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Super Continuum Generation at 800 nm in Highly Nonlinear Photonic Crystal Fibers with Normal Dispersion

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Introduction

Formation of broad spectra through propagation of short femtosecond-range high power pulses through nonlinear media (also known as super continuum generation, SCG) is a well known phenomena, but have recently attracted much attention with the emergence of highly nonlinear small-core photonic crystal fibers (PCFs), the theory of which is extensively described in the literature [1,2]. PCFs are attractive for study of nonlinear effects, as they can be designed to have very small effective areas, increasing the nonlinear effects. Furthermore, their dispersion properties can be designed to be very different from the dispersion in standard single mode fibers (SMFs) – e.g. to exhibit zero dispersion in the visible wavelength range, a freedom only available in PCFs. Applications of SCG cover such diverse fields as spectroscopy, sensor applications and telecommunication WDM sources.

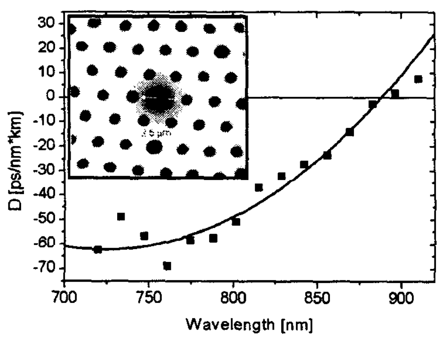

Fig. 1 *The PCF has zero dispersion at ~875 nm and D = -50 ps/km·nm at 800 nm. The insert shows the fiber structure with mode at 635 nm. The core of the fiber is 2.5 μm.*

In most previous SCG experiments, PCFs have been pumped in the anomalous dispersion regime or at the zero-dispersion wavelength in both the visible [3,4] and the infrared [5] wavelength range. In anomalous dispersion regime a multipla of nonlinear effect results in an ultra broad SC covering several hundred nm. However, the complex interplay of the many nonlinear effects present in the anomalous dispersion regime can result in instability of the SC. This instability is partly linked to the presence of solitons [6]. Furthermore, the complexity of the SCG in the anomalous dispersion regime makes it difficult to get a full understanding of the different features of the SC – an understanding crucial in the pursuit for more efficient fiber designs. SCG in tapered standard fiber have also been demonstrated, exhibiting similar results [7,8].

Simplicity and stability is a major issue for many applications of SCG, and we therefore, for the first time to our knowledge, present results from a PCF, pumped in the normal dispersion regime. The PCF is from Crystal Fiber, has a normal dispersion at 800nm of –50 ps/km·nm and zero dispersion at 875 nm. In figure 1, the dispersion of the fiber is shown along with the fiber structure and optical mode.

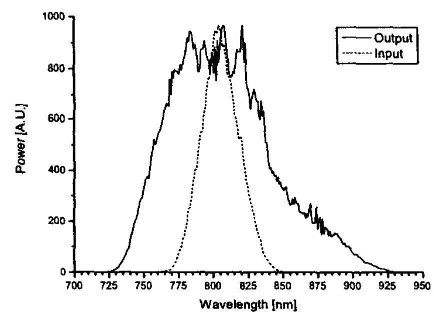

Fig. 2 *In- and output spectrum measured on 12.5 cm fiber. The coupled average pumping power is 53 mW and the pulse length is 25 fs.*

Results

The fiber is pumped at 800 nm with a mode locked Coherent Mira 900 Ti:Sapphire laser producing 30 nm broad 25 fs pulses with a repetition rate of 76 MHz, coupled in and out of the fiber with standard microscope objectives, the dispersion in which is compensated with a prism compressor. A maximum coupling efficiency of 30-40% is readily obtained. The in- and output is shown in figure 2 in case of 53 mW coupled average pumping power. The output spectrum features a self-phase modulation (SPM) induced three times broadening of the input pulse. The output spectrum is asymmetric with a lower slope on the high wavelength side, which is due to the drastic dispersion decrease in this wavelength region. There was observed no noticeable difference in the spectrum for pumping in different polarizations, indicating a negli-

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gible influence from birefringence. No spectral components induced by other nonlinear processes were observed outside the main peak in the wavelength range 400-1600 nm. This makes the output pulses suitable for subsequent compression with the prospect of generating sub 10 fs pulses. Furthermore, the output was very stable and the spectral shape was insensitive to fluctuations in pumping power.

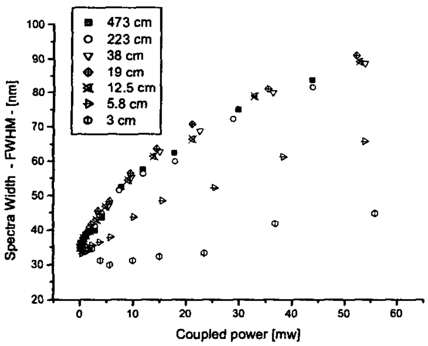

Fig. 3 *Spectral width of the output as a function of pumping power. Pumping pulse length is 25 fs.*

The full-width-half-max (FWHM) width of the best-fitted gaussian peak of the output spectrum is mapped as a function of fiber length and input power in figure 3. The spectral width of the output pulses is found to be constant for fiber length above 12.5 cm, below which the output narrows. The fact that longer fibers do not result in larger broadening is a result of the relative large dispersion at 800 nm. The dispersion length, L_D, of the fiber is 3.5 cm, resulting in a peak power reduction of a factor of four after 14 cm of propagation. Broader pulses at same pumping power can be obtained by designing the fiber with lower normal dispersion, thereby increasing the length over which the peak power is sufficiently high. The nonlinear length, L_{NL}, of the fiber at maximum pumping power is ~1mm.

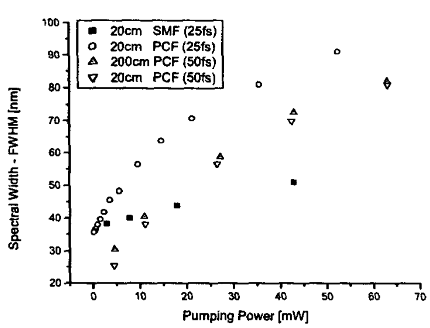

Fig. 4 *Comparison between the spectral width of the output from a SMF and a PCF at 25 fs pumping pulses. Shown also are spectral widths from the PCF pumped with 50 fs pulses.*

Analogous experiments with 50 fs pulses have shown results very similar to the ones for 25 fs pumping. The output spectrum is ~10% narrower, resulting in a relative broadening of a factor of five, compared to the factor of three observed for the shorter pulses. These results are shown in figure 4.

SPM is also observed in standard SMFs, but the effect is roughly three times weaker due to the larger effective area and larger dispersion in these fibers. In figure 4, the width of the output spectrum as function of pumping power is shown for both the PCF and a standard fiber single-moded at 800nm. Both fibers are 20 cm long.

Conclusion

More than 90 nm broad SPM induced pulses have been created from both 25 and 50 fs pulses in just 12.5 cm of fiber. The broadening is more than 2.5 times that observed in standard SMF. SPM broadening in PCFs has several advantages over more complex SCG effects in fibers with zero or positive dispersion at the pumping wavelength. The output is very stable, there is no loss of power to unwanted wavelengths and the spectral shape is relatively insensitive to fluctuations in pumping power. This also makes the output suitable for subsequent compression, for 10 fs-range pulse generation. By shifting the zero-dispersion and pumping wavelength to the telecom range, WDM sources become a potential application.

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