Optimised design of a fibre-based pulse compressor for gain-switched DFB laser pulses at 1.5 μm

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Abstract

An optical-fibre based pulse compressor for gain-switched DFB laser pulses has been optimised using a systematic procedure based on the initial complete characterisation of the laser pulses, followed by numerical simulations of the pulse propagation in different types of fibre to determine the required lengths for optimum compression. Using both linear and nonlinear compression techniques, an optimum compression factor of 12 is achieved.

Introduction

The development of future Terabit all-optical communication systems exploiting Optical Time Division Multiplexing (OTDM) will require stable laser sources around 1.55 μm producing sub-picosecond pulses [1]. A simple and reliable technique for pulse generation around 1.55 μm is the gain-switching of semiconductor laser diodes. Although the pulses generated using this technique are usually heavily chirped, and have durations exceeding 10 ps, it has been shown that near-transform limited sub-picosecond pulses can be obtained after fibre-based pulse compression [2]. Although many different fibre-based compression schemes have been proposed [3-5], the design of such compressors is usually only approximate. Typically, a simple model of the gain-switched laser pulses assuming symmetric gaussian profiles with a linear chirp is used to determine initial approximate lengths for the fibre used in the pulse compressor. This is then followed by trial-and-error length optimisation to obtain the best experimental compression [2].

It is clear that the generation of transform-limited sub-picosecond pulses from gain-switched lasers would be greatly simplified if the design of fibre pulse compressors could be performed in a systematic manner without *a priori* assumptions about the nature of the initial pulse characteristics, or the time-consuming process of trial-and-error optimisation. In this paper we report a systematic approach to fibre compressor design based on the complete intensity and chirp characterisation of the initial gain-switched laser pulses using the technique of frequency-resolved optical gating (FROG) [6]. The complete characterisation of the electric field of the laser pulses allows the design of the fibre-pulse compressor to be optimised by examining the propagation of the pulses in different types of optical fibre using numerical simulations based on the nonlinear Schrödinger equation (NLSE). We have recently demonstrated the utility of FROG for gain-switched laser pulse characterisation, and suggested its use in compressor design [7], in this paper we now present experimental verification of the use of FROG for this purpose. We report results showing the compression of initially-chirped 9.3 ps pulses to near chirp-free 800 fs pulses.

Experimental Set-up

The experimental set-up is shown in Fig. 1. The laser source was a distributed feedback (DFB) laser with an operating wavelength of 1538 nm, a threshold current of 24 mA, and a 10 GHz modulation bandwidth. The laser was biased below threshold at 5 mA, and gain-switched at a repetition rate of 500 MHz using electrical pulses from a step recovery diode. The electrical pulses had a duration of 80 ps and an amplitude of 13 V. The DFB laser pulses were characterised using spectral and autocorrelation measurements, as well as a second-harmonic generation FROG set-up to determine the pulse intensity and chirp [6].

The complete characterisation of the gain-switched laser pulse intensity and chirp was used to design of a two-stage pulse compressor via NLSE simulations. The first stage uses dispersion compensating fibre (DCF) to compensate for the linear part of the intrinsic negative chirp on the gain-switched laser pulses, thus generating near chirp-free pulses. The second stage consists of initially amplifying these pulses in an erbium doped fibre amplifier (EDFA), and then propagating the amplified pulses in dispersion shifted fibre (DSF) and standard single mode fibre (SMF). The propagation in the DSF is governed by the interplay of self-phase modulation and a small normal dispersion. This leads to temporal and spectral broadening, and the development of a large positive chirp across the pulse centre. This large chirp is then compensated in the SMF leading to a compressed output pulse. To optimise the compressor, NLSE simulations were used to propagate the fully characterised initial gain-switched laser pulses through various lengths of DCF, DSF and SMF in order to determine the lengths required to obtain the optimal compressed pulse with the minimum amount of low amplitude pedestal structure.

Experimental Results

Figure 2(a) shows the temporal intensity and chirp retrieved from the FROG measurement of the gain-switched laser pulses. We can see that the pulse has a full width at half-maximum (FWHM) of 9.3 ps and a slightly asymmetric pulse shape. The average power in the pulses was 140 μW, which corresponds to a pulse peak power of around 30 mW. Figure 3 presents NLSE simulation results showing the optimal evolution of these initially chirped pulses. The fibre lengths for optimum compression were found to be: 75 m of DCF (D =-102.5 ps/(nm.km), γ = 2 $W^{-1}km^{-1}$), 1.3 km of DSF (D=-0.6 ps/(nm.km), γ = 2.3 $W^{-1}km^{-1}$) and 80 m of SMF (D =16.0 ps/(nm.km), γ = 1.1 $W^{-1}km^{-1}$). The parameters D and γ in each case are the fibre dispersion and nonlinearity parameters respectively. The effect of the 6 m long EDFA, was also included in the simulations but at the amplification level of 17 dB used in our experiments, its effect on the pulse duration and chirp characteristics was found to be negligible.

With the compressor designed according to the simulation results, FROG measurements were used to measure the intensity and chirp of pulses at different points in the compressor in order to verify the accuracy of the numerical design procedure. These results are shown in Figure 2(b) and (c). The pulse in Figure 2(b) was measured after linear compression in the DCF, and it is clear that the chirp is significantly reduced, and the pulse is compressed by around a factor of 2 with a FWHM ≈ 4.5 ps. The solid and dashed lines in Figure 2(c) show the intensity and chirp of the pulse after the nonlinear compression stage. This stage results in a further factor of 6 compression with the final output pulse having a FWHM of 800 fs, and a pulse peak power of around 10 W. The pulses are essentially chirp-free across the pulse centre, and although there is a residual pedestal due to uncompensated nonlinear chirp developed in the DSF, its intensity is 16 dB lower than the pulse peak. To illustrate the accuracy of our numerical design procedure, the circles in Figure 2(c) show the expected output pulses obtained from the NLSE propagation of the input pulse through the compressor. It is clear that there is excellent agreement with the experimentally measured output pulse.

Conclusion

We have shown that the complete intensity and chirp characterisation of gain-switched DFB laser pulses using FROG allows the precise optimisation of a multi-stage fibre pulse compressor via NLSE simulations. We have presented experimental results using a compressor design optimised for high compression factors and minimal pedestal structure in order to obtain output pulses which may be suitable for ultra-high capacity telecommunications applications. From initially chirped 9 ps pulses, we obtain almost chirp-free 800 fs pulses. We expect that this method of compressor design will find wide application in optimising other forms of pulse compressor based on fibre Bragg gratings, fibre loop mirrors or dispersion decreasing fibre.

References

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Figure Captions

Fig. 1 Experimental setup used for pulse generation and compression.

Fig. 2 Intensity (solid line, left axis) and chirp (dashed line, right axis) of (a) pulse from the gain-switched DFB laser diode, (b) pulse after linear compression in the DCF, and (c) pulse after nonlinear compression stage in DSF and SMF. The circles in (c) show the expected pulse characteristics from the NLSE simulations.

Fig. 3 Evolution of pulse FWHM in the pulse compressor. Point A corresponds to the input pulse, while points B and C correspond to output of linear and nonlinear compression stages respectively.