Long-term performance of a cryogenic silicon-resonator-based laser system

C. Hagemann[1], D.G. Matei[1], C. Grebing[1], C. Lisdat[1], St. Falke[1], T. Legero[1], U. Sterr[1], F. Riehle[1], M. J. Martin[2], W. Zhang[2] and J. Ye[2]

[1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[2]JILA, National Institute of Standards and Technology and University of Colorado, 440 UCB, Boulder, CO 80309-0440, USA

Email: dan.matei@ptb.de

Cryogenic single-crystal optical cavities have the potential to provide highest dimensional stability and low thermal noise. We have recently set up a cavity-stabilized laser system[1] with short-term stabilities of $mod\ \sigma_y(\tau) \leq 1 \times 10^{-16}$ for averaging times of $\tau = 1 \ldots 10$ s.

This contribution discusses the long-term performance of the system. The temperature of the 21 cm long reference cavity was stabilized at 124 K within less than 1 K from the zero of its thermal expansion coefficient. Using a frequency comb, the laser frequency is continuously compared to a hydrogen maser that is referenced to a primary caesium fountain standard and during shorter intervals to the ^{87}Sr optical lattice clock at PTB[2]. This allows addressing the influence of perturbations in parameters like vacuum pressure and temperature on the frequency of the resonator modes and to devise an optimal approach to minimizing the effect of such perturbations. We were thus able to achieve variations in frequency of less than 2 kHz over a time span of 400 days. These findings were taken into account in a second system that is currently set up at PTB.

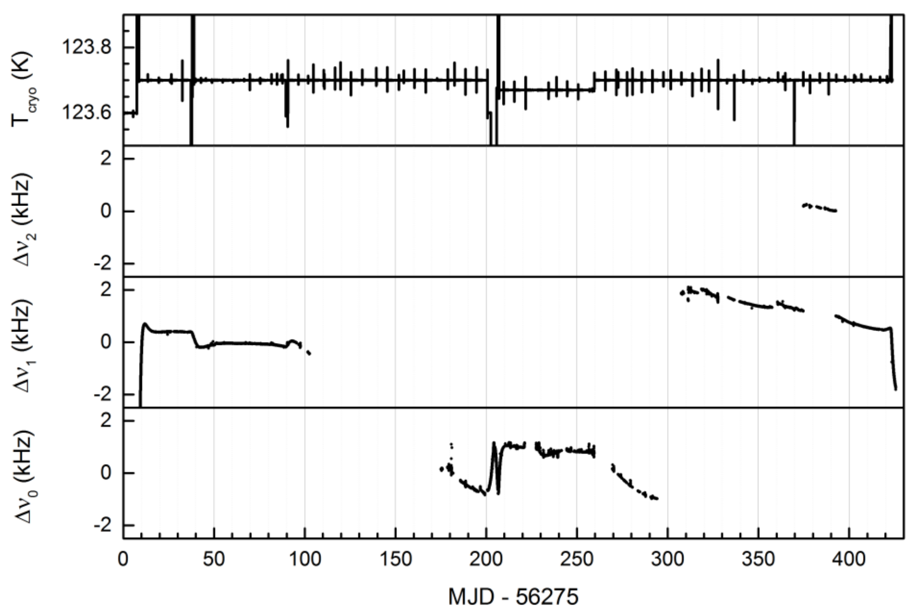

Fig. 1: The cryostat temperature (upper graph) was set at values between 123 K and 124 K. The small, regular spikes are generated by the periodic refilling of the liquid nitrogen reservoir, while the larger spikes are related to short-time malfunctioning of the cryostat. The laser frequency was stabilized at three different cavity eigenfrequencies (lower three graphs).

[1] T. Kessler et al., Nature Photonics, vol. 6, p. 687-692, 2012.

[2] St. Falke et al., arXiv:1312.3419 [physics.atom-ph], 2013.