All-Fibre 4x10 Gbit/s WDM Link With DFB Fibre Laser Transmitters and a Single Sinc-Sampled Fibre Grating Dispersion Compensator

Morten Ibsen, Alexander Fu, Harald Geiger and Richard I. Laming

Optoelectronics Research Centre, University of Southampton,
SO17 1BJ Southampton, United Kingdom
Tel: +44-1703-593138, Fax: +44-1703-593142,
E-mail: mi@orc.soton.ac.uk

ABSTRACT

Robust WDM transmission and dispersion compensation at 40 Gbit/s over 200 km standard fibre is demonstrated on a 100 GHz grid using four high power single-polarisation single-sided output DFB fibre laser based transmitters. Simultaneous dispersion compensation of the channels is performed with a single 4 channel chirped WDM fibre Bragg grating.

Indexing Terms - Sinc-sampled fibre Bragg gratings, DFB Fibre grating lasers, WDM transmission, Dispersion compensation.

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INTRODUCTION

Wavelength division multiplexing (WDM) systems have attracted growing attention over the past years because of their obvious advantages when upgrading system capacity [1]. Current system designs employ semiconductor laser technology for the transmission sources. These have the advantage of direct modulation for un-chirped data-rates up to ~ 2.5 Gbit/s; however, they do suffer from high temperature sensitivity and low fabrication yield. Fibre grating lasers have a high fabrication yield and can be temperature stabilised by simple means. The slow gain response of fibre lasers imply that they must be operated with an external modulation scheme if they are to be employed as signal sources, but this type of modulation approach must be adapted for un-chirped bit-rate operations of 10 Gbit/s and above anyway when operating semiconductor lasers. Distributed feedback (DFB) fibre lasers has the advantage of providing a large signal to noise ratio (SNR) between adjacent channels [2], which is of such critical importance in WDM systems to avoid cross-talk. Inherent fibre compatibility, pure single mode operation [3] and high power single sided CW output [4] are points that add to the list of advantages of employing DFB fibre lasers as the transmitter source in WDM systems.

Another interesting device well suited for all-fibre WDM applications is the recently developed sinc-sampled Bragg grating [5]. This grating provides a series of wavelength channels with accurate inter-channel separations that readily can be set to a specified ITU grid.

In this paper we combine the devices and demonstrate for the first time a WDM system comprising 4 high power DFB fibre lasers operating with single sided and single polarisation outputs. The lasers are demonstrated to be reliable signal sources in a 4x10 Gbit/s, 100 GHz channel spacing WDM transmission experiment over 200 km of standard fibre, with robust dispersion compensation performed by a single 4 channel 100 GHz spacing chirped sinc-sampled fibre Bragg grating.

EXPERIMENT

The experimental setup (Fig. 1) consists of 4 single polarisation asymmetric DFB-fibre lasers [3] of length 5 cm separated in frequency by 100 GHz. The lasers have phase shifts offcentret by 4 mm resulting in an output power ratio of ~50:1. Each is pumped with ~60 mW power from 980 nm pump diodes, resulting in single sided output powers of 7.1 dBm, 7.7 dBm, 7.0 dBm, and 7.7 dBm, and operating wavelengths of 1547.6 nm, 1548.4 nm, 1549.2 nm and 1550.0 nm respectively. The signal to noise ratio between the 4 DFB signal channels is in excess of 50 dB (0.08 nm resolution) and the polarisation purity of the devices is greater than 40 dB. Noise measurements of the lasers show RIN < -170 dB/Hz for frequencies larger than 20 MHz, indicating very quiet sources with performance well suited for high speed communication systems. The polarisation states of the lasers are individually aligned using polarisation controllers to allow modulation in a single modulator. The excess power of the lasers allows their output to be combined in an all-fibre multiplexer consisting of three 1550 nm 3 dB splitters, before each channel is modulated using a lithium niobate ($LiNbO_3$) modulator. Fig. 2a shows the output spectra of the 4 DFB fibre lasers measured directly after the modulator. The WDM channels are amplified and then transmitted over a 200 km standard telecommunication fibre (D=16 ps/nm/km @ 1.55 μm) link. Ultimately the high power of the fibre DFB's will obviate the requirements for amplification prior to transmission. After transmission the channels are simultaneously dispersion compensated with a single 4 channel sinc-sampled fibre grating [5], which is wavelength matched to the transmitted channels (Fig. 2). The grating has a sampling period of 1 mm resulting in the 100 GHz channel spacing [5] and is 25.8 cm long. It is chirped over 0.8 nm and is apodised over 10 % of the total length at either end to reduce the ripples in the dispersion characteristics. Each dispersion-compensating channel of the grating exhibits a reflectivity of ~60 % and dispersions of -3263 ps/nm, -3206 ps/nm, -3250 ps/nm and -3238 ps/nm respectively with a maximum in-band time delay ripple of ~50 ps (Fig. 2b&c). A uniform fibre grating used in an add-drop configuration, selects the channel under test and drops it onto the receiver and error detector. All the fibre gratings used in this experiment are manufactured using a continuous grating writing technique [5,6,7] which allows very complex grating structures to be formed.

