High-energy, 34 fs, fiber source via nonlinear compression in hypocycloid-core Kagome fiber

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Abstract: We report on the generation of 34 fs and 50 µJ pulses from a high energy fiber amplifier system with nonlinear compression in an air-filled hypocycloid-core Kagome fiber. The unique properties of such fibers allow to bridge the gap between solid core fibers-based and hollow capillaries-based post-compression setups, thereby operating with pulse energies obtained with current state-of-the-art fiber systems. The overall transmission of the compression setup is over 70%. Together with Yb-doped fiber amplifier technologies, Kagome fibers therefore appear as a promising tool for efficient generation of pulses with durations below 50 fs, energies ranging from 10 to several hundreds of µJ, and high average powers.

OCIS codes: (060.5295) Photonic crystal fibers, (140.3510) Lasers, fiber, (320.5520) Pulse compression, (320.7090) Ultrafast lasers, (320.7110) Ultrafast nonlinear optic.

1. Introduction

The generation of energetic and ultrashort pulses is usually limited by the available gain bandwidth of ultrashort amplifiers. In the case of Ytterbium-doped fiber amplifiers, the typical available bandwidth is of the order of 40 nm, limiting the pulse duration of high-energy fiber chirped-pulse amplifiers (FCPA) around 300 fs [1]. In order to decrease this pulsewidth well below 100 fs, e. g. to drive high-field physics experiments, or match material processing requirements, post-compression techniques are required. These techniques consist in nonlinearly broadening the spectrum of incident laser pulses mainly via self-phase modulation [2]. Suppression of the induced spectral chirp produced by the nonlinear interaction in the medium with appropriate dispersive elements then leads to pulse shortening. The nonlinear interaction is usually carried out in a waveguide to allow a strong confinement of the electric field over a long distance while maintaining a good spatial profile of the output beam. For the range of parameters usually available from state of the art FCPA, nonlinear compression is either performed in a silica solid-core fiber with energy limited by the self-focusing threshold (up to the µJ level [2]) or in gas-filled hollow core capillaries for higher input energy (up to several mJ), following a technique routinely used for Titanium-doped Sapphire (Ti:Sa) CPA systems [3]. In the latter case, the low output energy ($10< E < 500$ µJ) of FCPAs compared to bulk Ti:Sa systems necessitates longer interaction lengths, higher gas pressures, and lower diameters. This significantly increases the complexity and decreases the transmission of capillary-based nonlinear compression setups to 50% or less. There is therefore a clear lack of waveguide that could support efficient spectral broadening in a straightforward arrangement of high repetition rate sources with energy levels typically ranging from tens to hundreds of µJ.

The recent development of hypocycloid-core Kagome (HCK) fibers [4] is a promising way to bridge this gap of energy range for nonlinear compression setups between solid core fibers and gas-filled capillaries. Indeed, in such structure the solid silica core is replaced by a hollow-core satisfying the guiding condition through the so-called inhibited coupling allowing guiding for large core diameters in a large spectral range. This inhibited coupling mechanism, together with hypocycloid-core shape, characterized by negative curvature silica bridges along the core contour, allow an important decrease of the overlap integral between the intense guided mode and the surrounding silica structure. This ensures low propagation losses and dramatically reduced fiber damage threshold. A recent experimental effort to use such fibers in a standard nonlinear compression setup has allowed for the demonstration operation at a moderate energy level of 1.1 µJ. Another recent report focuses on self-compression of 500 µJ pulses in the anomalous dispersion regime [4]. In this case, the compression relies on high-order soliton propagation regimes, making the system less controllable than a standard compression setup. Both experiments have been performed with noble gas-filled fibers, which imply an increased complexity compared to air-filled structure at atmospheric pressure.

In this letter, we report on the use of an HCK fiber-based standard nonlinear compression setup to compress 330 fs 70 µJ input pulses down to 34 fs and 50 µJ. This result is achieved by exploiting self-phase modulation occurring in a 1.2 m long air-filled hypocycloid-core Kagome fiber, with high overall efficiency of more than 70%. The unique combination of waveguide properties and geometrical dimensions of these fibers make them the ideal structure to achieve nonlinear post-compression at the output of high-energy FCPAs with excellent overall transmission efficiency. The air-filled configuration allows a simple, compact and robust setup.

