64Gb/s Transmission over 57m MMF using an NRZ Modulated 850nm VCSEL

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Abstract: We report a directly modulated 850nm VCSEL-based optical link operating error free (BER < 1E-12) at 64Gb/s over 57m of OM4 multimode fiber. At 60Gb/s, the error free distance increases to 107m.

OCIS codes: *(060.2340) Fiber optics components (060.2360) Fiber optics links and subsystems; (060.2380) Fiber optics sources and detectors; (200.4650) Optical interconnects.*

1. Introduction

Serial line rates for Datacom optical interconnects continue to increase. Commercial products are available in the 25-28Gb/s range. Next generation Fibre Channel and Infiniband serial rates could potentially be above 50Gb/s and the Optical Internetworking Forum has begun work on several 56Gb/s serial interfaces. At data rates above 60Gb/s, electrical signaling distances are predicted to be viable up to the 10cm range with optical interconnects preferred beyond that distance [1]. Low power CMOS equalization circuits have been demonstrated to 66Gb/s [2]. For Datacom optical links, the highest NRZ serial data rates demonstrated error free, commonly defined as BER < 1E-12, thus far are 57Gb/s unequalized [3] and 56Gb/s equalized [4] both using 850nm VCSELs. In this paper, we extend both the data rate and the range of VCSEL based optical links to 64Gb/s over 57m of OM4 multimode fiber. To the best of our knowledge, this reported data rate of 64Gb/s is the highest data rate for any VCSEL link, regardless of wavelength.

2. Experiment

The full link is comprised of a driver chip with two tap feed forward equalization (FFE) wirebonded to an 850nm VCSEL and a GaAs PIN photodiode wirebonded to a receiver IC that also incorporates a two tap FFE at its output. The driver and receiver chips are fabricated in the IBM BiCMOS8HP process. The driver IC is similar to a previously published design [5], but with a 50 Ohm output impedance and a re-tuned output equalizer. The receiver is also an improved version of the design in [5]. The ICs and corresponding OEs are separately packaged on a printed circuit board with short (~12mm) 50 Ohm transmission lines to SMP coaxial connectors. All active components on the circuit boards are wirebonded. The wirebonds between the ICs to the VCSEL and Photodiode are ~250μm in length.

The VCSEL structure used in the experiments has been described in detail elsewhere [6]. It was grown by MOCVD at IQE Europe on a semi-insulating substrate. In short, the structure consists of *p*- and *n*-DBRs designed for low resistance and low free carrier absorption, a short 0.5-λ cavity for high optical confinement and efficient carrier transport, and an active region comprising five strained InGaAs quantum wells for high differential gain. Two primary oxide layers form the approximately 5 μm diameter electrical and optical apertures and four secondary, shallow oxide layers act to reduce the parasitic capacitance. The thickness of the topmost DBR layer was fine-tuned by a shallow surface etch post fabrication to optimize the photon lifetime for a large modulation bandwidth while keeping the modulation response as flat as possible. The VCSEL has a threshold current of 0.64 mA, slope efficiency of 0.7 W/A, series resistance of 120 Ω at 8.5 mA, and RMS spectral with of 680 pm at 8.5 mA. The maximum 3dB bandwidth (electrical) is approximately 26 GHz, see Figure 1(left). The photodiode, described in [7], has a 21μm active diameter and a 3dB electrical bandwidth of ~22GHz at -3V.

3. Results

The full link is characterized from 56 to 64Gb/s using PRBS7. The pattern generator is an SHF 12103A and the error detector is an SHF 11100A. The pattern generator output is connected to the Tx printed circuit board differentially through a pair of skew matched 10cm cables. The output amplitude is set for 500mV peak-to-peak single-ended. The receiver differential output is split with one side connected to the error detector and the other connected to an oscilloscope; both cables are 20cm long. For BER and bathtub measurements both Rx outputs are connected differentially to the error detector. The VCSEL output is coupled through a diffractive lens (similar to the one described in [8]) to a PRISM® LightTurn®[1] connector attached to 50/125 MMF. The photodiode input is coupled by a lensed 50/125 fiber probe.

