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40GBIT/S HIGH PERFORMANCE FILTERING FOR DWDM NETWORKS EMPLOYING DISPERSION-FREE FIBRE BRAGG GRATINGS

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Abstract: Near penalty-free filtering with high bandwidth utilisation at 40Gbit/s is demonstrated for the first time using fibre Bragg gratings. When tested in a typical add-drop configuration a 100GHz dispersion-free Bragg grating show Q-penalty variations of less than 1.0dBQ over most of the 1dB reflection-bandwidth confirming its superior performance.

Introduction

Bandwidth expansion is urgently required and currently there are a number of techniques to increase system capacity of both existing and future networks. The different approaches under investigation include wavelength division multiplexing (WDM) and time division multiplexing (TDM) or a combination of the two to reduce overall cost of components in a system /1/. When operating at higher bit-rates though dispersion effects begin to impose restrictions on data recovery and for example in 40Gbit/s transmission systems the tolerable dispersion-limit for ~1dB power penalty is only a few kilometer transmission in standard fibre (<100ps/nm). Therefore, operation at such high bit-rates calls for filters that can perform filtering duties without additional distortion from for example this dispersion mismatch or other filter irregularities. Furthermore, when packing channels onto a very dense frequency grid, a number of additional issues have to be considered including the ability to guaranty operation over most of the allocated grid window to obtain maximum bandwidth utilisation without sacrificing channel integrity. Filters that currently are in use in 40Gbit/s systems experiments and tests includes the thin-film designs, but the poor spectral squareness of these reduces the actual bandwidth utilisation to ~30% or less /2/ indicating that 40Gbit/s filtering on for example a 100GHz dense WDM (DWDM) grid not is possible with these filters without suffering sever signal-clipping. Typically when designing for high spectral squareness and low insertion-loss (or high channel drop), most filters, including standard apodised Bragg grating filters /3/, experiences a strong increase of the dispersion which can result in a reduction in actual bandwidth utilisation due to these dispersion effects also sometimes referred to as the dispersion limited useful bandwidth /3/. Recently we introduced a linear-phase Bragg grating filter design for dispersion free filtering with additional very high bandwidth utilisation for operation at 10Gbit/s at 25GHz and 50GHz channels spacings /4,5/ and showed how these greatly improve filtering performance in DWDM.
In this paper we show for the first time that near penalty-free operation at 40Gbit/s is possible from mux/demux Bragg gratings and demonstrate that as much as 75% bandwidth utilisation can be obtained when employing dispersion-free Bragg gratings.

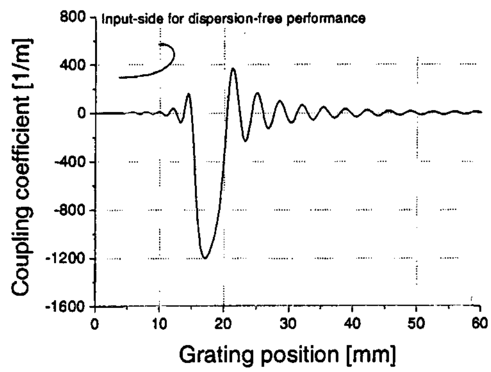

Figure 1: Refractive index profile of and input-side for dispersion-free Bragg grating.

Experiment and discussion

The dispersion-free Bragg grating demonstrated here is designed using an inverse scattering technique /6/ to have a ratio of the 1dB reflection bandwidth to the 30dB reflection bandwidth of 75%, a constant reflectivity of 99.9% and a linear-phase performance across the 1dB reflection-band to ensure zero dispersion. This yields a total length of the grating of 6cm and a maximum coupling coefficient of $\kappa \sim 1200 m^{-1}$ ($\delta n \sim 8 \cdot 10^{-4}$). Fig. 1 shows that refractive index profile of this 100GHz dispersion-free Bragg grating. The grating is written using our "continuous grating writing" technique, which provide full control of both the phase and amplitude profiles in the grating /7/. The entire grating is written using only positive refractive index, so grating-regions requirering a "negative" index-modulation is realised by inserting a discrete π-phaseshift everytime there is a sign-transition in the coupling coefficient profile. The measured reflection and time-delay spectra of the manufactured grating is shown in Fig. 2a and they confirm the near square spectral performance of the grating and additionally demonstrate the near constant time-delay (~5ps rms ripple) and thus dispersion-free characteristics of the grating.
To test the dispersion performance of the grating a CW laser externally modulated at 40Gbit/s simulates a transmitter

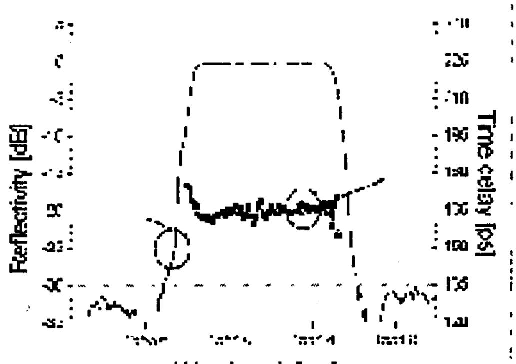

Figure 2a: Measured reflectivity and time-delay characteristics of the dispersion-free 100GHz Bragg grating.

