Kagome fiber based nonlinear pulse compression of 1.8 ps to 250 fs at 2.05 μm from Ho:YLF amplifier

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Abstract: We present Ar-filled Kagome fiber based nonlinear pulse compression of 225 μJ, 1.8 ps pulses from a Ho:YLF amplifier to 285 fs at 125 μJ, supporting a FL duration of 250 fs at 2.05μm.
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1. Introduction

Recent advancements in high energy, ultrashort laser pulses in mid-IR (MIR) are of great importance in strong field physics and attosecond science experiments [1]. The state-of-the-art approach to generate long wavelength MIR pulses requires frequency conversion via optical parametric amplification (OPA). However, the exclusive use of near IR pumps at 800 nm and 1 μm has limited the accessibility to longer MIR wavelengths (> 5 μm). Long MIR wavelengths are accessible by non-oxide crystals like ZGP and OP-GaAs based OPA, that require pumping at 2 μm. Hence mJ-level, sub-ps pulses at 2 μm are preferred for driving MIR-OPAs and CEP stable idler. Sub-ps pulses beyond Fourier Limited (FL) duration can be generated using nonlinear spectral broadening phenomena via self-phase modulation (SPM) in fibers. In the last decade, major developments in hollow-core photonic crystal fibers (HC-PCF) have been achieved [2]. Inhibited Coupling (IC) Kagomé-lattice HC-PCF offers enlarged core diameter, low dispersion, broad transmission bandwidth [3] and high transmission efficiency in mJ-level [4]. Self-compression in fibers via soliton effect occurs due to interplay between positive chirp induced by SPM and negative chirp induced by second order group velocity dispersion (GVD). Transferring such a compression technique and ratio starting from energetic ps-longer pulses is still a pressing challenge. This is particularly true in the case of 2 μm laser systems for which fs-pulse generation is still under development. However, due to the low dispersion of these fibers (typically 1 ps/nm/km), ps-pulses experience hundreds of km long dispersion length in these fibers and hence external compression is the way forward to compensate for the chirp introduced by SPM. Here, we demonstrate for the first time spectral broadening of ps-long pulses in IC HC-PCF at 2 μm resulting in pulse compression down to 285 fs. The pulses are spectrally broadened to a foot-to-foot bandwidth of 88 nm that supports FL duration of 250 fs.

2. Experiment and Results

The experimental setup for nonlinear compression is shown in Fig. 1. The laser system comprises of a conventional chirped-pulse amplifier based on a home-built Ho-doped fiber oscillator and a prototype Ho:YLF regenerative amplifier (RA) followed by a single pass booster amplifier (SPA) (Q-Peak Inc.). CVBGs are used to stretch and compress the pulses. A frequency-selective filter, an etalon of thickness 250 mm and a surface reflectivity of 3.3 % is used to counteract the effect of gain narrowing and broadens the output spectrum by ~ 50 %. The RA output is subsequently amplified in SPA to 1 mJ with output pulse durations of 1.8 ps. The complete details of the system can be found in Ref [5]. For spectral broadening a 7-cell IC Kagome HC-PCF, fabricated using the stack-and-draw technique, is used. The fiber is designed to operate at 2-μm wavelength whose hollow-core and outer diameter is 63 μm and 350 μm respectively having a mode field diameter of 44 μm and a numerical aperture of 0.014. The experimental layout is shown in Fig. 1(a). The laser beam is focused into a 3 m long 7-cell IC Kagome HC-PCF using a focusing lens of 50 mm. The fiber output is end capped into a gas cell, which maintains an Ar-gas pressure of 5 bar. Here Ar-gas acts that as the nonlinear medium, causes spectral broadening, which can be controlled by tuning the gas pressure. The gas pressure is chosen to maximize broadening while maintaining a decent output spectrum, i.e. it does not lead to pulse splitting or causes pronounced wings in the temporal profile.

