Stable femtosecond optical frequency comb at 1.3 μm using spectrally-tailored continuum from a nonlinear fiber grating

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In the past several years, the technological maturity of ultrafast lasers as well as supercontinuum generation in nonlinear optical fibers has revolutionized optical frequency metrology. One aspect of the frequency stabilization of a frequency comb is self-referencing, which often uses the octave-spanning supercontinuum from a nonlinear fiber to detect and stabilize the carrier-envelope offset frequency (f_0). Another aspect involves heterodyning specific modes of the comb with optical frequency references, hence, higher power at specific wavelengths in the supercontinuum is critical. Clearly, technologies that permit designed spectral enhancement on top of an octave-spanning supercontinuum would be very beneficial for optical frequency metrology. Frequency stabilized combs in the near-infrared region (1.3-1.5 μm) are important for the distribution of optical clock signals and low-jitter communication systems.

Here we demonstrate the use of tailored spectra from a nonlinear optical fiber that allow the robust generation of continuum at the specific wavelength important for experiments with the Ca optical frequency standard. The supercontinuum is generated with 1.2-nJ, 35-fs pulses centered at 1.3 μm from a 433-MHz Cr:forsterite laser that are injected into a ~2-m long piece of dispersion-flattened highly nonlinear optical fiber (HNLF) containing a fiber Bragg grating (i.e. a resonant structure with periodic modulations of the core refractive index). Such gratings have been shown to enhance the continuum near the Bragg resonance by more than 10× [1]. The grating had length ~3cm, Bragg resonance at 1310nm, and bandwidth of ~3nm. A significant spectral enhancement (~20 dB) at 1314 nm is observed in the HNLF containing the fiber grating, as shown in Fig. 1(a), compared to the HNLF without grating. At the same time, the f_0 beat is detected using the conventional f-to-$2f$ self-referencing technique and the signal-to-noise (S/N) ratio is >27 dB at 100 kHz resolution bandwidth (RBW). We use periodically-poled Lithium Niobate (PPLN) to frequency-double the spectral components of the supercontinua near 1314 nm from the HNLFs with and without a grating, and heterodyned them with the CW light from a stabilized diode laser at 657 nm. The beat signals with a stabilized CW light at 657 nm show ~24 dB enhancement for an HNLF that contains a fiber Bragg grating compared to an HNLF with no such grating [see Fig. 1(b) and 1(c)].

Thanks to this significant enhancement, we were able to synchronize the Cr:forsterite laser to a stable CW reference laser at ~456THz. The repetition rate of this optically-stabilized Cr:forsterite laser was then compared to that of a similarly-stabilized Ti:sapphire laser. The fractional frequency instability of the Cr:forsterite repetition rate relative to the Ti:sapphire laser is measured to be $\leq 3.5\times10^{-15}$ in 10-s averaging time and $\leq 2.7\times10^{-14}$ in 1-s averaging time, as characterized with the Allan deviation in Fig. 1(d).

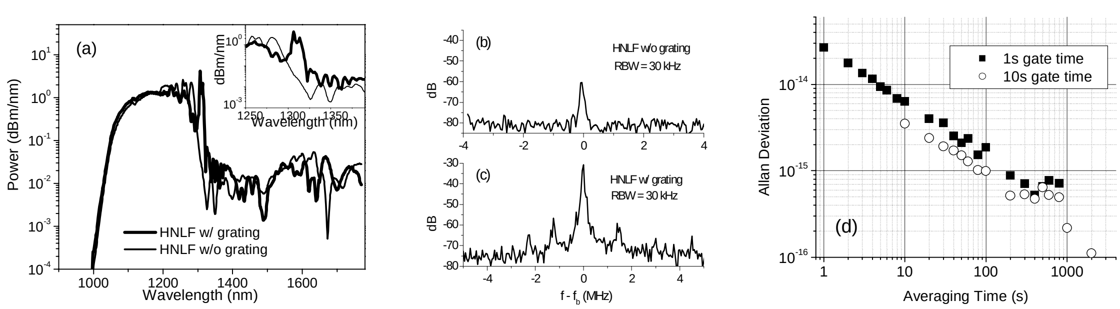

Fig. 1. (a) Supercontinua generated using a HNLF with and without a grating. The inset graph is the zoomed spectra around 1314 nm region. Beat notes observed between a CW laser at 657 nm and the frequency-doubled comb elements after a HNLF (b) without grating (S/N~20.5 dB) and (c) with grating (S/N~44.5 dB) at 30 kHz RBW. (d) The residual fractional frequency instability of the repetition rate as characterized with the Allan deviation.

References

P. S. Westbrook, J. W. Nicholson, K. S. Feder, Y. Li, and T. Brown, Appl. Phys. Lett. **85,** 4600 (2004).