L.4: Development of sub-100 Hz linewidth NPRO laser system

Interferometric gravitational wave detection requires lasers with ultra-narrow linewidth in the sub-100 Hz range. As part of capacity building for interferometric gravitational wave detection work at RRCAT, we have developed the technology for building non planar ring oscillator (NPRO) laser systems. Initially, a table top system was developed to establish the design parameters and optimized the controls system. Based on this work, an engineered version of the NPRO laser has been developed to be used as an oscillator for the laser system of the 10 m arm-length prototype interferometer being setup at RRCAT.

Figure L.4.1 shows the side view of the engineered version of NPRO Laser. The NPRO laser uses a 12 mm x 8 mm x 3 mm Nd:YAG crystal specially cut in a suitable geometry to form a monolithic ring cavity by means of three total internal reflections (TIR) at its side surfaces and one reflection at the input-output coupler face that is coated with a dichroic coating (AR at 808 nm, R=99.5% at 1064 nm) to facilitate optimal pumping. Since the Nd:YAG crystal has a small but finite Verdet constant, the NPRO crystal is placed in 0.3 T longitudinal magnetic field to ensure unidirectional propagation in the monolithic ring cavity. The induced Faraday rotation and the polarization rotation at each TIR face results in an optical-diode, which allows the laser beam at 1064 nm to propagate only in one direction in the ring cavity. The unidirectional ring laser configuration avoids spatial hole burning. Further, the homogeneously broadened Nd:YAG gain medium coupled with the monolithic cavity that is largely insensitive to the environmental perturbations results in the laser inherently lasing in a single longitudinal mode with a narrow (kHz level) linewidth. The optical pump beam parameters are suitably chosen to have maximal overlap with the fundamental transverse mode of the ring cavity to ensure that the laser operates in a single transverse mode (TEM_{00}). The measured M^2 parameter of the NPRO laser was 1.03 at 200 mW of output power. The measured short term linewidth of the free-running NPRO laser is around 600 Hz over 6 ms of integration time. This is reduced further to sub-100 Hz level by frequency locking of the NPRO laser to a stable high finesse reference cavity using Pound-Drever-Hall (PDH) technique to compensate for the line-width drift due to environmental perturbations. The linewidth of the engineered version of the NPRO laser oscillator with 200 mW output at 1064 nm was measured using Heterodyne Beat Method (HBM). The PDH based frequency-offset locking is used to optimize the detection of HBM signal and also to avoid the cross-talk of PDH error signal. A "fast" and a "slow" servo control is used to maintain frequency lock. To maintain frequency locking over long durations, the slow servo control corrects the NPRO ring cavity's optical length by way of temperature tuning of the Nd:YAG crystal. The fast servo control uses a PZT attached to the NPRO crystal to modulate the monolithic cavity's length by elastic compression to maintain frequency lock. The developed engineered NPRO laser oscillator has a frequency tuning rate of 4.1 MHz/V for fast tuning using the PZT actuation and a slow frequency tuning rate of -3.9 GHz/K by way of temperature control. Figure L.4.2 shows the long term lock performance of the laser system for 5 hours, where L.4.2(a) shows the slow servo control signal for temperature control of NPRO crystal, L.4.2(b) shows the transmission through the reference cavity with laser locked at 281.635 THz frequency and L.4.2(c) shows the fast servo signal value for actuation of PZT to maintain lock. Figure L.4.3 shows the measured short term linewidth of less than 75 Hz over 38 ms integration time with the laser in frequency locked condition.

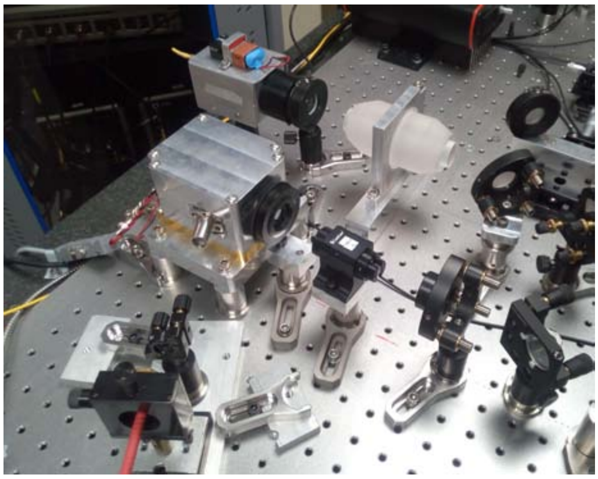

Fig. L.4.1: Side view of engineered NPRO laser.

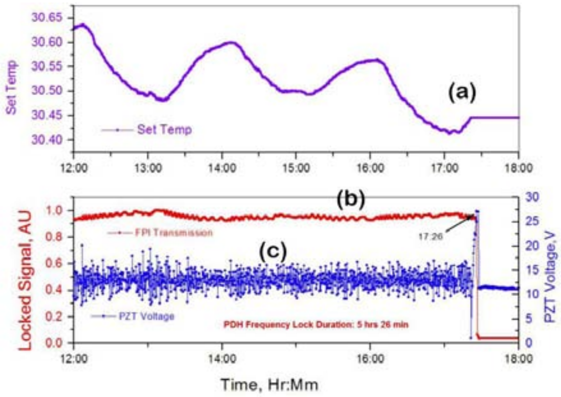

Fig. L.4.2: Frequency locked signal as a function of time.

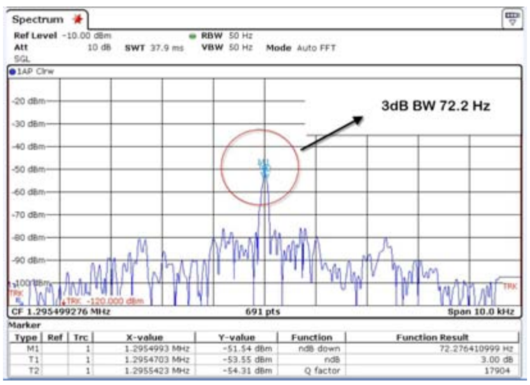

Fig. L.4.3: Heterodyne beat signal in dBm scale.

Reported by:
Jogy George (jogy@rrcat. gov.in)