3134

Full characterisation of the temporal response of phase-shifted SSFBGs using electroabsorption modulator based frequency resolved optical gating

Chun Tian, Zhaowei Zhang, Michaël A.F. Roelens, Periklis Petropoulos, Morten Ibsen and David J. Richardson
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
Phone: +44 2380 593136, Fax: +44 2380 593142, cht@orc.soton.ac.uk

Abstract

We report the use of electro-absorption modulator based frequency resolved optical gating (EAM-FROG) to characterise the temporal phase and amplitude response of phase-shifted fibre Bragg gratings.

1. Introduction

Super Structured Fibre Bragg Gratings (SSFBGs) [1,2] incorporating complex refractive index superstructure profiles such as distributed amplitude and phase modulation and/or discrete phase shifts have a wide range of uses in optical pulse shaping applications such as pulse multiplication [3], rectangular pulse generation [4] and OCDMA [5]. Previous attempts to assess the pulse shaping performance of such gratings have relied largely on either simple intensity based measurements of the shaped pulse profiles (e.g. electrical/optical sampling scope measurements or autocorrelation measurements), or by inferring the performance from measurements of the grating's amplitude and phase response. For many applications this is perfectly acceptable however, for others e.g. multi-level phase encoding for OCDMA, a means to measure directly the intensity and phase profiles of grating shaped pulses is highly desirable.

A number of all-optical Frequency Resolved Optical Gating (FROG) techniques, including Second Harmonic Generation Frequency-Resolved Optical Gating (SHG-FROG), have been developed that allow the complete phase and amplitude characterisation of short optical pulses. Unfortunately these techniques use a nonlinear optical process to perform the required gating and thus are really only suitable for measuring relatively high peak power, short duration pulses. This restricts their suitability for telecommunication applications where the pulse durations of interest can be quite long, and the power levels involved are relatively modest. However, a new form of FROG technique has recently been developed in which a fast Electro Absorption Modulator (EAM) is used to perform 'linear' frequency resolved sampling [6,7]. This EAM-FROG technique offers many advantages over conventional FROG techniques including a far greater sensitivity, increased dynamic measurement range, low polarisation-sensitivity and applicability to much longer optical pulses. Moreover, EAM-FROG can be easily implemented using readily available telecommunication grade components and equipment [8].

In this paper we demonstrate use of the EAM-FROG technique to characterise the pulse shaping performance of gratings incorporating individual discrete phase shifts of various magnitudes. Our results highlight the power and accuracy of this pulse characterisation approach and its suitability for characterising the impulse response of complex SSFBGs.

2. Experimental description

Figure 1 shows the schematic of our pulse-shaping/EAM-FROG characterisation setup. The input pulse train comprising 2.2ps pulses at a repetition rate of 5 GHz is first split using a 3dB fibre coupler. The pulses from one arm of the coupler are then reflected from the pulse-shaping grating under test. The shaped pulses are then input to the EAM.

The synchronous pulse train from the second arm of the coupler is passed through a computer controlled optical delay stage before being detected by a fast (>33GHz) optical detector to generate short electrical pulses at 5GHz. These pulses are then amplified and low-pass filtered in order to generate a 5GHz~sinusoidal electrical drive signal to the EAM. This drive signal creates a short (~50ps long) switching window that is synchronous with the shaped optical pulse train incident to the EAM. The shaped optical pulses are thus optically sampled by the EAM. By varying the optical delay in a controlled fashion and measuring the resulting spectrum on a high performance Optical Spectrum Analyser, (0.01nm resolution and >70dB dynamic range), we build up a spectrogram of the shaped optical pulses. The expression for the EAM-FROG spectrogram is given by

