separately appropriate chromatic dispersion compensating fibre is inserted before the optical receiver. The averaged value of the Q-factor is 16.1dB, corresponding to a 1.1×10^{-10} error rate. As the remarkable degradation of the signal transmission performance is not observed due to the high repeater output power and the ultralong distance transmission in this measurement, we have utilised the whole 7.5nm bandwidth for data transmission. The maximum and minimum value of the measured Q factor in each channel are 17.0 and 15.3dB, respectively. This 1.7dB difference is considered to be mainly due to that of the transmitters' characteristics and the incompleteness of the transmitter's pre-emphasis.

Conclusion: We have successfully achieved sufficient broadening of the usable bandwidth for 16 WDM signal transmission using gain equalised amplifier repeaters. We have also demonstrated 16 channel 2.5Gbit/s WDM transmission over 9000km, containing 134 repeaters. The amplifiers used are pumped by conventional 1.48μm LDs and the bandwidth used for data transmission is 7.5nm (0.5×15nm) with the transmitter's small amount of pre-emphasis. The measured Q-factor is ~16dB on average over 16 channels. Such a performance may be attributed to the well-controlled gain equalisation and manufacture of gain equalisation filters. These results demonstrate the promise of practical WDM transmission with a high capacity over ultralong distances.

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38.5km error free transmission at 10 Gbit/s in standard fibre using a low chirp, spectrally filtered, directly modulated 1.55μm DFB laser

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Indexing terms: Distributed feedback lasers, Optical communication

1.55μm DFB lasers with extremely high bandwidth and low wavelength chirp for local distribution at 10Gbit/s are described. Time resolved chirp measurements direct from the laser, and after a transient chirp reducing filter, show very small wavelength variations, allowing error free transmission over 18.4km (without filter) and 38.5km (with filter) in standard singlemode fibre without the use of dispersion compensation.

Introduction: With the drive to higher data rates for short (<50km) local distribution trunks, the push for a 10Gbit/s source has increased. Integrated DFB/electroabsorption modulation devices provide an attractive source at 1.55μm as their low chirp allows transmission through standard fibre (zero dispersion at 1.3μm) over 70km, and up to 130km with negative chirp operation [1]. Links up to 50km become attractive if the design does not require an erbium doped fibre amplifier, which increases system cost and complexity. This limitation puts a premium on high source output power, and therefore favours DFB lasers, which provide higher coupled output power than more complex integrated devices. The main limitation of 1.55μm DFB lasers is wavelength chirp, with low chirp requiring very low values of the linewidth enhancement factor 'α'. Singlemode sources operating at 1.3μm have low dispersion penalty, but require far higher output powers to overcome increased fibre losses.

Results and discussion: In this Letter we describe 1.55μm DFB lasers using *p*-doped compressively strained multiquantum-well (MQW) active regions to provide devices with extremely high modulation bandwidths and low wavelength chirp. The devices exhibit levels of differential gain far beyond standard strained MQW lasers, providing –3dB modulation bandwidths of 26GHz, and α factors as low as 1 [2, 3]. The packaged device used in these experiments includes a matching impedance to provide a 50Ω load to the driving amplifier, and has a –3dB modulation bandwidth of 25GHz at 80mA bias. A 10Gbit/s 2^{31}–1 PRBS signal is amplified to $4V_{pp}$ and applied to the laser with a variable DC bias.

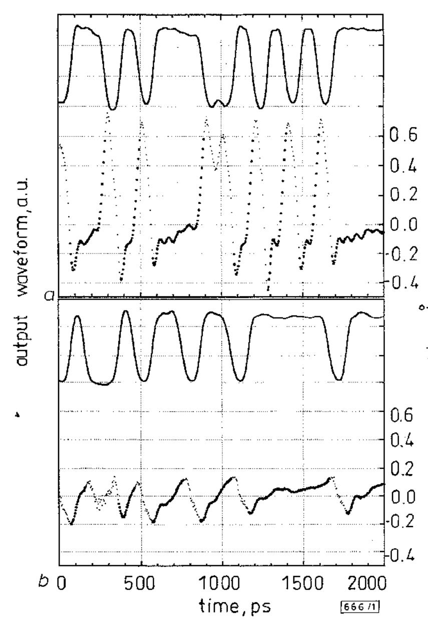

Fig. 1 *Output waveform and instantaneous wavelength traces for directly modulated DFB with bias of 80mA and $4V_{pp}$ at 10Gbit/s*

a No spectral filter
b With 2 Å spectral filter

The transient wavelength variation is measured using the time-resolved spectroscopy technique [4]. Output power and instantaneous wavelength traces are shown in Fig. 1*a* for a bias level of 80mA. A low peak to peak wavelength excursion of 1.1Å seen during the ON state (between half maximum power points) will allow transmission over 10–20km in standard singlemode fibre. The majority of the chirp occurs during the rise and fall transients, and is especially pronounced during OFF to ON transitions because the laser approaches threshold during the OFF state and relaxation oscillations occur during turn-on. This chirp can be reduced by increasing the DC bias to eliminate ringing during the transition, however it is accompanied by a reduced extinction ratio of 7.2dB for 80mA bias, compared to 10.2dB for 70mA bias.

