80 Gb/s Optimised Pulse Source using a Gain-Switched Laser Diode in Conjunction with a Nonlinearly Chirped Grating

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ABSTRACT

The authors demonstrate the generation of transform limited short optical pulses, which display excellent spectral and temporal qualities by employing a novel technology, based on an externally injected gain-switched laser in conjunction with a non-linearly chirped grating. Using this technique, 3.5 ps optical pulses, exhibiting a time bandwidth product of 0.45, are generated, which are suitable for use in high-speed 80 Gb/s OTDM communications systems.

Keywords: gratings, optical fibre communications, optical pulse compression, optical pulse generation, semiconductor lasers.

1. INTRODUCTION

The development of picosecond optical pulse sources with excellent temporal and spectral properties is vital for future implementation of high capacity optical communications systems using OTDM and hybrid WDM/OTDM technologies [1]. These sources will be important for enabling optical communication systems operating at line rates of 40, 80, and 160 Gb/s, employing Return to Zero (RZ) coding. The RZ coding is far less susceptible to nonlinearity and dispersion effects in the transmission fibre [2]. The work we present here is a development on previous work, which exhibited a 2.5 GHz pulse source using a Nonlinearly Chirped Fibre Bragg Grating (NC FBG) [3]. In this paper, the technique is improved, such that 3.5 ps pulses at a repetition rate of 10 GHz are generated and the technique also optimises the shape of pulse output spectrum. The output pulses generated are near transform limited and have pulse pedestals that are virtually eliminated to around 35 dB below the peak of the pulse. These pulse sources would be suitable for use in 80 Gb/s OTDM systems or in hybrid WDM/OTDM systems.

The pulse generation method involves gain-switching which has been readily recognised as one of the simplest techniques available. A disadvantage of gain-switching technique is that a large nonlinear frequency chirp is present across the wings of the pulse that could degrade the performance of systems which employ them. It has been reported how this chirp can be used to compress the pulses using Dispersion Compensating Fibre (DCF) [4] or linearly chirped fibre gratings [5], to obtain near transform limited pulses. However, due to the chirp being nonlinear this compression typically results in pedestals on either side (wings) of the pulses thus rendering them unsuitable for use in practical systems. Hence we propose a simple and effective method, with the use of NC FBGs, which compensates for the chirp entirely across the pulse thus eliminating the pedestals and generating transform limited pulses.

2. EXPERIMENTAL SETUP

The experimental set-up employed in this work is shown in Fig. 1. A high-speed 1550 nm DFB (1) laser is gain-switched at 10 GHz using a signal generator and a high power RF amplifier. External injection is provided to improve the Side Mode Suppression Ratio (SMSR) and temporal jitter of the gain-switched pulse from a second DFB (2) laser via the circulator. The temporal jitter of the resulting pulses is measured to be < 1ps and the SMSR is improved from 15 dB to 30 dB. The generated pulses before and after the grating were characterised using an Optical Spectrum Analyser (OSA), a high-speed oscilloscope in conjunction with a 50 GHz pin detector, and also a Frequency Resolved Optical Gating (FROG) measurement scheme [6].

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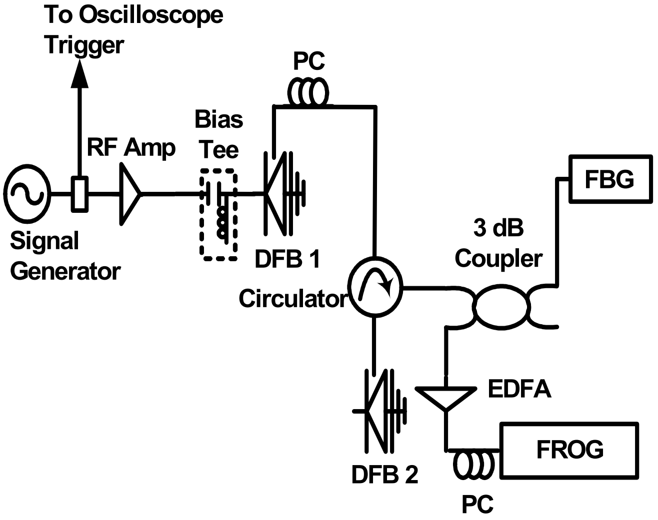

Fig. 1. Experimental Setup.

