Towards 40 Gb/s Operation of Integrated DBR Laser-EA Modulators at 980 nm

Chad S. Wang, Yu-Chia Chang, and Larry A. Coldren
ECE Dept. University of California, Santa Barbara, CA 93106

Phone: 805.893.7065, Fax: 805.893.4500, E-mail: cswang@engineering.ucsb.edu

Abstract: Short-cavity, 980nm DBR lasers with integrated EAMs were designed and fabricated using a quantum well intermixing processing platform. Open eyes at 40Gb/s and preliminary error free operation at 25Gb/s were achieved, suitable for optical interconnect applications.

1. INTRODUCTION

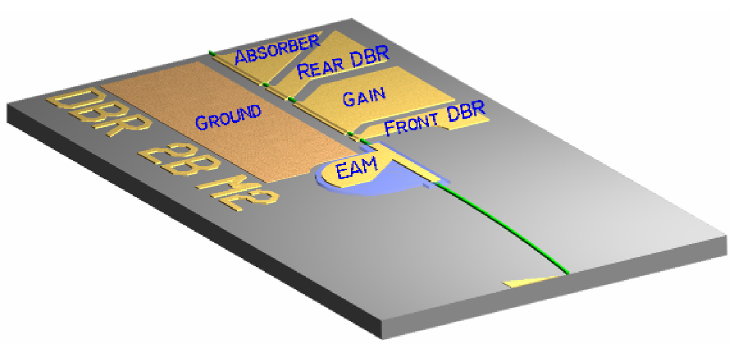
As photonics continue to push towards faster bit-rates, they become more attractive in replacing electronics for use in interconnect applications [1]. Currently, the fastest vertical cavity lasers have shown 30 Gb/s operation and 3 dB bandwidths of 24 GHz at 1.1 µm [2]. Direct modulation of vertical cavity laser suffers from relaxation oscillation effects, resulting in distorted eyes that require preemphasis 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 Gb/s [4]. Here we present high-speed performance of a distributed Bragg reflector (DBR) laser integrated with an EAM operating at 980 nm. Open eyes at 40 Gb/s and preliminary error free operation at 25 Gb/s were achieved.

2. DEVICE

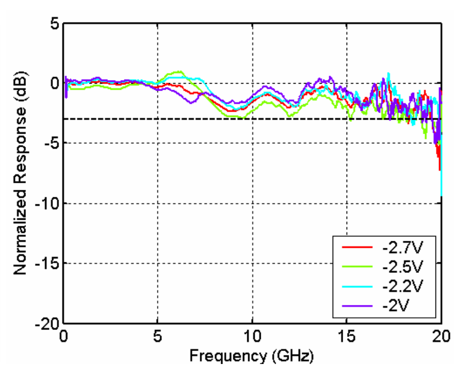
We have previously demonstrated short-cavity DBR lasers integrated with EAMs [5,6]. The integrated DBR laser-EAM consists of 5 sections: rear absorber, rear DBR mirror, gain section, front DBR mirror, and EAM, followed by a curved output waveguide for low back reflection, as shown in the side-view schematic of Fig. 1a. 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. An impurity-free quantum well intermixing process was used 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].

3. RESULTS

The DBR laser had a threshold current of 11 mA and demonstrated output powers up to 2.5 mW at a gain section current of 50 mA. 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 -2.8V. Small-signal modulation of the integrated EAM exceeded 20 GHz of 3 dB bandwidth, as shown in Fig. 1b. Fig. 2b shows the setup used for various 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 ground-signal probes. Approximately -1 dBm of power was coupled into a single mode lensed fiber at a 50 mA laser bias. The optical signal was first measured using an

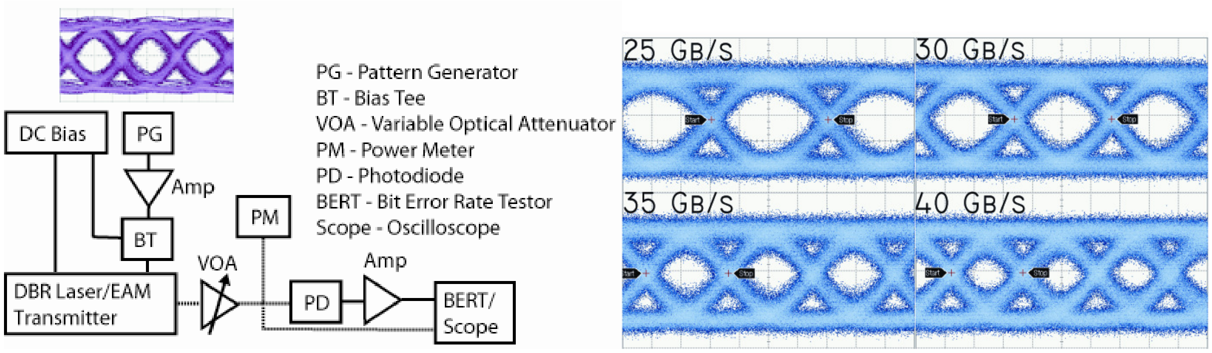


(a)



(b)

FIGURE 1. (a) Side view schematic of the integrated short-cavity DBR laser-modulator, illustrating the Absorber, Rear DBR, Gain, Front DBR, and EAM sections. (b) 3 dB modulation bandwidth of 125 µm EAM at various biases. The noise at high frequency was due to equipment limitations; the bandwidth was measured using a calibrated 6 GHz New Focus photodiode and two 20 GHz New Focus amplifiers.



