Pound-Drever-Hall Locking of a Chip External Cavity Laser to a High-Finesse Cavity Using Vescent Photonics Lasers & Locking Electronics

1. Introduction

A Pound-Drever-Hall (PDH) lock[1] of a laser to a high-finesse cavity was performed as a precursor to a NICE-OHMS[2] ultra-high sensitivity spectroscopy experiment. The efficacy of the PDH lock is explored in this application note.

2. Cavity Geometry and Parameters

The key components of the high-finesse cavity are a 10 cm long fused silica spacer, high-reflectivity mirrors (Newport 10CV00SR.70F), a piezo (Piezomechanik HPSt 500/10-5/5) used in the NICE-OHMS experiment to lock the cavity to a molecular transition, and a vacuum chamber as shown in Figure 1 and Figure 2.

The mirrors used in the cavity have reflectivity at the target wavelength of >99.97% resulting in a nominal finesse of 30,000 for the cavity. The actual finesse of the cavity was measured by locking the laser to the cavity and jumping the laser out of lock while monitoring the light power transmitted through the cavity. In this way, the finesse was measured to be 13,840±250 (see Figure 3). Most likely, the measured finesse is lower than the calculated finesse due to mirror contamination from outgassing of the PZT. A summary of the cavity and mirror parameters is given in Table 1.

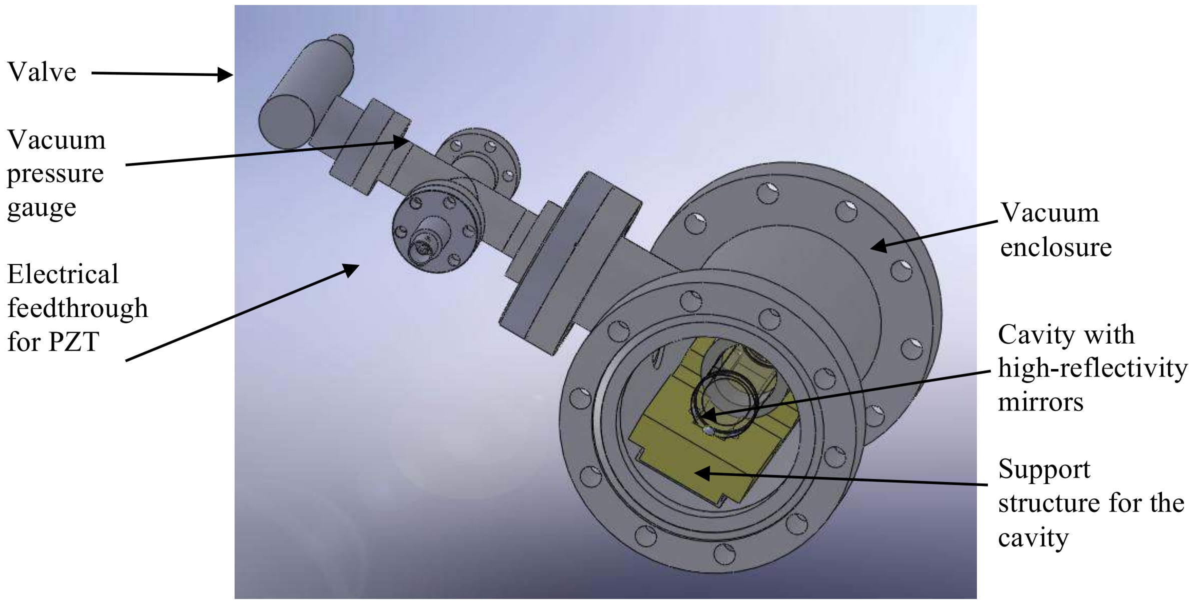

Figure 1. Schematic of the cavity inside the vacuum chamber.