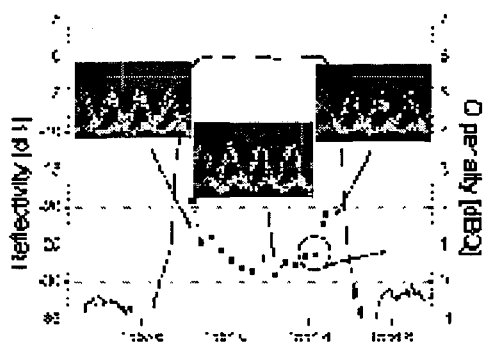

Figure 2b: Measured Q-penalties + additional eye-diagrams across the bandwidth for the dispersion-free 100GHz Bragg grating.

which then is scanned across the bandwidth of the grating. The 40Gbit/s transmitter consist of electronically multiplexing of four 10Gbit/s streams to 40Gbit/s driven at 50% duty-cycle and a 2^{31}-1 PRBS /8/. When analysing the grating this is placed in a typical drop configuration and to test the pure dispersion induced penalties the power input to the receiver is kept constant. In this the 40Gbit/s signal is optically de-multiplexed back down to 10Gbit/s. When scanning the wavelength across the bandwidth of the grating the Q-factor at each position is recorded and the eye-diagrams are observed to study the quality of these. The Q-factors from the grating then are compared with the back-to-back measurement of the receiver ($Q_{b\text{-}to\text{-}b}$ ~14dB). To quantify the induced penalty from insertion of the grating the Q-penalty is defined as $dBQ=10\cdot\log(Q_{b\text{-}to\text{-}b}/Q_{grating})$ and the results of these experiments and the eye-diagrams of 3 positions (centre and either edge) within the reflection-band are summarised in Fig. 2b. These results show that the Q-penalty is less than 1dBQ across most of the 1dB reflection-bandwidth, thus confirming the near penalty-free operation on the grating.

To compare the performance of the dispersion-free Bragg grating with a filter of similar spectral squareness (~75%), a standard apodised Bragg grating of length 15mm is made /3/. This grating also has a maximum coupling coefficient of κ~1200m^{-1} and is apodised using a "standard" symmetric Blackman profile. It can be seen that the dispersion-free grating and this "standard" apodised grating (Fig. 2&3, reflectivities) are spectrally near equivalent but the time-delay

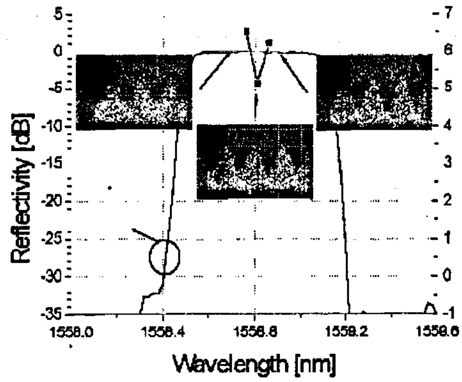

Figure 3: Measured reflectivity and Q-penalties + additional eye-diagrams for the "standard" apodised Bragg grating.

in the case of the "standard" grating shows a maximum deviation of ~50ps from the centre to the edge of the grating and therefore confirms the non-zero dispersion across the reflection band increasing to ~+ and - 250 ps/nm respectively at the edges of this filter (not shown due to limited space). When tested under similar conditions as the dispersion-free grating it is indeed found to be impossible to recover the eye-diagrams even in the centre of the stop-band, and the Q-factors are less than ~3dB confirming Q-penalties in excess of 5dBQ across the full bandwidth demonstrating the severe dispersion induced penalties from this filter (Fig.3).

As highlighted in Fig. 1 the refractive index profile required to obtain dispersion-free performance of the Bragg gratings is asymmetric. This asymmetry only affects the phase-response of the grating, and when measured from the opposite side the time-delay can be seen not to be constant and therefore that the dispersion is non-zero. This is also confirmed by testing it from this side under similar conditions as discussed above. The Q-factors in this case are as with the standard Bragg grating ~3dB. Therefore, these devices are directional and will *only* provide linear-phase performance with an input direction as indicated in Fig. 1.

Conclusions

We have reported the first demonstration of 40Gbit/s operation on Bragg gratings for uniform add-drop applications in DWDM networks. We show how dispersion-free Bragg gratings can enhance the bandwidth utilisation for WDM transmission at frequency separations down to 100GHz at 40Gbit/s and have demonstrated the superior performance from these filters compared with "standard" apodised Bragg gratings. Our results confirm that to obtain high bandwidth utilisation with minimum dispersion induced penalty, dispersion-free Bragg gratings indeed are near ideal devices.

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