Technical feasibility of 100 Gb/s over >100m MMF using VCSELs with reduced spectral width

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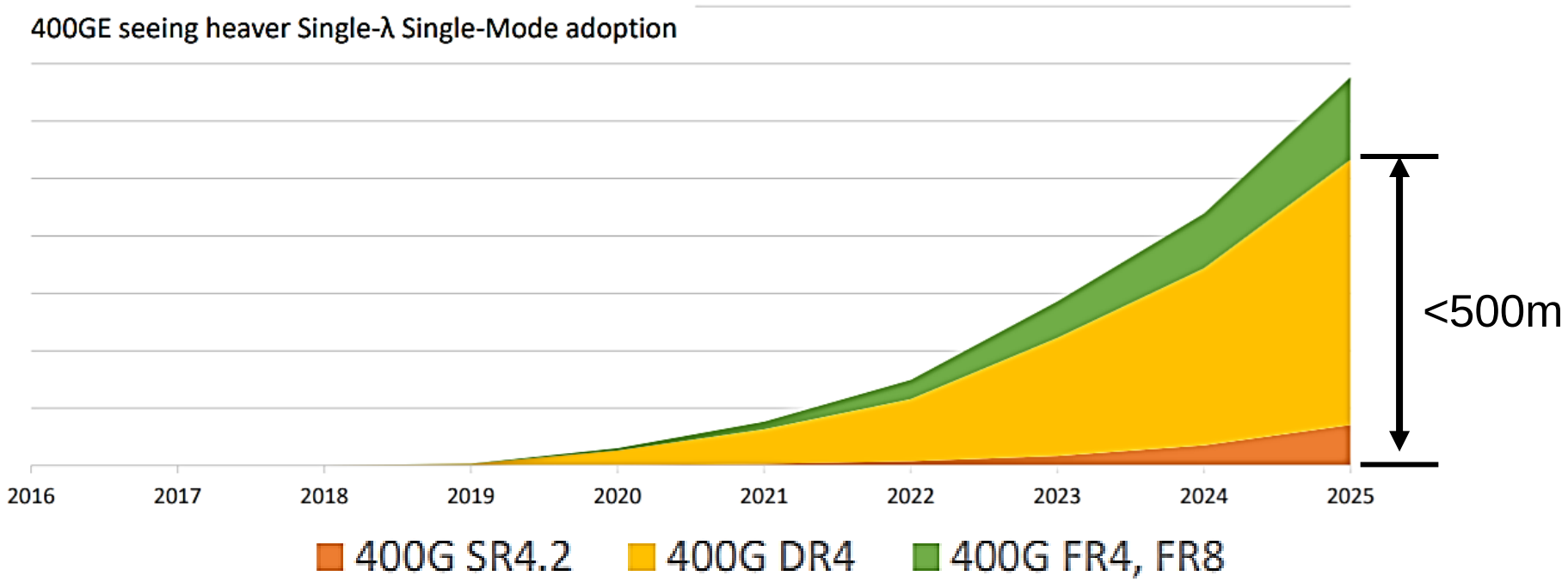
400G data links

Data Courtesy of Lightcounting

400G Market Sizes

Brian Welch, Cisco
April 9, 202 Ad Hoc Meeting
IEEE 802.3 100 Gb/s Wavelength Short Reach PHYs SG



- 100G per wavelength 400G SR4 is not yet included
- The market share will relate to the transmission distance

Present 25Gbaud VCSEL transmission distances

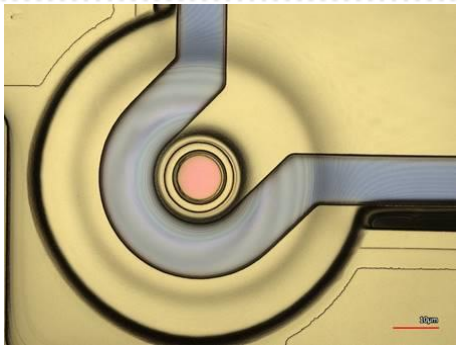
	100G transceivers			
Fiber type	100GBase-SR4	eSR4	BiDi	SWDM
OM3	70	200	70	75
OM4	100	300	100	100
OM5	100	300	150	150

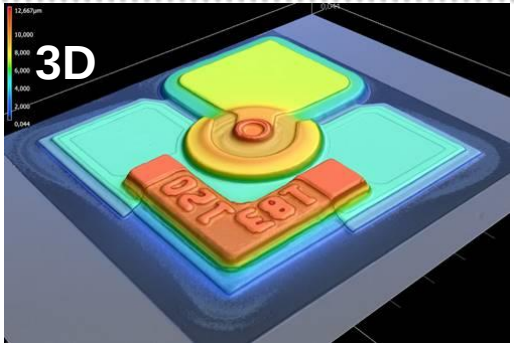
TABLE 3: Transmission distance (in meters) per fiber type and transceiver type

