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1m Long continuously-written fibre Bragg gratings for combined 2nd and 3rd order dispersion compensation

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Abstract: The authors present the realisation of high-quality 1 m long continuously-written fibre Bragg gratings designed to compensate both 2nd and 3rd order fibre dispersion. These compact devices are ideal for counteracting the effects of fibre dispersion in high bit-rate transmission systems.

Introduction: The coming of age of the Erbium-doped fibre amplifier (EDFA) has led to the widespread adoption of 1.55 μm as the preferred telecommunications wavelength. Short pulse propagation through non-dispersion shifted fibre in the EDFA window leads to a temporal broadening with a 2^{nd} order dispersion of ~17 ps/nm/km. The use of chirped in-fibre Bragg gratings to compensate for this chromatic dispersion has already yielded excellent results in systems trials with transmission rates of up to 40 Gb/s [1]. Even some dispersion shifted fibres (such as AT&T's TrueWave fibre) are designed to have a non-zero 2^{nd} order dispersion in order to suppress four wave mixing. The fundamental limit of bandwidth and dispersion compensation length offered by a single grating is governed by its physical length. In our earlier work [2] we were first to present a continuously-written 1m long grating capable of compensating 50 km of non-dispersion-shifted fibre over a bandwidth of ~10 nm.

With high bit-rate systems it becomes increasingly important that not only 2^{nd} order, but also 3^{rd} order dispersion effects of fibre are exactly compensated for. Until now most successful fibre-grating dispersion compensating schemes have concentrated on just 2^{nd} order dispersion compensation [3-5], with the first (4cm) fibre gratings for higher order dispersion demonstrated by [6]. This paper presents the first examples of 1m long continuously-chirped fibre-gratings designed for the combined compensation of both 2^{nd} and 3^{rd} order dispersion. These gratings are continuously-written in order that they can be used over their entire bandwidth without being affected by performance-degrading glitches in the reflection spectra or time delay characteristic.

Experiment: The development of a powerful moving fibre/phase-mask scanning grating fabrication system at the Optoelectronics Research Centre gives us the flexibility to fabricate single chirped fibre gratings designed to compensate for both 2nd and 3rd order dispersion. This opens the way to broad-band high bit-rate communications. The gratings described in this letter were fabricated with a Coherent FReD frequency-doubled Ar-ion laser using ~100mW of UV power at 244 nm in fibre with an N.A. of ~0.2. Figures 1-3 are results from a dispersion characterisation system based around a tunable laser and a high-accuracy wavemeter; the wavelength resolution of the scan is 5 pm, and the accuracy is 0.1 pm.

Gratings designed to compensate for purely 2nd order dispersion have a local Bragg wavelength that varies linearly with along the length of the grating. Figure 1 shows a 1 m long grating designed to compensate for the second order dispersion from 100 km of non-dispersion shifted fibre over a bandwidth of 5 nm. Both the time delay and reflection of this grating are (clearly) of the highest standard reported to date for a grating of this dispersion-bandwidth product. The strength is uniform to within <1 dB and the time delay deviation is within < 0.5% of the correct value.

In order to compensate for both 2nd and 3rd order dispersion the local Bragg wavelength should vary with a square-root function of the position in the grating. The grating shown in figure 2 was designed to compensate for 578 km of dispersion shifted AT&T TrueWave fibre over a bandwidth of 10 nm (based on 2nd and 3rd order dispersion values of 1.67 ps/nm/km and 0.09 ps/nm^2/km respectively).

Although the lower 2nd order dispersion of such fibre allows data transmission over longer uncompensated lengths than non-dispersion shifted fibre, the 3rd order component must still be compensated for high bit-rate, wide bandwidth systems. For this grating the deviation from linear time delay is ~650 ps at either edge of the bandwidth (figure 3). This clearly shows quadratic wavelength dependence consistent with the desired 3rd order dispersion compensation of 0.09 ps/nm^2/km for a 10 nm bandwidth grating compensating 578 km of fibre.

The strength of the grating shown in figure 2 can be seen to fall at the short wavelength end. This is a result of a non-linear chirp rate along the length of the grating, and could be overcome in the fabrication process by apodising the grating as the chirp rate falls with increasing wavelength. The ripples in the time delay are believed to result from non-uniformities in the phase mask used for fabrication; a higher quality phase mask should alleviate this problem. Nonetheless, there are no serious glitches and the time delay is still within 0.5% of the correct value.

Discussion: The virtues of continuously-written long fibre grating are that they can be wide bandwidth devices capable of compensating for the dispersion of significant fibre lengths. The excellent quality now available from linearly chirped gratings (figure 1) puts fibre-grating dispersion compensation performance on a par with dispersion compensating fibre, but without the problems of non-linearity. The added functionality of 3rd order dispersion compensation (figures 2-3) gives these gratings a significant advantage over other compensation methods in high bit-rate, long haul fibre links.

