Frequency-Stabilized External Cavity Diode Lasers for an Undergraduate Teaching Laboratory Magneto-optical Trap

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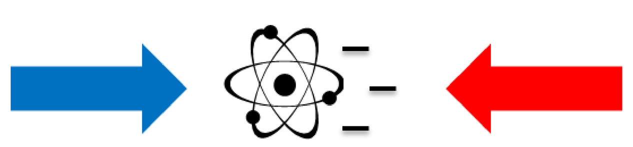
Abstract

Two external-cavity diode lasers were built for an undergraduate teaching lab Rubidium MOT. The lasers were frequency stabilized and linewidth narrowed by locking to the D2 transition of a Rubidium 87 saturated absorption spectrum using a homemade locking circuit.

Magneto-optical Trap Requirements

A magneto-optical trap (MOT) uses six laser beams to cool a collection of atoms at the point where they intersect. Each beam is slightly red-shifted from an atomic transition in the target atoms so that only atoms moving towards the laser will absorb photons. The net effect of this process is to form an "optical molasses" that removes most of the atom's kinetic energy.



Doppler shifting causes selective absorption based on velocity

To keep the atoms in the trap during the cooling process, this optical molasses is placed in spatially varying magnetic field. The subsequent Zeeman splitting causes different polarizations of light to be selectively absorbed on either side of the center. By oppositely polarizing counter-propagating beams, this selective absorption confines the atoms' movement.

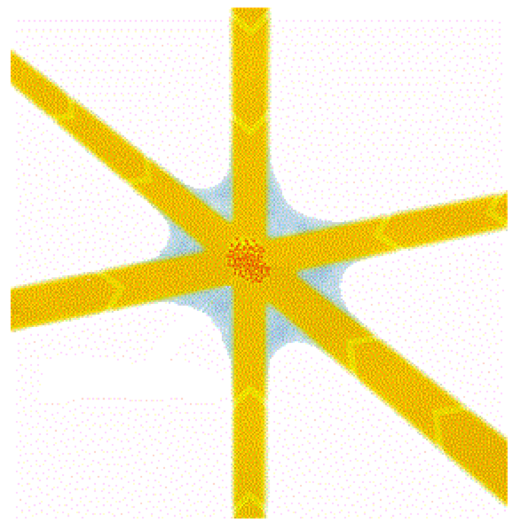
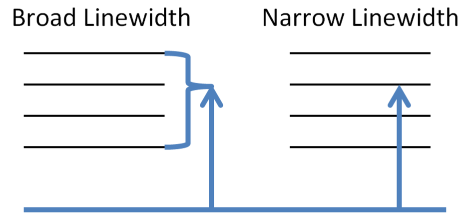


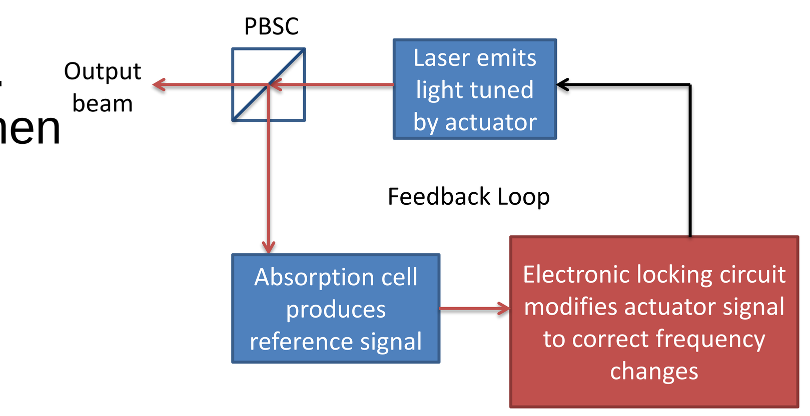
Image credit: 1997 Nobel Prize

In order to discriminate between atoms moving with and against the laser beam, the laser must produce a very narrow frequency range (linewidth). In addition, to stimulate a specific atomic transition for the duration of an experiment, the laser must be able to stay at a given frequency for long periods of time.



