Phase-stabilized Prism-based Cr:forsterite Laser Frequency Comb for Absolute Frequency Measurements

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Abstract: A prism-based Cr:forsterite frequency comb is stabilized, with a repetition rate of 116 MHz. The flexibility of the prism-based system aids in achieving the carrier-envelope-offset frequency (f_0) beat note width of ~1.5 MHz.
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Optical frequency metrology is a fast growing research field constantly looking for alternative reference sources for a wide range of applications; Cr:forsterite is an appealing gain medium in the near infrared. The output is compatible with telecommunications wavelengths and its gain bandwidth makes it a good alternative to Ti:Sapphire systems for longer wavelength configurations. Previous work using Cr:forsterite by groups at NIST have successfully demonstrated a self-referenced frequency comb, actively stabilized, using a chirped mirror laser design with ~420 MHz repetition rate [1,2]. The laser exhibited excellent long-term stability when compared with Ti:sapphire, but exhibited unusually broad f_0 beat notes with widths of up to 6.7 MHz, attributed to noise during the supercontinuum generation process seeded by the pump laser noise.

Here we report a similar system, with dramatically narrower f_0 beat note widths in spite of employing the same pump laser. The reduced f_0 beat may be due to higher pulse energies, or the added control allowed by the prism. Subtle adjustments in the laser prisms and curved mirror dramatically effect the f_0 beat width and strength. We have developed the first prism-based stabilized Cr:forsterite comb, and intend to reference the comb to a GPS – disciplined rubidium clock, and use the resulting comb to perform absolute frequency measurements of the acetylene v_1+v_3 band absorption lines inside photonic bandgap fiber cells [3].

The laser design is shown below in Fig. 1 a. The pump laser is a cw Yb glass laser with a center wavelength at 1075 nm and with 10 W maximum output. The AOM in the pump beam deflects a variable amount of power in order to achieve f_0 stabilization. The 15 mm long Cr:forsterite crystal has the same bulk properties as that measured in Ref. [4] (doping of 0.2% by weight, absorption coefficient of 1.1cm^{-1} at 1075nm), and a length of 15 mm. Dispersion compensation is achieved in the cavity with an SF6 prism pair, Brewster cut and spaced ~30 cm apart. The laser has an output coupler (E) of 6%, and a PZT-mounted mirror (I) after the second prism for stabilization of the repetition rate. The cavity arms make an angle of ~30° to compensate astigmatism. For a 1075 nm pump power of 7 W - 9 W, the laser emits ~220 mW, and autocorrelation reveals ~30 fs pulse duration FWHM. To spectrally broaden the laser output, ~200 mW are directed into a dispersion-shifted highly nonlinear fiber (HNLF) with dispersion D = 1.19 ps/(nm km) at 1550 nm. A power of 130 mW emerges from the HNLF fiber, spanning over an octave in bandwidth. The laser and supercontinuum spectra are shown in Fig. 2b, but the supercontinuum spectrum is truncated due to the frequency range of the OSA used to measure the spectrum. Other measurements reveal a large peak in the spectrum at 2040 nm, which is frequency-doubled in a periodically poled lithium niobate (PPLN) crystal and beat against the high-frequency end of the octave to reveal the f_0 beat signal, as is standard in self-referenced combs. The resulting f_0 beat is detected in a New Focus 125 MHz near-IR detector, and sent to an RF spectrum analyzer as well as a loop filter. The rf electronics that act on the f_0 beat are shown in Fig. 1. The repetition rate is detected on a similar detector. The rf electronics filter the f_0 and the repetition frequency (f_r) signals, and feed back to the pump power and cavity length (mirror I), respectively.