From the FROG measurement we can accurately characterize the intensity and chirp profile across the optical pulses from the gain-switched laser with external injection. With the external injection, the gain-switched pulses have a nonlinear chirp profile in the wings of the pulse. We subsequently use this measured non-linear chirp across the pulse to design and fabricate a NC FBG with a chirp profile opposite to that measured across the pulse. The reflective and group delay profiles of the fabricated filter are shown in Fig. 2. As can be seen in the figure, the reflection profile of the grating is made to ensure equalization in such a way that an optimised output Gaussian spectrum is achieved.

We also fabricated a linearly chirped fibre grating which had a chirp profile that was opposite to a linear approximation of the chirp across the gain-switched pulse. By placing the fibre gratings after the gain-switched laser (with external injection) we subsequently characterise the pulse compression in the fibre gratings using the FROG measurement technique.

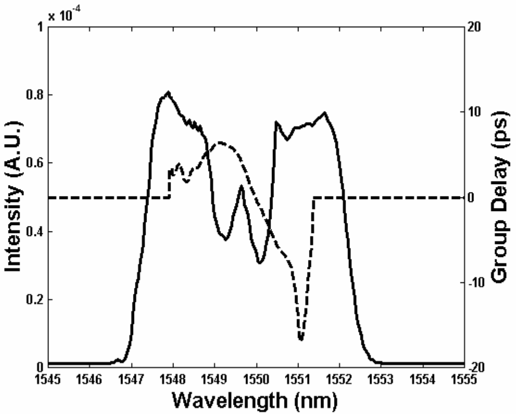

Fig. 2. Reflection and group delay profiles of the nonlinearly chirped fibre grating.

3. RESULTS AND DISCUSSIONS

The input pulses from the externally injected gain switched laser had a duration (FWHM) of about 10 ps as shown in Fig. 3. Also shown (superimposed) in the same figure is the chirp profile of this externally injected gain switched pulse. We can clearly see how the frequency chirp becomes non-linear in the wings of the pulse generated, due to the gain-switching mechanism. The nonlinear chirp has a large magnitude, thus resulting in the pulse having a time bandwidth product (TBP) of 1.5.

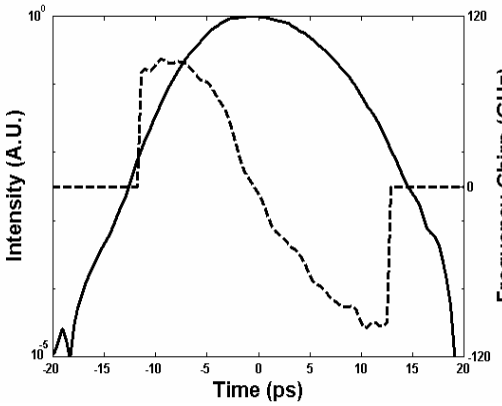

Fig. 3. Intensity and chirp of optical pulses from the externally injected gain-switched laser.

By placing the non linear and linear fibre gratings after the externally injected gain switched laser, we subsequently characterize the pulse compression in the fibre gratings using the FROG technique. Fig. 4a and b show the measured intensity and chirp profile of the gain switched optical pulses after compression with the linearly and non-linearly chirped fibre gratings respectively. In both cases we can see that the gratings have eliminated any frequency chirp across the centre of the pulses. However, when the linearly chirped grating is used we can see how the non-linearity of the chirp directly from the gain-switched laser, results in significant pedestals on the leading and trailing edge of the pulse (Fig. 4a). These pedestals, which are around 23 dB down from the peak of the pulse, would clearly pose significant problems (through inter-symbol interference) for the use of these pulses in high-speed OTDM signals [7].

On the other hand, the compression in the non-linear fibre grating results in a 3.5 ps FWHM pulse (pulse and corresponding chirp profile shown in Fig. 4b). The resultant chirp is very flat and has a very small order of magnitude across the pulse thus giving a TBP of 0.45. Also, an excellent Temporal Suppression Ratio (TSR > 35 dB) is exhibited, as can be seen in the figure, where the pedestals have almost been eliminated.

