AMPLIFIER DESIGN IMPLEMENTING HOLLOW-CORE PHOTONIC BANDGAP FIBER FOR FIBER-LASER BASED INFRARED FREQUENCY COMBS

KSU PHYSICS

JINGANG LIM, DANIEL V. NICKEL, BRIAN R. WASHBURN

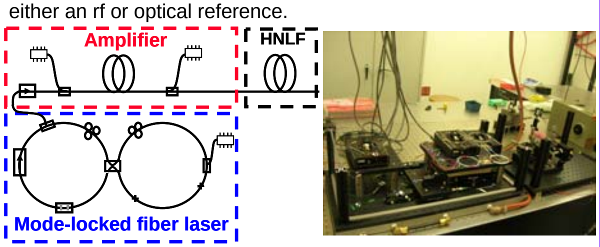
Department of Physics, Kansas State University, 116 Cardwell Hall Manhattan, KS 66503, USA

Abstract

Infrared frequency combs based on mode-locked erbium-doped fiber lasers typically require an external amplifier since the pulses directly from the laser have insufficient peak power to generate an octave-spanning supercontinuum for self-referencing. Here we implement a unique, all-fiber erbium-doped fiber amplifier that uses hollow-core photonic bandgap fiber for pulse compression. Through a combination of experiment and numerical simulations we have demonstrated temporal compression in the hollow-core photonic bandgap fiber, thus increasing the pulse's peak power.

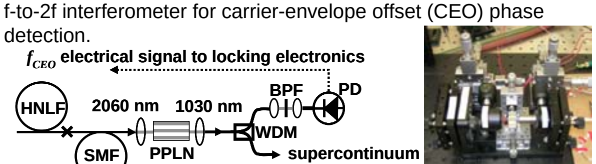
Fiber-laser based frequency comb

Mode-locked erbium-doped fiber lasers are the ideal source for a phase-stabilized infrared frequency comb since they offer many advantages compared to conventional solid-state system. All fiber-laser-based frequency combs consists of an octave spanning supercontinuum source that is phase-stabilized to either an rf or optical reference.



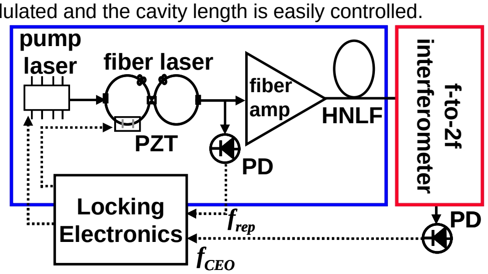
All-Fiber Supercontinuum Source

Fiber optic designs allow one to make a compact, fiber-based f-to-2f interferometer for carrier-envelope offset (CEO) phase detection.



Collinear f-to-2f interferometer

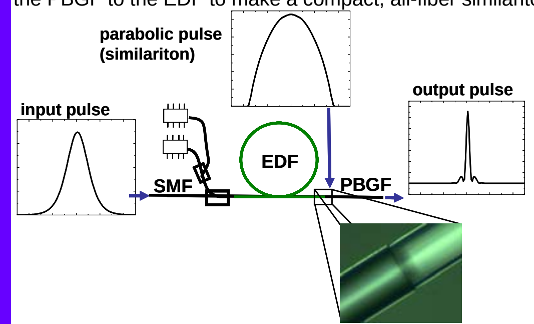
Phase stabilization of the fiber comb is more straightforward than for solid-state systems since the laser pump current can be directly modulated and the cavity length is easily controlled.



Phase-stabilized fiber frequency comb

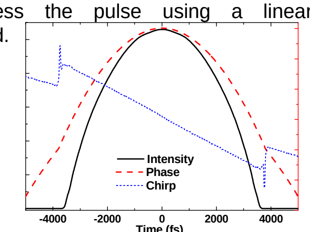
Amplifier Design using Similariton Compression in a Hollow-core Photonic Bandgap Fiber

One difficulty that fiber-laser based frequency combs have compared to their solid-state counterparts is that pulses directly from the laser do not have enough peak power to generate the octave bandwidth. External amplification is used to increase the pulse energy and decrease the pulse duration. Typically pulses can be temporally compressed by over 30% and experience larger than 10 dB gain using nonlinear solitonic compression in single mode fiber (SMF). Improvement to the amplifier can be used by generating similaritons in the positive dispersion erbium-doped fiber (EDF) section and then linearly compressing the similariton in a negative dispersion medium with a small nonlinearity. A hollow-core photonic bandgap fiber (PBGF) can serve as this medium. Fortunately, we can directly fusion splice the PBGF to the EDF to make a compact, all-fiber similariton amplifier.



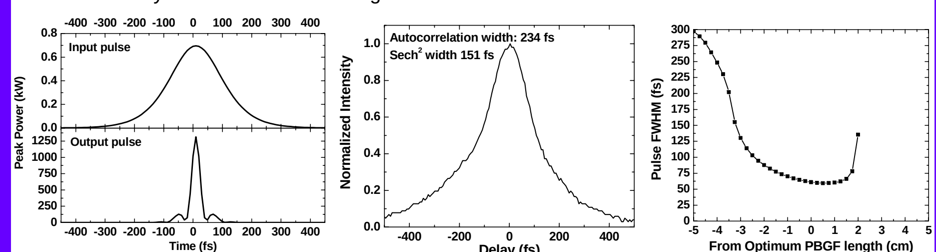
All-fiber similariton amplifier with directly spliced PBGF

How are the similaritons to be use for pulse compression and amplification? Similaritons have phase distortion is parabolic, thus pulse's frequency chirp, is completely linear. This allows one to compress the pulse using a linear method.



Numerical and Experimental Results

We have numerically modeled nonlinear pulse propagation by solving the nonlinear Schrödinger equation. The results show the amplification and temporal compression of 209 fs FWHM pulses from an erbium-doped figure-eight laser. The pulse propagates through 6 m of EDF and is compressed to 50 fs after 0.3 m of PBGF. The difficulty in experimentally obtaining the 50 fs pulses arises due to a technical inability to cut off millimeter lengths of the PBGF.



Numerical and experimental temporal compression from the amplifier

Future Directions

- More systematic study of the temporal compression versus PBGF lengths.
- Pre-chirping pulse before EDF to help improve the tolerance on the PBGF length
- Locking the fiber comb to a an acetylene-filled photonic bandgap fiber wavelength reference developed by Kristan Corwin at Kansas State University (see Poster #23).

References

B. R. Washburn, S. A. Diddams, N. R. Newbury, J. W. Nicholson, M. F. Yan, and C. G. Jørgensen, *Opt. Lett.* **29**, 250 (2004).
T. R. Schibili, K. Minoshima, F.-L. Hong, H. Inaba, A. Onae, H. Matsumoto, I. Hartl, and M. N. Fermann, *Opt. Lett.* **29**, 2467 (2004).
V. I. Kruglov, A. C. Peacock, J. D. Harvey, and J. M. Dudley, JOSAB, vol. 19, pp. 461-469, 2002.
R. Fox, B. R. Washburn, N. R. Newbury, and L. Hollberg, *App. Opt.* **44**, 7793 (2005).
R. Thapa, K. Knabe, K. L. Corwin, and B. R. Washburn, *Opt. Express* **14**, 9576 (2006).