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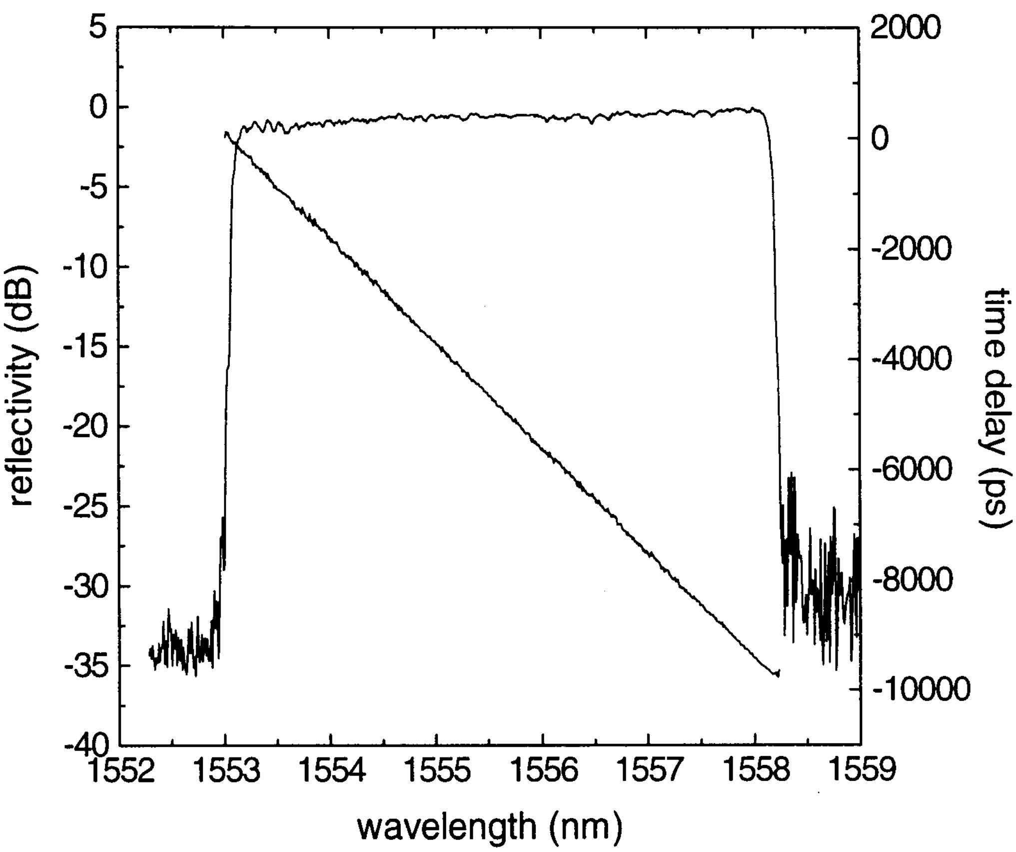

Fig 1. *Reflectivity and time delay of a 1m x 5 nm grating designed to compensate for 2nd order dispersion of 100km of non-dispersion shifted fibre*

