35 Gbit/s error-free operation of 980 nm DBR laser with integrated electroabsorption modulator

C.S. Wang, Y.-C. Chang and L.A. Coldren

High-speed, single-frequency transmitters at 980 nm are reported, with open eye diagrams up to 40 Gbit/s and error-free operation up to 35 Gbit/s. The transmitters consist of a short-cavity, distributed Bragg reflector (DBR) laser with an integrated electro absorption modulator fabricated using a quantum well intermixing processing platform. This represents the fastest bit-rate operation to date from a single transmitter in the 830–1100 nm datacom wavelength range.

Introduction: Parallel optical interconnects are becoming increasingly cost-beneficial over copper-based electronics for board and chip-level interconnect applications as their bandwidth–path-length product continues to increase [1]. Current efforts are aimed towards extending the bit-rate operation of vertical cavity lasers, and presently the fastest vertical cavity lasers have shown 30 Gbit/s operation and 3 dB bandwidths of 24 GHz at 1.1 μm [2]. However, direct modulation of vertical cavity lasers suffers from relaxation oscillation effects, resulting in distorted eyes that require pre-emphasis to reshape [3]. Using an integrated modulator outside of the laser cavity, such as an electroabsorption modulator (EAM), produces cleaner eyes without difficult driver circuitry. This approach has demonstrated efficient transmitters at 1.55 μm operating at 40 Gbit/s [4]. In this Letter, we report high-speed performance of a small-footprint distributed Bragg reflector (DBR) laser integrated with an EAM operating at 980 nm. Open eye diagrams at 40 Gbit/s and error-free operation at 35 Gbit/s were achieved. To the best of the our knowledge, this represents the fastest demonstrated bit-rate operation of a single transmitter at the 830–1100 nm datacom wavelengths.

Device structure: We have previously demonstrated short-cavity DBR lasers integrated with EAMs that can be formed in dense arrays [5, 6]. The integrated DBR-laser/EAM-transmitter consists of five sections: rear absorber, rear DBR mirror, gain section, front DBR mirror and EAM, followed by a curved output waveguide for low back reflection, as shown in the schematic diagram in Fig. 1. The gain section of the device is 110 μm long designed for low thresholds and high slope efficiency, and the integrated EAM is 125 μm long. The entire transmitter totalled 465 μm in length without the curved output waveguide. The active region contains three 8 nm-wide $In_{0.18}Ga_{0.82}As$ quantum wells (QWs) with 8 nm GaAs barriers. An impurity-free quantum well intermixing process was used to blue-shift the absorption edge to monolithically integrate high-speed QW-EAMs with the DBR laser. The passive and EAM band-edge was detuned from the active and lasing band-edge by ∼25 nm. Details of the device structure and process can be found in [5, 6].

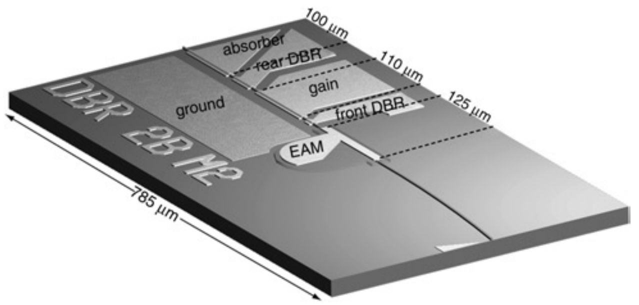

Fig. 1 *Schematic diagram of integrated short-cavity DBR laser-modulator, illustrating absorber, rear DBR, gain, front DBR and EAM sections*

Results: The DBR laser had a threshold current of 11 mA and demonstrated output powers up to 2.5 mW. The 125 μm-long integrated EAM exhibited slightly greater than 15 dB of optical extinction at −6 V with greater than 7 dB/V peak extinction efficiency at −2.8 V. More efficient EAMs have been demonstrated with less band-edge shift [5]. Small-signal modulation of the integrated EAM exceeded 20 GHz of 3 dB bandwidth [6].

