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μ J-level normal dispersion fiber optical parametric chirped-pulse oscillator based on a collapsed-ends photonic crystal fiber

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Abstract. We demonstrate the generation of broadband tunable and synchronized pulses exceeding the microjoule level using the new concept of fiber optical parametric chirped-pulse oscillation (FOPCPO). The oscillator is based on a collapsed-ends photonic crystal fiber pumped in the normal dispersion regime by a fiber laser.

1 Introduction

Optical parametric amplifiers and oscillators delivering ultrashort pulses are a well-established technology that allowed considerable progresses in many research and industrial applications [1]. Multi-mJ energies and few-cycles pulse durations are now reached using solid-state optical parametric sources but their complexity, cost, and alignment sensitivity hinder their use outside the laboratory environment.

In the last years, significant advances have been made in their fiber-based counterparts which rely on degenerate four-wave mixing (DFWM - third-order nonlinearity of silica). Nonlinear wavelength conversion of ultrashort pulses has then been obtained with a variety of fiber systems. In particular, using the concept of fiber optical parametric chirped-pulse amplification (FOPCPA) [2-5] has allowed to overcome the saturation of the nonlinear process and the μ J level has been obtained, but either using complex optical fiber designs or using Raman assistance. However, such systems operate in the anomalous group velocity dispersion of the fiber which limits the parametric sidebands near the pump wavelength. FOPCPA pumped in the normal dispersion regime and delivering sub-picosecond pulse with wide wavelength separations have been reported but are still limited in terms of tunability as they require a seed source [6-7].

A way to circumvent this limitation is to use a resonant fiber optical parametric oscillator (FOPO) where the dispersion map can be tailored. High energy levels and ultrashort pulses – along with excellent signal-to-noise ratios - have then been obtained in FOPOs combining DFWM in photonic crystal fibers (PCF) with pumping in the normal dispersion regime [8,9]. Further energy scaling is however quite limited due to high peak powers.

In order to get around this latter limitation, a natural idea is then to combine FOPCPAs capabilities in terms of energy by using chirped pulses with FOPOs' flexibility and wavelength tunability. Such a concept – termed FOPCPO - was first investigated numerically and showed great potential for bandwidth control of parametric waves [10]. We then demonstrated experimentally the feasibility of this concept by generating broadly-tunable highly-chirped pulses with energies exceeding 200 nJ in such a FOPCPO [11]. We now confirm this idea and report on the generation of broadband signal and idler waves exceeding the μ J level in a FOPCPO pumped in the normal dispersion regime by a fiber laser.

2 FOPCPO: experimental setup

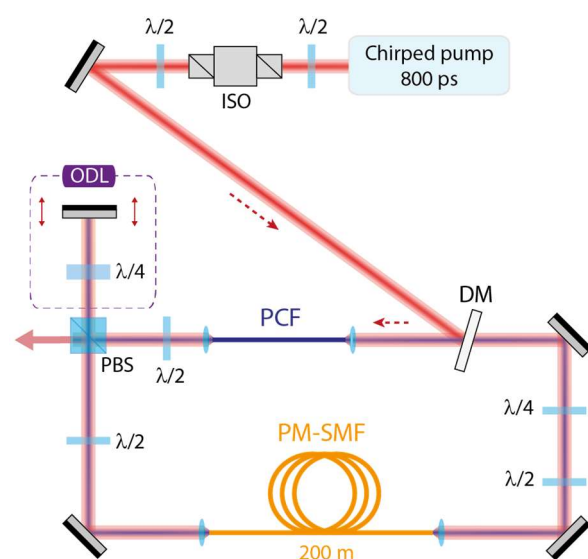


Fig. 1. Experimental setup of the FOPCPO cavity. (ISO: optical isolator; ODL: Optical Delay Line; DM: Dichroic Mirror; PBS: Polarizing Beam Splitter; PM-SMF: Polarization Maintaining Single-Mode Fiber; PCF: Photonic Crystal Fiber).

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Our FOPCPO cavity is detailed in Fig. 1. It comprises an 8 cm long photonic crystal fiber (commercially available SUP5-125, product line Perfos®) with a 5 μm core and a zero-dispersion wavelength at 1055 nm. In order to support high peak powers while keeping good coupling efficiency and beam quality, the end facets of the PCF have been collapsed. It is pumped in the normal dispersion regime by an ytterbium fiber laser (Active Fiber Systems GmbH) delivering highly-chirped pulses (800 ps) at 1032 nm with 15 W average power at a 1 MHz repetition rate. An optical delay line (ODL) comprising a 200 m long polarization maintaining fiber and a free-space section is used to make the signal wave resonant with pump pulses and to adjust the signal and idler wavelengths via time-dispersion tuning.

3 Results and prospects

The FOPCPO generates linearly-chirped 350 ps pulses whose energy scales as depicted in Fig. 2. With appropriate feedback, we obtain signal and idler pulses with energies reaching 1.5 μJ together with broad spectra and signal-to-noise ratios exceeding 80 dB (*NB*: these measurements have been taken through an unoptimized filtering system inducing losses).

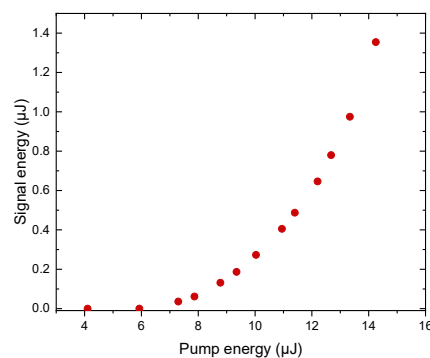


Fig. 2. FOPCPO's energy scalability.

Due to the normal dispersion pumping, using time-dispersion tuning (i.e. varying the cavity length with the ODL) allowed to finely adjust the signal and idler wavelength on a broad wavelength range, as shown in Fig. 3.

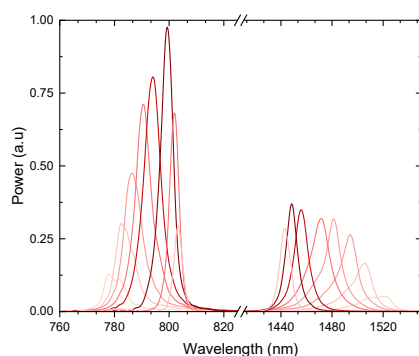


Fig. 3. FOPCPO's tunability.

A tunability of 30 nm is obtained for the signal while it reaches 70 nm for the idler, together with relatively large bandwidths ($>10\text{nm}$).

These preliminary results confirm the remarkable potential of combining normal dispersion fiber optical parametric oscillation with chirped pulse pumping to generate multi- μJ tunable and synchronized pulses. These features would then make FOPCPOs prominent sources for applications such as coherent Raman scattering or multiphoton imaging [12,13]. Extra details about our system's performances and pulse compression will be given during the conference.

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