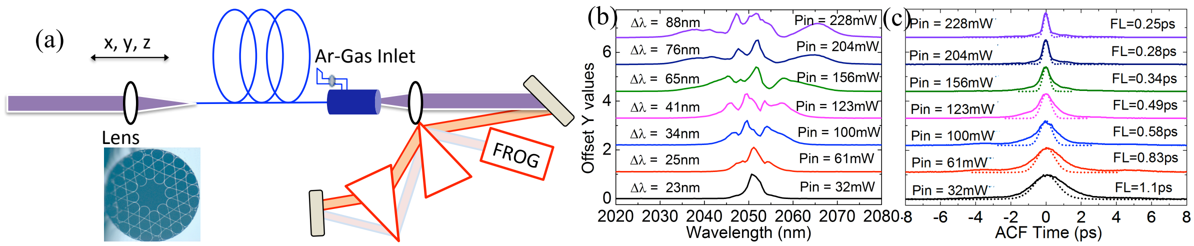

Fig. 1. (a) Experimental layout (b) Spectral Evolution (c) Temporal evolution with increasing input energy

The input energy is varied from 32 μJ to 228 μJ and the spectral evolution is shown in Fig. 1(b). Maximum broadening of 88 nm (foot-to-foot) is obtained with an input energy of 228 μJ. To compensate for the positive chirp introduced by SPM, the pulses are then compressed using a pair of 1-inch uncoated Brewster-cut silicon prisms whose tip-to-tip distance is 1.1 mts corresponding to a negative group delay dispersion value of -16200 fs^2. The corresponding measured autocorrelation traces (solid) and calculated Fourier transforms (FT) (dotted) after the prism compressor are shown in Fig. 1(c). It can be seen, that at an incident energy of 228 μJ, the measured autocorrelation trace matches quite well with that of the calculated FT thereby suggesting that the chirp compensation from the prism compressor has been effectively achieved with very little amount of remaining chirp. To further characterize the phase associated with the pulse and to determine the temporal profile, a home-built SHG-FROG is used whose results are shown in Fig. 2. Fig. 2(a) and (b) show the measured and retrieved FROG traces that looks similar. The retrieved (black) and the independently measured (red) spectrum shown in Fig. 2(c) also matches quite well which suggests reliable FROG reconstruction that has FROG convergence error of 0.2 %. The blue coded curves show the retrieved spectral phase. The retrieved temporal profile (black) of the pulse is shown in Fig. 2(d) with the calculated FT (dotted red trace) of the spectrum and the retrieved temporal phase is shown in blue, which is smooth and flat suggesting the possibility to easily compress to FL duration. The retrieved pulse duration is 285 fs while the FL duration is 250 fs. With around 45% energy lost in the fiber and the prism compressor, the output energy of the compressed pulse is 125 μJ. In the inset of Fig. 2(d) the output beam profile in near field is shown as observed by a CCD camera; the shape is elliptic with diameters is 2.73 and 3 mm.

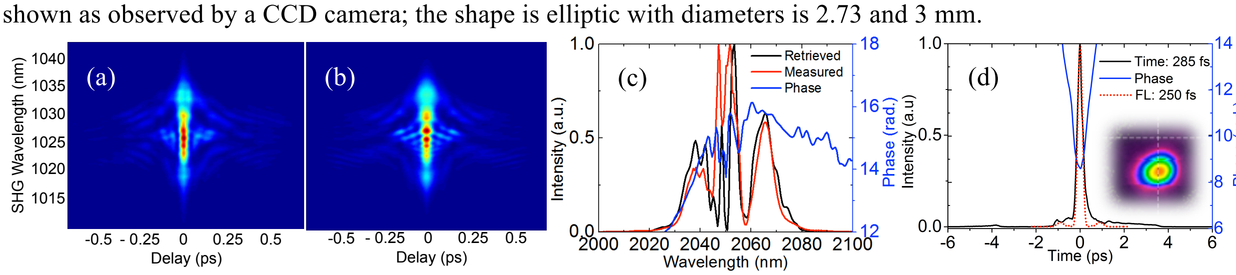

Fig. 2. (a) Measured (b) Retrieved FROG traces (c) Measured (red) and retrieved (black) spectra with spectral phase (blue) at the output of 7-cell fibre in presence of Ar-gas of 5 bar and incident energy of 225 μJ (d) Retrieved (black) and calculated FL (red dotted) temporal profile with temporal phase (blue)

3. Conclusion

We demonstrate nonlinear spectral broadening of 2 μm, 1.8 ps-long pulses in gas filled IC Kagome-type HC-PCFs to a FL duration of 250 fs. The pulses are externally compressed to 285 fs with 125 μJ energy using a prism compressor. As an outlook, the output pulses can be used to produce a white light seed for an MIR OPA and the remaining energy from the Ho:YLF amplifier can be used for pumping. Pumping and seeding the OPA from the same laser pulse offers a carrier-envelope-phase stable MIR idler.

4. References

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