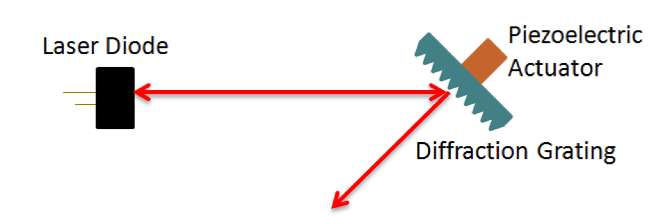
Stabilizing and Narrowing Frequency

An absorption spectrum is generated from the output beam. The electronic feedback circuit then fixes the laser's frequency with respect to fixed atomic transition lines, stopping it from drifting.



An external cavity in the Littrow configuration forces the diode to lase over a narrow frequency range, producing a narrow linewidth. This frequency can then be controlled by altering the length of the cavity between a diffraction grating and the laser diode with a piezoelectric actuator.

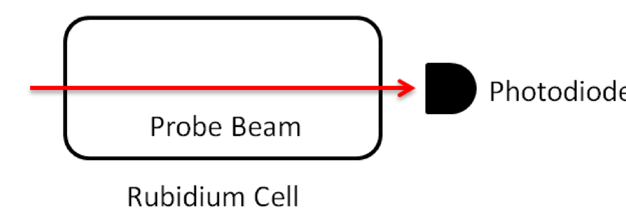
The Littrow Configuration



Generating a Feedback Signal

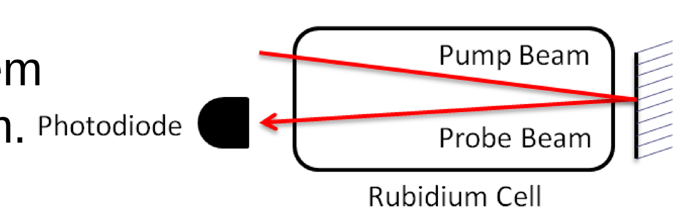
The simplest way to generate an absorption signal is to pass the laser beam through a Rubidium cell. However, the Doppler effect limits the resolution of this spectrum (Doppler broadening).

Absorption Spectroscopy



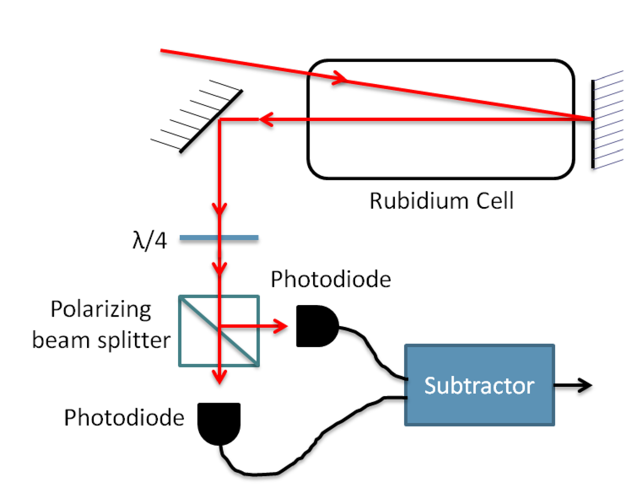
Doppler broadening can be avoided by passing the laser beam through the rubidium cell twice. When the pump and probe beams interact with the same atoms, the strong pump beam saturates them, rendering them transparent to the weak probe beam. Since only zero velocity atoms can interact with both beams, the resulting spectrum is free of Doppler broadening.

Saturated Absorption Spectroscopy



An even higher resolution spectrum can be obtained by putting the cell in a magnetic field. The Zeeman sublevels will selectively absorb different polarizations, producing two absorption signals slightly shifted that, when subtracted, produce sharp peaks at the transition frequency.

Dichroic Atomic Vapor Laser Locking (DAVLL)



