WideBand OM4 Multi-Mode Fiber for Next-Generation 400Gbps Data Communications

Denis Molin(1), Frank Achten(2), Marianne Bigot(1), Adrian Amezcua-Correa(3), Pierre Sillard(1)

(1) Prysmian Group, Haisnes, France, denis.molin@prysmiangroup.com
(2) Prysmian Group, Eindhoven, The Netherlands
(3) Prysmian Group, Champs-sur-Marne, France

Abstract *We define the bandwidth requirements for OM4 performance within the wavelength window of 850 to 950nm. We have manufactured a MMF meeting these requirements while maintaining full compatibility with legacy OM4. This MMF enables 400Gbps using wavelength division multiplexing.*

Introduction

Multimode fibers (MMFs) have constantly evolved from the very beginning of optical communications industry through the recent and on-going explosion of the Ethernet traffic. Enabled by VCSEL technology and OM4 level performance, MMFs have proved to be the medium of choice for data communications, delivering reliable and cost-effective 10 to 100Gbps solutions.

In order to meet the future increase of demand, the MMF capacity will ultimately have to be increased[1]. The combination of Wideband (WB) MMFs[2] and longer-wavelengths VCSELs for Coarse Wavelength Division Multiplexing (CWDM) is certainly an interesting option to be considered. However, the high modal bandwidth of OM4 fibers, has until now, only been achieved over a narrow wavelength range. The feasibility of WB-MMFs with OM4 performance over a broader wavelength range is a challenge to overcome for next generation multimode systems.

In this paper, we detail the specifications for a WB-MMF with OM4 performance from 850 to 950nm. We also share experimental results from a fabricated fiber. Such a WB-MMF would enable 400Gbps CWDM solutions, while being fully compatible with the current 40G-BASE-SR4 and 100G-BASE-SR4 Standards.

Tab. 1: CWDM Channels at 25Gbps for 400Gbps

Channels #	Wavelength range (nm)
1	850-870
2	875-895
3	900-920
4	925-950

Effective Modal Bandwidth (EMB)

OM4 MMFs typically have graded-index 50µm-diameter cores. The Alpha parameter that governs the shape of this graded-index core is tuned to maximize the modal bandwidth at 850nm, the typical operating wavelength of high speed data communications[3]. OM4 MMFs have effective modal bandwidths (EMB) higher than 4,700 MHz-km at 850nm allowing for 100Gbps data communications. To support future 400Gbps systems, one solution consists of using 4 CWDM channels at 25Gbps over 4 MMFs (see. Tab.1). That is the same number of fibers as that used in the 40G-BASE-SR4 and 100G-BASE-SR4 Standards. The issue is that when the EMB is optimized at 850nm, it does not exceed 4,700 MHz-km at longer wavelengths than 900nm. Calculations, based on the scalar wave equation[4], also show that tuning the Alpha to shift the highest-EMB wavelength to longer values does not help to get EMB>4,700MHz-km at both 850 and 950nm (cf. Fig.1).

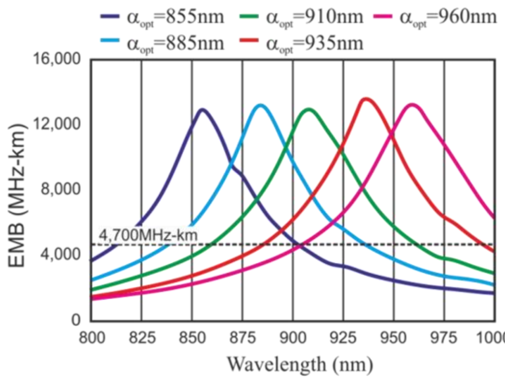

Fig. 1: Simulated EMB wrt. Wavelength of 50µm GI-MMFs optimized at different wavelengths

Effective Bandwidth (EB)

We have recently demonstrated that the system performances of OM4 fibers is better predicted by the effective bandwidth[5] (EB) that results from the Modal and Chromatic Dispersion Interaction (MCDI)[6]. As a result, it is thus more relevant and accurate to specify WB MMFs with EB than with EMB over the whole 850-950nm window. As an example, the absolute value of the chromatic dispersion decreases from ~100ps/nm/km to ~65ps/nm/km at 850nm and 950nm, respectively. Thus one can expect less stringent EMB requirements at 950nm than at 850nm for same power penalties. Whereas, the

EB metric accounts for the difference in chromatic dispersion at all wavelengths.

WB OM4 MMFs should thus have EBs from 850 to 950nm larger than the minimal EB of legacy OM4 at 850nm.

