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Low power penalty 80 to 10 Gbit/s OTDM demultiplexer using standing-wave enhanced electroabsorption modulator with reduced driving voltage

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fibre types for long-haul 40 Gbit/s transmission. It is also worth mentioning that ultra-long-haul transmission of 10 Gbit/s channels on TWRS fibre on the same platform used in this experiment has been demonstrated earlier [7].

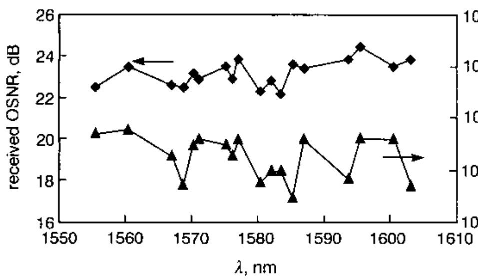

Fig. 4 *Received OSNR and BER after 1600 km transmission of TWRS*

Conclusion: We have demonstrated DWDM transmission performance at 40 Gbit/s over distances greater than 1000 km for various commercially available fibre types with large (>2 dB) *Q*-margins. The transmission was achieved by using forward and backward Raman amplification and backward-pumped DCMs. The singleband all-Raman platform is proved to support transmission over commercial fibre types for 40 Gbit/s long-haul and for 10 Gbit/s ultra-long-haul applications. A single platform approach for both data rates is very attractive for commercial viability of 40 Gbit/s systems.

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References

1 CAI, J.-X., NISSOV, M., PILIPETSKII, A.N., DAVIDSON, C.R., MU, R.-M., MILLS, M.A., XU, L., FOURSA, D., CORBETT, P.C., SUTTON, D., and BERGANO, N.S.: '1.28 Tb/s (32 × 40 Gb/s) transmission over 4,500 km'. Proc. ECOC 2001, Amsterdam, The Netherlands, 2001, Th.M.4.5.

2 ZHU, B., LENG, L., NELSON, L.E., KNUDSEN, S., BROMAGE, J., PECKHAM, D., STULZ, S., BRAR, K., HORN, C., FEDER, K., THIELE, H., and VENG, T.: '1.6 Tb/s (40 × 42.7 Gb/s) transmission over 2000 km of fiber with 100-km dispersion managed spans'. Proc. ECOC 2001, Amsterdam, The Netherlands, 2001, Paper PD.M1.8.

3 BIGO, S., IDLER, W., ANTONA, J.-C., CHARLET, G., SIMONNEAU, C., GORLIER, M., MOLINA, M., BORNE, S., DE BARROS, C., SILLARD, P., TRAN, P., DISCHLER, R., POEHLMANN, W., NOUCHI, P., and FRIGNAC, Y.: 'Transmission of 125 WDM channels at 42.7 Gb/s (5 Tb/s capacity) over 12 × 100 km of TeraLight ultra fiber'. Proc. ECOC 2001, Amsterdam, The Netherlands, 2001, Postdeadline Paper PD.M1.1

4 GNAUCK, A.H., RAYBON, G., CHANDRASEKHAR, S., LEUTHOLD, J., DOERR, C., STULZ, L., AGARWAL, A., BANERJEE, S., GROSZ, D., HUNSCHE, S., KUNG, A., MARHELYUK, A., MAYWAR, D., MOVASSAGHI, M., LIU, X., XU, C., WEI, X., and GILL, D.M.: '2.5 Tb/s (64 × 42.7 Gb/s) transmission over 40 × 100 km NZDSF using RZ-DPSK format and all-Raman-amplified spans'. Proc. OFC 2002, Anaheim, CA, USA, 2002, Postdeadline Paper FC2-1

5 MIYAMOTO, Y., KUWAHARA, S., HIRANO, A., TADA, Y., YAMANE, Y., and MIYAZAWA, H.: 'Reduction of non-linear cross talk by carrier suppressed RZ format for 100 GHz-spaced N × 43 Gbit/s WDM in non-zero dispersion shifted band'. Proc. ECOC 2001, Amsterdam, The Netherlands, 2001, Th.B.1.3.

6 GROSZ, D.F., KUNG, A., MAYWAR, D.N., ALTMAN, L., MOVASSAGHI, M., LIN, H.C., FISHMAN, D.A., and WOOD, T.H.: 'Demonstration of all-Raman ultra-wide-band transmission of 1.28 Tb/s (128 × 10 Gb/s) over 4000 km of NZ-DSF with large BER margins'. Proc. ECOC 2001, Amsterdam, The Netherlands, 2001, Postdeadline Paper P.D.1.3

Low power penalty 80 to 10 Gbit/s OTDM demultiplexer using standing-wave enhanced electroabsorption modulator with reduced driving voltage

Hsu-Feng Chou, Yi-Jen Chiu, L. Rau, Wei Wang, S. Rangarajan, J.E. Bowers and D.J. Blumenthal

Low power penalty 80 to 10 Gbit/s demultiplexing using a novel standing-wave enhanced electroabsorption modulator is reported. In this new design, an electrical standing-wave pattern is formed deliberately along the travelling-wave electrodes, reducing the driving voltage required for high-speed demultiplexing.

