The spectral characteristics of nonlinear pulse compression in an integrated Bragg waveguide filter.

P.Millar*, N.G.R. Broderick, D.J. Richardson
University of Southampton, Optoelectronics Research Centre,
Department of Physics and Astronomy,
Southampton, SO17 1BJ, UK.
Phone: +44 (0)1703 593144, Fax: +44 (0)1703 593142
Email: ngb@orc.soton.ac.uk

J.S. Aitchison, R. De la Rue, T. Krauss
University of Glasgow, Department of Electrical and Electronic Engineering, Oakfield Avenue, Glasgow,G12 8QQ, UK.
Phone: +44 (0)141 3306126, Fax : +44(0)1413304907
email: p.millar@elec.gla.ac.uk.
*(permanent address: University of Glasgow, Department of Electrical and Electronic Engineering, Oakfield Avenue, Glasgow,G12 8QQ, UK.)

Abstract

We present measurements of nonlinear pulse compression from 400 ps to 80 ps and the spectral broadening associated with soliton formation inside an integrated Bragg filter.

The spectral characteristics of nonlinear pulse compression in an integrated Bragg waveguide filter.

P.Millar*, N.G.R. Broderick, D.J. Richardson,University of Southampton, Optoelectronics Research Centre, Department of Physics and Astronomy,Southampton, SO17 1BJ, UK.,Phone: +44 (0)1703 593144, Fax: +44 (0)1703 593142Email: ngb@orc.soton.ac.uk. **J.S. Aitchison, R. De la Rue, T. Krauss**University of Glasgow, Department of Electrical and Electronic Engineering, Oakfield Avenue, Glasgow,G12 8QQ, UK.Phone: +44 (0)141 3306126, email: p.millar@elec.gla.ac.uk. *(permanent address: University of Glasgow, Department of Electrical and Electronic Engineering, Oakfield Avenue, Glasgow,G12 8QQ, UK.)

Introduction

Interest in optical devices based on the properties of nonlinear Bragg gratings has steadily increased in recent years as potential applications within future optical network systems become more apparent. Suggested device applications include optical pulse filtering, shaping, multiplexing, power limiting and all-optical switching. Nonlinear propagation effects in periodic structures have been experimentally explored in many material systems including colloidal crystals[1], InSb planar devices[2], optical fibers[3-5], MQW material[6] and more recently, by our group, in bulk AlGaAs[7].

To date the emphasis in both experimental and theoretical studies of nonlinear Bragg gratings has concentrated on the temporal characteristics of pulses travelling within such periodic structures[1-9]. As a result, no information regarding the spectral evolution of pulse propagation in Bragg filters has been reported, despite the fact that knowledge of the spectral shape of the propagating pulse is essential in order to understand the pulse formation process leading to, for example, nonlinear pulse compression. Therefore, in this paper, we aim to redress this imbalance by presenting experimental nonlinear spectral broadening results obtained using a Bragg grating written in an integrated AlGaAs waveguide. The nonlinear spectral broadening achieved in this device was associated with the compression of a pulse from 400 ps to 80 ps. The data presented shows that in the nonlinear regime; interesting features appear in the output spectrum of a pulse tuned initially to lie within the grating stopband.

Fabrication

A high quality AlGaAs wafer was used to fabricate the integrated grating filters. The wafer was grown by molecular beam expitaxy and had the following structure. The lower cladding layer was 4 μm thick and contained 24% Al, the guiding layer was 1.5 μm thick and contained 18% Al and finally the upper cladding layer was 1 μm thick containing 18% Al. AlGaAs was chosen as the device material as the fabrication technology is well developed. In addition, AlGaAs has an enhanced nonresonant nonlinearity when operating at a wavelength below the half-band gap region, which can be tailored to lie within the 1.55 μm low loss telecommunications window. At this wavelength the detrimental effects of two- and three- photon absorption can minimised through wafer design. The nonlinear refractive index was measured to be ~ 1.5 x 10^{-13} cm^2/W which is 3 orders of magnitude greater than that of silica. Therefore the peak powers required to observe nonlinear effects in this material are considerably lower than for comparable structures in optical fibres. In addition, AlGaAs waveguides provide good optical power confinement over long interaction lengths with sufficient power handling capabilities to perform this type of nonlinear experiment. For example in this experiment upto 1.2 kW of power (660 W launched) was steered into the guides without optical damage occurring. Furthermore, the high nonlinearity of the AlGaAs guides allow a high rep rate sources to be used which enabled spectral measurements to be made with ease. Fig.1 is a schematic of the waveguide filter. The grating filters were based on a weak grating on a strip-loaded waveguide, to minimise excess scattering losses. A one step electron beam lithography process was used to define the grating and the ridge guides simultaneously. Gratings, 8 mm long were written on 1 cm long single moded waveguides, 5 μm wide. A grating period of 235 nm was selected to position the grating stopband around the maximum power range of the laser at ~ 1533 nm.. The waveguides were etched using Reactive ion etch down to a depth of 0.9 μm. Due to reactive ion etching lag the grating etch depth was approximately 0.3 μm, resulting in an effective index modulation of ~4.4 x 10^{-4}.

