L.3: A new laser frequency stabilization technique: polarization enhanced tunable Doppler-free dichroic lock (PET-DFDL)

Laser frequency stabilization is essential for applications of lasers in high resolution spectroscopy, interferometry, atom-cooling, quantum optics, etc. Recently, a new laser frequency stabilization technique has been demonstrated at RRCAT to lock a diode laser using a locking signal generated from Doppler-free dichroism in Rb atoms. The technique is named as polarization enhanced tunable Doppler-free dichroic lock (PET-DFDL). The technique uses the absorption signals of a pair of circularly polarized probe beams overlapped with the oppositely circularly polarized counter propagating pump beams in an absorbing atomic medium (Rb-vapor cell in this case) in presence of a dc magnetic field. The difference of absorption of σ^+-polarized and σ^--polarized probe beams (in presence of their respective oppositely circularly polarized pump beams and a dc magnetic field) generates a dispersive locking signal, called PET-DFDL signal, as shown in Figure L.3.1. Because of higher slope and amplitude of locking signal generated in PET-DFDL technique as compared to conventional Doppler-free dichroic lock (DFDL) technique in which pump beams are plane polarized, the peak-to-peak frequency fluctuation of the locked laser gets considerably reduced with PET-DFDL locking technique. The reduced fluctuations in the laser frequency are useful in the above mentioned applications of the laser.

The experimentally observed locking signals for F = 2 →F' transitions in ^{87}Rb atom are shown in Figure L.3.1 for conventional DFDL technique and our recently invented PET-DFDL technique. The locking performance of the PET-DFDL technique has been compared with the DFDL technique on an external cavity diode laser (ECDL) system. During this comparison, the settings of PID controller used for frequency locking of the laser system were kept same. The error signals, after locking laser with these two different techniques, are shown in Figure L.3.2 along with corresponding peak-to-peak deviation in the laser frequency. The plots of Figures L.3.2(a), L.3.2(b) and L.3.2(c) show the frequency fluctuations in free running, after locking with DFDL signal, and after locking with PET-DFDL signal, respectively. A magnetic field of ~ 9.8 G was applied along with ~ 120 µW power in pump beams and ~10 µW power in probe beams, in both DFDL and in PET-DFDL techniques. The slopes of DFDL and PET-DFDL signals at F=2 → F'=3 transition in ^{87}Rb atom were ~ 20 mV/MHz and ~ 82 mV/MHz, respectively. It is evident that peak-to-peak frequency fluctuations after locking with PET-DFDL (<300 kHz) signal were much smaller than that after locking with DFDL signal (< 600 kHz).

The PET-DFDL technique was finally used for locking the cooling laser frequency for U-magneto-optical trap (U-MOT) in the atom-chip set up. The number of cold ^{87}Rb atoms in U-MOT was reached to ~ 4×10^7 at ~15 MHz red-detuning of cooling laser beams. The fluctuations in number of cold atoms in the MOT were reduced to less than 8% after locking the laser frequency with PET-DFDL technique.

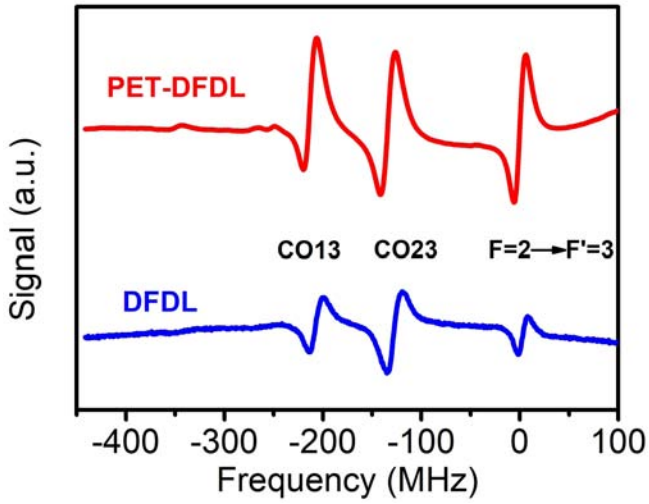

Fig. L.3.1: The experimentally observed locking signals in DFDL and PET-DFDL techniques for F = 2 →F' transitions in ^{87}Rb atom. The x-axis shows the frequency detuning from cooling transition of ^{87}Rb atom.

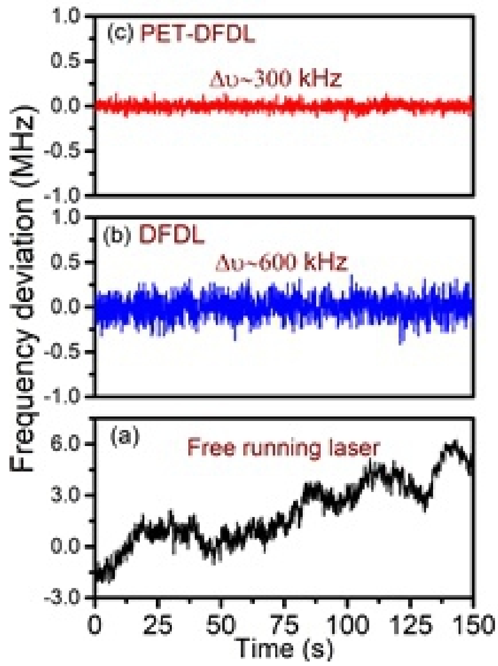

Fig. L.3.2: The measured variation in laser frequency (from recorded error signals) with time in different cases; (a) free running (unlocked) laser, (b) laser locked using DFDL signal, and (c) laser locked using PET-DFDL signal.

The details of this work are available in the paper- "Polarization enhanced tunable Doppler free dichroic lock technique for laser frequency locking" by V. Singh, V. B. Tiwari and S. R. Mishra, J. Opt. Soc. Am. B, 38, 249-255 (2021).

Reported by:
S. R. Mishra (srm@rrcat.gov.in)