4×50Gb/s NRZ Shortwave-Wavelength Division Multiplexing VCSEL link over 50m Multimode Fiber

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Abstract: We demonstrate for the first time a 4x50Gb/s NRZ SWDM VCSEL link over 50m OM4 multimode fiber achieving error free operation (BER<1E-12). Transmission of 4×44Gb/s SWDM over 100m OM4 fiber with error free is also presented.

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

Optical interconnects targeting both short and long reaches in intra- and inter-datacenter networks, as well as access and metro networks, have recently received an increased interest due to the tremendous growth in data traffic [1]. To address this exponential growth, high bandwidth, energy efficient and low cost optical transceivers are needed. Today the short-reach optical interconnects (up to 300m) deployed inside the datacenter are dominated by low cost VCSEL-based multimode-fiber links [2]. There is a desire to extend the bandwidth of VCSEL-based multimode fiber links from today's 40Gb/s and 100Gb/s to future 200Gb/s and 400Gb/s solutions while preserving a link distance of at least 100m. One viable approach is to add more fibers to the link which widens the parallel interface. Another approach discussed in the IEEE 400Gb/s Ethernet Task Force, is Shortwave Wavelength Division Multiplexing (SWDM) in the spectral region between 860-1100nm [3-6]. In this spectral region, a decrease in effective modal bandwidth (EMB) can be partially offset by the increase in chromatic bandwidth. In [4], 4×45Gb/s SWDM transmission with PAM-4 modulation format has been reported with BER<2E-4. Signal pre-distortion could be deployed to increase the speed to 50Gb/s PAM-4 per channel as in [5]. The authors in [6] also reported 51.56Gb/s PAM-4 SWDM transmission over novel wide band multimode fiber. However gaining spectral efficiency with higher order modulation format would require considerable power consumption from signal processing and latency from forward error correction (FEC). Non-return to zero (NRZ) signal on the other hand would benefit from system simplicity and low latency which is critical for current data center applications. In previous work [3], we presented NRZ transmission results from four complete transmitters in the range of 850-940nm at 40Gb/s over a distance of 100m on OM4 fiber and up to 200m at 26Gb/s. In this paper, we report the recent achievement on the complete four-channel SWDM link including the MUX and DEMUX elements with each channel operating error free (BER<1E−12) at 50Gb/s yielding 200Gb/s aggregated bandwidth over 50m OM4 multimode fiber. Transmission of 4×44Gb/s SWDM over 100m OM4 fiber is also demonstrated. No crosstalk penalty is observed at this 44Gb/s operation on all four channels.

2. Experiment

Fig. 1 shows the experiment set up for four-channel SWDM transmission over OM4 multimode fiber. The details of VCSELs used in this work (at wavelengths 850nm, 880nm, 910nm and 940nm) were reported previously in [3]. The four VCSELs are wire-bonded separately to the differential output of two high-speed 130nm BiCMOS driver ICs with 2-tap FFE similar to the one reported in [7]: 850nm and 880nm VCSELs are bonded on the same transmitter, 910nm and 940nm VCSELs are co-packaged on the other transmitter. The difference in this work is that 100Ω load resistance is used for 850nm-880nm transmitter while the 910nm-940nm transmitter employs 50Ω load resistance for optimizing bandwidth to achieve 50Gb/s operation. The inset image in fig.1 depicts an example of the transmitter which includes the driver IC wire-bonded to the VCSELs and decoupling capacitors co-packaged on a printed circuit board. The 880nm device is biased at 11mA while the other 3 are biased slightly lower from 8 to 9mA. The 130nm BiCMOS receiver ICs with 480Ω TIA have been described in [8]. In this experiment two surface illuminated PIN photodiodes have been used, one for the 850nm wavelength and the other for 880,910 and 940 nm wavelengths for optimal responsivity. A picture of receiver assembly is shown in Fig. 1. Both transmitter and receiver are running at 28^{o}C temperature in all measurements.

Lens coupling is deployed at receiver side in all experiments to couple light from OM3 multimode fiber into the photodiode. At transmitter side, for individual channel characterization at each wavelength, lens coupling is also employed, but for multichannel characterization (crosstalk characterization) 26μm lensed fibers are used to simultaneously couple output light from the VCSELs to meet the close spacing of the co-packaged VCSELs. The custom V-groove fiber holder is used for positioning all 26μm fibers of four channels to vertically couple into and out the transmitter multiplexing module (MUX) and receiver de-multiplexing module (DEMUX) as depicted in fig.1. The 26μm fiber core has been chosen to emulate a VCSEL's numerical aperture (NA) profile as would be seen by the free space MUX element. An inset picture shows the V-groove fiber with 1.3mm pitch that matched the spacing of the plastic molded lenses in the MUX and DEMUX modules. The MUX module essentially consists of three thin-film dichroic filters and one mirror at the end as illustrated in Fig.1. The DEMUX module has similar structure with additional filters to enhance the out-of-band suppression for each channel at receiver side. The measured throughput optical spectra of the MUX and DEMUX with reference white light source are shown on the right of Fig.1 (upper right for MUX and lower right for DEMUX). The MUX demonstrates suppression ratio of more than 15dB while the DEMUX shows suppression greater than 25dB. The measured loss through MUX and DEMUX is ~2.5dB for each side. The fibers used in these experiments are OM4 grade with an EMB that peaks >860nm and a DMD profile that is strongly left tilted. The experiments are carried out with 2m fiber for back-to-back measurement, 50m and 100m fibers for long transmission distance. All measurements include a 9m fiber link (mixed OM3 and 26μm multimode fiber) used for optical coupling to the VCSELs, MUX module, DEMUX module and photodiode. At the receiver side, only one channel-of-interest is measured at a time. The high speed modulation format is NRZ and the pattern is PRBS-7. To measure BER at 1E-12 and below, the measurement is running for 100s at each data point. Error free is defined as BER<1E-12 and no error is detected in 200s measurement time.