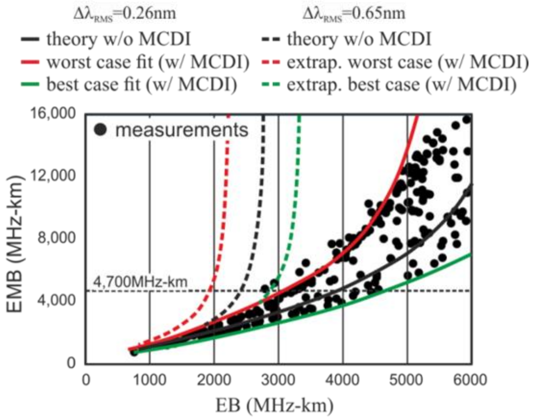

Fig. 3: Measurements at 850nm of EMB vs. EB for a plurality of OM3 and OM4 MMFs with a 10G-BASE-SR transceiver with $\Delta\lambda_{RMS}$=0.26nm (black circles); worst and best fitting envelopes (solid red and green lines); theoretical curve without MCDI (solid black line); extrapolated curves for $\Delta\lambda_{RMS}$=0.65nm (dashed lines)

Minimal EB of legacy OM4

We have demonstrated that EB can be computed using specific MMF and VCSEL metrics[5]. We have applied this measurement procedure to assess the EB delivered by hundreds of MMFs when coupled to one transceiver.

This measurement procedure consists of characterizing separately the MMFs and the VCSELs. The MMF metrics are obtained through standardized Differential Mode Delay (DMD) measurements. The VCSEL metrics are based on the optical spectrum measurements at the output of a nominal fiber illuminated by the source under test. The optical spectrum is recorded by scanning the output of the fiber with a probe fiber, similar to that used in the DMD measurements. 3 curves as function of the radial position of the probe fiber are then obtained: the received coupled power $P_{source}(r)$, the center wavelength $\lambda_c(r)$, and the RMS spectral width $\Delta\lambda(r)$.

We have characterized a 10G-BASE-SR transceiver (Finisar FTLX8571D3BCL) that has a center wavelength of 852.57nm and a RMS spectral width of 0.26nm. The multiple peaks visible in the optical spectrum show that this source is indeed transversally multimode: each peak corresponds to a transverse mode. The source metrics are reported in fig. 2. As expected by theory, the center wavelength decreases with the offset radius because the higher-order fiber modes, present at the largest offset radius, are mainly excited by the highest order VCSEL modes that exhibit the lowest wavelength of the discrete optical spectrum[4,6]. We have then calculated the EB and the corresponding EMB. The EMB was obtained by simply setting $\Delta\lambda(r)$ to zero and $\lambda_c(r)$ constant and equal to 852.26nm.

Fig.3 reports the EMB with respect to EB we obtained. As expected, the EB does not depend bi-univocally on the EMB because of the MCDI. From Fig.3, we can derive the following inequalities:

$$0.8 \cdot EB_{\mathrm{w/o}\ MCDI} < EB < 1.2 \cdot EB_{\mathrm{w/o}\ MCDI} \quad (1)$$

where $EB_{\mathrm{w/o}\ MCDI}$ is the EB calculated from the EMB and the chromatic dispersion bandwidth[7] (CB):

$$EB_{\mathrm{w/o}\ MCDI} = \frac{1}{\sqrt{\frac{1}{EMB^2}+\frac{1}{CB(\Delta\lambda_{RMS})^2}}} \quad (2)$$

We assume that these inequalities do not depend on the bit rate and are thus also typical of 25Gbps transceivers (optical spectrum of 25Gbps VCSELs are similar to those operating at 10Gbps[8]). Ideally, this should be assessed by including 25Gbps sources in the analysis.

The minimal EB expected from an EMB of 4,700MHz-km with a transceiver with a RMS spectral width of 0.26nm at 850nm is less than 3,000MHz-km (CB=7,000MHz-km). Extrapolated

