180 Gbps PAM4 VCSEL Transmission over 300m Wideband OM4 Fibre

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Abstract: Successful 180 (4x45) Gbps transmission is demonstrated over OM4 fibres using a 45-Gbps-PAM4 chip. Real time BERs<2e-4 were achieved for four SWDM grid channels in the 850-950nm wavelength range over 100m/200m/300m of wideband OM4 fibres.
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1. Introduction

Cost effective and large-scale installation of data centre networks is essential due to the exponential growth of bandwidth demand. VCSEL based Multimode Fibre (MMF) system technology has been proposed as a low cost and power efficient solution for 100 Gbps data centre networks over parallel multimode fibres [1].

The IEEE recently standardized 100GBASE-SR4 (4 x 25Gbps NRZ modulation format) with a maximum reach of 100m on four OM4 fibres and MPO connectivity. However in order to support the explosive demand in data traffic and cloud services, data centres are required to migrate to higher transmission rates, achieve higher capacity, extend reach, and maintain duplex connectivity. Higher order modulation formats [2,3], such as four-level Pulse Amplitude Modulation (PAM4) and digital signal processing (DSP) techniques, as well as short wavelength division multiplexing (SWDM) with novel wideband MMF [4-6] have been proposed to increase capacity over a single MMF with longer reach for data centre networks and predicted to capture a larger market share in the near future.

This paper describes the successful combination of the above, which results in a transmission of 180 Gbps PAM4 VCSEL based technology (four 22.5 Gbaud PAM4 optical channels) over 100m and 200m of conventional OM4 fibres as well as 100m, 200m, and 300m of wideband OM4 fibres optimized for SWDM in the 850nm to 950nm wavelength range. To extend the reach and improve performance, a digital 45 Gbps PAM4 commercial chip is used for modal and chromatic dispersion equalization. We show the optical eye diagrams and measured bit error rates (BERs) as a function of the inner eye Optical Modulation Amplitude (OMA) over abovementioned MMFs for 850nm, 880nm, 910nm, and 940nm VCSELs. 300m transmission was achieved for all four SWDM grid channels with BERs<2e-4 over the wideband OM4 fibre. The inner eye OMAs ranged from -16.2 dBm to -13.6 dBm for all fibre types and lengths and all channels at extinction ratio (ER) of ~3.0 dB and BER of 2e-4.

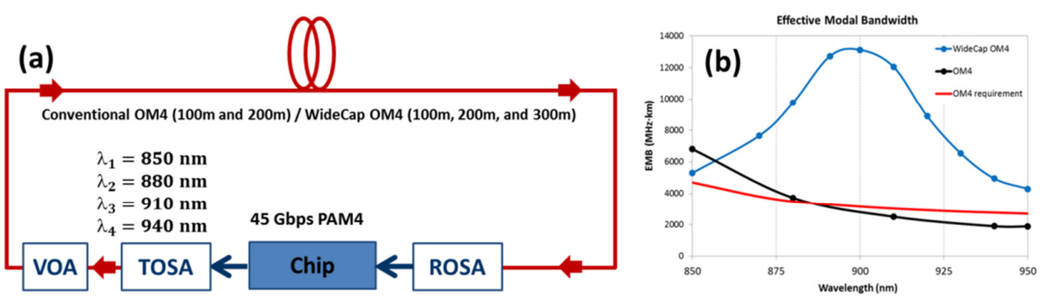

Fig. 1 (a) Schematic of the experimental setup and (b) measured effective modal bandwidth of the wideband OM4 (blue), OM4 (black), and OM4 bandwidth requirement (red).

2. Experimental Setup and Results

Figure 1 (a) shows a schematic of the experimental setup comprising a TOSA, a ROSA, a Variable Optical Attenuator (VOA), different MMF types and lengths, and a single chip. The chip performed the main functions, such as 45 Gbps PAM4 clock and data recovery, pulse shaping at the transmitter, adaptive modal and chromatic dispersion equalization at the receiver, and real-time BER measurement. Two sets of MMF types and various fibre

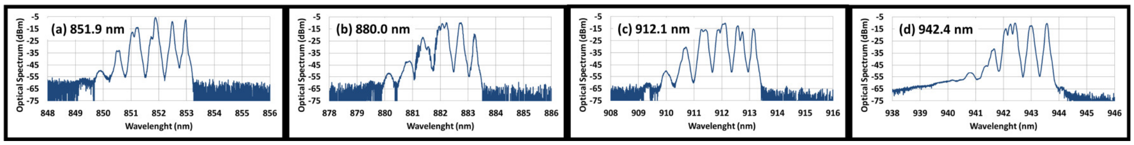

Fig. 2 Measured optical spectrums at a) 851.9nm, b) 882.0nm, c) 912.1nm, and d) 942.4nm.