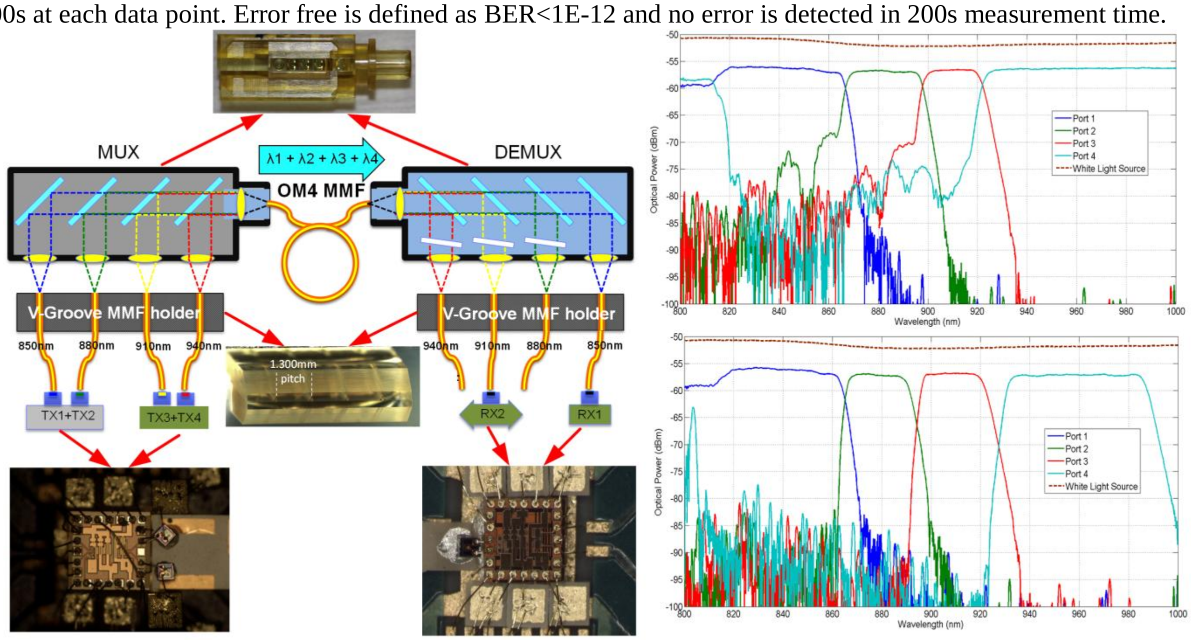


Figure 1. Experiment setup of SWDM VCSEL link with inset picture of transmitter, receiver assemblies, V-groove fiber holder, MUX/DEMUX module, and throughput optical spectra of the MUX (upper right) and DEMUX (right lower) modules.

