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LONG CONTINUOUSLY CHIRPED FIBRE BRAGG GRATINGS FOR COMPENSATION OF LINEAR- AND 3rd ORDER -DISPERSION

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Abstract:

For the first time long broadband chirped fibre Bragg gratings with a dispersion profile designed to compensate 3rd order-dispersion are presented. These results demonstrate how the increased demands for dispersion compensation at very high bit-rates can be met using chirped fibre Bragg gratings.

Introduction:

The field of fibre Bragg gratings is now well established with devices finding many important applications. In particular chirped fibre Bragg gratings have already proven their suitability as chromatic dispersion compensators in a series of experiments [1,2] where they have been incorporated in real systems at 10 Gbit/s with excellent results. Furthermore they have been shown to allow 40 Gbit/s error-free transmission at 1.55 μm over 109 km of non-dispersion shifted fibre as we recently reported [3]. As the bit rates are being increased the effect of higher order dispersion and polarisation mode dispersion starts to become a limiting factor on the recovery of the data after transmission over long distances. Higher order dispersion therefore needs to be compensated in order to explore the full potential of the already installed and future fibre links. Chirped fibre gratings are therefore attractive alternatives to other proposed dispersion compensation schemes because they can be designed to compensate for both 2nd- and 3rd-order dispersion simultaneously over large bandwidths.

In this paper we report long continuously chirped broadband fibre Bragg gratings designed to compensate both the 2nd and 3rd order dispersion of the new reduced dispersion fibre types such as AT&T "TrueWave". These fibre types are important since the chromatic dispersion is small enough to allow a large number of channels to be transmitted over longer distances than standard fibre without dispersion compensation whilst being large enough to suppress four wave mixing. However, unfortunately the transmission capacity of this fibre will be limited by the uncompensated 2nd and increased 3rd order dispersion. Typical values for which are ~3.2 ps/nm/km and 0.19 ps/nm^2/km at 1556 nm [4].

We report long continuously chirped broadband fibre Bragg gratings designed to compensate for 317 km and 627 km of transmission in dispersion reduced fibres. As an example we chose dispersion characteristics matching AT&T "TrueWave" fibre.

Experiment:

1 m long continuously chirped gratings are written using a modified version of the moving fibre/phase-mask scanning-beam technique [5] and an intra-cavity frequency doubled Ar-ion laser producing 80 mW of UV-light at 244 nm. Deuterium loaded fibre with a numerical aperature on ~0.2 is used as host fibre. The gratings are written in pairs with and without 3rd order dispersion in order to demonstrate the differences in the dispersion slopes. The time taken to write each grating is 17 min. The gratings are characterised with a resolution of 10 pm using a tunable laser together with a high precision wavemetre.

Varying the wavelength linearly along the length of the grating during writing gives a linear time delay over the full length of the grating. By varying the wavelength with a quadratic term on top of the linear dispersion along the length of the grating a quadratic change in the dispersion with wavelength and hence a quadratic change in the delay of the grating is achieved.

Fig 1 shows the reflection, time delay and deviation from linear time delay spectra for two 1 m long 9.5 nm chirped gratings, with Fig.1a showing the grating with linear dispersion of 1016 ps/nm ± 40 ps and Fig.1b the corresponding 1 m grating with average dispersion of 1016 ps/nm and a deviation from the linear dispersion slope on ~680 ps at the bandwidth etches of the grating. Both gratings compensate for 317 km of chromatic dispersion in the fibre discussed above, with the second grating compensating for the additional 3rd order dispersion component theoretically determined from $(0.5 \times 0.19\ \mathrm{ps/nm^2/km} \times 317\ \mathrm{km} \times (0.5 \times 9.5\ \mathrm{nm})^2)$. Fig 2 shows two 1 m gratings with bandwidths on 4.8 nm and linear dispersions of 2025 ps/nm, equivalent to 627 km of same fibre. Fig.2b shows in addition a quadratically chirped grating designed to compensate the 3rd order dispersion that causes a deviation from linear dispersion on ~350 ps at the bandwidth etches with a theoretically value calculated from $(0.5 \times 0.19\ \mathrm{ps/nm^2/km} \times 627\ \mathrm{km} \times (0.5 \times 4.8\ \mathrm{nm})^2)$ to be 343 ps.

Discussion:

The deviations in the reflection spectra and time delay curves presented are due to stiching type errors in the phase-mask used. This is seen because the same type of underlying structure is present at both series of plots. Normalisation of the deviation from the linear time delay on Fig.1b vs the deviation from the linear time delay in Fig.1a would then show the pure 3rd order term. This is shown on Fig.1b as a dotted curve on the deviation from the linear time delay. Furthermore are environmental changes during writing are a limiting factor in the reduction of the time-delay ripples/deviations.

