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Dispersion Engineered Tapered Photonic Crystal Fiber for Broadband and Tuned 2 μm Emission Using Degenerate Four-wave Mixing

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Abstract: We numerically demonstrate a broadband parametric gain around 2 μm using a tapered Photonic crystal fiber.

Myriads of mid-infrared (IR) applications require broadband ultra-short pulses often combined with a wide spectral tunability. There are few efficient solid-state laser (SSL) materials emitting in this spectral range (typically doped with Tm^{3+} , Ho^{3+} , Cr^{2+} , and Er^{3+}). However, their efficiency rapidly decreases as the emission wavelength increases [1], and except Tm - or Cr -doped matrices, these active materials cannot support ultra-short pulses with duration <50 fs. Even the most advanced sources offer only limited or no tunability. To circumvent these limitations, intense pulses at ~ 2 μm are obtained by either difference frequency generation (DFG), parametric down-conversion and amplification, or degenerate four-wave mixing (d-FWM) from conventional IR lasers such as Ti:Sapphire based systems or rare-earth doped lasers as they provide sufficient intensity to drive these non-linear processes. Furthermore, broadband and large tuning ranges are accessible with dispersion engineered fibers, even with a single pump, and the spanning of the phase-matching curve depends on the peculiar dispersion properties. Highly nonlinear photonic crystal fiber (HNL-PCF) exhibits numerous advantages for this purpose while they afford large flexibility in their design and the related chromatic dispersion properties. In this paper we will particularly focus on the specific case of broadband and large tuning ranges using d-FWM in optical fibers as it emerges as the most appropriate effect for the efficient conversion of near-IR intense Yb -based laser sources with high average power towards widely tunable short and intense pulses in the mid-IR.

Here we present a numerical study dealing with the spectral broadening of the parametric gain around 2 μm using a home-made tapered photonic crystal fiber (PCF). Our aim is to further investigate d-FWM in order to extend the exploitable range of parametric gain over a spectral width of 200 nm, 5 times larger than the broadening which can be reached with an untapered PCF. To do so, a tapered fiber based on a small variations applied on the diameter (Fig. 1) of the untapered PCF is numerically investigated by solving the generalized non-linear Schrodinger equation (GNLSE) [3]. The idea is to longitudinally change the dispersion properties seen by the pump wave length (1.03 μm) and then progressively shift the tuned signal wavelength. Therefore, we will accordingly cover a wide spectral range around 2 μm . Indeed, the tapered fiber considered here relies on a concatenation of four fibers of length 20 cm (F1, F2, F3 and F4) with different diameter, as shown in Fig.1. The dispersion properties of each fiber were calculated separately using the parameters summarized in Table 1. Fig. 2 shows the numerical results from solving the GNLSE for each of the fibers and the tapered fiber.

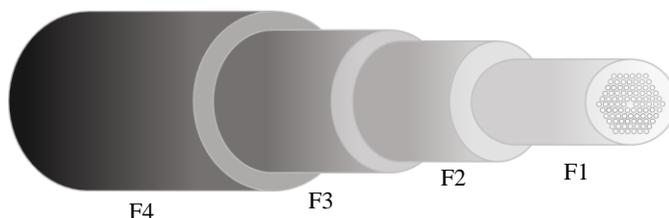


Fig. 1. Schematic representation of the modeled geometric parameters' variation along the tapered PCF.

Table 1. Parameters used in the calculation. d_{hole} and Λ denote the hole diameter and the Pitch of the untapered PCF.