RESULTS AND DISCUSSION

Bit error rate (BER) vs. received power for the 4 dispersion compensated channels and back-to-back with DFB laser no.1 are shown in Fig. 3. The figure shows a maximum power penalty of 1 dB for error free operation. This variation could be due to the fact that a different pick-out grating is used for each channel. In order to test the quality of the dispersion compensating grating, a wavelength scan across the bandwidth of channel 2 was made. In this case the received power was kept constant at -34.5 dBm and the BER was recorded. A variation of 2 orders of magnitude in the error rate around 10^{-8} was measured, corresponding to a less than ±0.75 dB power penalty (Fig. 3). The effect of cross talk between adjacent channels was also evaluated by comparing BER data for the WDM system with data obtained when transmitting only one of the wavelength channels at a time. No degradation in the performance of the system was observed. In order to compare the performance of the fibre DFB laser transmitters with a traditionally used tunable semiconductor laser source (TUNICS) a single channel BER measurement tuned onto channel 3 using this source was performed. Again no significant difference was observed (Fig. 3).

CONCLUSIONS

We have demonstrated the first 4 channel 10 Gbit/s NRZ WDM transmission experiment over a 200 km standard fibre link employing high power all-fibre DFB lasers as transmitter sources. Simultaneous dispersion compensation of the 4 channels was performed using a sinc-sampled multichannel fibre grating that exhibits identical dispersion characteristics on a 100 GHz comb of wavelength channels. We believe that this experiment demonstrates that the technology of fibre DFB lasers has matured and that they are an attractive transmitter alternative to semiconductor DFB lasers and are ready to take part in the realisation of highly transparent all-fibre WDM transmission systems.

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FIGURE CAPTIONS

Fig. 1. Schematic diagram of the experimental setup.

Fig. 2. a) DFB fibre lasing spectra after the modulator.

b) Reflection and

c) time delay characteristic of the 4 channel chirped sinc-sampled fibre Bragg grating.

Fig. 3. BER performance of simultaneous 4x10 Gbit/s WDM transmission system. (Insert) Dispersion compensated eye of channel 4 for BER = 10^{-9}.

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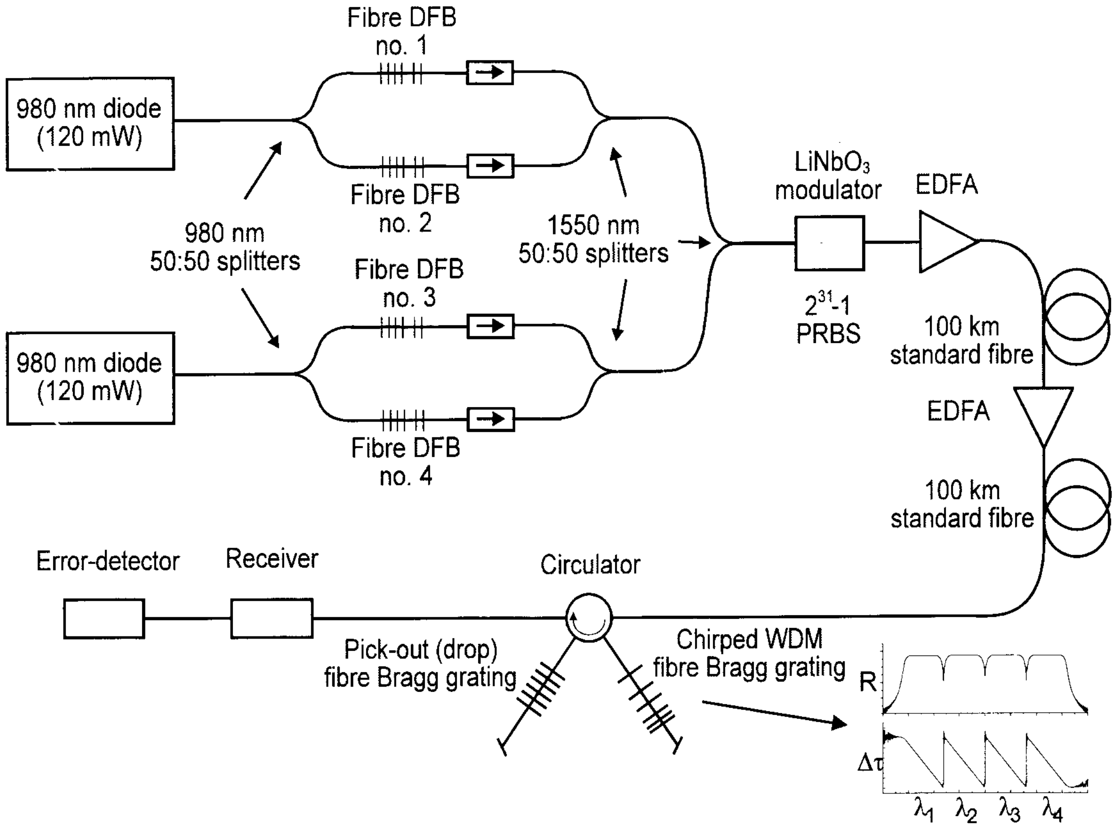