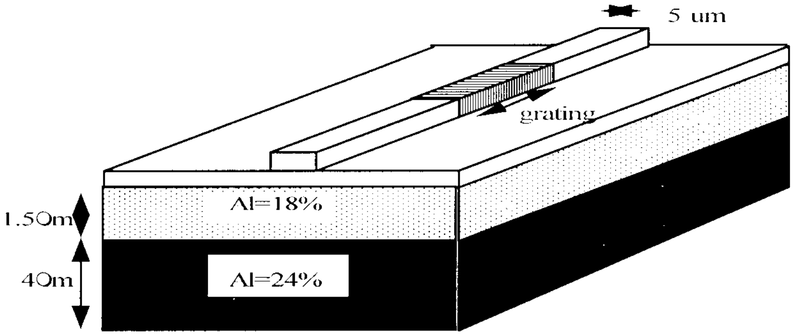


Figure 1: Schematic of the integrated Bragg waveguide filter.

Experimental Set-up

We used light pulses from an externally modulated DFB laser, amplified by a large mode area erbium doped fibre amplifier cascade which generated linearly polarised 415 ps (spectral bandwidth of ~ 3GHz), rectangular shaped pulses with a repetition rate of 100 kHz. The wavelength range of this laser system was 1.52-1.56 μm. The pulses were coupled into and out of the waveguides using an endfire rig with x40 objective lenses. The output pulse was incident alternatively, via an optical fibre, onto a high resolution commercial spectrum analyser and fast optical detector/sampling scope, which had a temporal resolution of 50 ps. Hence both the spectral and temporal characteristics of the transmitted pulse were measured. The average input power was monitored before the input coupling lens, using a pyroelectric meter and the pulse peak power calculated using measurements from a fast photodiode and oscilloscope. A lambda/2 plate before the input lens was used to control the input polarisation. The peak input power launched into the guides was estimated to be 50% of the peak power from the laser.

Experimental results

The grating transmission spectrum is shown in fig. 2. The maximum reflectivity was ~ 99%.The width of the stopband was ~ 0.2 nm. The grating spectrum appears in this figure to be asymmetric this is partly due to the fact that it was measured using the amplified spontaneous emission from the amplifier stage. Fig. 2 also shows the transmitted pulse spectrum of a pulse tuned to lie at the centre of the gap at 1533.873 nm, for a low input peak power of 60 W (light launched into guide). The input pulse width was 415 ps. A comparison was made between the input pulse spectrum and the transmitted pulse spectrum. No change in the spectral shape of the pulse was observed in the linear regime. The incident power was then increased to 385 W. Fig. 3 (a) shows the high power output pulse spectrum superimposed on the gratings transmission spectrum. Figure 3 (b) shows the temporal shape of the output pulse for input peak powers of 60 W, 200 W and 350 W. Comparing fig. 2 to fig. 3 (a) it is obvious that significant pulse shaping and spectral broadening occurs at high powers. Figure 3(b), shows that the pulse was compressed from 400 ps to 80 ps at high input powers, confirming that spectral broadening does occur as the transformed limited pulse has been compressed by a factor of 5. To confirm that the nonlinear spectral broadening was due to the grating itself, we repeated the experiment again with a pulse tuned to lie outside the grating stopband, on the long wavelength side, at 1534.429 nm. We found that no significant spectral broadening occurred at high input powers and the pulses temporal width increased slightly from 415 ps in the linear regime to 420 ps in the nonlinear regime. As shown in fig.3 (a), the output pulse spectrum is doubly peak with one peak at the centre wavelength and another shifted to the short wavelength side. Also, a considerable amount of power is now outwith the grating stopband. The temporal characteristics of this transmitted pulse also had a 2 peak characteristic with a delay of 250 ps between each peak.