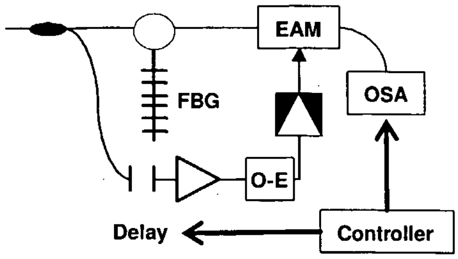


Fig. 1 Schematic of the pulse-shaping/ EAM-FROG characterisation setup

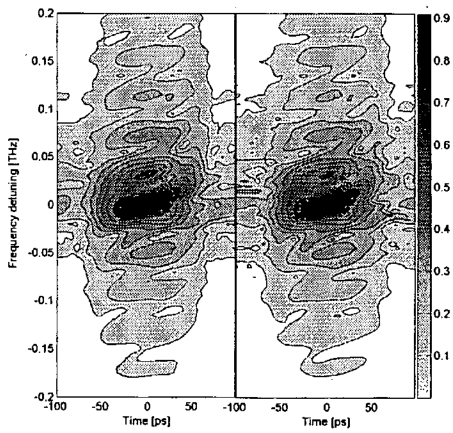
$$I_{spect}(\omega,\tau) = \left| \int_{-\infty}^{\infty} E(t)G(t-\tau)\exp(-i\omega t)dt \right|^2$$

where $G(t-\tau)$ is a variable-delay gate function, defined by the optically driven EAM switching window. A relatively standard blind deconvolution algorithm was then used to extract the electric field E(t) of the shaped optical pulses from the spectrogram.

We characterised the temporal response of four different phase-shifted SSFBGs using the above set up. Each grating is 5mm long, with no, or just one, abrupt phase shift at its centre. The four values of phase shift investigated were: 0 (uniform grating), 0.5π, π, and 1.5π ($= -0.5\pi$). The spectral bandwidth of the gratings is around 0.3nm and the peak reflectivity around 50%. Since the spectral bandwidth of the 2.2ps pulses is around 1nm the pulse spectrum is reasonably flat over the grating's bandwidth ensuring that the reflected shaped optical pulse is close to the impulse response of the grating.

3. Results and discussions

Figure 2 shows a typical measured (a) and retrieved (b) spectrogram of the 2.2ps pulses reflected from the $\pi/2$ phase shifted grating. As can be seen excellent agreement between the retrieved and experimental spectrograms is obtained confirming the quality of the measurement processes.



(a) *(b)*

Fig. 2 (a) measured and (b) retrieved spectrogram of the 2.2ps pulses reflected from the $\pi/2$ phase shifted grating, the rms retrieval error is 0.0024 on a 128x128 grid.

In Figure 3a and b, we plot the retrieved temporal pulse characteristics (intensity and phase) for the uniform and $\pi/2$ phase-shifted gratings respectively, and in Figs 3c and d the corresponding pulse spectra. The theoretical predictions for the idealised grating response are superposed. All of the key features of the expected pulse shaping are observed experimentally. In the time domain these include the formation of a narrow dip in the centre of the main body of the $\pi/2$ grating pulse due to the presence of the phase shift in the centre of the grating, and the formation of ringing structures (with associated π-phase shifts) at the trailing edge of both shaped pulses due to multiple reflections within the grating. Note that the temporal resolution of the measurement is not limited by the (~50ps) temporal width of the EAM gating window and is sufficient to resolve the ~2ps rise time of the reflected pulses. This is due to the fact that in FROG both temporal and spectral data are used to determine the pulse shape as opposed to conventional optical sampling where the width of the sampling window ultimately defines the temporal resolution [9]. In the spectral domain the retrieved spectra agree well over more than 4 orders of magnitude. Equally good temporal and spectral agreement between theory and experiment was obtained for the π and 1.5π phase shifted grating measurements. (Data from these experiments is not included due to space limitations).