Figure 2 a shows the f_0 beat, measured when both f_0 and f_r were locked. That beatnote displays a clear sign of being phase-locked, notably a narrow peak on top of a broad background. However, that narrow peak has width greater than the resolution bandwidth, indicating that the lock is not optimized. Also, the pedestal on which sits the narrow peak is narrower than the beat notes observed by NIST, which we attribute in part to the added control imparted by the prisms. The beatnote is still much wider than those in Ti:sapphire base combs, and the excess noise is most likely due to high-frequency noise on the pump laser. Indeed, by dividing the frequency f_0 by 256 instead of

16, we found that the servo error signal had a clear noise component at about 1.5 MHz, which is difficult to remove with a servo circuit.
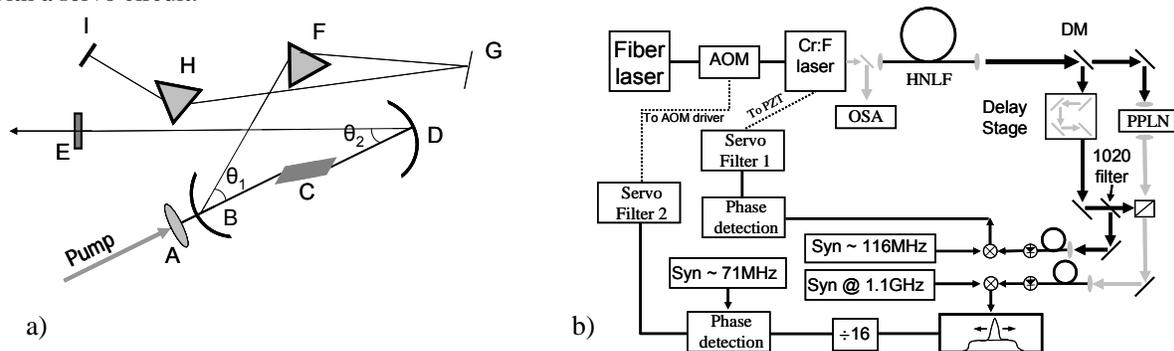

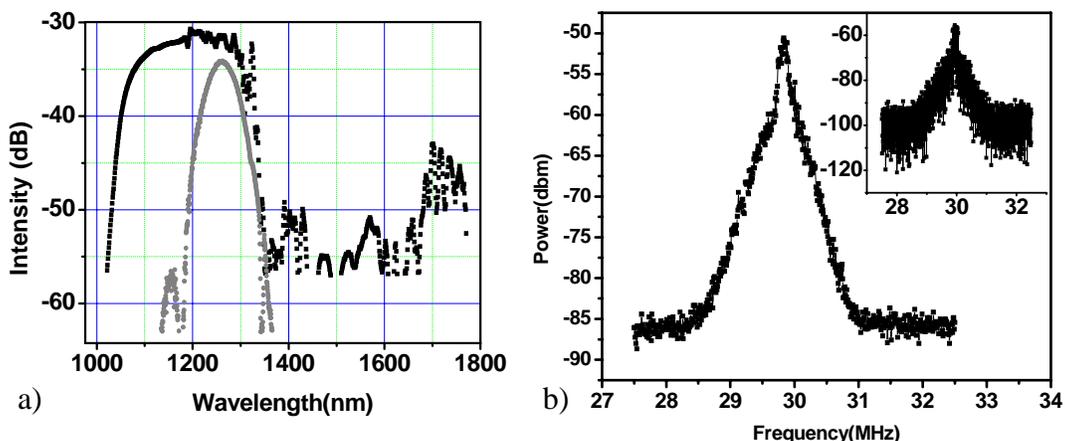Fig. 1. a) Laser cavity configuration. b) Servo control schematic used to lock f_r and f_0.

Fig. 2. a) Laser spectrum (grey) and supercontinuum spectrum (black). The spectrum does not show the significant optical power beyond 1.7 μm, where the OSA is no longer sensitive. b) f0 beat measured on rf spectrum analyzer with RBW of 30 kHz and a reduced video BW. Inset shows same signal, with Resolution BW = Video BW = 30 kHz. (inset). The narrow feature has a width of ~ 200 kHz, and the larger feature has a width of ~1.5 MHz.

Next, we plan to reference the synthesizers to a GPS-stabilized Rb clock. Then we plan to characterize the long-term stability of the acetylene-filled fiber-based references that we are currently developing [3]. Ultimately, such references may prove advantageous as a high-short-term stability reference for a portable optical frequency comb.

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