Advanced Fibre Bragg Gratings for High Performance Dispersion Compensation in DWDM Systems

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We present experimental results of fibre Bragg gratings designed by inverse-scattering for dispersion compensating 80km of standard fibre on a 50GHz grid. The device offers significantly improved bandwidth utilisation and dispersion linearity over conventional designs.

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1. Introduction

The increasing application of DWDM transmission schemes with bit rates of 10 Gb/s and 50 GHz channel spacing places a strict requirement on dispersion management. The use of chirped fibre Bragg gratings to compensate the dispersion of fibre links is a well-known approach that has become increasingly prevalent over recent years. An ideal dispersion compensator should either provide continuous operation over the full bandwidth of a transmission system, or be capable of being closely packed with other such devices in order that every available DWDM channel can be transmitted. These criteria have, to date, been difficult to fulfill with grating technology: a single dispersion compensating grating with a bandwidth of >30nm needs to be several metres in length raising questions of fabrication practicality and packaging concerns; traditional short (<10cm) chirped gratings, which may be packaged athermally and are more straightforward to fabricate, have a low bandwidth filling-factor, and a non-linear group delay response.

In this paper, we present, for the first time, experimental results of gratings designed by a newly-developed layer-peeling inverse-scattering algorithm for single-channel dispersion compensation compatible with 50 GHz DWDM channel spacing. Gratings made by this design procedure have a very high bandwidth utilisation factor, both in terms of reflectivity and linear group delay. They are designed to accommodate RZ signals on a 50 GHz grid, but alternatively will provide high ASE rejection on a 100 GHz grid whilst maintaining a broad useable bandwidth. We believe that this approach overcomes the limitations normally associated with short chirped gratings, whilst retaining their desirable fabrication and packaging characteristics.

2. Design of Gratings for DWDM Dispersion Compensation

It is well known that chirped fibre Bragg gratings (CFBGs) must be apodised in order to linearise their in-band reflectivity and group delay. In order to achieve useable characteristics for dispersion compensation with short (~10 cm, or less) chirped fibre Bragg gratings (CFBGs) the refractive index profile must be quite strongly apodised. A significant reduction in the useable bandwidth (-1dB) of the device compared to its full (-30 dB) width is observed in an attempt to linearise the group delay. It has been noted that asymmetrically apodised CFBGs can give improved performance [1] but the characteristics of such a device still fall significantly short of realising an ideal top-hat reflectivity profile and linear group delay.

Figure 1 shows the spectral characteristics of two apodised CFBGs designed by standard methods to provide dispersion compensation for 80 km of non-dispersion shifted fibre (NDSF) with –30 dB bandwidths of 50 GHz and 100 GHz respectively; the gratings have a partial raised-cosine apodisation profile and have a reflectivity of 90%. It is found that the group delay linearity of the 50 GHz grating is far from ideal with a large variation in dispersion across the device bandwidth. It is also questionable whether a grating such as this would be capable of supporting 10 Gb/s RZ pulses since the useable (-1 dB) bandwidth is just 0.17 nm. The grating designed with a 100 GHz –30 dB bandwidth has a higher filling factor and the group delay linearity is significantly better in the centre of the reflection bandwidth. If such a device was used for 50 GHz channels spacing, however, two channels would sit close to the edge of the reflection bandwidth: there would be a significant variation in grating reflectivity across the bandwidth of a pulse, especially with RZ modulation. The group delay is also clearly non-linear for the higher-wavelength channel that is reflected predominantly from the front part of the grating.