2. Experimental setup and results

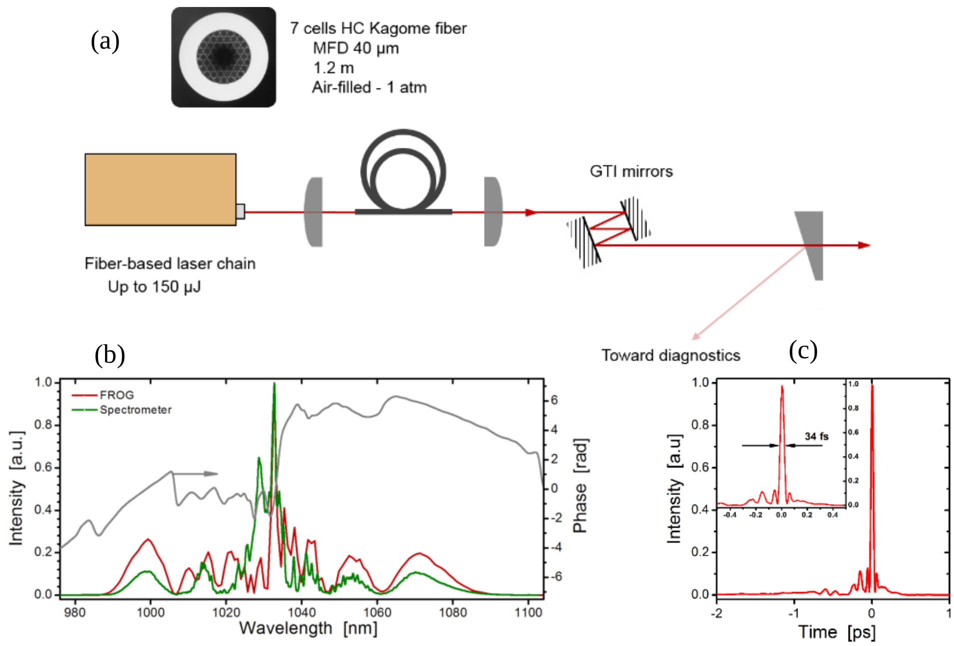

Fig. 1. (a) Experimental setup of the nonlinear compression experiment. Insert: Section of the 40 µm MFD hypocycloid core Kagome fiber used in our experiment. (b) Experimental and retrieved spectra at maximum output energy. (c) 34 fs output temporal profile at 50 µJ.

The experimental setup is depicted in Fig. 1(a) and starts with a FCPA that can generate 330 fs 150 µJ pulses at 50 kHz. Output pulses are first spectrally broadened into a 1.2 m-long air-filled 7-cell hypocycloid Kagome hollow-core fiber (see *Fig 1(a)*), with a mode field diameter of *40* µm. Here, the important peak power available from the FCPA source and the strong confinement induced by the hollow-core fiber lead to a high intensity pulse propagating in the waveguide. This high intensity is sufficient to induce nonlinear spectral broadening, even for a low nonlinear index gas such as air. The input energy in the Kagome fiber is gradually increased and the negative dispersion introduced by the compressor simultaneously optimized to provide the shortest pulses with best temporal quality. Best results are obtained for an output energy of 50 µJ and total compressor GVD of -2100 fs². In this configuration the compressor efficiency is 93%. .Finally, a wedged window is used to sample the beam for output spatial and temporal characterizations. Temporal characterizations of the output pulse at 50 µJ of energy are carried out with a second harmonic generation frequency-resolved optical gating (SHG-FROG) device together with independent spectrum measurement. Results are plotted in Fig. 1(b, c). The spectral width measured at -10 dB is 90 nm. In the time domain, the retrieved 34 fs FWHM temporal profile is shown in Fig. 1(c).

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