Design of fibre gratings for 3rd order dispersion compensation of standard single-mode fibres with a chromatic dispersion of 17 ps/nm/km and a dispersion slope of 0.08 $\mathrm{ps/nm^2/km}$ is more critical. For a 1 m long chirped grating designed to compensate transmission through 100 km of standard fibre the 3rd order component would give rise to a deviation from the linear time delay on the etches of a 5.7 nm bandwidth chirped grating of ~33 ps. As the deviation from the linear time delay is ~±30-40 ps for the linearly chirped gratings this task is not realistic at the present time. Improvements on the grating writing set-up are been undertaken and at the time of the conference we hope to present results for 3rd order dispersion compensation of standard fibre.

Conclusion:

We have demonstrated 1 m long chirped fibre gratings with dispersion profiles designed to cope with both linear- and 3rd order dispersion. In this paper these gratings have been designed to compensate 317 km and 627 km of the dispersion reduced AT&T "TrueWave" fibre. We strongly believe that this shows that the technology of chirped fibre Bragg gratings has matured and is ready to take a leading role in the area of dispersion compensating devices.

Acknowledgements:
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References:

1. W.H. Loh, R.I. Laming, A.D. Ellis, and D. Atkinson: "Dispersion compensated 10 Gbit/s transmission over 700 km of standard single mode fibre with 10 cm chirped fibre grating and duobinary transmitter", Proceeding OFC'96, paper PD3O, San Jose, USA, 1996.
2. M.J. Cole, H. Geiger, R.I. Laming, S.Y. Set, M.N. Zervas, W.H. Loh and V. Gusmeroli: "Broadband dispersion-compensating chirped fibre Bragg gratings in 10 Gbit/s NRZ 110 km non-dispersion-shifted fibre link operating at 1.55 μm", *Electron. Lett.*, **33**, (1), pp.70-71, 1997.
3. L. Dong, M.J. Cole, A.D. Ellis, M. Durkin, M. Ibsen, V. Gusmeroli and R.I. Laming: "40 Gbit/s 1.55μm Transmission over 109 km of non-dispersion shifted fibre with long continuously chirped fibre gratings", in proceedings of, *OFC'97*, PD6, San Jose, USA, 1997.
4. http://www.steinkuehler.de/truewave25.htm.
5. M. J. Cole, W. H. Loh, R. I. Laming, M. N. Zervas and S. Barcelos: "Moving fibre/phase-mask scanning beam technique for enhanced flexibility in producing fibre gratings with a uniform phase-mask", *Electron. Lett.*, 1995, **31**, (17), pp.70-71.

I a)