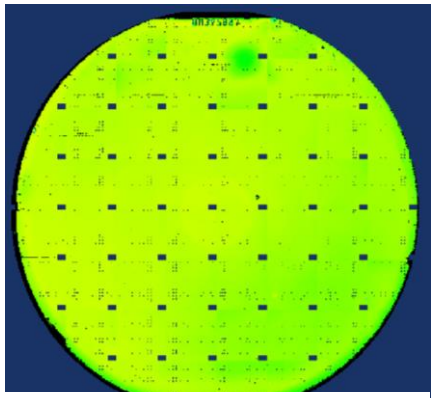
Scott Gregg Corning, Cabling, September 2017

- **25Gbaud VCSELs** transmission over **200m OM3 and 300m OM4** is possible as 100G eSR4
- **50Gbaud VCSELs** transmission **should be, thus, possible** over **100m OM3, 150m OM4**

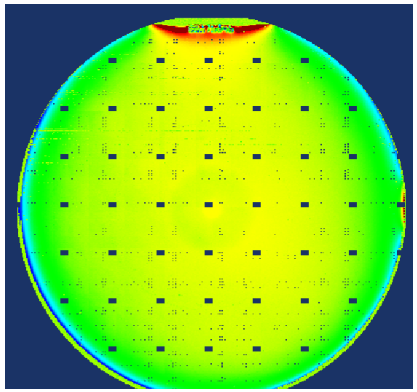
VCSEL and PIN Technology at ~30GHz







Uniform power



Uniform emission wavelength

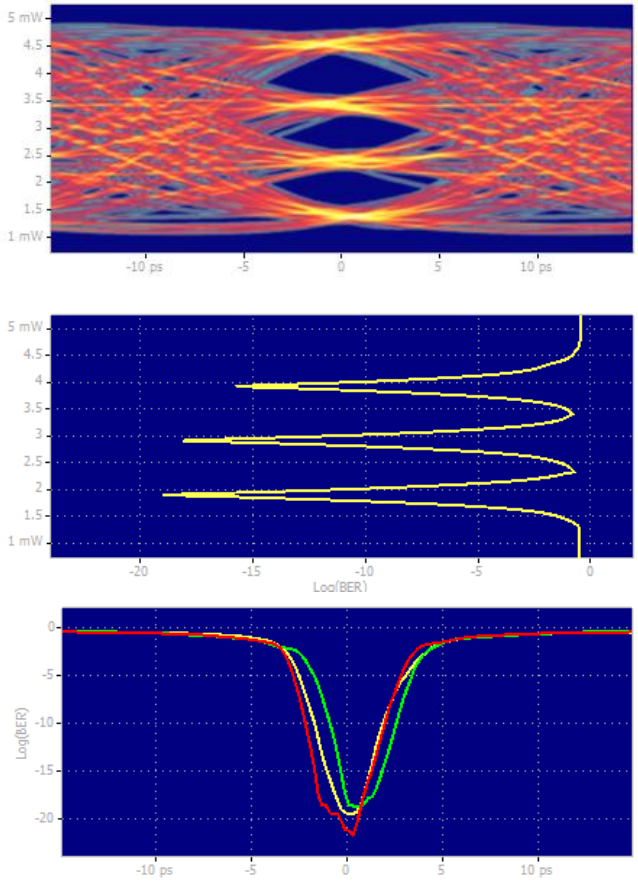
Many companies

→ 4'' wafer technology >120 000 single VCSELs

