Tunable spectral enhancement in supercontinuum with a long-period fiber grating

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Abstract: A tunable narrow-band enhancement of supercontinuum generated in a microstructured fiber is created by modifying the broadened spectrum in a long-period fiber grating followed by propagation with self-phase modulation.

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It was recently shown [1,2] that the intensity of a narrow region within a supercontinuum can be greatly enhanced, in excess of 10 dB, by introducing a fiber Bragg grating (FBG) in the fibre in which the supercontinuum is generated. A significant application of this effect was demonstrated by Kim et al [3] who produced 24 dB of signal increase in a supercontinuum-based frequency comb optical stabilization scheme by using an FBG. We recently showed [4] that this spectral enhancement can be simply explained in terms of the dynamics of self-phase modulation (SPM), and that it depends only upon a small spectral phase or amplitude perturbation in the spectrum of an ultrafast pulse that is subsequently subject to SPM. In this paper we demonstrate a spectral enhancement using a UV written long-period fibre grating (LPFG) which allows for the additional freedom to tune the enhancement spectrally and to switch it on and off. Since the different stages of the process develop independently, they occur in different fibres, each of which is optimized for its role in the process and the fibers are spliced together with low loss to create an integrated device.

Fig. 1 shows the principle of our method. In the first phase, an ultrafast (Ti:sapphire) laser pulse propagates through a short length of photonic crystal fiber (PCF). The processes of self-phase modulation, soliton fission and Raman self-frequency shift [6] act to broaden the initial transform limited laser spectrum into a broadband supercontinuum which covers the range of the LPFG resonance. The output of the PCF is then coupled into the UV-LPFG written in an ultra high-NA fiber (UHNAF) chosen for mode-matching to the initial PCF. Finally the modified supercontinuum is coupled into a second piece of PCF, chosen for high nonlinearity and low dispersion. According to the Bloch wave analysis [7], the phase velocity of the propagating light in a LPFG is modified near the resonant wavelength, which leads to a different phase development within a narrow spectral band when the light propagates through the LPFG. The phase feature imposed by the alteration of the propagation constant near the resonance is comparable to that in an FBG. As a result, nonlinear propagation in the second PCF causes a strong spectral increase near the LPFG coupling resonance similar to that obtained using the FBG. The spectral enhancement can be tuned in both wavelength and magnitude by heating or by changing the ambient index of the LPFG.

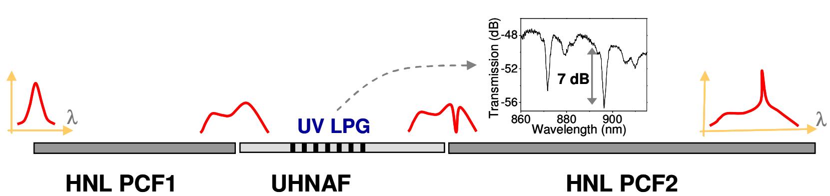

Fig. 1: Schematic diagram of the experiment, with the spectrum of the signal shown at different stages; inset: linear transmission spectrum of LPFG.

In our experiment we choose a 50 mm length of Crystal Fiber NL-2.0-740 PCF for supercontinuum generation. This fiber creates significant spectral broadening of our input 80 fs 775 nm Ti:sapphire laser pulse. For the central section a short 50 mm length of hydrogen-loaded Nufern UHNA3 fiber is used. A LPFG of period 25 μm and length 20 mm is written into its core by the use of a rapid expose-and-scan writing technique with a femtosecond UV laser source. The inset to figure 1 shows the linear transmission loss spectrum of the LPFG, with the narrow resonances in the spectral region around 880 nm. The initial PCF fiber is spliced with a loss of 1-2 dB to the UHNA3 fiber containing the LPFG. Finally a third section of PCF, a 700 mm length of Crystal Fiber NL-3.0-870, is spliced with 1 dB loss onto the distal end of the UHNA3 fiber. This fiber has a dispersion zero at 868 nm and a nonlinear coefficient of 0.049 $W^{-1}m^{-1}$ and can generate strong SPM of the perturbed supercontinuum pulse.