(a) (b)

FIGURE 2. (a) Test-set used to obtain BER and eye-diagrams. Dashed lines denote optical connections made with optical fibers. Also shown is the 40 Gb/s input eye from the bias tee to the EAM. (b) Optical eye diagrams at 25, 30, 35, and 40 Gb/s were measured using the oscilloscope optical port.

Agilent 86109A oscilloscope which contains a 30 GHz internal photodiode. Fig. 2b shows open optical eye diagrams measured using this oscilloscope optical port, taken at 25, 30, 35, and 40 Gb/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 1.8 V_{pp} at 20 Gb/s down to 1.6 V_{pp} at 40 Gb/s. Electrical eye diagrams were measured using a 25 GHz New Focus 1434 IR external photodetector followed by a 25 GHz SHF 100CP amplifier, producing ~50 mV amplitude eyes. Corresponding electrical eyes measured using the New Focus detector and SHF amplifier are shown in Fig. 3a, taken at 20 and 25 Gb/s. Higher data rates at 30 Gb/s and beyond could not be taken due to the limited performance of the receiver photodetector and amplifier. Using an SHF 50 Gb/s BERT, Fig. 3b shows error-free bit error rate measurements (BER) at 2^7-1 word lengths achieved at 20 and 25 Gb/s using the current receiver electronics.

4. Conclusion

Short-cavity DBR lasers emitting at 980 were integrated with high-speed QW-EA modulators using a QWI platform. Open eyes diagrams were achieved at 40 Gb/s, and error-free BER were performed at 25 Gb/s. To the best of our knowledge, these results represent the fastest integrated EAMs at the datacom wavelengths. Higher-speed BER measurements plan to be performed with faster receiver electronics.

5. References

[1] H. Cho, P. Kapur, and K.C. Saraswat, "Power comparison between high-speed electrical and optical interconnects for interchip communication," *IEEE J. of Lightwave Tech.*, vol. 22, no. 9, pp. 2021-2033, 2004.

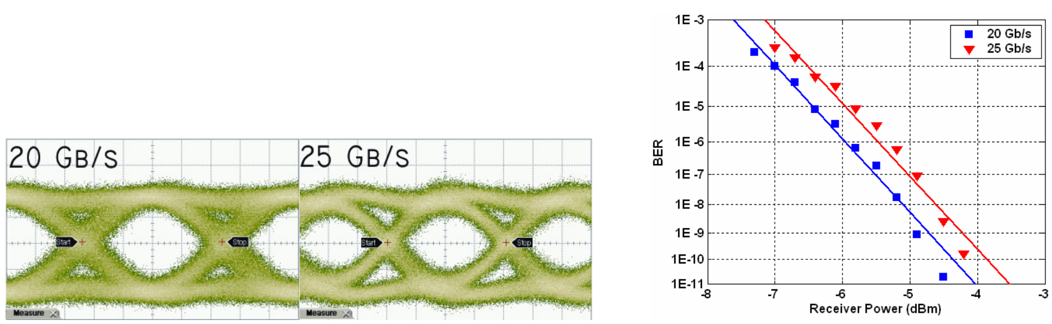
[2] K. Yashiki, N. Suzuki, K. Fukatsu, T. Anan, H. Hatakeyama, and M. Tsuji, "1.1-µm-Range Tunnel Junction VCSELs with 27-GHz Relaxation Oscillation Frequency," *Proc. Optical Fiber Communications Conf.*, paper no. OMK1, 2007.

[3] L. Schares, et al., "Terabus: Terabit/Second-Class Card-Level Optical Interconnect Technologies," *IEEE J. of Sel. Topics in Quant. Electron.*, vol. 12, no. 5, pp. 1032-1034, 2006.

[4] J.W. Raring, L.A. Johansson, E.J. Skogen, M.N. Sysak, H.N. Poulsen, S.P. DenBaars, and L.A. Coldren, "40-Gb/s Widely Tunable Low-Drive-Voltage Electroabsorption-Modulated Transmitters," *IEEE J. of Lightwave Tech.*, vol. 21, no. 1, pp. 239-248, 2007.

[5] G.B. Morrison, C.S. Wang, E.J. Skogen, D.D. Lofgreen, and L.A. Coldren., "980 nm DBR Lasers Monolithically Integrated with EA Modulators for Optical Interconnect Applications," *Proceedings of the Integrated Photonics Research and Applications*, paper no. IWF2, 2005.

[6] C.S. Wang, Y.-C. Chang, J.W. Raring, and L.A. Coldren., "Short-Cavity 980 nm DBR Lasers with Quantum Well Intermixed Integrated High-Speed EA Modulators," *Proc. International Semiconductor Laser Conf.*, paper. no. WC8, 2006.



(a) (b)

FIGURE 3. (a) Electrical eye diagrams at 20 and 25 Gb/s measured by electrical receiver and amplifier, and (b) corresponding bit error rate at for 20 (squares) and 25 (triangles) Gb/s operation.