Introduction: The electroabsorption modulator (EAM) has been shown to be a key component in realising high-speed optical time-division multiplexing (OTDM) systems [1, 2]. The functionality of the EAM includes pulse generation, data modulation, optical demultiplexing and clock recovery. Except for data modulation, which is broadband in nature, the EAM is usually driven by a monotonic electrical signal and acts as an optical gate. Therefore, it is of interest to improve the single frequency performance of the device. Recently we reported a standing-wave enhanced mode of the EAM for 40 GHz optical pulse generation [3]. In this Letter, we apply this concept to 10 Gbit/s and demonstrate 80 to 10 Gbit/s demutiplexing with reduced microwave driving voltage. Previously, demultiplexing at this bit rate using electrically gated EAM must be achieved with tandem EAMs [4] or a single EAM with a high bias (10 V) and a high driving voltage (11 V_{pp}) [5].

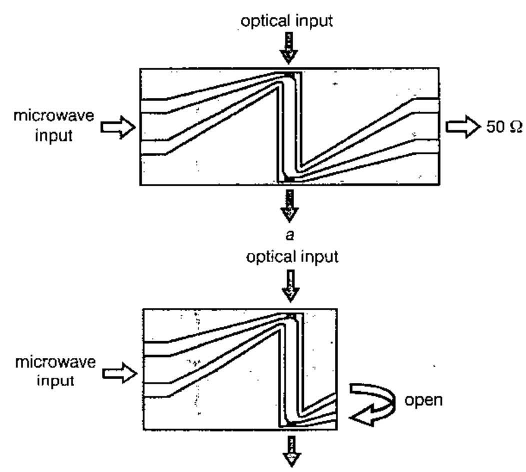

Fig. 1 *Schematic drawing of operation modes*
a Travelling-wave mode
b Standing-wave enhanced mode

Operation modes: Travelling-wave electrodes (CPW lines) are incorporated into the EAM used in this Letter to overcome the RC time limitation [6]. With >20 GHz of bandwidth, the length of the active waveguide can be as long as 300 μm, resulting in a static extinction ratio of more than 50 dB [7]. The maximum modulation efficiency can reach 30 dB/V for the TM polarisation. Travelling-wave operation was verified both experimentally and theoretically [8]. The operation modes for the 80 to 10 Gbit/s demultiplexer are shown schematically in Fig. 1. In the travelling-wave mode, the EAM is terminated with a 50 Ω load, whereas in the standing-wave enhanced mode, an open termination is used instead to reflect the microwave and forms a standing-wave along the CPW line. Since the length of the active waveguide is only 1/20 of the 10 GHz microwave wavelength, the termination CPW line is cleaved shorter so that the open can be closer (~150 μm) to the active waveguide to maximise the microwave distribution. This deliberately formed standing-wave increases the microwave swing inside the device with the same driving voltage. The advantage of the standing-wave enhanced mode is clearly demonstrated with a 10 GHz optical pulse generation, as shown in Fig. 2. To generate pulses with the same width, the standing-wave enhanced mode requires lower microwave driving voltage.

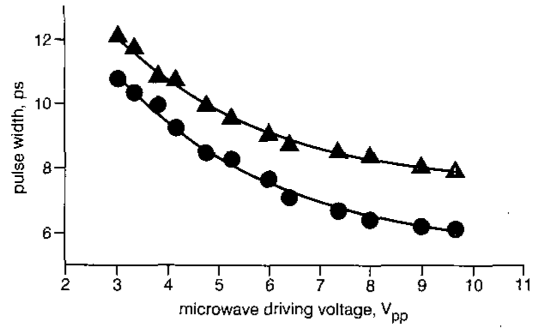

Fig. 2 *Shortest pulse generated against microwave driving voltage*

▲ travelling-wave mode
● standing-wave enhanced mode

Demultiplexing experiment: Fig. 3 shows the experimental setup for the 80 to 10 Gbit/s OTDM demultiplexer. 10 GHz, 5 ps pulses at 1555 nm are generated from a modelocked fibre ring laser and compressed to around 2 ps. This pulse train is modulated by a $LiNbO_3$ modulator with $2^{31} - 1$ PRBS and then optically multiplexed to 80 Gbit/s. The standing-wave enhanced EAM is reverse-biased at 4 V and driven by 6.4 V_{pp} of 10 GHz microwave. The gating window is 7.3 ps for the TM polarisation and 10.6 ps for the TE polarisation. Although the gating window of the TM polarisation is shorter, the output power is 10 dB lower than that of the TE polarisation. Therefore, TE polarisation is used in the experiment to get a better signal-to-noise ratio. A phase shifter is adjusted manually to synchronise the gating widow with the channel to be demultiplexed. Fig. 4 shows both the input 80 Gbit/s and the demultiplexed 10 Gbit/s eyes. The demultiplexed 10 Gbit/s eye is clearly open. The ripples are due to the response of the photodetector. Bit error rate (BER) curves and receiver sensitivities at 10^{-9} BER are shown in Fig. 5. The power penalty is low and varies slightly from 0.4 to 0.7 dB. No error-floor is observed and the slope of the demultiplexed curve is almost the same as the back-to-back curve. These results well demonstrate that the standing-wave enhanced EAM can be a high-performance OTDM demultiplexer with a lower driving voltage.

