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Picosecond supercontinuum generation with back seeding of different spectral parts

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Abstract

We study supercontinuum generation with picosecond pumping and the spectrum obtained when coupling back the part of the output around 1200-1700 nanometres or the part around 700-900 nanometres with a variable time delay.

Introduction

A decade has passed since the introduction of photonic crystal fibres (PCFs), which made it possible to produce a supercontinuum (SC) with relatively low peak power. In this time, there has been great activity in research related to SC generation. The basic processes that generate and limit the SC are now mostly understood and focus has shifted toward specializing the SC toward particular applications such as fluorescence microscopy [1] or optical coherence tomography (OCT) [2, 3].

The focus of SC research has now shifted to how the generated spectrum can be controlled and tailored to fit particular applications. One branch of this research centres on how one can produce tuneable peaks in the SC. The most successful solutions to this problem to date have been based on utilizing gratings for phase matching control [4, 5] or peak generation by four-wave mixing (FWM) [6, 7].

Here we demonstrate a new method by which a tuneable peak can be produced in an SC spectrum. In order to produce this peak we feed back part of the SC and time match it with the pump pulses. The interaction between the pump pulse and the part of the output which has been fed back greatly changes the output spectrum as can be seen in fig. 1.

Experimental setup

The SC was generated in 4 m of 1050-Zero-2 fibre, commercially available from Crystal Fibre A/S. A diagram of the measurement setup can be seen in fig. 2.

The SC was pumped at 1064 nm with 13.4 ps pulses with a pulse repetition frequency of 70 MHz and an average power of 120 mW. The pump system was based on a custom made polarisation-maintaining modelocked ytterbium doped fibre laser. The laser was amplified in 2 amplifiers based on ytterbium doped single mode fibre and finally in a double clad high-power amplifier.

The output from the amplifier had a random polarisation which was converted to linear polarization using a λ/4 and λ/2 waveplate before being passed through a linearly polarised free space isolator. Beyond the isolator, the orientation of the pump polarisation relative to the fibre structure is controlled using another λ/2 waveplate. The light is coupled into the PCF with a coupling efficiency of 50% using an achromatic lens.

The output spectrum of the PCF is sampled using a 10% beam splitter whose reflection is collected by a fibre and analyzed using an optical spectrum analyser (OSA).

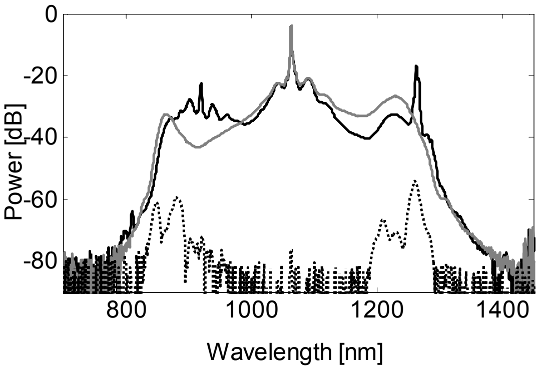

Fig. 1. Spectrum of the supercontinuum without (gray solid) and with (black solid) feedback and the feedback itself (black dotted).

In order to produce a feedback effect, the PCF is mounted between two mirrors as in a Fabry-Perot cavity. Mirror 6 (see fig. 2) is a spectrally flat silver mirror while the reflection spectrum of mirror 10 is used to control which part of the spectrum is fed back. The reflection shown in fig. 1 is the reflection present when a mirror with high reflectance at 1200-1700 nm is used. The multi-peaked structure of the feedback spectrum in the area 1200-1300 nm is due to ripples in the transmission of the 45° 1064 nm (pump wavelength) mirrors. The light in the 850-950 nm region is reflected because the 1200-1700 nm mirror does not have an anti reflex coating for these wavelengths.

The length of the Fabry-Perot cavity is adjusted so that its round trip time exactly matches a whole number of periods of the pump pulse train. The light which is fed back will therefore enter the input of the PCF together with the pump pulse so that they can interact as they propagate through the PCF.

Results

As can be seen in fig. 1, the addition of feedback greatly modifies the spectrum of the generated SC.

