Absolute frequency stabilization of an extended-cavity diode laser by Noise-Immune Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy

Hemanth Dinesan, Eugenio Fasci, Giovanni Casa, Antonio Castrillo and Livio Gianfrani

Dipartimento di Matematica e Fisica, Seconda Università degli Studi di Napoli, Viale Lincoln 5, Caserta, Tel.: +39-0823-274628, E-mail: livio.gianfrani@unina2.it

Phase- and frequency- noise reduction of an extended-cavity diode laser is an extremely important prerequisite for precision laser spectroscopy in atomic and molecular physics. In those experiments in which absolute frequency stabilization is required, the laser frequency can be locked to a narrow sub-Doppler line of a molecular sample [1]. This is the case of the Italian experiment on the Boltzmann constant, in which Doppler-broadening thermometry is being developed and optimized with the ambitious goal of approaching the accuracy of one part over 10^6 [2].

In this work we have exploited the potential of NICE-OHMS for stabilizing the frequency of an extended-cavity diode laser against the center of a saturated $H_2^{18}O$ line at 1.38 µm. Invented at JILA by John Lewis Hall, NICE-OHMS (standing for Noise-Immune Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy) can reach the outstanding sensitivity of $\approx 10^{-14}$ cm^{-1} (with 1-s averaging time), in the detection of ultra-narrow sub-Doppler features in coincidence with weak molecular absorption lines [3]. The noise immune property relies on the precise match of the FM modulation frequency (used to generate sidebands around the central laser frequency) to the free-spectral-range of the high finesse cavity (used as enhancement cavity for the establishment of the nonlinear regime of laser-gas interaction) [4].

Our approach of absolute frequency stabilization involves three different feed-back loops. In a first stage, the laser frequency is locked to a resonance of a high-finesse cavity (with an empty-cavity finesse of about 8900, leading to a cavity mode-width of ≈85 kHz) by using the Pound-Drever-Hall method. The second stage consists in locking a pair of sidebands at the cavity free-spectral-range splitting frequency, by using the DeVoe-Brewer method [5]. Hence, the nonlinear regime of laser-gas interaction is reached by filling the optical cavity with a ^{18}O-enriched water sample, at a pressure of 20 mTorr. In the third loop, the cavity mode is locked to the center of the sub-Doppler dispersion signal, as observed in coincidence with the Lamb-dip, which exhibits a line width of about 2 MHz (FWHM). An Allan deviation analysis done on the error signal resulting from NICE-OHMS, yields a relative frequency stability of 2.5×10^{-13} at the optimum integration time of 30 s.

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