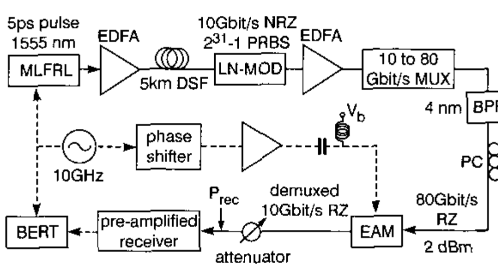

Fig. 3 *Experimental setup for 80 to 10 Gbit/s demultiplexing*

——— optical link
· · · · · · electrical link

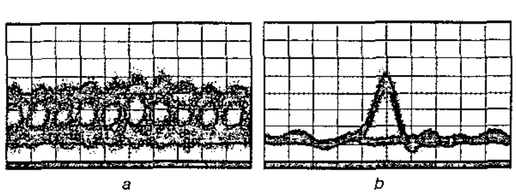

Fig. 4 *Eye diagrams*

a 80 Gbit/s
b Demultiplexed 10 Gbit/s

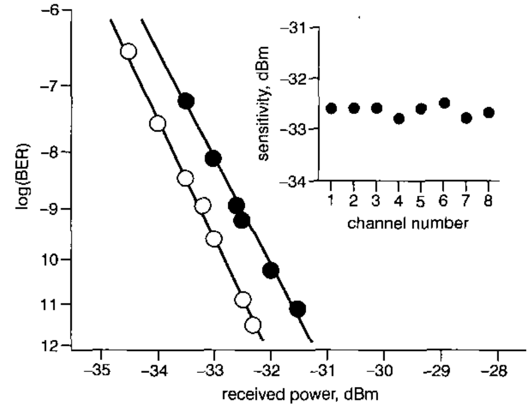

Fig. 5 *Bit error rate curves*

○ back-to-back
● channel 1
Inset: Receiver sensitivity for 8 channels

Conclusions: 80 to 10 Gbit/s OTDM demultiplexing using a standing-wave enhanced EAM is demonstrated with reduced microwave driving voltage. The averaged power penalty is 0.55 dB and no error-floor is observed. We believe that the newly proposed standing-wave enhanced mode will also improve the performance of the EAM in other single frequency operations.

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References

1 KAMAN, V., and BOWERS, J.E.: '120 Gbit/s OTDM system using electroabsorption transmitter and demultiplexer operating at 30 GHz', *Electron. Lett.*, 2000, **36**, pp. 1477–1479

2 MIKKELSEN, B., RAYBON, G., and ESSIAMBRE, R.-J.: '160 Gb/s TDM transmission systems'. Proc. ECOC 2000, Paper 6.1.1, Vol. 2, pp. 125–128

3 CHOU, H.-F., CHIU, Y.-J., and BOWERS, J.E.: 'Using standing-wave electroabsorption modulators to generate 40 GHz optical pulses'. Tech. Dig. CLEO 2002, Paper CMI1, pp. 41–42

4 YU, J., KOJIMA, K., CHAND, N., OUGAZZADEN, A., LENTZ, C.W., GEARY, J.M., FREUND, J.M., and MASON, B.: 'Simultaneous demultiplexing and clock recovery of 80 Gb/s OTDM signals using a tandem electro-absorption modulator'. Proc. IEEE/LEOS Annual Mtg, 2001, Paper TuBB4, Vol. 1, pp. 358–359

5 MARCENAC, D.D., ELLIS, A.D., and MOODIE, D.G.: '80 Gbit/s OTDM using electroabsorption modulators', *Electron. Lett.*, 1998, **34**, pp. 101–103

6 ZHANG, S.Z., CHIU, Y.-J., ABRAHAM, P., and BOWERS, J.E.: '25 GHz polarization-insensitive electroabsorption modulators with traveling-wave electrodes', *IEEE Photonics Technol. Lett.*, 2000, **12**, pp. 711–713

7 CHIU, Y.-J., CHOU, H.-F., KAMAN, V., ABRAHAM, P., and BOWERS, J.E.: 'High extinction ratio and saturation power traveling-wave electroabsorption modulator', *IEEE Photonics Technol. Lett.*, 2002, **14**, pp. 792–794

8 CHOU, H.-F., CHIU, Y.-J., and BOWERS, J.E.: '40 GHz optical pulse generation travelling-wave using sinusoidally-driven travelling-wave electroabsorption modulator', *Electron. Lett.*, 2002, **38**, pp. 379–380