Compact and Manufacturable Ultrastable Optical Reference Cavities: 10^{-14} Stability in Less Than 10 mL Volume

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Compact ultrastable laser systems are at the heart of mobile optical atomic clocks, optically derived low phase noise microwaves, and precision environmental sensing using optical fibers. We have developed several sub-10 mL vacuum-gap Fabry-Perot cavities that provide ~10^{-14} factional frequency stability [1-3], an order magnitude better stability than other reference cavities of similar size. Furthermore, to facilitate the move away from individual cavity assembly, we have devised a lithographic technique to define and etch mirror surfaces that enable multiple, million-finesse mirrors to be manufactured onto a single substrate [4].

Figure 1 shows representative cavities, vacuum packaging, as well as phase noise and frequency stability results [1-3]. Figure 1(a) shows a cavity whose volume is ~5 mL. A laser frequency-stabilized to this cavity exhibits phase noise limited by the cavity thermal noise out to ~10 kHz offset, as shown in Fig. 1(b). When paired with an optical frequency comb, the low phase noise of this cavity supports microwave generation with performance comparable to the lowest noise optically derived microwave signals to date for offset frequencies greater than ~100 Hz. This is despite the fact that the cavity volume use here is more than 10x smaller than cavities used in previous microwave generation demonstrations.

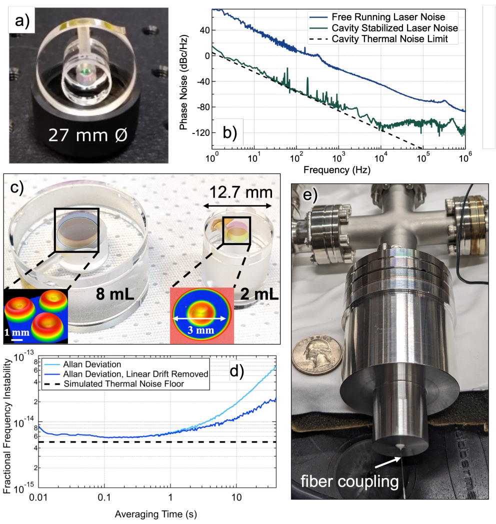

Fig.1. (a) Compact cavity designed for low phase noise, as well as low acceleration and holding force sensitivity. (b) Phase noise of a laser locked to the cavity in (a). (c) 8 mL and 2 mL volume cavities with micro-fabricated mirrors. (d) Allan deviation of a laser locked to the 8 mL micro-fabricated mirror cavity. (e) Compact vacuum enclosure of the 2 mL cavity.

In Fig. 1(c), two cavity structures are shown that are created with micro-fabricated mirrors whose finesse can exceed 1 million at 1550 nm. The 8 mL-volume structure contains 3 micro-fabricated mirrors on one substrate (each with radius of curvature near 1 m), and therefore contains three independent high finesse optical reference cavities. By reducing to a single mirror per substrate, the cavity volume shrinks to only 2 mL, as also shown in Fig. 1(c). The fractional frequency stability of one of the cavities in the 8 mL structure is shown in Fig. 1(d). Here, the instability at 1 second reaches 7×10^{-15}, and stays in the low-10^{-14} range beyond 10 seconds. This is the lowest frequency instability of a laser locked to any optical cavity of similar volume. Fig. 1(e) shows a compact vacuum enclosure containing the 2 mL cavity pictured in Fig. 1(c). The cavity is directly fiber coupled, such that all free-space coupling optics are eliminated. Phase noise and frequency stability measurements for this system are ongoing. The exemplary results from these sub-10 mL cavities demonstrate a path towards compact and mobile ultrastable laser systems that can be manufactured at scale.

References

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