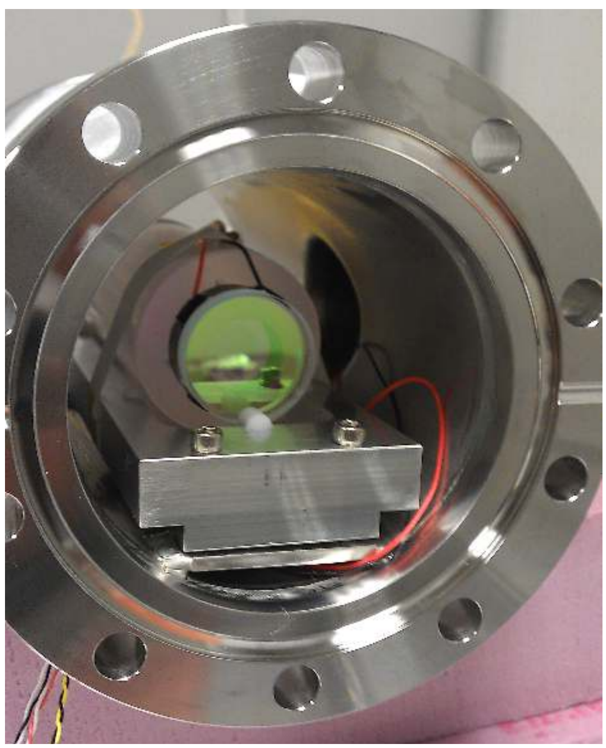

Figure 2. Photo of cavity inside vacuum enclosure.

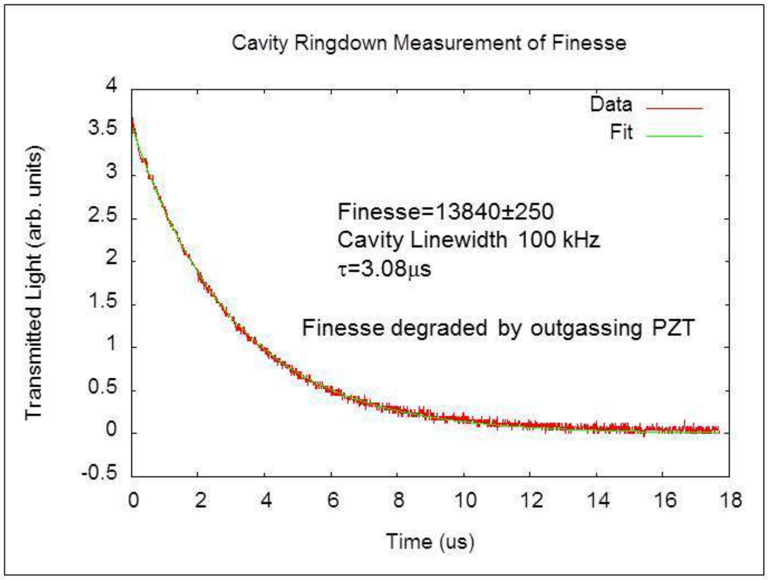

Figure 3. Cavity finesse measured using cavity ringdown spectroscopy.

Parameter	**Value**
Cavity Length	10.3 cm
FSR	1.453 GHz
Mirror Radius	1 m
Nominal Finesse	30,000
Measured Finesse	13,840±250
Power Buildup Factor (PBF)	2,400
Beam waist at cavity mirror	0.340 mm
Beam waist at center of cavity	0.331 mm
Mode Separation	212.10 MHz
Mirror Reflectivity on HR side	99.97%
Mirror Reflectivity on AR side	R_{avg}<0.5%, R_{max}<1.5%
Mirror Optical Loss	<100 ppm
Mirror Wavelength Range	1457 nm-1659 nm

Table 1. A summary of cavity and mirror parameters.

3. Chip External Cavity Laser (CECL) Source

For this experiment, we built a Chip External Cavity Laser (CECL)[3]. The CECL is a short external-cavity diode laser with no moving parts (no PZT.) The cavity is closed with a fixed-position diffraction grating. Tuning is accomplished through the change in carrier density and temperature (index of refraction) of the chip as the current is varied. A photo of a CECL laser is shown in Figure 4. This laser design can be made to tune >10 GHz mode hop-free and typically has a linewidth of 100-500 kHz. The 1380 nm laser used in this experiment had an open-loop linewidth of 300 kHz as shown in Figure 5.