Operation at 10Gbit/s makes it practical to use a narrowband spectral filter [5, 6] to remove the transient chirp. A major requirement is for a DFB with extremely short rise/fall transients, allowing a stable operating wavelength to be reached within one bit period. By passing the DFB output through a 2Å filter centred on the ON state wavelength, the transient chirp is reduced to extremely low levels. An optical spectrum analyser (OSA) with preselector output (HP 70951A) was used as the filter. In a practical system a fibre Bragg grating could be used, which could also provide a stable wavelength reference for WDM systems. This simple filter would remove the large loss of using an OSA filter (10dB), and also eliminate the low frequency amplitude variation seen in the power out of the OSA. Fig. 1*b* shows the measured chirp for the optimum filter wavelength setting. This results in a peak to peak chirp of only 0.33Å. The use of a spectral filter has the added advantage of increasing the extinction ratio significantly, by selectively transmitting power at the ON stale wavelength, giving an extinction ratio of 13.9dB for 100mA DC bias. This allows the device to be operated at a higher DC bias, and therefore produce cleaner waveforms with low turn-on jitter and reduced chirp, followed by the filter which provides a good extinction ratio.

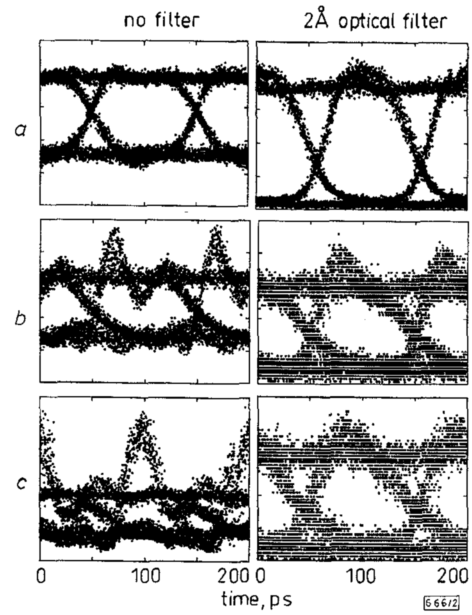

Fig. 2 *Eye diagrams for 100mA DC bias and 4V_{pp} at 10Gbit/s, 2^{31}–1 PRBS, with and without 2Å spectral filter*

a Back-to-back
b After 18.4 km of standard singlemode fibre
c After 38.5 km of standard singlemode fibre

The measured eye diagrams for back-to-back, and transmission through 18.4 and 38.5km of standard singlemode fibre for the cases with and without a spectra filter are shown in Fig. 2. The corresponding BER measurements are shown in Fig. 3. Without the filter, error free transmission (10^{-10} BER) is achieved over 18.4km of fibre, due to the intrinsically low chirp from these devices. Using the spectral filter the back-to-back sensitivity is increased due to the higher extinction ratio, and error tree transmission is achieved over 38.5km with a sensitivity of –17.3dBm, giving a 3dB penalty. The filtered system transmission is optimised by increasing the laser DC bias (lower extinction before the filter). This keeps the chirp to the long wavelength side of the ON state wavelength by removing any overshoot/ringing in the output waveform, so that the filter can be set to the ON wavelength and remove the power in the transients. In these experiments the transmission distance is limited by low frequency amplitude noise added by the OSA, which should be removed by moving to a simple fixed filter.

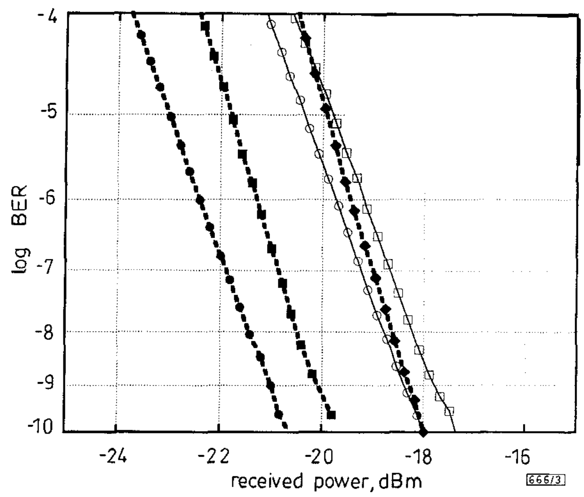

Fig. 3 *BER comparisons for cases shown in Fig. 2*

○ back-to-back, no filter
□ 18.4 km, no filter
● back-to-back, filtered
■ 18.4 km, filtered
◆ 38.5 km, filtered

Conclusions: We have described a directly modulated 1.55µm DFB with very low wavelength chirp. Transmission at 10 Gbit/s over 18.5km of standard fibre is obtained. By passing the output through a narrow spectral filter the laser chirp is significantly reduced, allowing error free transmission over 38.5km without using dispersion compensation or fibre nonlinearities.

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