lengths were used for this experiment including: conventional OM4 fibres (100m/200m) and wideband OM4 fibres (100m/200m/300m). The wideband OM4 fibre [4] (trademark WideCap OM4) is manufactured by Prysmian Group.The measured Effective Modal Bandwidth (EMB) is shown in Fig. 1 (b). This fibre is designed for peak EMB at ~890nm so that the EMB is higher than the bandwidth requirement for OM4 performance [4] at all wavelengths from 850-950nm. In comparison, the conventional OM4 fibre fails at wavelengths longer than 885nm. An EMB of 4300MHz.km is obtained at 950nm which is more than twice that of the conventional OM4 fibre (1900MHz.km). The wideband OM4 is then expected to reduce system penalties for the two longest wavelengths compared to the conventional OM4 fibre. The measured VCSEL centre wavelengths were 851.9, 882.0, 912.1, and 942.4nm (Fig. 2 (a-d)). RMS spectral bandwidths (SBWs) were 0.558, 0.370, 0.5011, and 0.527nm from the short wavelength to the long wavelength, respectively. The measured RIN OMAs were ~-137 dB/Hz. A mode preserved VOA was used to adjust the optical power.

A single chip was used to generate 45 Gbps PAM4 optical data stream. The 25G VCSELs were directly and differentially driven by 22.5-Gbaud PAM4 scrambled pseudo-random bit sequences (PRBS) of length 2^{31}-1 produced by integrated DACs, with ~0.8 Vpp electrical signal. The VCSELs were biased at 11 mA. The chip DSP provided functionality for digital pre-emphasis compensation. Figs. 3 (a-d) show the measured received optical eye diagrams with the digital pre-emphasis compensation turned on at TX.The measured transmitter ERs ranged from 3.0 dB to 3.2 dB at four wavelengths. The first, second, third, and forth columns show the VCSEL eyes at 851.9nm, 882.0nm, 912.1nm, and 942.4nm, respectively. Different rows show VCSEL optical eyes after transmission over different MMF types and lengths as labelled in the figures. Open eyes were observed at 100m OM4 as well as 100m and 200m WideCap OM4 for all four channels. Closed eyes were observed for 200m conventional OM4 fibres for all four wavelengths. At 300m WideCap OM4, the most open eyes were obtained at 882.0nm and 912.1nm wavelength channels where the EMB is the highest.

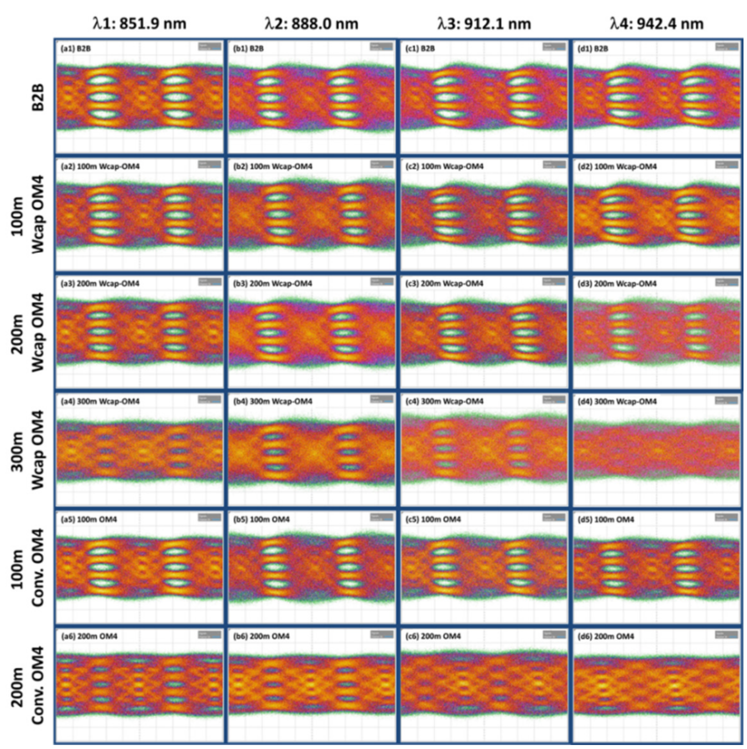

Fig. 3 Optical eye diagrams after transmission. The first, second, third, and fourth columns are corresponding to 851.9nm, 882.0nm, 912.1nm, and 942.4nm optical channels. The first, second, third, fourth, fifth, and sixth rows are corresponding to the received eye diagrams for B2B, 100m, 200m, 300m WideCap OM4 as well as 100m and 200m conventional OM4 fibres.