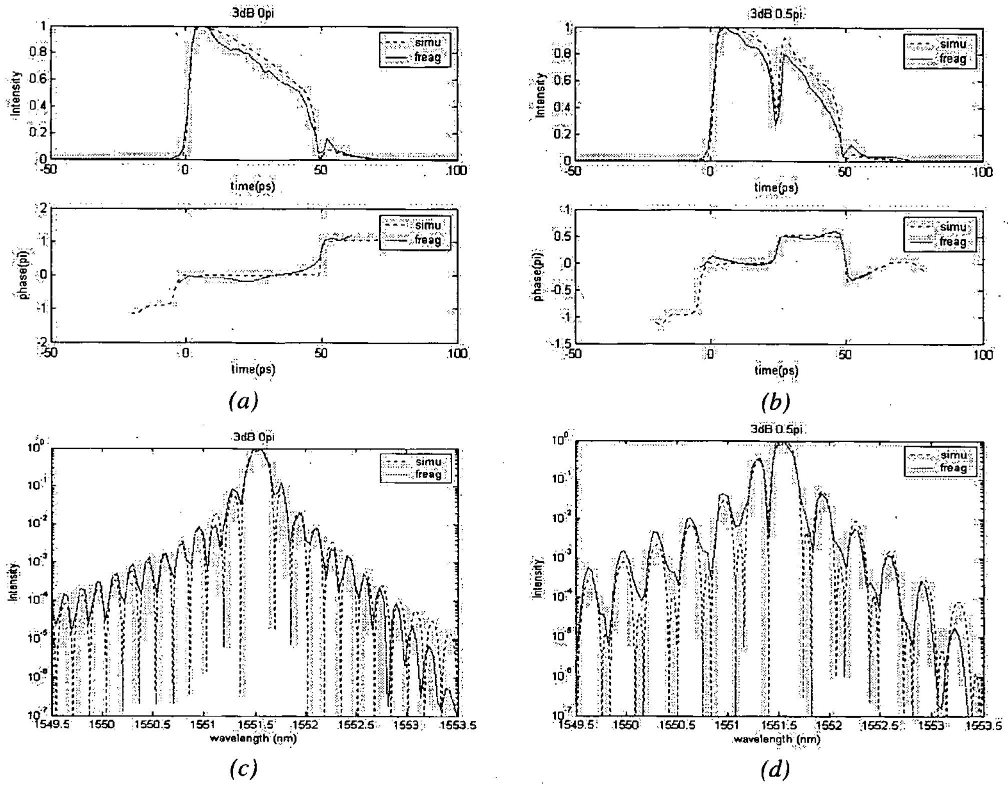


Fig. 3 Retrieved and simulated temporal intensity and phase profile for the pulses reflected from (a) the uniform and (b) the π/2 phase-shifted grating, and the corresponding pulse spectra (c) and (d).

3. Conclusion

In conclusion we have proposed and demonstrated the use of EAM-FROG as a practical and accurate tool with which to characterise the temporal and spectral, phase and amplitude responses of fibre Bragg gratings. Although we have so far only demonstrated application of the technique to relatively simple phase-shifted gratings we are confident that it can be used to characterise far more complex SSFBG structure.

[1] H. Storoy *et al.*, *Optics Letters*, vol. 27, p. 1315, 2002.
[2] M. Ibsen *et al.*, *IEEE Photonics Technology Letters,* vol. 10, p. 840, 1998.
[3] P. Petropoulos *et al.*, *Optics Letters*, vol. 25, p. 521, 2000.
[4] P. Petropoulos *et al.*, *J. Lightwave Technology*, vol.19, p. 746, 2001.
[5] P.C. Teh *et al.*, *J. Lightwave Technology*, vol.19, p. 1352, 2001.
[6] C. Dorrer and I. Kang, *IEEE Photonics Technology Letters*, vol. 16, p. 858, 2004.
[7] C. Dorrer and I. Kang, *Optics Letters*, vol. 27, p. 1315, 2002.
[8] M. Roelens *et al.*, *Proceedings of ECOC 2004*, paper We4.P116, 2004.
[9] R. Trebino *et al.*, *Review of Scientific Instruments*, vol. 68, p. 3277, 1997.