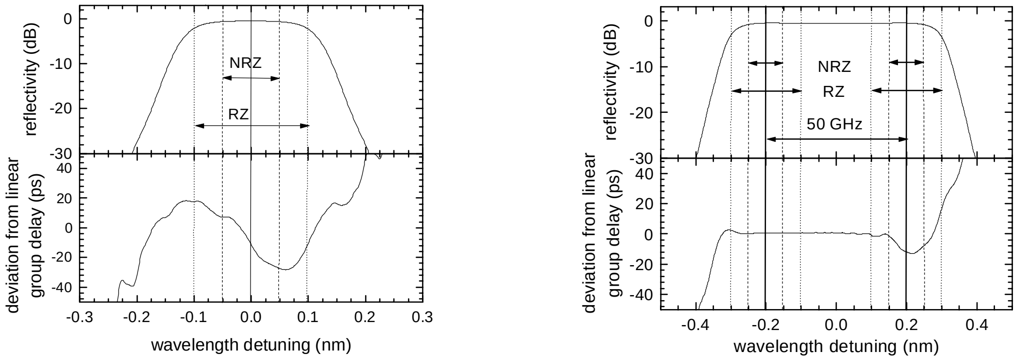

Figure 1. Response of CFBGs designed using traditional apodisation for 50 GHz (*left*) and 100 GHz (*right*) full bandwidth

We have recently developed an exact algorithm for the design of fibre gratings based on a layer-peeling inverse scattering technique [2]. Using this technique we designed a grating structure with the following characteristics: –1dB bandwidth of 0.3 nm; –30 dB bandwidth of 0.4 nm; 90% reflectivity; dispersion compensation for 80 km of NDSF with a dispersion of 17 ps/nm/km; maximum length 10 cm. The apodisation and chirp profiles of the resulting structure are shown in figure 2. It is possible to design devices with a higher bandwidth-utilisation factor still, but the resulting gratings are somewhat longer: an important design consideration was to minimise the length to provide compatibility with both phase mask-scanning grating fabrication techniques and conventional athermal packaging designs.

3. Experimental Results

The grating design show in figure 2 was fabricated using a technique similar to [3] whereby the grating is built up of many beam-sized single-exposure sub gratings separated by a Bragg period, or a fraction thereof; the phase mask used was unchirped and just 1.5 mm x 2 mm in size. Such a grating could equally be fabricated by a phase mask-scanning method [4]. The UV source used was a frequency-doubled Ar-ion laser; the beam was modulated under computer control with an acousto-optic modulator. The germanosilicate fibre used has an NA of 0.2 and was loaded with deuterium at room temperature under a pressure of 145 bars for 10 days. The grating was fabricated at a speed of 1.5 mm/s with ~25 mW average power incident on the fibre. The spectral measurement was made using a tunable laser modulated at 200 MHz in conjunction with a network analyser; the wavelength steps were 5 pm.

Figure 3 shows the characteristics of the device. The reflection and the group delay measurements closely match the theoretical response obtained from using the profile shown in figure 2. Notably the bandwidth utilisation factor (-1 dB bandwidth / -30 dB bandwidth) of the experimental grating is 70%: this is significantly greater than the 41% theoretical value for the linearly-chirped grating designed using conventional apodisation. This grating offers a –1 dB bandwidth of 0.29 nm for a full (-30 dB) bandwidth of 0.41 nm. The out-of-band noise level, whilst not ideal, is less than –35 dB.

The group delay of the grating is also shown in comparison to the theoretical results for both the inverse scattering and the conventional apodisation designs. The inverse scattering design gives (both theoretically and experimentally) extremely linear group delay over the complete reflection bandwidth. The low level of noise on the experimental group delay (±10 ps peak to peak) has a very short spectral period (~10 pm compared to typical pulse widths of 100 – 200 pm) and, from recent results [5], should not have a significant effect on the transmission of 10 Gb/s signals. The peak-to-peak group delay noise of the experimental grating is less than the theoretical deviation of the traditional apodised CFBG with the same bandwidth. Most importantly, the experimental grating does not exhibit the longer period group delay non-linearity typically associated with short apodised CFBGs. This group delay non-linearity, inherent to traditional short CFBGs, is comparable to 10 Gb/s pulse widths and suggests a more significant penalty in terms of transmission systems. The 0.29 nm –1 dB bandwidth allows compatibility with increasingly popular RZ transmission formats. The use of such gratings on a 100 GHz grid will