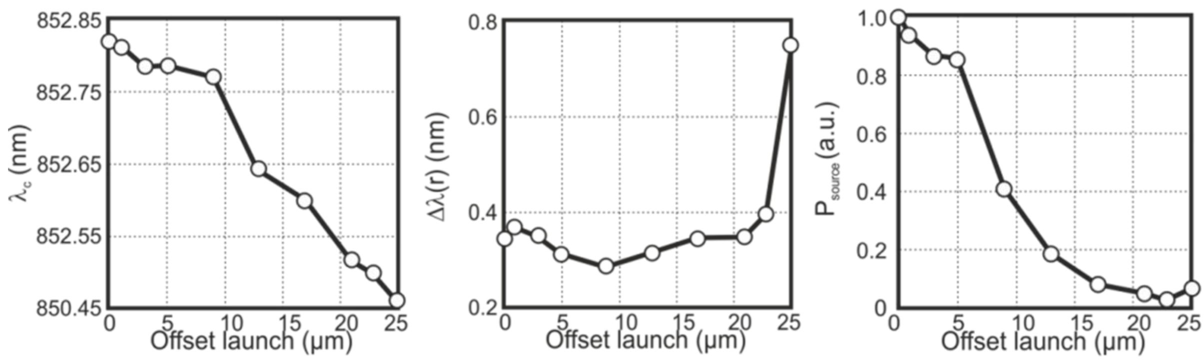

Fig. 2: Measurements of the VCSEL metrics.

to 0.65nm RMS spectral width, the largest spectral width authorized by the 40/100GbE Standard, the minimal EB of an OM4 is expected to be less than or equal to 2,000MHz-km at 850nm, since CB decreases down to 2,800MHz-km. Finally, the minimal EB of legacy OM4 MMFs, considering a RMS spectral width of 0.65nm, is 2000MHz-km at 850nm.

Wideband specifications

Given the above considerations, WB OM4 MMFs have to guarantee an EB larger than 2,000MHz-km over the whole 850-950nm window. For practical considerations, this can be translated into an equivalent EMB specification using Ineqs.(1) (see Tab.2). As expected, the EMB requirements are significantly lower at 950nm than at 850nm. According to the calculation of Fig.1, MMFs with a highest-EMB wavelength close to 875nm are expected to fulfill these specifications.

Tab. 2: EMB Specifications of WB OM4 MMFs

EB>2000MHz-km over 850-950nm		
Wavelength (nm)	EMB (MHz-km)	CB (0.65nm RMS) (MHz-km)
850	>4700	2800
875	>4200	3150
900	>3600	3500
925	>3300	3950
950	>3100	4450

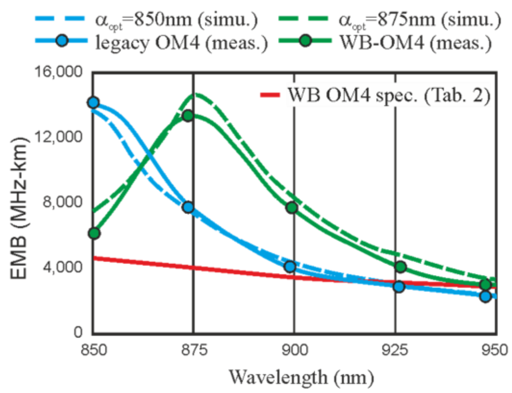

Fig. 4: Measured and simulated EMB of WB OM4 and legacy OM4 wrt. wavelength.

Fiber realization

Using our versatile Plasma Chemical Vapor Deposition process, we have realized a bend-insensitive trench-assisted graded-index 50µm-diameter-core MMF optimized at 875nm, by correctly tuning the Alpha parameter. The DMDs have been measured at different wavelengths from 800 to 1000nm using a tunable Titanium-Sapphire laser. The results are reported in Fig.4, where a legacy OM4 MMF, optimized at 850nm, has been added for sake of comparison. As expected, our optimized WB OM4 MMF fulfills the EMB specifications of Tab.2 (red line on fig. 4), while the legacy OM4 MMF fails at <920nm. Finally, we note a fair agreement between our calculations and the measurements.

Conclusions

Extending the OM4 performance up to 950nm and using CWDM appears to be a promising solution to meet the future 400GbE Standard. Such a solution, fully compatible with current 40G-BASE-SR4 and 100G-BASE-SR4 Standards, requires the development of a new class of Wideband-OM4 MMFs. A simple extension of the EMB-based OM4 specifications at longer wavelengths (i.e. EMB>4,700MHz-km) is, however, too conservative and hardly feasible because it does not take into account the reduction of the chromatic dispersion impairments.

Because it is a much better indicator of the system performance and takes into account MCDI, we have shown that EB is better suited to set the specifications of such WB OM4 MMFs. Using specific MMF and VCSEL metrics, we have derived the minimal EB of OM4 MMFs and we have proposed a corresponding EMB requirement for wideband operation. Finally, we have fabricated and characterized a WB MMF meeting these specifications from 850 to 950nm.

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