Fibre DFB
no. 1
980 nm diode
(120 mW)
Fibre DFB
no. 2
980 nm
50:50 splitters
Fibre DFB
no. 3
1550 nm
50:50 splitters
LiNbO3
modulator
EDFA
2^31-1
PRBS
100 km
standard fibre
980 nm diode
(120 mW)
EDFA
Fibre DFB
no. 4
100 km
standard fibre
Error-detector
Receiver
Circulator
Pick-out (drop)
fibre Bragg grating
Chirped WDM
fibre Bragg grating
R
Δτ
λ1 λ2 λ3 λ4

Fig. 1

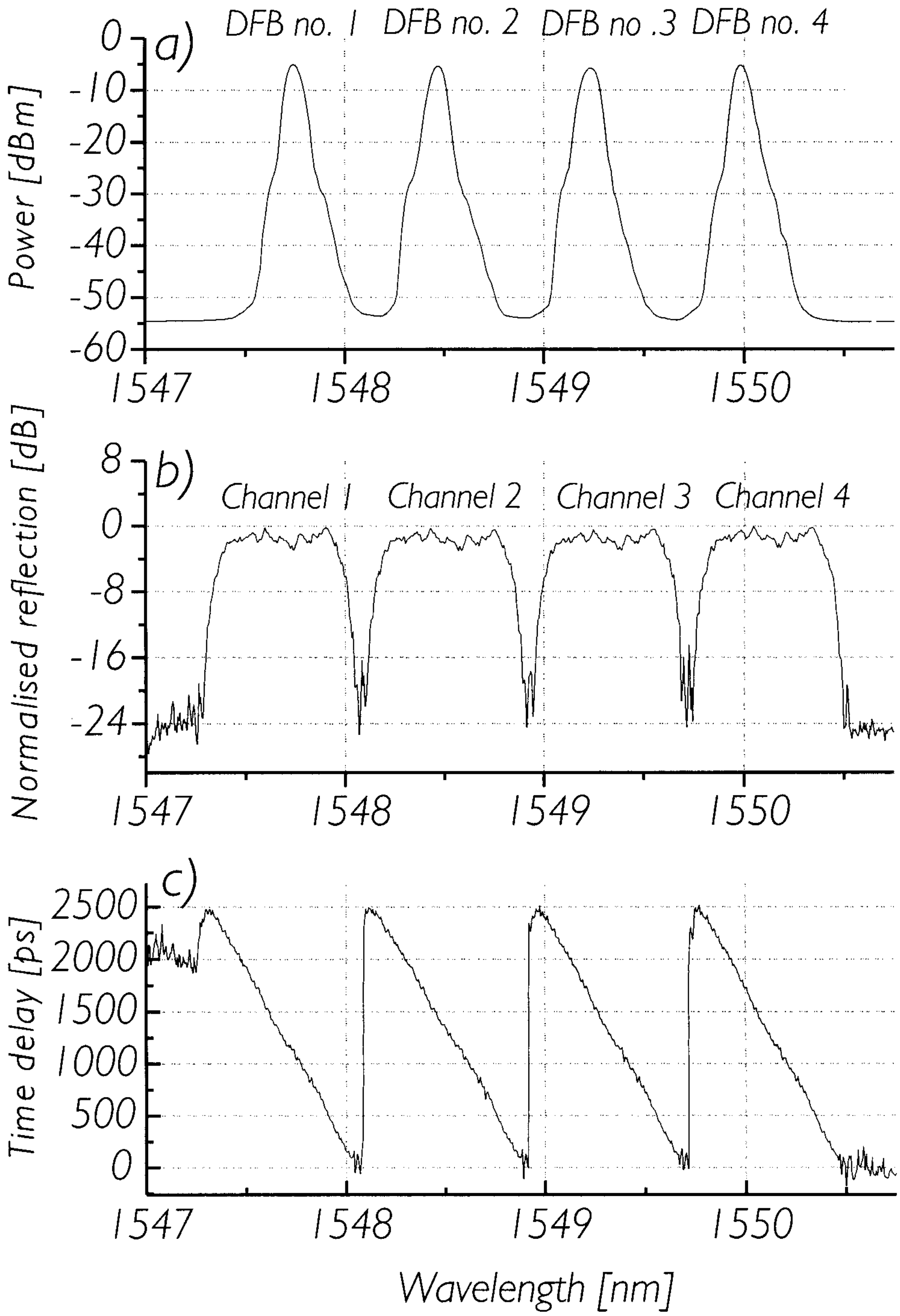
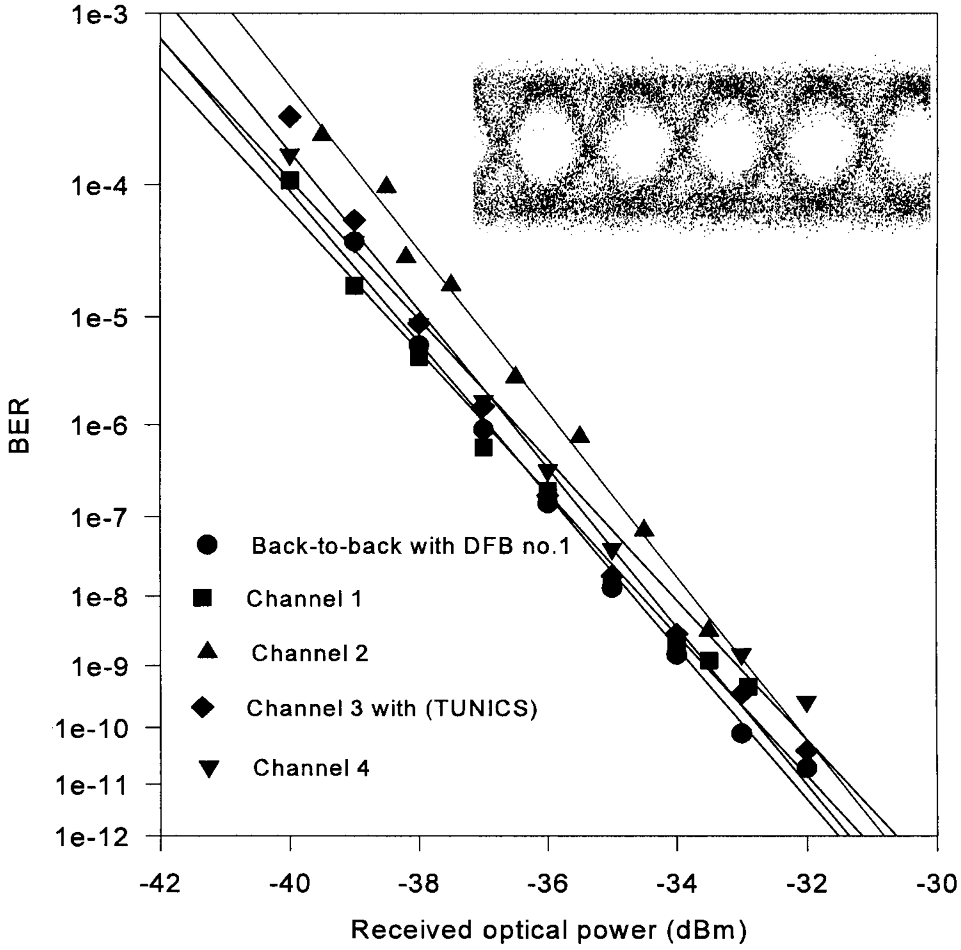

a)
DFB no. 1
DFB no. 2
DFB no .3
DFB no. 4
Power [dBm]
0
-10
-20
-30
-40
-50
-60
1547
1548
1549
1550
b)
Channel 1
Channel 2
Channel 3
Channel 4
Normalised reflection [dB]
8
0
-8
-16
-24
1547
1548
1549
1550
c)
Time delay [ps]
2500
2000
1500
1000
500
0
1547
1548
1549
1550
Wavelength [nm]

Fig. 2



1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
1e-9
1e-10
1e-11
1e-12
BER
-42
-40
-38
-36
-34
-32
-30
Received optical power (dBm)
● Back-to-back with DFB no.1
■ Channel 1
▲ Channel 2
◆ Channel 3 with (TUNICS)
▼ Channel 4

Fig. 3.