Fig. 2 shows the test setup used for the large-signal modulation experiments. The NRZ signal from the pattern generator was amplified using a 38 GHz SHF 806E amplifier and fed into an Anritsu V255 65 GHz bias tee. This was used to drive the integrated EAM which was terminated with a 50 Ω load mounted directly on the ground-signal probe. Approximately −1 dBm of power was coupled into a 1 m-long single-mode lensed fibre. The optical signal was first measured using an Agilent 86109A oscilloscope, which contains a 30 GHz internal photodiode. Fig. 3*a* shows open optical eye diagrams measured using the oscilloscope optical port, taken at 25, 30, 35 and 40 Gbit/s. They demonstrate RF extinction ratios ranging from 5 down to 3.8 dB using a DC drive voltage of −2.8 V with peak-to-peak drive swings ranging from 1.75 V_{pp} at 25 Gbit/s down to 1.6 V_{pp} at 40 Gbit/s. Electrical eye diagrams were measured using a 25 GHz New Focus 1414 IR external photodetector followed by a 40 GHz SHF 810 amplifier, producing ∼150 mV amplitude eyes. Corresponding electrical eyes measured using the New Focus photodetector and SHF amplifier are shown in Fig. 3*b*, taken at 25, 30, 35 and 40 Gbit/s. The noise in the electrical eyes is due to the receiver electronics, and the 40 Gbit/s eye diagram begins to suffer slight degradation owing to bandwidth limitations of the New Focus photodetector. Using an SHF 12100A/11100A 50 Gbit/s bit error rate (BER) tester and an Ando AQ-3105 calibrated variable optical attenuator, error-free BER measurements at $2^7 - 1$ word lengths were achieved at 30 and 35 Gbit/s, as shown in Fig. 4. 40 Gbit/s operation possessed an error floor of 5×10^{-8} BER at −1 dBm fibre coupled power.

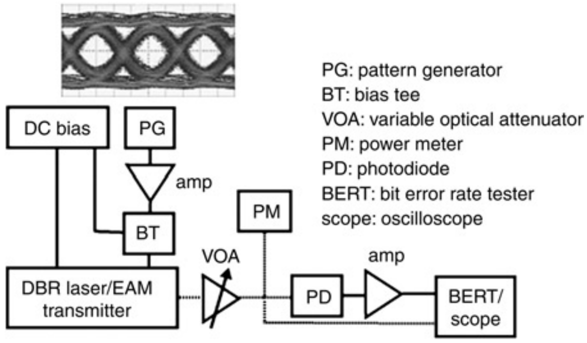

Fig. 2 *Test setup used to obtain BER and eye diagrams*

Dashed lines denote optical connections made with optical fibres. Also shown is 40 Gbit/s input eye diagram from bias tee to EAM

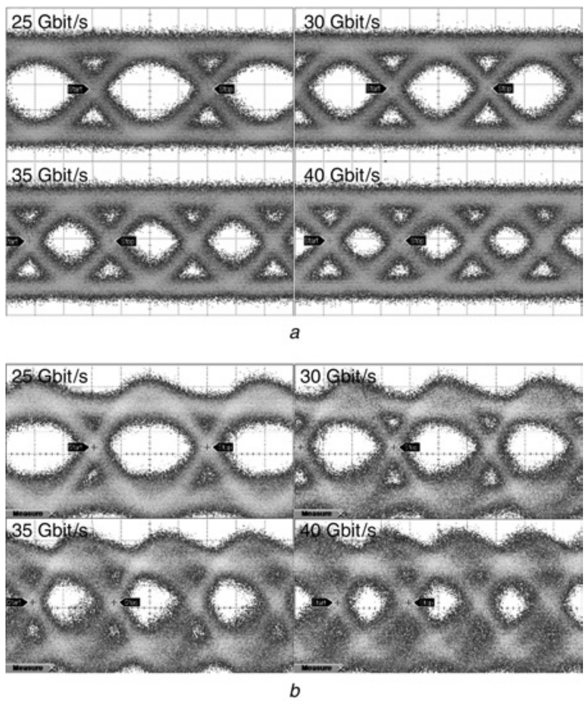

Fig. 3 *Optical eye diagrams at 25, 30, 35 and 40 Gbit/s measured using oscilloscope optical port: extinction ratios range from 5 dB at 25 Gbit/s down to 3.8 dB at 40 Gbit/s; and corresponding electrical eye diagrams at 25, 30, 35 and 40 Gbit/s measured using external photodetector and amplifier*

