.

3.3 The External Cavity

In order to ensure that our laser would be ultra-stable, we needed to isolate the beam source and associated optics from outside disturbances. In order to do this, we chose to build the laser inside of an external cavity, which serves as a mechanical, acoustic, and thermal isolator. The laser cavity is made of stainless steel which is not easily machined compared to softer metals like aluminum, but provides greater hardness and is less thermally conductive. This means that the laser will not gain or lose much heat to adjacent pieces or the surrounding atmosphere.

For simplicity, we built the laser cavity in three separate, half-inch thick layers. By choosing to work in layers, we enabled ourselves to use a computer numerical controlled (CNC) plasma cutter to cut out the basic shapes of the three layers. After making CAD drawings of the three layers with appropriate offsets, a program called Torchmate Lite was used to generate the appropriate G-code file, which is the machine code that a CNC controlled machine can read. Using this process, we can make cuts within 80 mil of the final dimensions.

After the rough cuts were made using the plasma cutter, we moved onto drilling and tapping the five holes which are used to hold the layers of the laser together when stacked. Since tapping stainless steel threads produces a risk for breaking a tap, we performed this step before investing time in finishing the rough edges that the plasma cutter left. Since the plasma cutter does not leave a nice finished edge on the piece being machined, and is not precise enough to make a final cut, we needed to remove some additional material using a more precise method. In order to get a nice finish on the edges, we then used a CNC milling machine with a roughing mill, and then an end mill to get to the final dimensions, with only about 1 mil of error. Once the edges of the middle layer were completed, additional holes were drilled and tapped that were needed for the differential adjusters and for the output path of the laser.

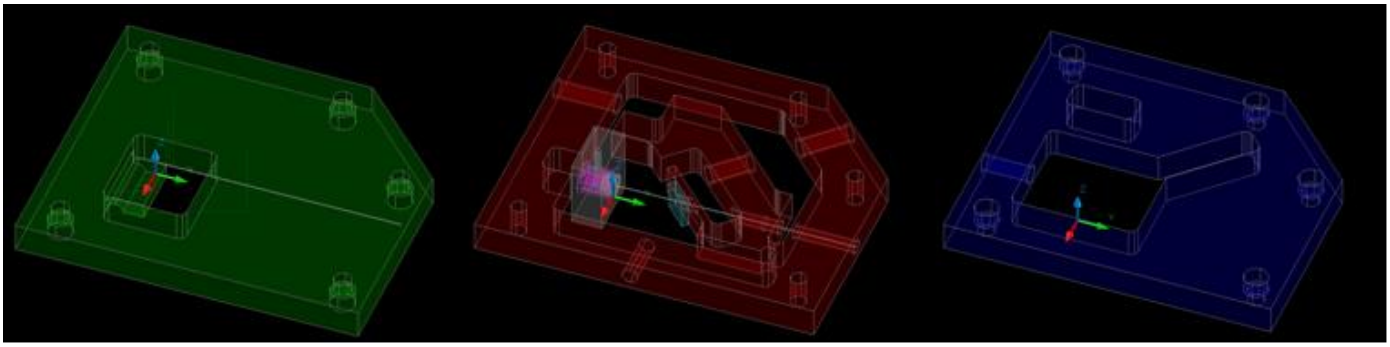

Figure 3-3: The initial CAD drawings used to generate the G-code for plasma cutting and milling the three layers of the laser cavity.

After the three layers were completed, additional metal plates were added to the outside of the laser to seal off any airflow. Doing this ensures greater thermal and acoustic isolation from outside sources. To accomplish this, the bottom plate was drilled and tapped so that a stainless steel plate covered up the opening that faced downward. The top layer is sealed off using an aluminum heat sink, which was machined flat using a fly-cutter and placed across the top of the laser. A rubber gasket was placed between the top layer and the heat sink to thermally isolate them.

In order to reduce the amount of contact surface area between the laser cavity and the optics table, we decided to mount our laser using two stainless steel ‘L’ brackets. The mounting was done simply by drilling and tapping four holes (2 for each bracket) in the bottom layer of the cavity. These ‘L’ brackets allow the laser to sit up off the table with only the minimal surface area of the brackets in contact with the table. Now that the creation of the laser cavity has been shown, we can move to discussing the internal components of the laser. Figure 3-4 shows the CAD drawing of the external cavity and heat sink.