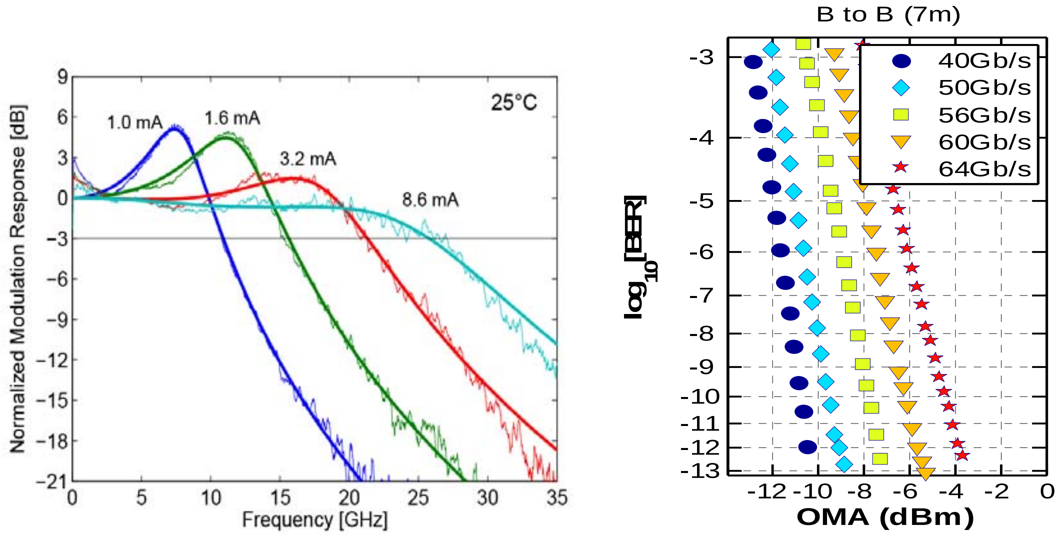

Figure 1. (left) Normalized small signal modulation response (S21) measured at 25°C for the 5 µm aperture VCSEL at increasing bias currents, (right) BER vs. OMA vs. Data Rate for 7m.

The link is comprised of minimum of 7m of 50/125 OM3 grade fiber to connect from the transmitter through a variable optical attenuator (VOA) to the receiver using a minimum of 5 connectors. Figure 1(right) shows BER vs. OMA versus data rate at 7m. The sensitivity at 64Gb/s is -3.8dBm OMA. Spools of 50, 100 and 150m of OM4 fiber are added to this 7m for distance measurements. Error-free operation is obtained up to 64Gb/s at 57m. Figure 2 shows the eye diagrams at 7m and bathtub curves for several link lengths for 3 data rates: 56, 60, and 64Gb/s using the same driver and receiver settings. The bathtubs for 56 and 60Gb/s are taken with 2dB on the VOA while the ones for 64Gb/s have a 0dB VOA setting. The VCSEL bias is 8.5mA and the photodiode supply voltage is -7V. The transmitter temperature is 25°C. At 64Gb/s, the eye opening is 0.26 unit interval (UI), or 4.0ps at 7m, however, the test equipment eye opening is only 0.48UI (7.4ps) at this data rate. At 57m, the eye opening has reduced to 0.12UI and there is a 1.4dB power penalty. The total link power dissipation is 1.68W = 900mW Tx + 780mW Rx, corresponding to energy consumption of 26.3pJ/bit for the system at 64Gb/s, with the VCSEL itself contributing 320fJ/bit.