a Optical eye diagrams
b Corresponding electrical eye diagrams

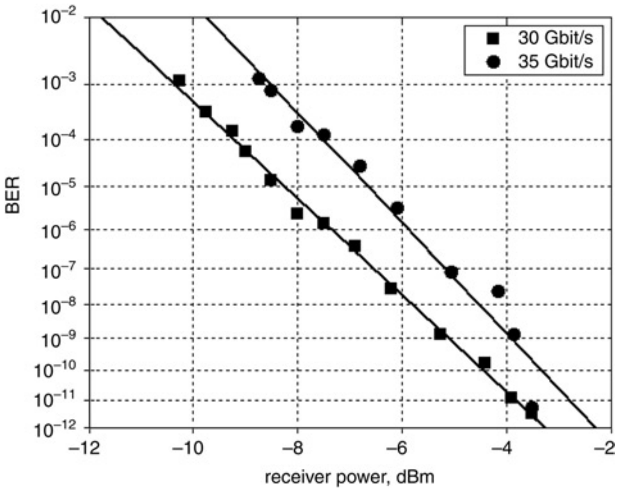

Fig. 4 *Bit error rate measurements at 30 (squares) and 35 (circles) Gbit/s*

Conclusion: Short-cavity DBR lasers emitting at 980 were integrated with high-speed QW-EA modulators using a quantum well intermixing platform. Open eye diagrams at 40 Gbit/s and error-free BER at 35 Gbit/s were achieved. To the best of our knowledge, these results represent the fastest bit-rate operation from a single transmitter at the datacom wavelength range.

Acknowledgments: The authors thank D.J. Blumenthal and H.N. Poulsen at the University of California, Santa Barbara, for helping with the RF test setup. This work is sponsored by DARPA through C2OI.

© The Institution of Engineering and Technology 2007
14 July 2007
Electronics Letters online no: 20072073
doi: 10.1049/el:20072073

C.S. Wang, Y.-C. Chang and L.A. Coldren (*Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106-9560, USA*)

E-mail: cswang@engineering.ucsb.edu

References

1 Cho, H., Kapur, P., and Saraswat, K.C.: 'Power comparison between high-speed electrical and optical interconnects for interchip communication', *IEEE J. Lightwave Technol.*, 2004, **22**, (9), pp. 2021–2033

2 Yashiki, K., Suzuki, N., Fukatsu, K., Anan, T., Hatakeyama, H., and Tsuji, M.: '1.1-μm-range tunnel junction VCSELs with 27-GHz relaxation oscillation frequency'. Proc. Optical Fiber Communications Conf., 2007, paper no. OMK1

3 Schares, L., *et al.*: 'Terabus: terabit/second-class card-level optical interconnect technologies', *IEEE J. Sel. Top. Quantum Electron.*, 2006, **12**, (5), pp. 1032–1034

4 Raring, J.W., Johansson, L.A., Skogen, E.J., Sysak, M.N., Poulsen, H.N., DenBaars, S.P., and Coldren, L.A.: '40-Gbit/s widely tunable low-drive-voltage electroabsorption-modulated transmitters', *IEEE J. Lightwave Technol.*, 2007, **21**, (1), pp. 239–248

5 Morrison, G.B., Wang, C.S., Skogen, E.J., Lofgreen, D.D., and Coldren, L.A.: '980 nm DBR lasers monolithically integrated with EA modulators for optical interconnect applications'. Proc. Integrated Photonics Research and Applications, 2005, paper no. IWF2

6 Wang, C.S., Chang, Y.-C., Raring, J.W., and Coldren, L.A.: 'Short-cavity 980 nm DBR lasers with quantum well intermixed integrated high-speed EA modulators'. Proc. Int. Semiconductor Laser Conf., 2006, paper. no. WC8