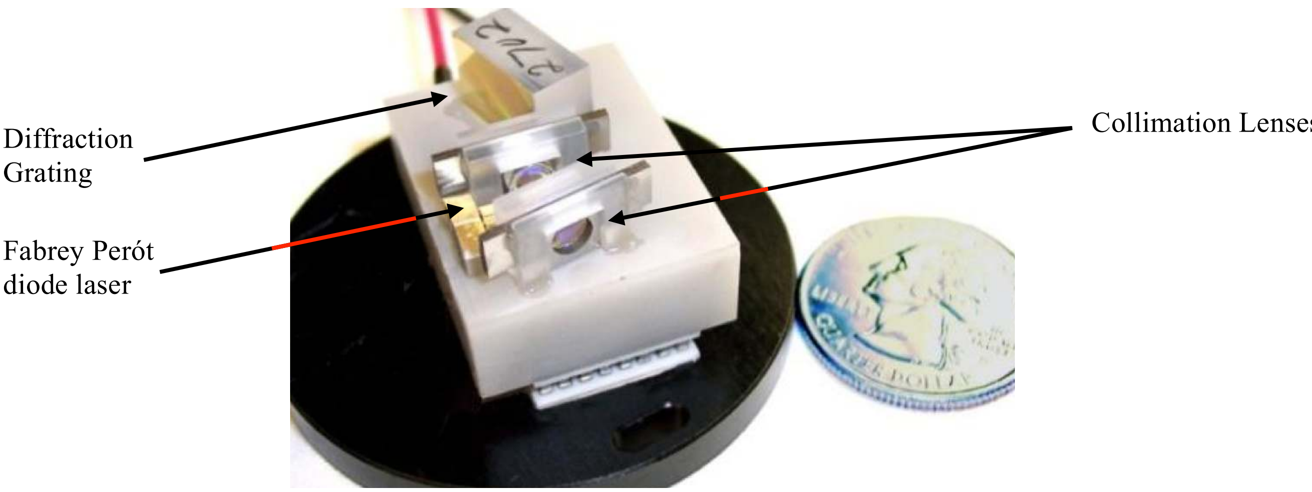

Figure 4. Photo of a Chip External Cavity Laser (CECL)

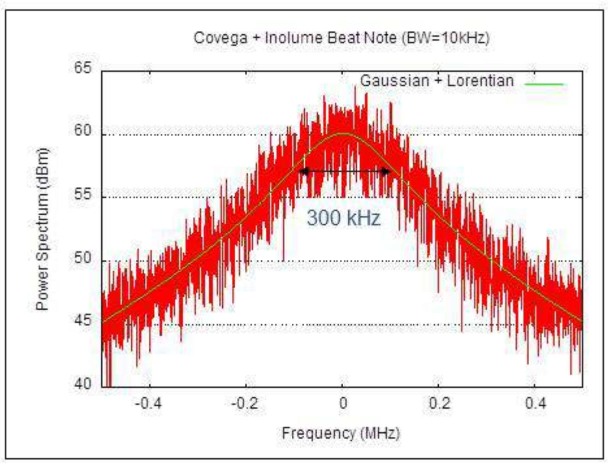

Figure 5. The linewidth of a typical CECL laser is 300 kHz in the IR.

4. Pound-Drever-Hall Locking the Laser to the Cavity

The goal of the work germane to this application note was to lock the laser to the cavity. This lock performs two related functions. First, it keeps the laser on-resonance with the cavity so that the cavity can be loaded with light for the NICE-OHMS experiment. Second, it narrows the linewidth of the laser below the linewidth of the cavity and reduces noise due to the conversion of frequency noise into amplitude noise. We used the Pound-Drever-Hall (PDH) technique to lock the laser to the cavity.

The conceptual design of the experiment is shown in Figure 6. The locking of the laser to the cavity was performed with the electronics in the upper left of the figure and locking of laser sidebands to the free spectral range of the cavity, as required for the NICE-OHMs experiment, was accomplished with the electronics shown in the lower center portion of the figure. A Vescent Photonics D2-125 Laser Servo generated the loop filter and error signal for each of these locks. Sidebands were applied to the laser not with an external modulator as shown, but by modulating the current driving the diode.