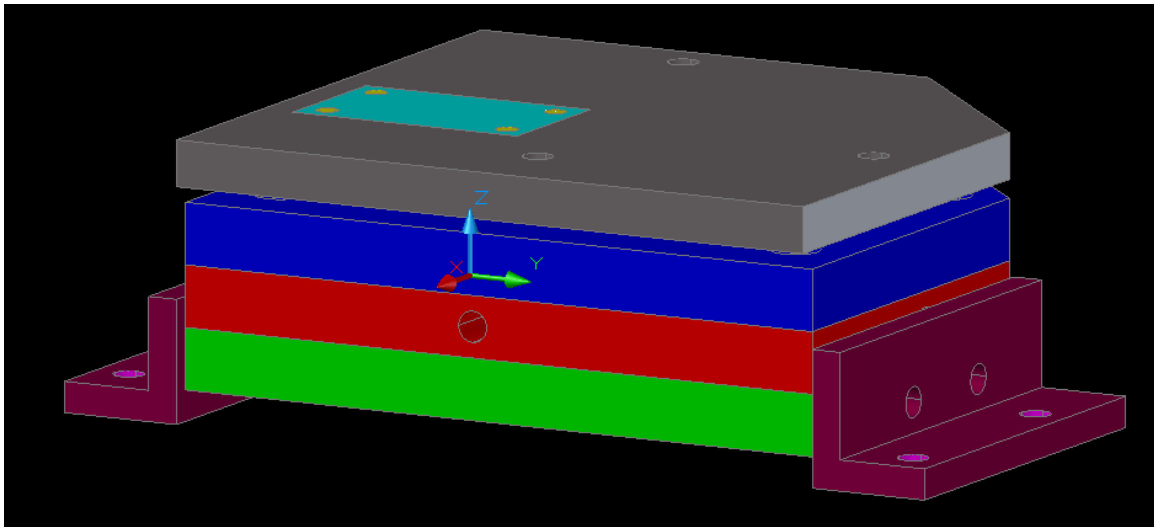

Figure 3-4: A CAD drawing of the outside of the ECDL. Each separate layer is shown in its own color. The ‘L’ brackets are shown to the left and right holding the laser off the table, and the heat sink is placed on top. The hole in the red layer is the optical path.

3.4 The Flexures

A pivotal concept in the grating laser design is the ability to finely tune the frequency of light being emitted by the laser. To do this, we built three flexures into our external cavity: two in the middle layer, and a vertical flexure built into the bottom layer. The idea is when a force is applied against the stainless steel flexure joint, the stainless steel will bend at the thinnest point. The flexures were machined using an end mill and have a thickness of about 100 mil. It is critical that when the force is removed, the material is hard enough, and the flexures are thick enough that the metal will bend back to its original position. Otherwise, over time, the laser will lose its ability to be tuned, and the laser will not be usable. This force is applied to each flexure by a finely threaded ¼”-80 screw or differential adjuster.

For the vertical flexure, which is located on the bottom layer of the laser cavity, and larger flexure arm on the middle layer, we chose to use differential adjusters. A differential adjuster is basically a screw in a screw. The course adjustment is external and is simply a ¼”-80 screw, which means that the screw moves 1/80” per revolution. The internal, fine adjustment is slightly more complex. It is accessed by using a small 1/16” hex wrench through the clearance hole that is associated with turning the coarse adjustment. The inside of the main body of the adjuster is threaded with M3 x 0.4 and holds an actuator in place. When the fine adjustments are made with the 1/16” hex wrench, the actuator moves on this inner threading, but since it is also internally threaded, it also pulls the front tip of the mechanism backward. Each revolution advances the actuator 400 micrometers forward and simultaneously pulls the front tip of the adjuster 375 micrometers in the opposite direction, allowing for very fine adjustments to be made of 25 micrometers per revolution [4].

For the second flexure on the middle layer which moves the small arm where the diffraction grating is located, we use a ¼”-80 screw with a piezoelectric actuator mounted on the tip. The screw can be used to make manual adjustments, but it is also important to actively adjust the force on the flexure as the laser is lasing in order to maintain a stable frequency of emission. The piezoelectric actuator is wired to a current controller which uses a feedback loop to control the voltage across the piezoelectric element. By altering the voltage, the piezoelectric element will expand or contract linearly, which ultimately changes the frequency of light being emitted by the laser. By actively making these adjustments while lasing, we are able to overcome obstacles such as thermal expansion and maintain a steady frequency output.

Another problem we predicted could arise with the tunable flexures is that the end of the screw or differential adjusters may not slide smoothly against the stainless steel they push on. As the adjusters are screwed in or out, the end slides against the metal. If the finish on the laser cavity is not smooth enough, the adjuster will jerk as it pushes the flexure arm, which will cause large frequency jumps rather than a smooth, continuous adjustment. To avoid this, we mounted small sapphire disks at all the locations where differential adjusters or screws are pushing on the cavity. These disks are very hard and smooth, and ensure that we will not experience any jerking while making frequency adjustments.

3.5 Temperature Stabilization

As the diode begins lasing, there will be a temperature increase inside of the laser cavity, specifically located around the diode. In order to eliminate thermal expansion, we needed to incorporate a method which could remove this heat and regulate the internal temperature of the laser. In order to accomplish this, we first use a heat sink to remove as much heat as possible from the area around the diode. By using a conducting copper foil that is clamped near the diode, we are able to transport a substantial amount of the heat produced from the diode to the aluminum heat sink. The heat sink also has a thermoelectric cooler that sets between the top layer of the laser cavity and the heat sink. The heat sink sits on top of the laser cavity and is open to the air. The idea is that the heat will be pulled away from the diode and to the heat sink, where it will be temporarily stored as the heat is given to the surrounding atmosphere. In order to make sure that the heat sink is not allowing the heat to come back to the laser cavity, an insulating rubber gasket has been placed between the heat sink and the top layer of the laser. The three screws that fix the heat sink to the top layer of the laser are made out of nylon, also for insulating purposes.