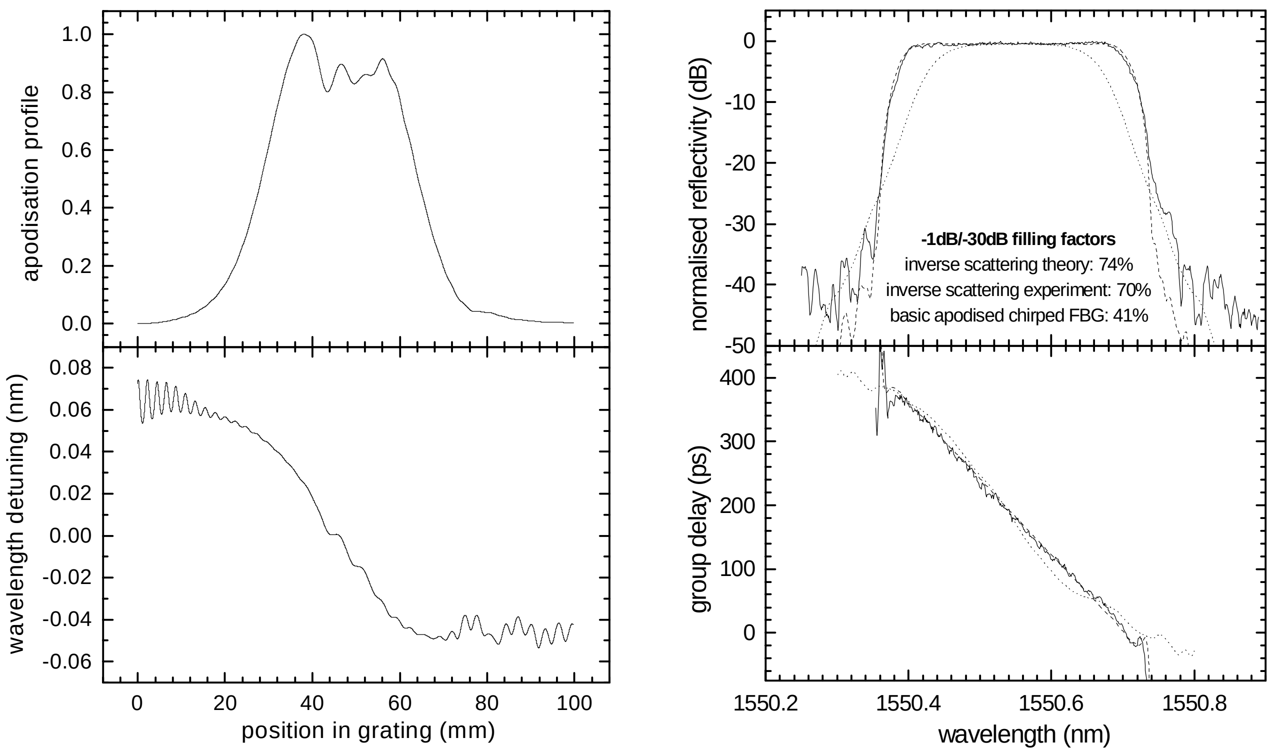

Fig. 2. (*left*) Apodisation and chirp characteristics of grating designed using the inverse-scattering algorithm

Fig. 3. (*right*) Experimental (*solid line*) and theoretical (*dashed line*) characteristics of a grating designed by inverse-scattering compared to the theoretical characteristics (*dotted line*) of a grating with traditional apodisation.

provide ideal dispersion management characteristics, whilst providing a new level of filtering rejection for ASE and non-soliton energy in partial non-linear transmission systems. Such an approach can be used efficiently to suppress both soliton interaction and timing jitter [6].

4. Summary

We have presented experimental results of a fibre Bragg grating designed by a new inverse-scattering algorithm suitable for dispersion compensating 80 km of NDSF on a 50 GHz grid. The device offers significantly improved bandwidth utilisation and group delay linearity over conventional designs. The device is <10 cm in length; it is thus compatible with compact athermal packages and phase mask-scanning fabrication techniques. We envisage the increasing application of such gratings in 10 Gb/s DWDM systems, either to accommodate RZ-modulated signals on a 50 GHz grid, or to provide a high level of ASE filtering on a 100 GHz grid whilst maximising the useable bandwidth.

5. References

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