10 kHz Accuracy Spectroscopy in Acetylene-filled Hollow-core Kagome Fiber as Measured with Optical Frequency Combs

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Synopsis Two frequency combs are used to characterize the accuracy and stability of an optical reference based on a $^{12}C_2H_2$–filled, kagome-structured hollow-core photonic crystal fiber. The accuracy of this reference is ±9 kHz, and the fractional instability is 1.2×10^{-11} or less in 1 s.

High-accuracy, fiber-based spectroscopy is desirable for many portable applications, including frequency references and trace gas analysis. The narrowest sub-Doppler linewidths attained in hollow core photonic crystal fiber (HC-PCF) use large-core kagome structured fiber [1], but their large core size supports multiple spatial modes [2] which could potentially degrade the accurate determination of a sub-Doppler line center. Here we demonstrate that such fibers can yield highly accurate frequency measurements despite these modal properties. The accuracy and stability of such a system approaches that of high-finesse free-space setups [3, 4], making this frequency reference attractive for portable optical telecommunication systems.

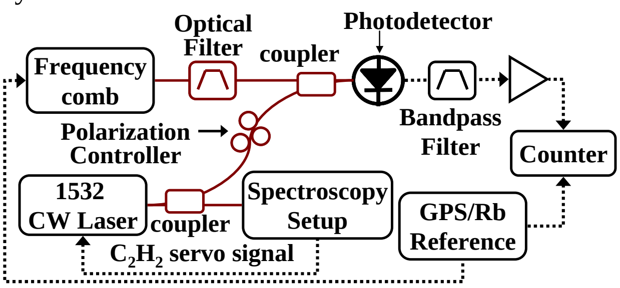

Figure 1. Schematic of the heterodyne beat.

The optical reference under investigation is a continuous-wave (CW) fiber laser frequency-stabilized to the $^{12}C_2H_2$ P(13) $\nu_1+\nu_3$ overtone transition inside kagome HC-PCF using a frequency modulation (FM) saturated absorption spectroscopy (SAS) setup, where the ends of the kagome fiber reside in separate vacuum chambers. The frequency of the CW laser locked to the optical reference is determined by heterodyning it with a self-referenced carbon nanotube fiber laser frequency comb [5] or Cr:forsterite laser frequency comb. Both combs are referenced to a GPS disciplined Rb clock, and a schematic of this setup is shown in Fig. 1. The beat between a comb and the reference has a fractional frequency instability of 1.2×10^{-11} in 1 s, as calculated with a triangle deviation.

The comb's repetition frequency and carrier-envelope offset frequency are counted and averaged to calculate the absolute frequency of the reference. Alignment into the multimode kagome fiber was found to have ~100 kHz shifts on the frequency of the optical reference, so ~20 measurements were conducted where the spectroscopy setup was realigned between refilling of the kagome fiber with various pressures of acetylene. The absolute frequency of the $^{12}C_2H_2$ P(13) $\nu_1+\nu_3$ overtone at zero pressure is found to be 195,580,979,377 kHz ±9 kHz, in agreement with previous measurements [3, 6] and is therefore the highest accuracy measurement in fiber to date [7]. The standard deviation of the data at a given pressure is ±15 kHz, but could be lower in a completely sealed cell (solid core fibers spliced to the ends of HC-PCF) where the input alignment would be fixed, and the presence of a frequency offset is likely. Investigation into linewidth reduction techniques [8] is underway to try to further reduce alignment sensitivity. This work establishes that large-core hollow photonic crystal fibers are suitable for optical frequency references and precise molecular spectroscopy. This research was supported by the AFOSR under contract No. FA9950-08-1-0020, the NSF under Grant No. ECS-0449295.

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