Pulses of four optical cycles from an optimized optical fibre/grating pair/soliton pulse compressor at 1.32 µm

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Abstract. In this Letter, we report on the generation of pulses as short as 18 fs by means of an optimized two-stage optical fibre-grating pair and high-order soliton-effect pulse compressor. These are the shortest pulses yet reported in the near-infrared spectral region and correspond to four optical cycles at 1.32 µm.

Following the first theoretical proposal of soliton generation in single-mode optical fibres [1] and the first experimental observation [2], the relevant application of solitons as information carriers has been treated by several authors [3–5].

At present, high-order soliton generation in optical fibres represents the most elegant way of generating sub-hundred-femtosecond pulses in the near-infrared (NIR) spectral region as has been realized by Tai et al. [6] and more recently by Gouveia-Neto et al. [7]. In both cases, a c.w. mode-locked Nd:YAG laser operating at 1.32 µm was used as the source of pulses and the application of a combination of an optical fibre-grating pair pulse compressor and high-order soliton generation in a single-mode dispersion-shifted fibre provided the means for the generation of sub-hundred-femtosecond pulses.

In this Letter, to illustrate the potential of the method, we report on the generation of pulses of four optical cycles at 1.32 µm by means of such an optimized femtosecond pulse compressor.

The experimental scheme is shown in figure 1. A c.w. mode-locked Nd:YAG laser (modified Quantronix model 116) was used as the initial source of 90 ps pulses at 100 MHz repetition rate with an average power of 1.8 W, corresponding to a peak power of 200 W. The pulses were optically compressed by means of an optical fibre-grating pair pulse compressor which has been described in detail elsewhere [8]. It is sufficient to mention here that for 800 mW coupled into 200 m of fibre (dispersion minimum around 1.5 µm) and a 2.5 m overall grating separation, pulses as short as 1.1 ps (assuming sech² pulse shape) were derived, as shown in figure 2. The compressed pulses had an average output power of 550 mW, corresponding to a peak pulse power of 5 kW. These pulses were then coupled into a piece of single mode fibre 40 m long, with zero dispersion at 1.27 µm, an effective core area of 96 µm² and a dispersion value $D = -5 \text{ ps nm}^{-1} \text{ km}^{-1}$ at 1.32 µm, while the loss was < 0.5 dB km⁻¹.

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Figure 1. Experimental arrangement.

Figure 2. Background free autocorrelation trace of the 1.1 ps pulses from the fibre-grating compressor at 1.32 µm.

at 1.32 µm. A maximum average power of up to 170 mW was coupled into this second fibre, which corresponded to 1.6 kW peak power. Temporal measurements were made by means of a second-order autocorrelation technique in the background-free configuration, using a <100 µm thick LiIO₃ angle-tuning crystal which gave a resolution of better than 10 fs. A 0.25 m scanning spectrograph in conjunction with a Ge photodetector was used to simultaneously record the pulse spectra.

The soliton period Z₀ [2] for the fibre parameters and pulse-duration listed above was approximately 132 m and the fundamental soliton power 8.2 W. For peak powers up to 1.6 kW coupled into the fibre, a soliton number N = 14 is predicted, corresponding to a theoretically predicted [9] compression factor (γ/τ₀) of 57 at the point of first optimal narrowing.

As observed previously, the experimental compression ratio for a given soliton number agreed quite well with theoretically predicted results [7], however, the position for the optimal narrowing length disagreed by a factor of 2.75 [7]. The optimal fibre length under the present experimental conditions was determined empirically in a fibre-cut-back process. Autocorrelations of the pulse profiles on exit from the second fibre were recorded as the fibre length Z was varied. The same rapid soliton-formation process in the initial few metres of the fibre was observed [7]. However, for the situation described here the optimum length was found to be 11 m
(2.5 times the predicted value of 4 m, from [9]) and pulses as short as 18 fs, as shown in figure 3, were measured (sech^2 pulse-shape assumed) for this fibre length. This corresponds to a compression ratio of ×60, which agrees quite well with the theoretically predicted value of ×57. For a further cut-back, the pulses became extremely unstable even for variation of 50 cm from the optimum fibre length.

As can be seen from figure 3, the soliton pulses were situated on the top of a broad pedestal lasting for 1.7 ps and accounting for 69% of the total energy. This resulted in the peak power of the 18 fs soliton pulses being 29.3 kW. The corresponding spectrum for the 18 fs pulses is shown in figure 4. This consisted of a barely resolvable narrow self-phase modulated region around the input wavelength corresponding to the pulse pedestal and a highly broadened spectral region associated with the 18 fs pulses.

![Figure 3](image1.png)

**Figure 3.** Background free autocorrelation trace of the 18 fs duration optimally compressed high-order soliton pulses.

![Figure 4](image2.png)

**Figure 4.** Spectrum corresponding to the high-order soliton pulses of figure 3.
In conclusion, by means of an optimized fibre-grating and soliton-effect pulse compressor, pulses as short as 18 fs (four optical cycles at 1.32 µm) have been generated, showing the potential of such a technique for the generation of hypershort pulses in the NIR region. These pulses also represent, to the author's knowledge, the largest compression ratio (×5000) using optical fibres yet reported. It should be possible to reduce the pedestal component using an intensity-dependent polarization discrimination technique [10] where the pulses should find useful applications in ultrafast NIR spectroscopy, pump-probe techniques and optical sampling. Since the preparation of this manuscript, a similar approach using high-order soliton generation from Raman solitons in a two-fibre experimental configuration has generated pulses of 18 fs at 1.6 µm [11].

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References