Sample Saturated Absorption Spectra

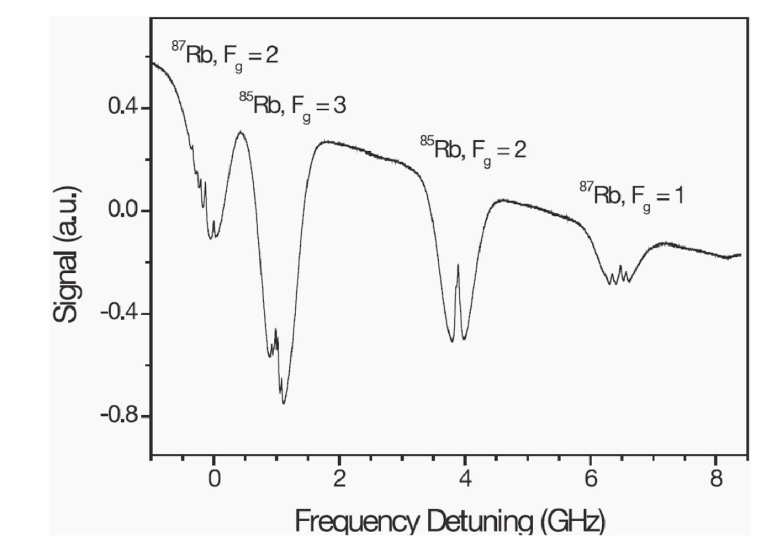
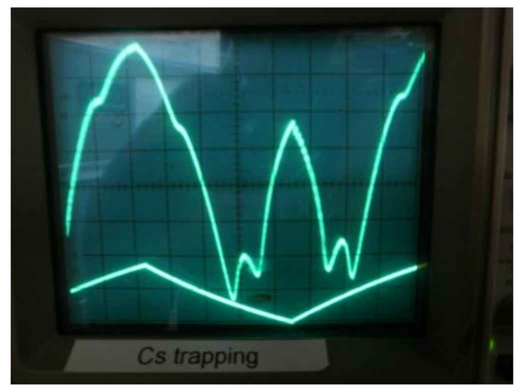
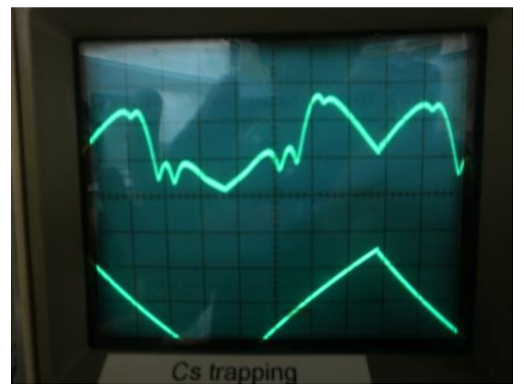


Image credit: Georgia Tech Saturated Spectroscopy lab manual



^{85}Rb, $F_g = 3$

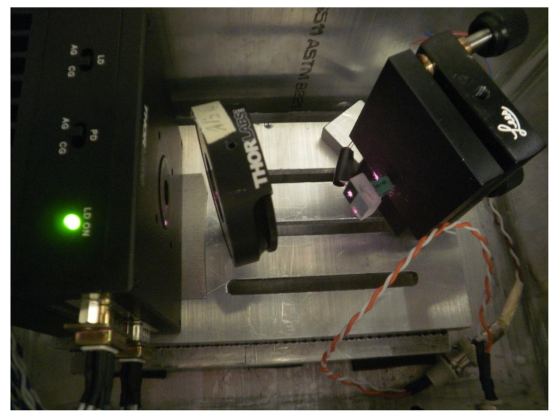


^{87}Rb, $F_g = 1$

The oscilloscope images to the right show saturated absorption spectra (probe beam intensity vs. frequency) of two different Rubidium 87 transitions.

Conclusions and Future Work

We placed two diodes in external cavities and built an analog locking circuit to stabilize them using the saturated absorption spectroscopy and DAVLL techniques explained here. Both lasers currently output ~30mW while staying locked at 780.241nm for several hours at a time.



The lasers will now be combined with a Cold Quanta Rubidium miniMOT™ to create a MOT. Eventually, this MOT will become part of and Advanced Physics Lab at the University of Rochester

Image credit: www.coldquanta.com

References

A narrow band tunable diode laser system with grating feedback, and a saturated absorption spectrometer for Cs and Rb K.B. MacAdam, A. Steinbach, and C. Wieman (1992). Am. J. Phys. 60(12) 1098-1111.

"Molecule Chips" by Michaela Tscherneck, 2008
https://urresearch.rochester.edu/institutionalPublicationPublicView.action?institutionalItemId=5635&versionNumber=1

Stabilizing a Diode Laser to an External Reference by Thijs Hoogeveen, 2003
https://www.kvi.nl/~trimp/web/Theses/ThijsHoogeveen.pdf

1997 Nobel Prize Website
http://www.nobelprize.org/nobel_prizes/physics/laureates/1997/illpres/trapping.html

The Georgia Tech Saturation Spectroscopy lab manual
http://advancedlab.physics.gatech.edu/labs/SaturationSpectroscopy/SatSpecManual.pdf