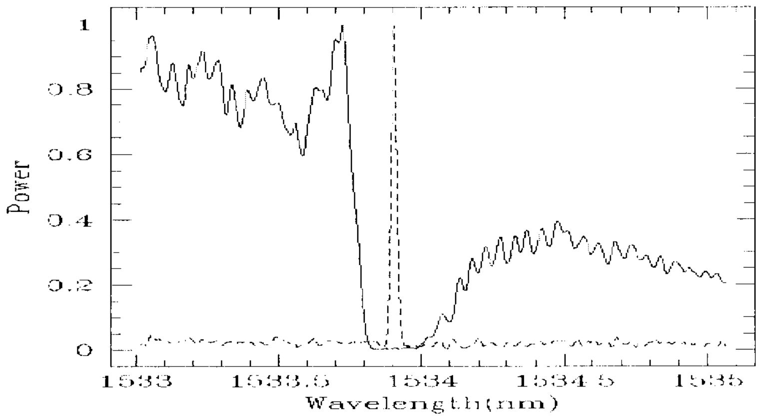
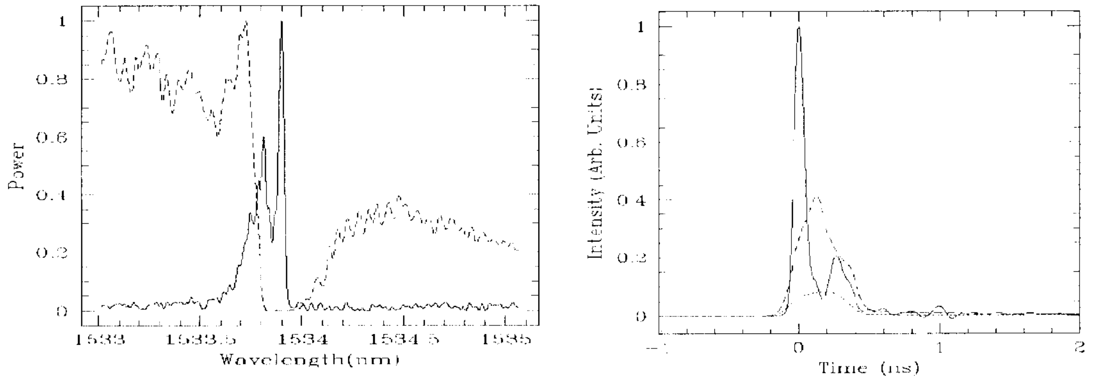


Figure 2: Grating transmission spectrum (solid line) and output spectral pulse shape in linear regime.



(a)

(b)

Figure 3(a) :Graph showing the output spectral pulse shape (solid line) for high input peak power of 385 W and the gratings spectrum. b) Transmitted temporal pulse shape for input power of 350 W (solid line), 200 W (long dashed line) and for an input power of 60 W (short dashed line).

Conclusion

We presented spectral measurements which demonstrate that nonlinear spectral broadening, due to pulse compression, within an AlGaAs Bragg filter is asymmetric in nature with the majority of the broadening occurring on the short wavelength side of the stopband. At high input peak powers several distinct peaks appeared in the transmitted pulse spectrum and temporal pulse shape. We are currently modeling the system and have so far obtained qualitative agreement with the experimental results and expect to obtain better agreement in the near future.

References

1. C.J. Herbert, W.S. Capinski and M.S. Malcuit, Opt. Lett., **17**,1037 (1992).
2. J.E. Ehrlich, G. Assanto and G.I. Stegeman, Appl. Phy. Lett., **56**, 602 (1989).
3. N.G.R. Broderick, D. Tavener, D.J. Richardson, M. Ibsen and R. I. Laming, Phy. Rev. Lett., **79**, 4566 (1997).
4. B.J. Eggligton, R..E. Slusher, C.M.de Sterke, P.A. Krug and J.E. Sipe, Phy. Rev. Lett.,**76**,1627 (1996).
5. D. Taverner, N.G.R. Broderick, D.J. Richardson, M. Ibsen and R.I. Laming, Opt. Lett., **23**, 328 (1998).
6. D. Campi, C. Coriasso, A. Stano, L. Faustni, C. Cacciatore, C. Rigo and G. Meneghini, App. Phy. Lett., **72**, 537 (1998).
7. P.Millar, J.S.Aitchison, N.G.R. Broderick, D.J. Richardson, Opt. Lett. (to be published May 1999).
8. H.G. Winful and J.H. Marburger and E. Garmire, Appl. Phy. Lett., **35**, 379 (1979).
9. H.G. Winful, Appl. Phy. Lett., **46**, 527 (1985).