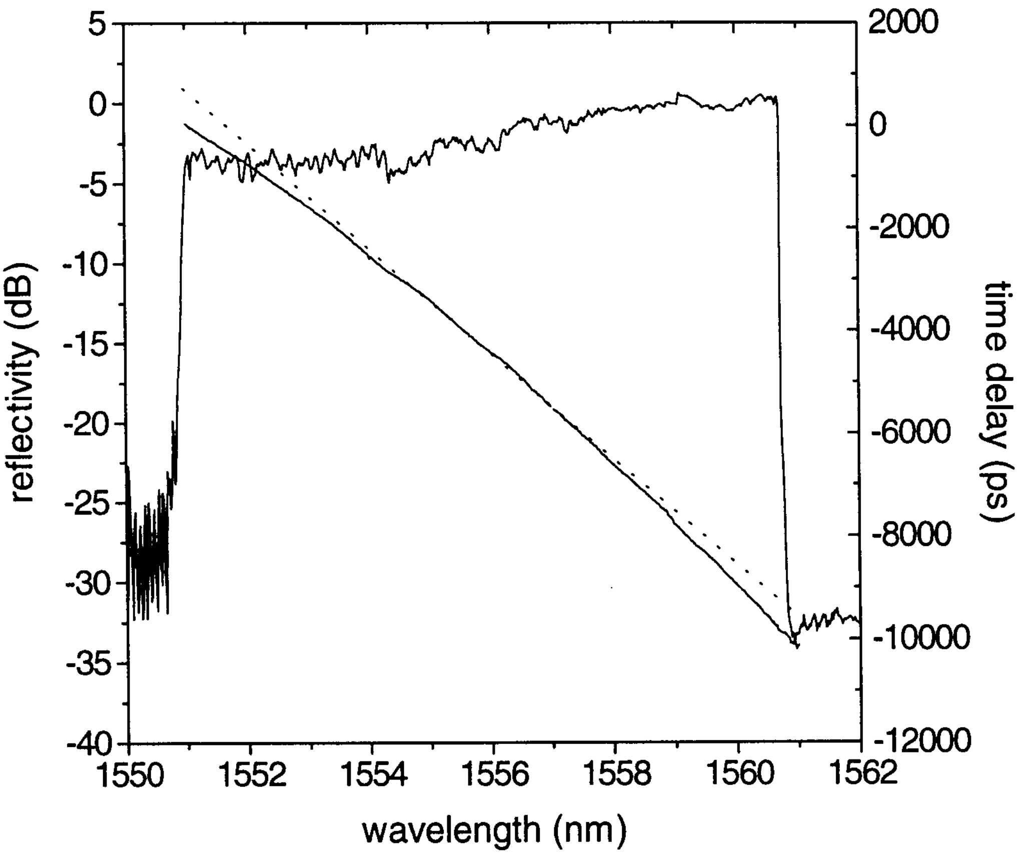

Fig 2. *Reflectivity and time delay of a 1m x 10 nm grating designed to compensate for 2nd and 3rd order dispersion of 578 km of AT&T TrueWave fibre. The dotted line shows the theoretical linear time delay of -1.67 ps/nm·km for a 578 km link of this fibre.*

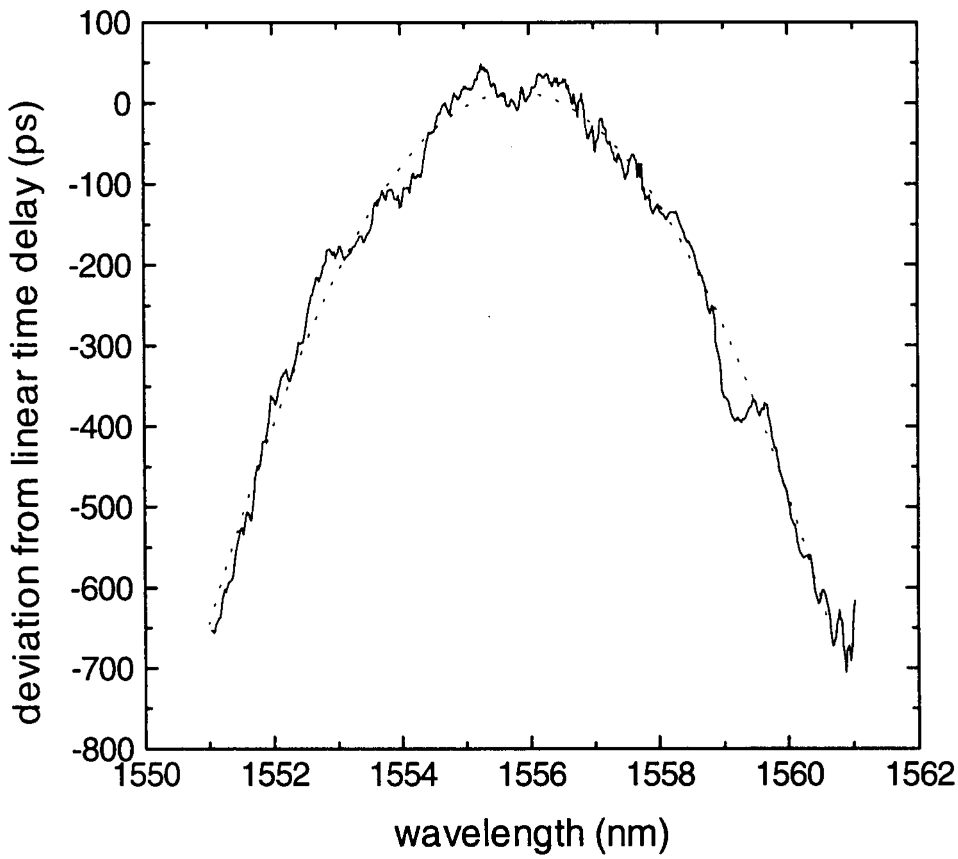

Fig 3. *Deviation from linear time delay of the grating shown in figure 2. The dotted line shows the theoretical quadratic deviation of time delay from linearity of -0.09 ps/nm^2·km for a 578 km link of AT&T TrueWave fibre.*