Error signals from the PDH technique are shown in Figure 7. When the locking circuit for locking the laser to the cavity was engaged, significant linewidth narrowing and noise-reduction is observed as shown in Figure 8. As shown in the figure, 30 dB of noise reduction is achieved when the laser is locked to the cavity giving 1000-fold reduction in the laser linewidth to about ~300 Hz.

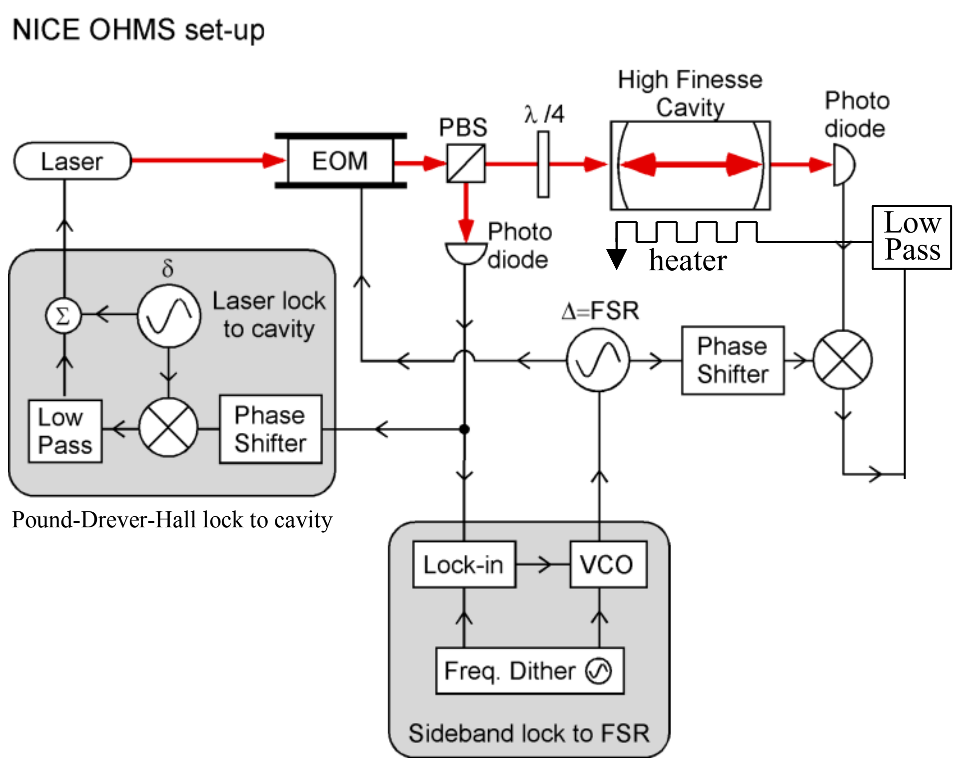

Figure 6. Experimental design for locking of a CECL laser to a high-finesse cavity

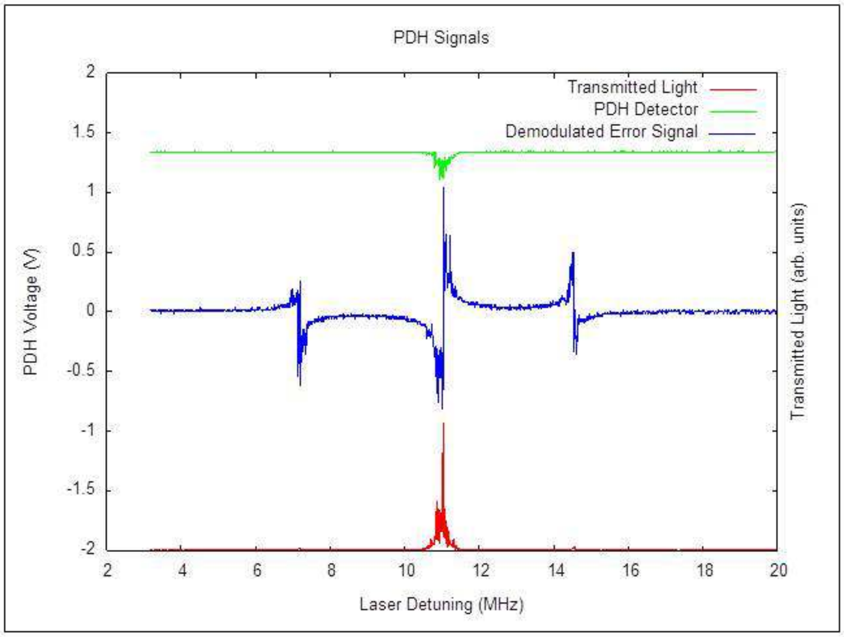

Figure 7. PDH Error Signals as the laser frequency is swept across the cavity resonance. Note that the vertical axis is arbitrary for the PDH detector signal and the transmitted light, since these signals are offset for visual clarity.