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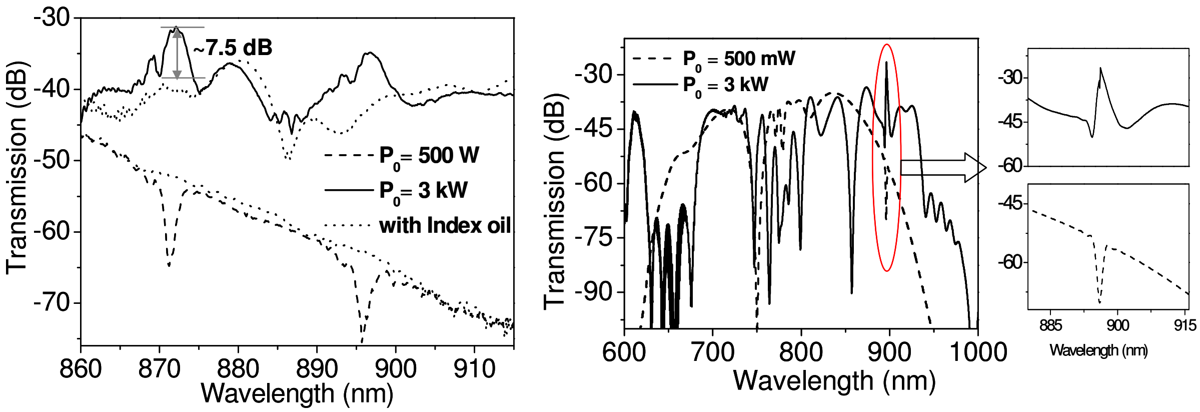

(a) (b)

Fig. 2(a) Spectral intensity at output from the final fiber at low power (dashed line) and at high power (solid line). Dotted curves show corresponding spectra after the coherent cladding mode coupling in the LPFG has been eliminated by immersion in index-matching fluid. Fig. 2(b): Modelling results at low power (dashed line) and high power (solid line).

The dashed line in Fig. 2(a) shows the output spectrum at a peak power of 500 W coupled into the first PCF. Consistent with the linear spectrum it exhibits a sequence of narrow loss features due to the cladding mode coupling in the LPGF. The solid line shows the measured spectrum when the power is increased to 3 kW. The sharp loss feature at 872 nm has transformed into a strong transmission *increase* of 7.5 dB. We verify that the enhancement caused by the LPFG by comparing the spectra at high and low powers to spectra obtained when the grating is immersed in index-matching oil (dotted curves in fig. 2(a)). The index-matching oil effectively removes the narrow-band resonances in the spectrum, since the coupled cladding modes no longer coherently interfere. In the presence of index-matching oil both the narrow-band loss and the enhancement disappear, showing them to be due to the LPFG.

The results of modelling a system encapsulating the three stages used in our experiment are summarized in Fig. 2(b). In the simulation, we included only a single resonance of the LPFG near 896 nm for simplicity. At low powers (dashed line) the final fiber provides purely linear pulse propagation, and the loss profile of the LPFG is preserved. By contrast, at higher powers (solid line) the effect of SPM acts on the narrowband loss and phase profile of the LPG to create a strong local spectral increase, as seen in the experiment.

Fig. 3 shows the spectral results in the vicinity of the LPFG resonance at ~ 896 nm at four different temperatures. The position of the spectral increase is seen to increase by 10 nm with temperature as the coupling resonance of the LPFG is tuned, demonstrating thermal tunability of the wavelength of the spectral enhancement.

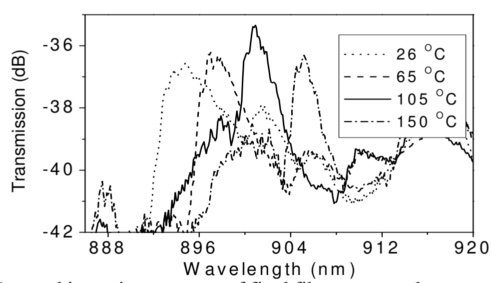

Figure 3: Spectral intensity at output of final fiber at several temperatures as indicated in the caption

In summary, we have demonstrated a tunable local increase of the spectrum of a fiber-generated supercontinuum using a long-period fiber grating. Such a tunable spectral increase offers to greatly increase the flexibility of local spectral enhancement as useful in applications such as optical metrology.

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