Fiber	F1	F2	F3	F4
Λ (μm)	4.75	$4.75*(1+0.5\%)$	$4.75*(1+1\%)$	$4.75*(1+1.5\%)$
d_{hole}/Λ	0.67	0.67	0.67	0.67

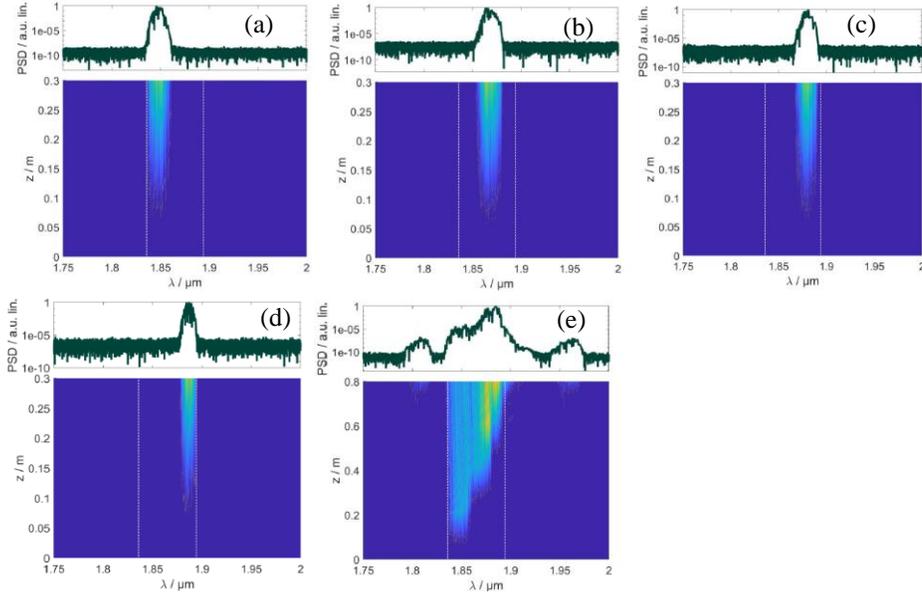


Fig. 2. Results from numerical simulations showing spectral evolution of the signal generated by d-FWM in (a) F1: untapered PCF (b) F2: untapered PCF (c) F3: untapered PCF (d) F4: untapered PCF and (e) tapered PCF. The input pulse at 1.03 μm has 44 kW peak power and 50 ps full width at half maximum (FWHM) with a repetition rate of 10 MHz.

We have performed taper models from the effective indices and effective areas calculated using the finite element method. We first calculated the signal generated around 1800 nm with each of the four fibers F1, F2, F3 and F4. We can see from the Fig. 2 (a, b, c, d, and e) that the central wavelengths of the generated signal are slightly shifted from each other, and increase with the increase of the diameter. Then, we simulated a taper in steps, each step consisting of a single fiber of constant diameter. By including the four fibers, of 20 cm each, the generated signal covers the entire variation obtained for the fibers taken separately, so allowing to widen the spectrum of the signal obtained around 2 μm . From practical point of view and in order to experimentally validate the theoretical results, 14 m length of the taper have been fabricated according to the profile shown in Fig. 3 and is being experimentally tested. The experimentally results will be shown during the conference.

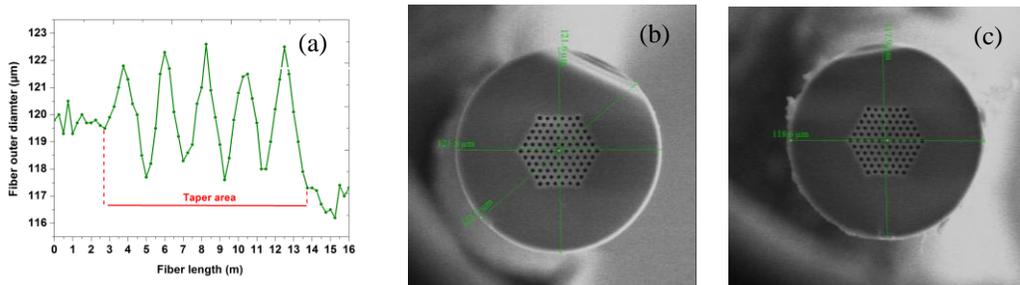


Fig. 3. (a) Outer diameter along the tapered PCF. MEB of taper cross section (c) biggest core end, (d) smallest core end.

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