Cryogenic Single Crystal Silicon Cavity

Jacques Millo[1], Clément Lacroûte[1], Alexandre Didier[1], Julien Paris[2], Vincent Giordano[1], Enrico Rubiola[1], Yann Kersalé[1]

[1]Time and Frequency Dept., FEMTO-ST Institute, Besançon, France

[2] MyCryoFirm, Paris, France

Email: millo@femto-st.fr

Oscillators presenting the best short term frequency stability are cavity-stabilized-lasers. The performances of such systems are limited by the thermal flicker noise of the ultra-stable cavity used as a frequency reference, with a resulting fractional frequency stability in the low 10^{-16} decade[1,2].

We are developing an ultra-stable laser with reduced thermal noise, compatible with a fractional frequency stability of 3×10^{-17}. This noise floor is improved with respect to the ULE or fused silica cavities by the use of single crystal silicon[3] with a mechanical quality factor higher than 10^7 around 10K [4]. The thermal noise is also reduced by working at cryogenic temperatures. Furthermore, the thermal sensitivity of the cavity can be strongly reduced thanks to a turning point of the coefficient of thermal expansion (CTE) around 17 K[5]. To operate the cavity at this temperature a custom low vibration cryocooler is being designed. The thermo-mechanical setup of the cavity housing is optimized to filter the external temperature fluctuations, including those at the cycling frequency of the cryocooler pulsed tube (typically 1 Hz), while keeping enough thermal conductivity to reach the targeted temperature.

The spacer of the cavity is designed using finite element modeling, with a projected sensitivity to vibrations lower than 4×10^{-12} / (m s^{-2}) per axis, which is compatible with the residual displacement noise in the cryocooler. The optical axis is oriented horizontally and the cylindrical spacer is held in 3 points in order to maximize symmetries. Both ends of the 140 mm long spacer are tapered to minimize tilts of mirrors.

The design of the cavity and the setup will be presented. Additionally we also show the results of two studies concerning two important issues. First, the residual amplitude modulation of the EOM used for the Pound-Drever-Hall technique has to be controlled at a level compatible with our objectives. Second, an optical setup is being developed that measures and compensates the residual motion of the cavity with respect to the laser source, which induces a Doppler shift onto the error signal used to lock the laser.

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