While the heat sink will be an effective method of removing heat from the laser diode, we will need to implement an additional method in order to accurately maintain a constant temperature. In order to provide more stability, we also place a thermoelectric (TE) cooler near the diode. This TE cooler is connected to a temperature controller, which is regulated by a feedback loop coming from a thermistor on the laser diode by calculating changes in resistance due to temperature fluctuations. The TE cooler is annulus shaped so that the lens tube can run through the center of it, allowing it to sit very near to the laser diode.

Chapter 4

Current Progress

4.1 Overview

Our current progress leaves us with one nearly finished laser, and three more being rapidly machined to match the first one. We decided building one laser to near-completion would be beneficial to our cause, as we were able to make changes to other three lasers in order to avoid encountering the same problems. The externals of the prototype laser can be seen below in Figure 4-1. Note the three layers of the cavity sit up, off the table and are supported by ‘L’ brackets for increased isolation from the table. The heat sink is seen fixed to the top of the laser, with a black rubber gasket isolation it from contacting the laser cavity. We can also see the D-sub connector protruding from the side of the laser. This connector is a hub to all of the electronic devices located within the laser.

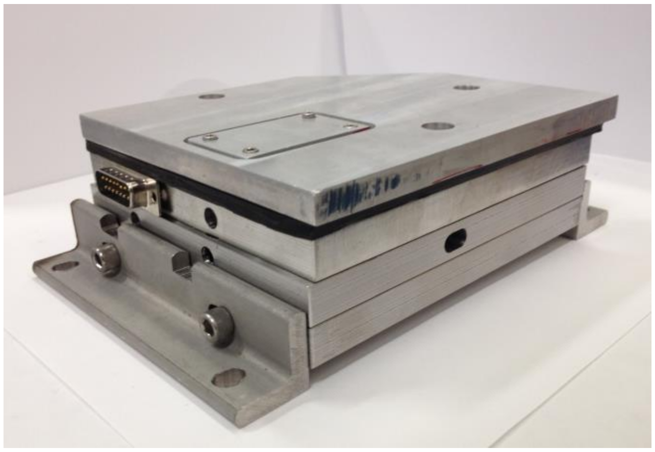

Figure 4-1: A photograph of the current state of the external cavity of the first laser completed.

In order to see the inside components of the laser, the top layer and heat sink have been removed in Figure 4-2. In the image, we see the diode mount, lens tube, TE cooler, safety switch, piezoelectric actuator, and diffraction grating all fixed into their proper place.

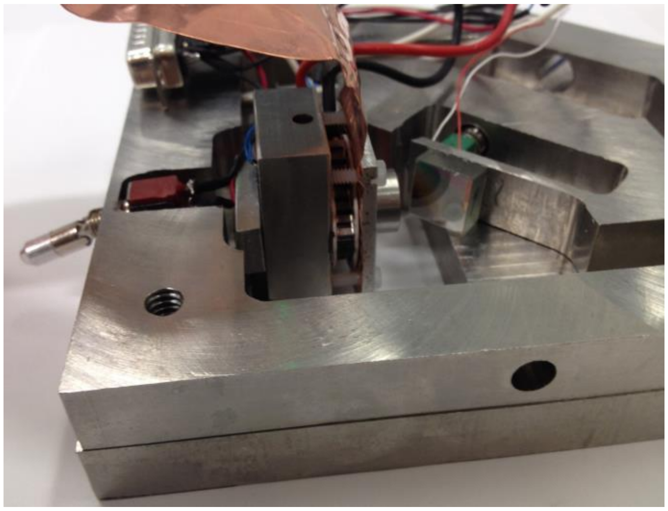

Figure 4-2: A photograph of the inside of the first laser completed exposing the diode mount, lens tube, TE cooler, safety switch, copper foil, diffraction grating, and piezoelectric actuator.

4.2 Conclusion

As one great discovery leads to another, no great experiment ever really has an end. From our current progress, plans are to continue moving forward with the completion of the Cesium-133 laser system for use in the experiment outlined in Chapter 1. While, this marks the end of my time in the group, the work outlined here will be continued over the next several years by other members so that the collision microscope experiments between Cs-133 and K-40 can be performed.

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The Evan Pugh Scholar Award (2012-2013)
Myriant Corporation Scholarship for Excellence in Bio-Energy and Energy Sustainability
Sigma Pi Sigma member
Alpha Lambda Delta member
National Society of Leaders and Success
The President Freshmen Award (2010-2011)
The President Sparks Award (2011-2012)
Penn State Altoona Honors Program
Ruth Graham Scholarship
Endicott Interconnect Scholarship