68 cm long cavity with 0.46 ms optical storage time

Adam L. Parke, Henry Bourne, Marco Schioppo

Time and Frequency Department, National Physical Laboratory (NPL), Teddington, UK

Email: marco.schioppo@npl.co.uk

The new emerging generation of timekeepers is based on narrow-linewidth atomic transitions in the optical domain. The measurement capability of these so-called optical clocks strongly relies on lasers with linewidths comparable to those of the clock transitions (mHz level). These ultrastable lasers derive their performance from frequency stabilisation to optical reference cavities.

Here we present our latest work towards an ultrastable laser at 1542 nm with a target fractional frequency instability of 2×10^{-17}, beyond the current state-of-the-art, limited by the Brownian thermal noise of the cavity mirrors' high reflectivity coating (operating at room temperature). The cavity mirrors have 10.2 m radius of curvature, optically contacted to a 68 cm long ULE spacer, yielding a beam diameter ($1/e^2$) on the mirrors of 1.9 mm. We show that in this configuration we measure a cavity finesse of 640,000, corresponding to a single mirror total loss of 5 ppm and a ring-down 1/e optical power decay time of 0.46 ms.

We frequency stabilise a commercial laser to a 350 Hz linewidth cavity resonance and we achieve a contrast of 50%. We present a novel cuboid geometry for the ULE spacer and we discuss advantages and disadvantages with respect to a more traditional cylindrical design. We show that by placing weights on the spacer and by adding lateral constraints it is possible to tune its sensitivity to accelerations for all the degrees of freedom, achieving a minimum sensitivity $\leq 10^{-10}$/g. The stability of this laser will be available to optical clocks at NPL through an optical frequency comb and in the future to external users and collaborators connected by metrological optical fibre links[1].

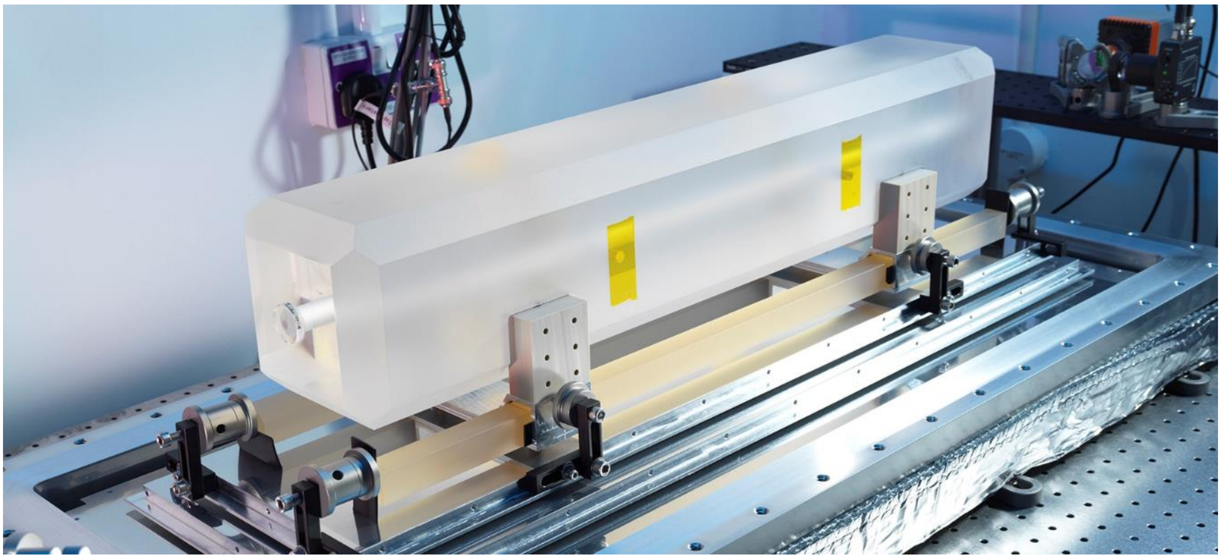

Fig. 1: Photo of the 68 cm long optical reference cavity. The cavity spacer has a cuboid geometry. The cavity sits on three polished aluminium baseplates acting as in-vacuum thermal shields. The cavity will be surrounded by three thermal shields covering the full solid angle and it will operate at a target vacuum level $\leq 10^{-7}$ mbar.

[1] M. Schioppo *et al.*, "Comparing ultrastable lasers at 7×10^{-17} fractional frequency instability through a 2220 km optical fibre network", Nat Commun., vol. 13, 212, 2022.