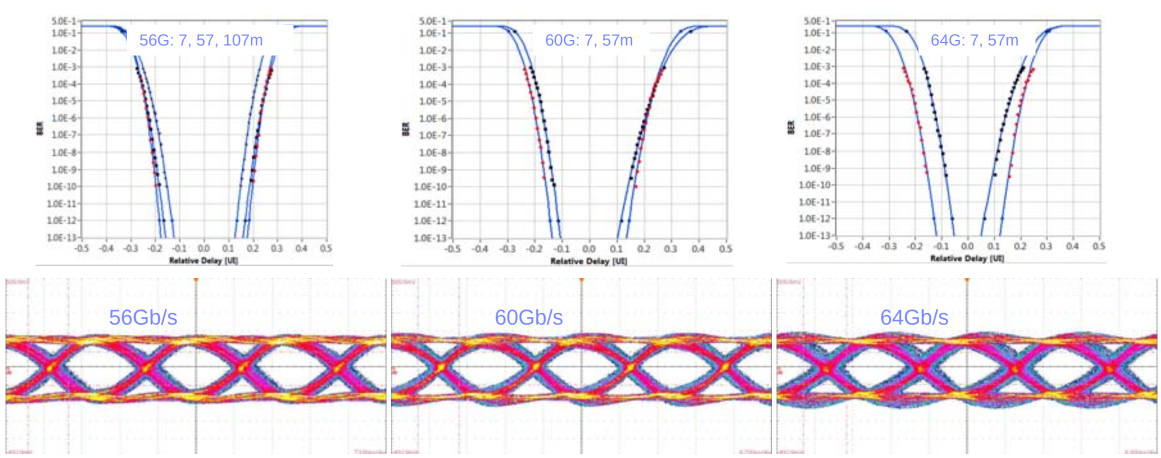

Figure 2. Link Eye Diagrams and Bathtub curves for three data rates: 56, 60, and 64Gb/s (left to right). For the eye diagrams, vertical scale is 100mV/div and the horizontal scales are 7.1, 6.7, and 6.3ps/div, respectively.

Figure 3 shows BER vs. OMA for 56, 60, and 64Gb/s for various lengths. The maximum available OMA was -0.7dBm due to coupling and insertion losses. For each curve, a point below BER=1E-12 is measured with a

[1] PRIZM® and LightTurn® are trademarks or registered trademarks of US Conec Ltd.

minimum measurement time of 100s. The insertion of the 50m spool incurred a 1dB penalty at 56 and 60Gb/s and ~1.4dB at 64Gb/s. The penalty for 100m was 4.2dB for both 56 and 60Gb/s. At 50Gb/s, a distance of 157m is achieved with a received power of -6dBm.

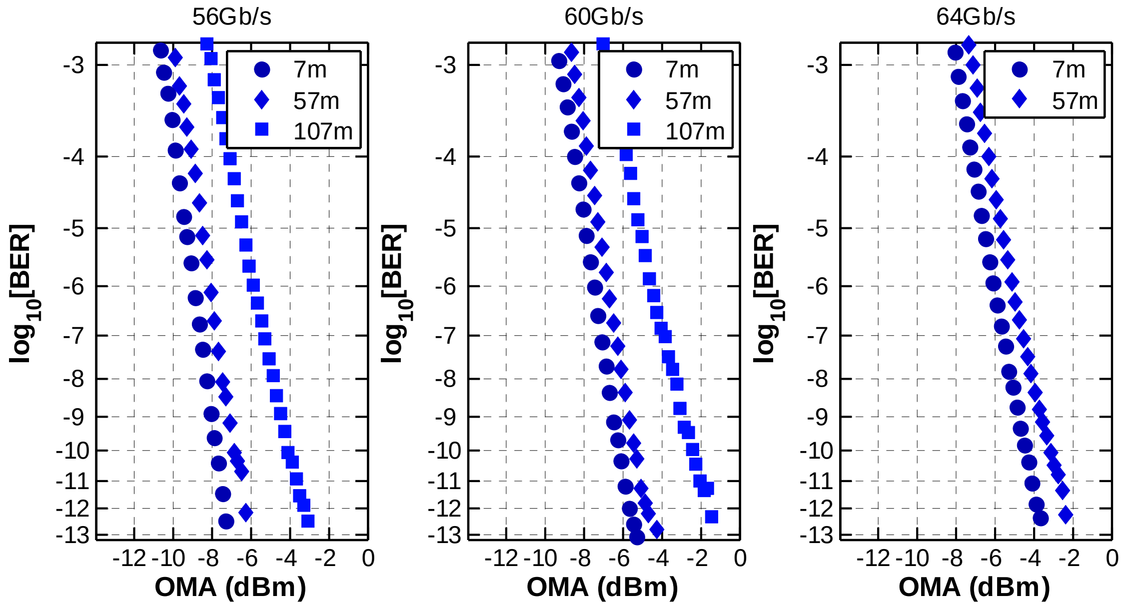

Figure 3. BER vs. OMA for data rates of 56, 60, and 64Gb/s and distances of 7, 57, and 107m.

4. Conclusion

We have demonstrated a full IC-to-IC optical link operating with margin at 64Gb/s, the highest serial bit rate yet published for any NRZ directly-modulated VCSEL. This performance is made possible by a high bandwidth VCSEL and by the use of transmitter equalization which allows the total link to exceed the bandwidths of the individual OE devices. We show, with the use of OM4 fiber, that 100m links, which cover more than 80% of HPC and data center cabling needs, can be achieved with margin and that NRZ, which is the most convenient modulation format, can be used for data rates above 60Gb/s. VCSEL technology continues to advance at a rapid pace and should be suitable as an interconnect solution for at least the next decade.

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