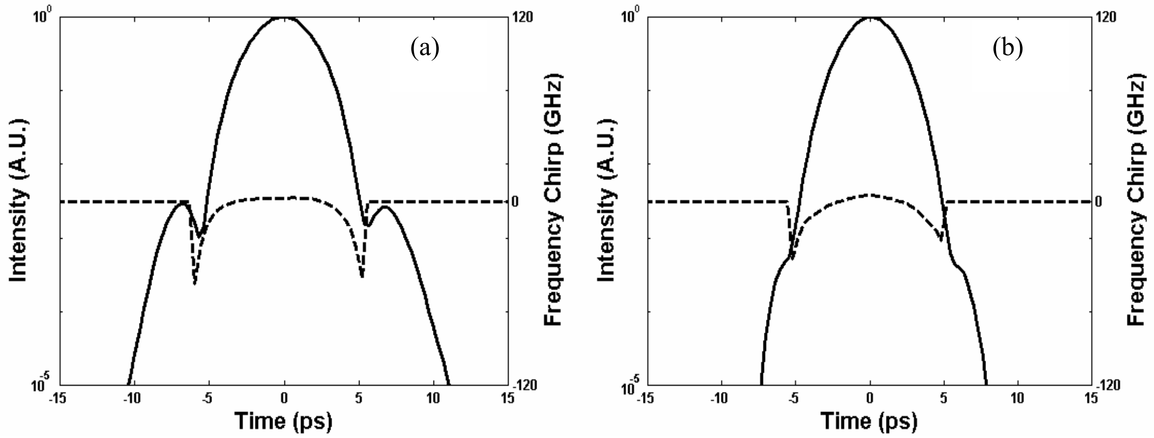

Fig. 4. Intensity and chirp of externally injected gain-switched pulses after (a) linearly chirped and (b) nonlinearly chirped gratings.

The spectra and the group delay of the input and output pulses are shown in Figure 5a. It is clear that the group delay has been compensated for entirely by the NC FBG. The output spectrum is more Gaussian shaped and symmetric in comparison to the input, which is due to the compensation by the nonlinear reflection profile of the NC FBG. The OSA spectrum, which is in excellent agreement with the pulse spectrum obtained from the FROG measurement, shows that the spectral width is around 130 GHz and is shown in Fig. 5b.

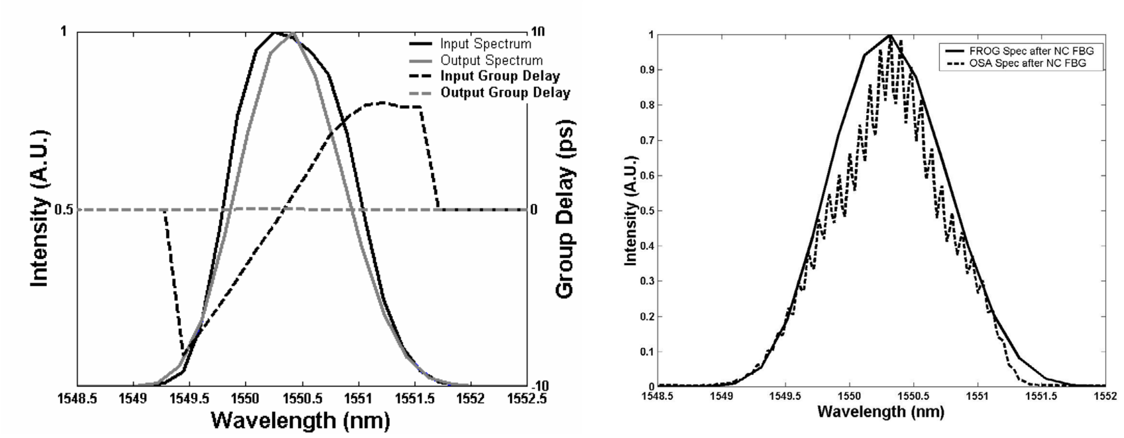

Fig. 5. (a) The input and output spectrum to the NC FBG and their corresponding group delays and (b) a comparison of the spectrum obtained by the FROG and the OSA after the NCFBG.

This pulse generation/compression scheme exhibits excellent repeatability and stability over long periods of time, within laboratory conditions. This could mainly be attributed to bias current and temperature of the two DFB lasers being controlled with the aid of current/temperature controllers. Hence, drifts in wavelength of the lasers, due to current or temperature variations were negligible. Furthermore, the wavelength variation with temperature of the fabricated NC FGB being relatively small (~0.009 nm/ºC) also leads to the stable generation of optimised pulses over long periods of time.

4. CONCLUSIONS

We have demonstrated the generation of near transform limited 3.5 ps gain switched pulses that exhibit an excellent TSR by using an NC FBG. The initial gain-switched pulses display a large nonlinear chirp across the wings of the pulse. The gratings are designed with a nonlinear group delay profile that is opposite to the group delay of the input pulse to compensate for the chirp, and the spectrum is optimised using a nonlinear reflection profile. The resultant output pulses display excellent temporal and spectral purity, which would make this pulse source ideal for use in 80 Gb/s OTDM systems.

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