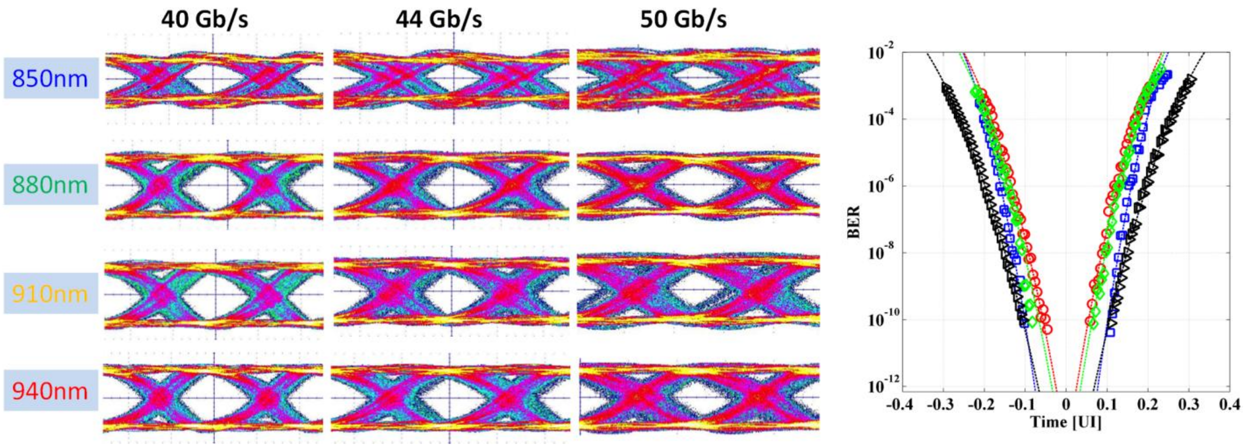
3. Results

The experiments with individual channel transmission (one wavelength at a time) are first carried out at different bitrate with distance up to 100m OM4 fiber. Fig. 2 (a) shows the received electrical eyes of all four individual channels of the SWDM link at bit rate 40, 44 and 50 Gb/s over 50m fiber. Fig. 2(b) depicts the bathtub curves from jitter measurement at 50Gb/s over 50m transmission for all four wavelengths. The estimated eye opening at BER=1E-12 is from 0.05UI to 0.15UI for all four channels. Fig. 3(a) and (b) plot the BER versus optical modulation amplitude (OMA) measurement results for all four individual channels at 50Gb/s over 50m fiber and 44Gb/s over 100m, respectively. A BER <1E-12 is obtained with no evidence of an error floor in both operation scenarios. In fig. 3(a), at 50Gb/s over 50m, the 940nm channel show the best performance with required OMA (for BER=1E-12) is below −6dBm while the channel 880nm show the worst performance with required OMA is -2dBm, all channels obtain error free within 4dB variation of each other. At 44Gb/s with longer transmission distance, 100m OM4 fiber, the variation in required OMA (for error free) between channels is ~3dB as in fig. 3(b).

For channel-crosstalk measurement, we investigate all four channels with the presence of one or two aggressive neighbor channels with channel-of-interest as shown in fig. 3(c). The experiment is running at 44Gb/s, back-to-back link (2m fiber to connect MUX and DEMUX modules). As from BER measurement results in fig. 3(c), no penalty is observed from crosstalk, thanks to the large channel spacing (~30nm) of SWDM and good out-of-band suppression of the MUX and DEMUX modules.

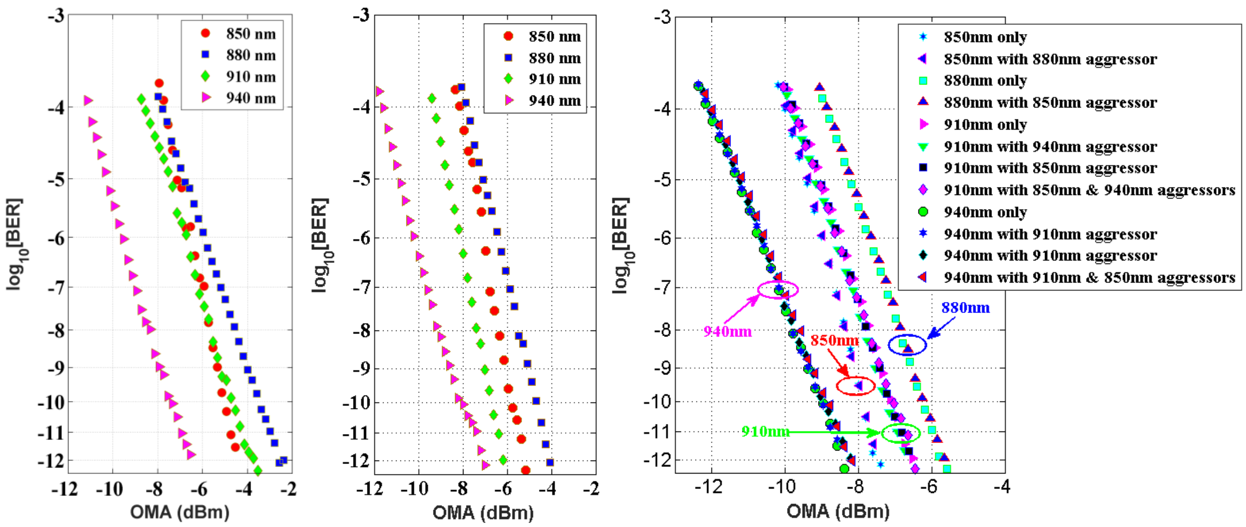
4. Conclusion

The four-channel SWDM VCSEL links have been demonstrated with error free up to 50Gb/s NRZ per each channel over 50m OM4 fiber and 44Gb/s over 100 OM4 multimode fiber. No crosstalk penalty has been observed on all four channels at 44Gb/s. The experiment demonstrates the bandwidth capacity of standard multimode fiber and shows that it is practical to support future 200Gb/s and 400Gb/s solutions using the same parallel interface width as today's 40Gb/s and 100Gb/s multimode fiber solutions.



(a) (b)

Figure 2. (a) Received electrical eye diagrams after 50m OM4 fiber at data rate from 40 to 50Gb/s (left to right) for all four SWDM channels and (b) bathtub curves for jitter measurement of all channels at 50Gb/s over 50m OM4 fiber.



(a) (b) (c)

Figure 3. BER versus OMA of all four channels at (a) 50Gb/s over 50m OM4 fiber, (b) 44Gb/s over 100m OM4 fiber, (c) back-to-back with crosstalk (aggressive channels) at 44Gb/s.

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