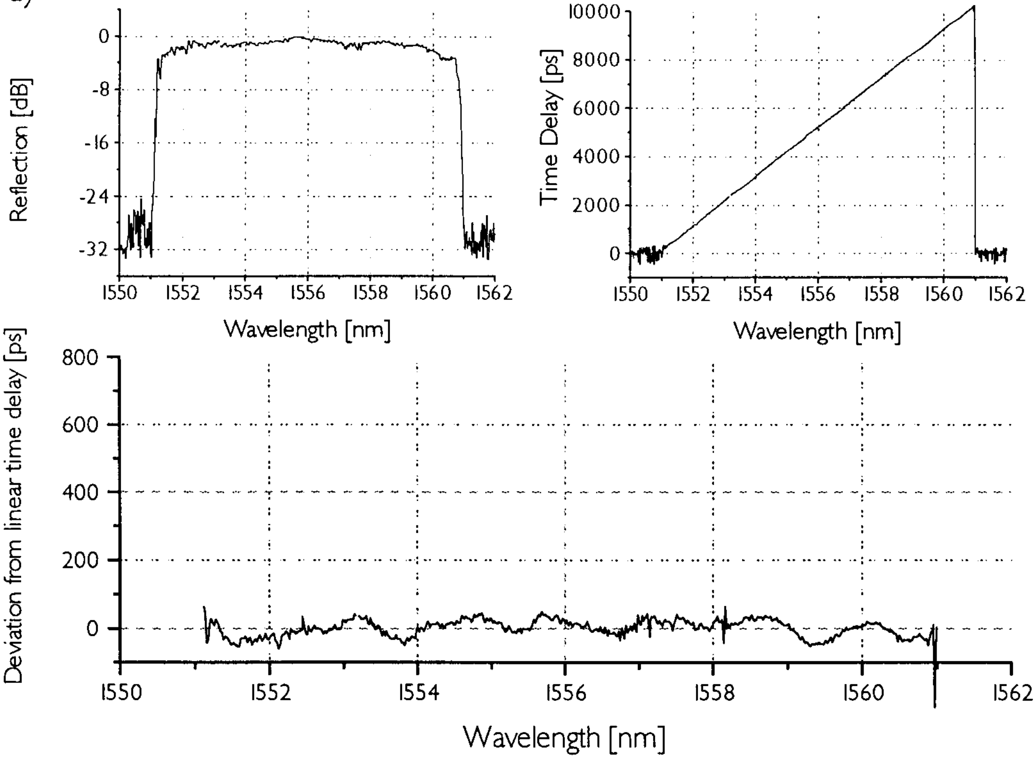

Figure 1a.Reflection spectrum, time delay and deviation from linear time delay of a 1 m long linearly chirped grating with a bandwidth of 9.5 nm and a dispersion slope of 1016 ps/nm

I b)

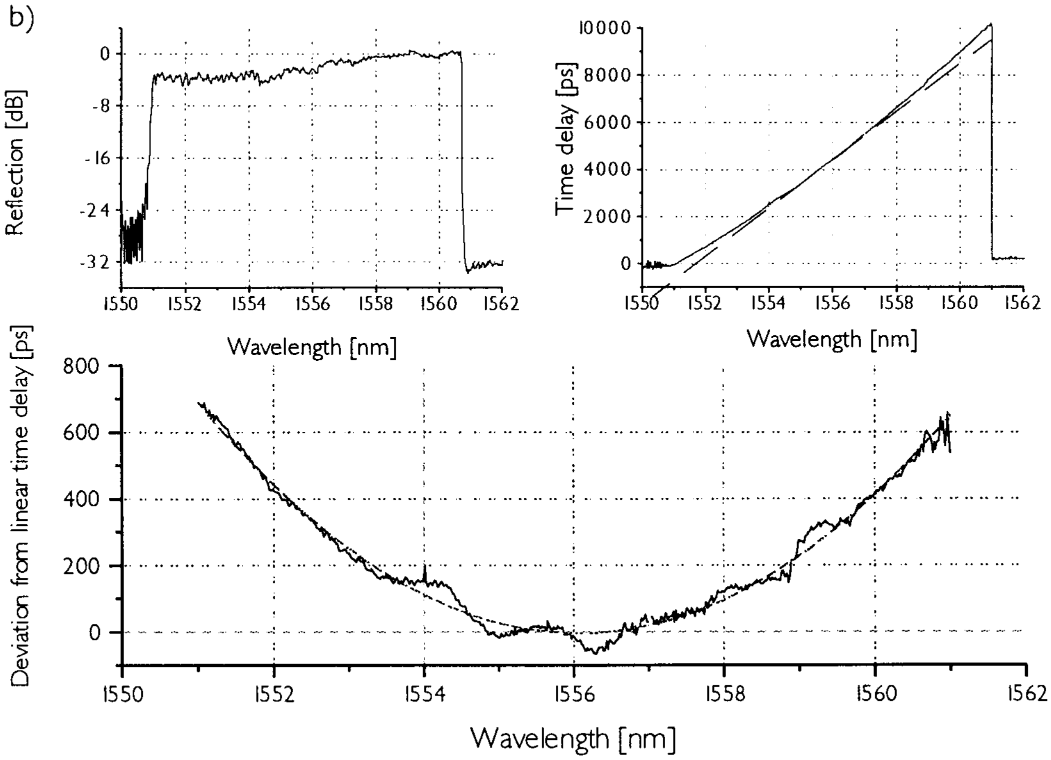

Figure 1b.Reflection spectrum, time delay and deviation from linear time delay of a 1 m long quadratically chirped grating with a bandwidth of 9.5 nm and a linear dispersion of 1016 ps/nm and a maximum deviation of 680 ps at the etches of the bandwidth.