Real-time BER measurement was performed by connecting the detected signals to the chip receiver through ROSA TIA differential outputs. Figs. 4 (a-d) show the BER measurements after adaptive equalization at RX as a function of inner eye OMAs using a digital pre-emphasis at TX. The KP4 (2e-4) BER FEC threshold level determines the required inner eye OMA (=average optical power-6.7 dB at ER of 3.0 dB) for 45 Gbps PAM4 modulation format through each MMF types and lengths. Note BER increases at OMA >-11 dBm due to the nonlinear distortion of limiting TIA. However this has minimal impact at the low optical power levels corresponding to KP4 FEC limit. The measured OMAs were -16.2 dBm, -16.2 dBm, -16.1 dBm, and -16.1 dBm for B2B at KP4 level for 851.9nm, 882.0nm, 912.1nm, and 942.4nm VCSELs, respectively. The measured OMA penalties were ≤0.2 dB over 100m WideCap OM4 fibre at KP4 level for all four channels in comparison with B2B OMAs. The OMA penalties were 0.6 dB and 1.1 dB for 912.1nm and 942.4nm VCSELs over 100m conventional OM4 fibre at KP4 level. While the measured OMA penalties over 200m WideCap OM4 fibre were ≤1.1 dB, OMA penalty was ~2.5 dB over 200m conventional OM4 fibre at KP4 level for 942.4nm wavelength. Higher BER error floors were observed for 912.1nm and 942.4nm channels over 200m conventional OM4 fibre. These results show the limitation of the conventional OM4 fibres for extending the reach over 100m in SWDM applications. OMA penalties ≤2.3 dB were captured for all channels over 300m WideCap OM4 fibre at KP4 level. The depicted eye diagrams (Fig. 3) were also consistent with measured BERs.

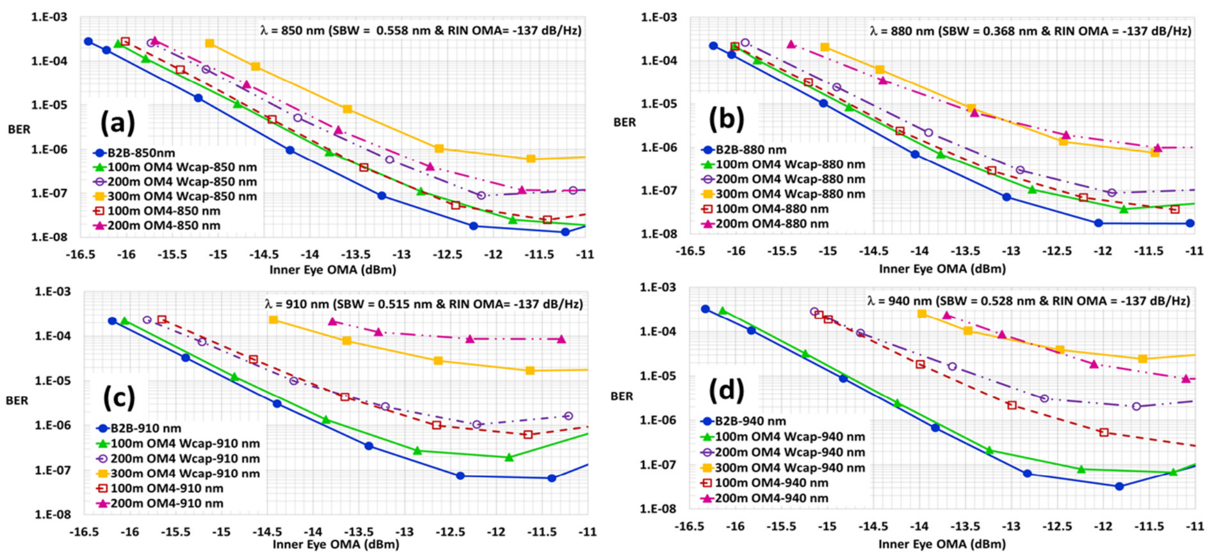

Fig. 4 Measured BER B2B (blue), 100m (green), 200m (purple), 300m (yellow) of WideCap OM4 as well as 100m (red) and 200m (pink) conventional OM4 fibers for a) 851.9nm, b) 882.0nm, c) 912.1nm, and d) 942.4nm channels.

3. Conclusion

We presented initial experimental data on 180 Gbps SWDM4 system and demonstrated successful transmission over 300m of wideband OM4 fibres with BERs<2e-4 (KP4 FEC threshold). These results show that the combination of SWDM4 VCSEL technology and PAM4 modulation as well as novel wideband OM4 fibre can increase the reach, achieve higher capacity, and support duplex connectivity for the next generation of data centres with highly dense switches.

4. Acknowledgement

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5. References

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