The strong peak generated at 1270 nm, when feedback is present, corresponds to the strongest peak in the

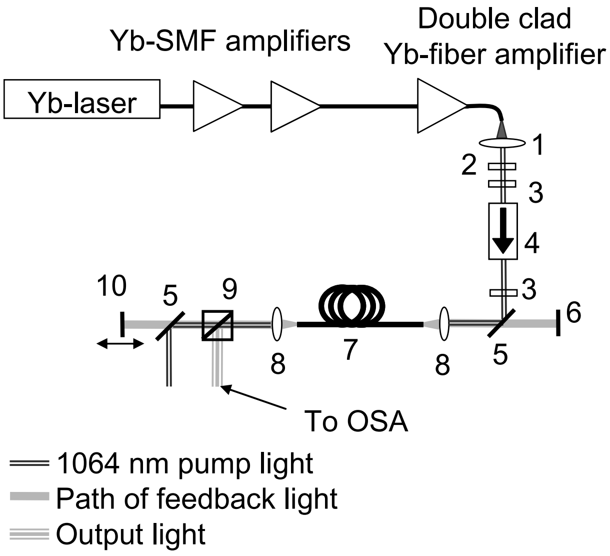

Fig. 2. Measurement setup. 1 Lens f=4.5 mm, 2 $\lambda/4$ waveplate, 3 $\lambda/2$ waveplate, 4 Optical isolator, 5 1064 nm 45°mirror, 6 Ag mirror, 7 PCF-fibre, 8 Achromatic lens with f=4.5 mm, 9 Beam splitter, and 10 control mirror

feedback. This indicates that the position of the peak is controlled by the feedback mirror and thus that it can be tuned by tuning the spectrum of the feedback. The sum of the frequencies of the 1270 nm and the 924 nm peaks is just 0.5 % less than twice the frequency of the pump. This indicates that the peaks could be created by a parametric gain process with the pump, as their frequencies live up to the requirement of energy conservation through such processes. The two smaller peaks at 903 and 938 nm similarly fit with FWM between the 1270 nm peak, the pump and the pump side peaks at 1035 and 1095 nm.

Fibres similar to the one used here have previously [8] been shown to have two pairs of FWM phase matching wavelengths. The exact position of the pairs of matching wavelength is very sensitive to the variations in the dispersion curve caused by small variations in the fibre, created during the drawing process. However, these two pairs of FWM matching wavelengths could correspond to the peaks at 1035 and 1095 nm and the peaks at 923 and 1270 nm respectively.

The feedback was tested using a control mirror with high reflection at 1200-1700 nm. It mainly fed back the long wavelength light, as can be seen in fig. 1. We also tested the system using a mirror with a broad reflection centred at 870 nm. This mirror mainly fed back the short wavelength part of the spectrum, but this did not increase the amount of light generated at the short wavelengths in the output SC. Instead, both the peak at 1270 nm and the peaks around 900 nm were reduced.

This shows that the peak generation process is only dependent on light being fed back at the long wavelengths and that strengthening of the spectrum at 850-950 nm can only take place when the pump can create FWM with light at 1270 nm.

Additionally, we investigated the effect of varying the delay of the feedback light and found that the strong peak at 1270 nm disappeared if the delay was changed more than +/- 2 ps. This shows that the generation of the strong peak is dependent on good time matching with the feedback light.

Conclusions

We have demonstrated a new method which can be used to modify the output spectrum of an SC source significantly. It can both be used to amplify the spectrum by 18 dB in a narrow region, e.g. at 1270 nm in fig. 1, and to produce an increase in a wide region of over 100 nm, e.g. in the 850-950nm region on fig. 1. This means that time matched spectral feedback is a very powerful method for modifying an SC spectrum.

The position of the strongest peak generated in the output corresponds to the wavelength of the strongest feedback and this indicates that the position of the peak can be changed by controlling which wavelength is fed back into the PCF.

This effect has been shown experimentally using long picosecond pulses unlike many earlier spectral shaping methods, which have only been demonstrated using more complicated femtosecond lasers. This means that this method is more easily adaptable for commercial SC sources which generally use picosecond or longer pulses.

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