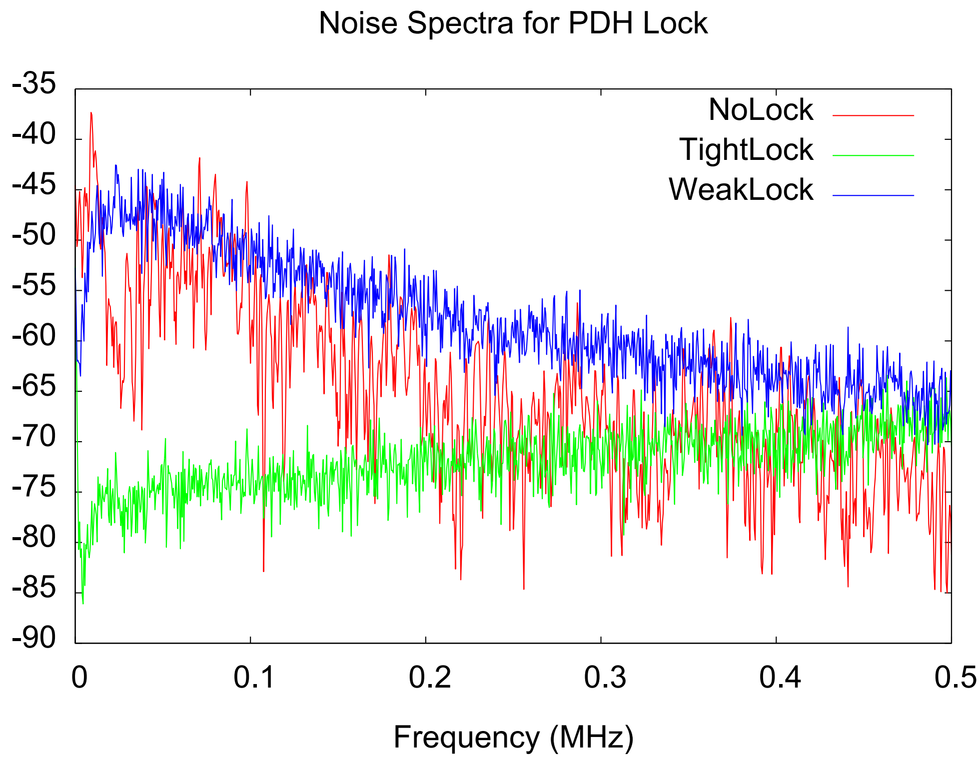

Figure 8. Frequency spectrum of the PDH error signal. The weak-lock signal gives an accurate frequency spectrum of the unlocked laser above ~50 kHz. The no-lock signal confirms that the true spectrum continues to rise below 50 kHz.

5. Summary

A Chip External Cavity Laser was locked to a high-finesse cavity. The lock was shown to reduce the linewidth of the laser to below that of the cavity to about 300 Hz.

6. References

[1] R. W. P. Drever, J. L. Hall, F. V. Kowalski, J. Hough, G. M. Ford, A. J. Munley and H. Ward, "Laser Phase and Frequency Stabilization Using an Optical Resonator," Appl. Phys. B 31, 97-105 (1983).

[2] Ma, L.-S., Ye, J., Dube, P., and Hall, J. L., "Ultrasensitive frequency-modulation spectroscopy enhanced by a high-finesse optical cavity: theory and application to overtone transitions of C_2H_2 and C_2HD," Journal of the Optical Society of America B 16, 2255 (1999).

[3] http://www.vescent.com/products/lasers/d2-100-cecl/