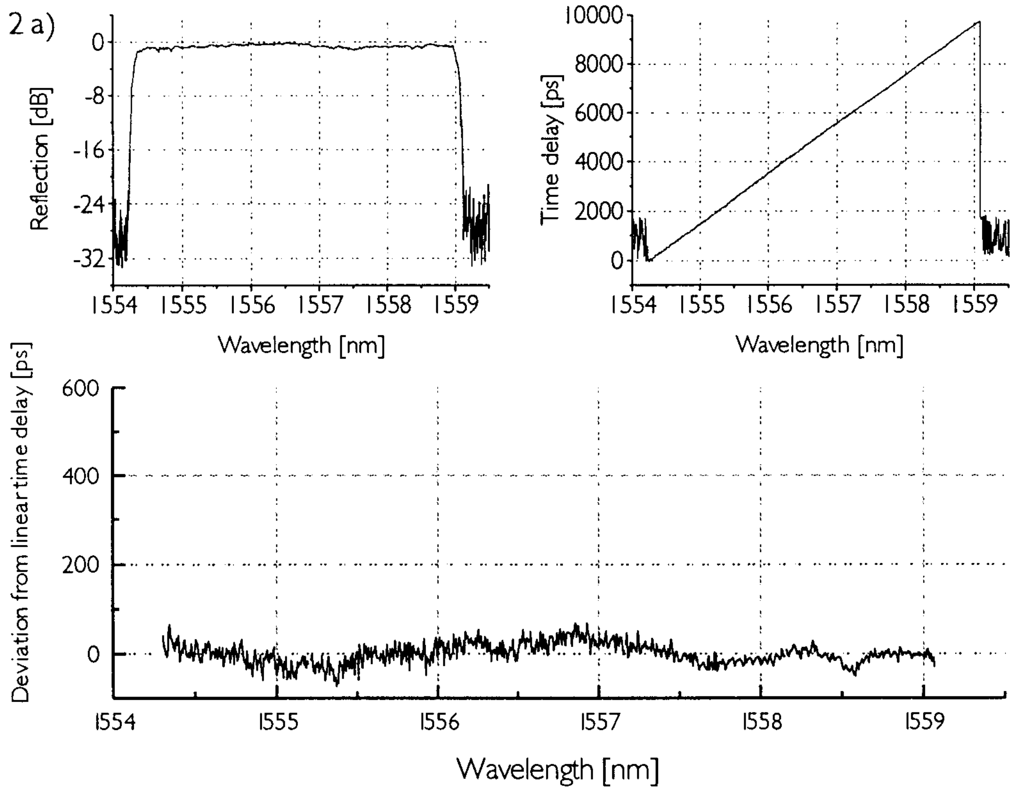

Figure 2a.Reflection spectrum, time delay and deviation from linear time delay of a 1 m long linear chirped grating with a bandwidth of 4.8 nm and a dispersion slope of 2025 ps/nm.

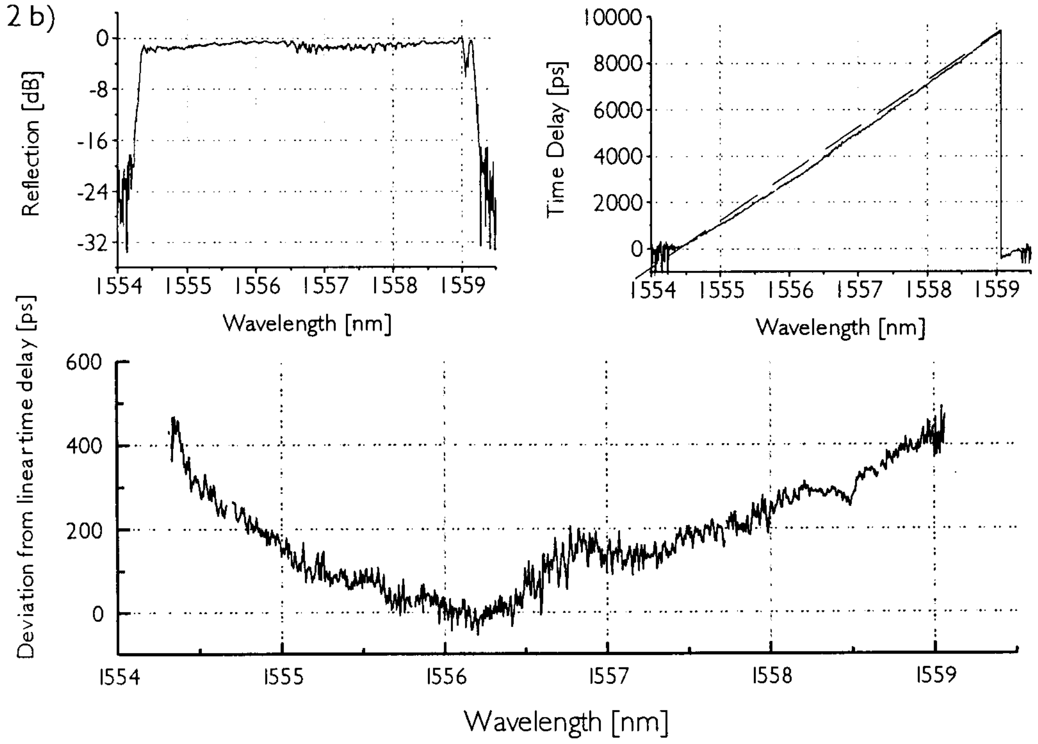

Figure 2b.Reflection spectrum, time delay and deviation from linear time delay of a 1 m long quadratically chirped grating with a bandwidth of 4.8 nm and a linear dispersion slope of 2025 ps/nm and a maximum deviation of 343 ps at the etches of the bandwidth.