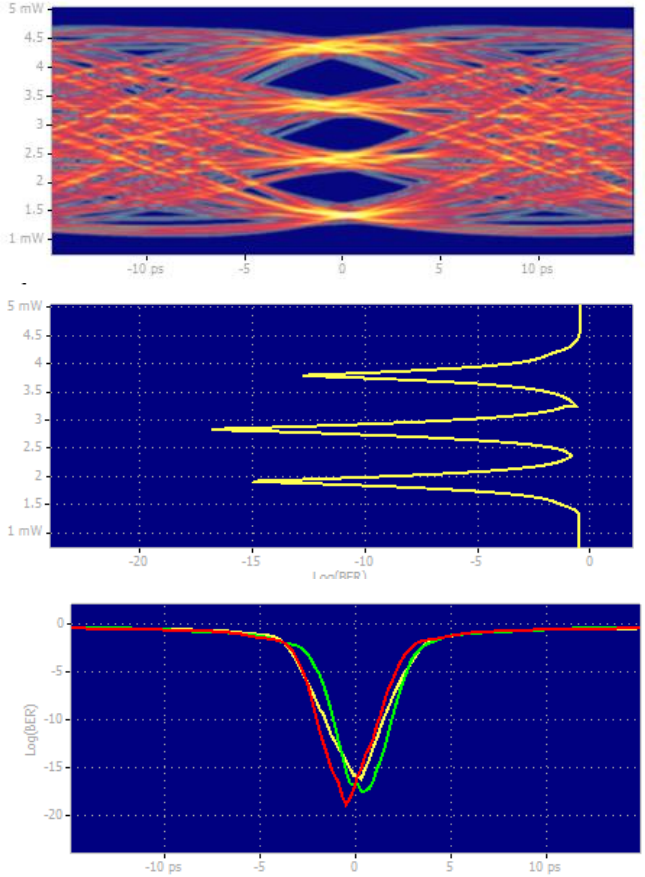
→ High yield (>95%) and uniformity

100Gb/s over 30m OM3 MM 850nm VCSEL

100 Gbit/s back-to-back



100 Gbit/s 30m OM3 fiber

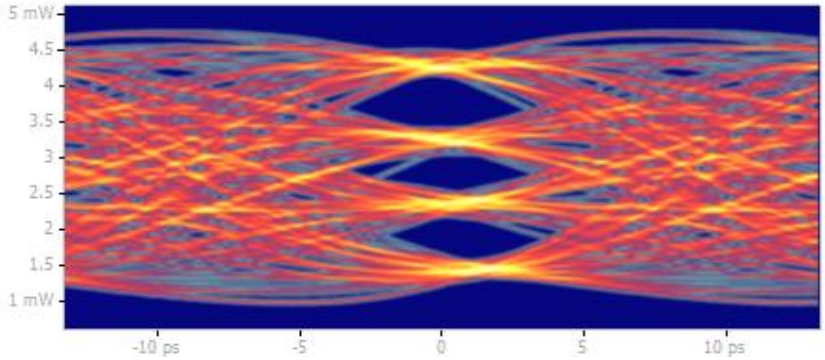


→ Moderate impact of OM3 fiber length at 100Gb/s

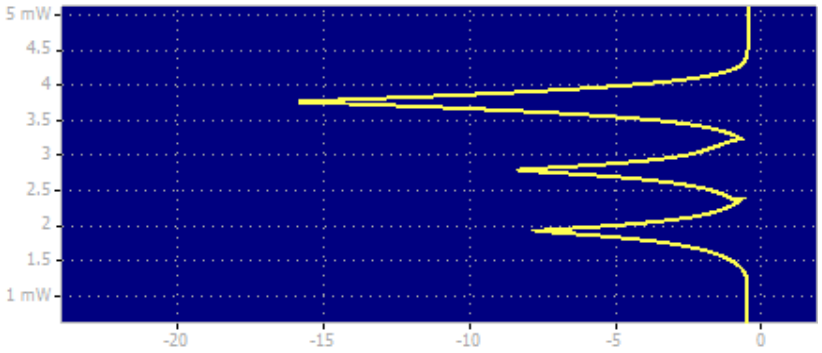
→ All eyes are error-free at BER $<10^{-12}$

112Gb/s over 30m OM3 MM 850nm VCSEL

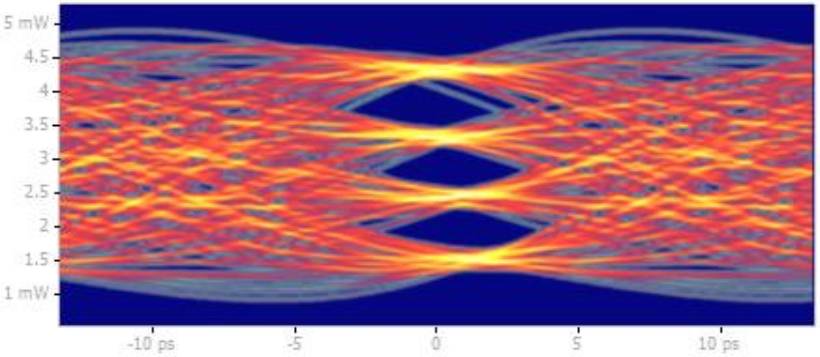
112 Gbit/s back-to-back



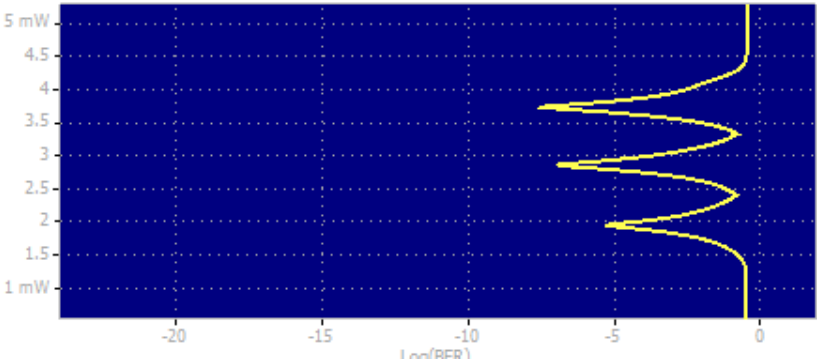
BER eye



112 Gbit/s 30m OM3 fiber



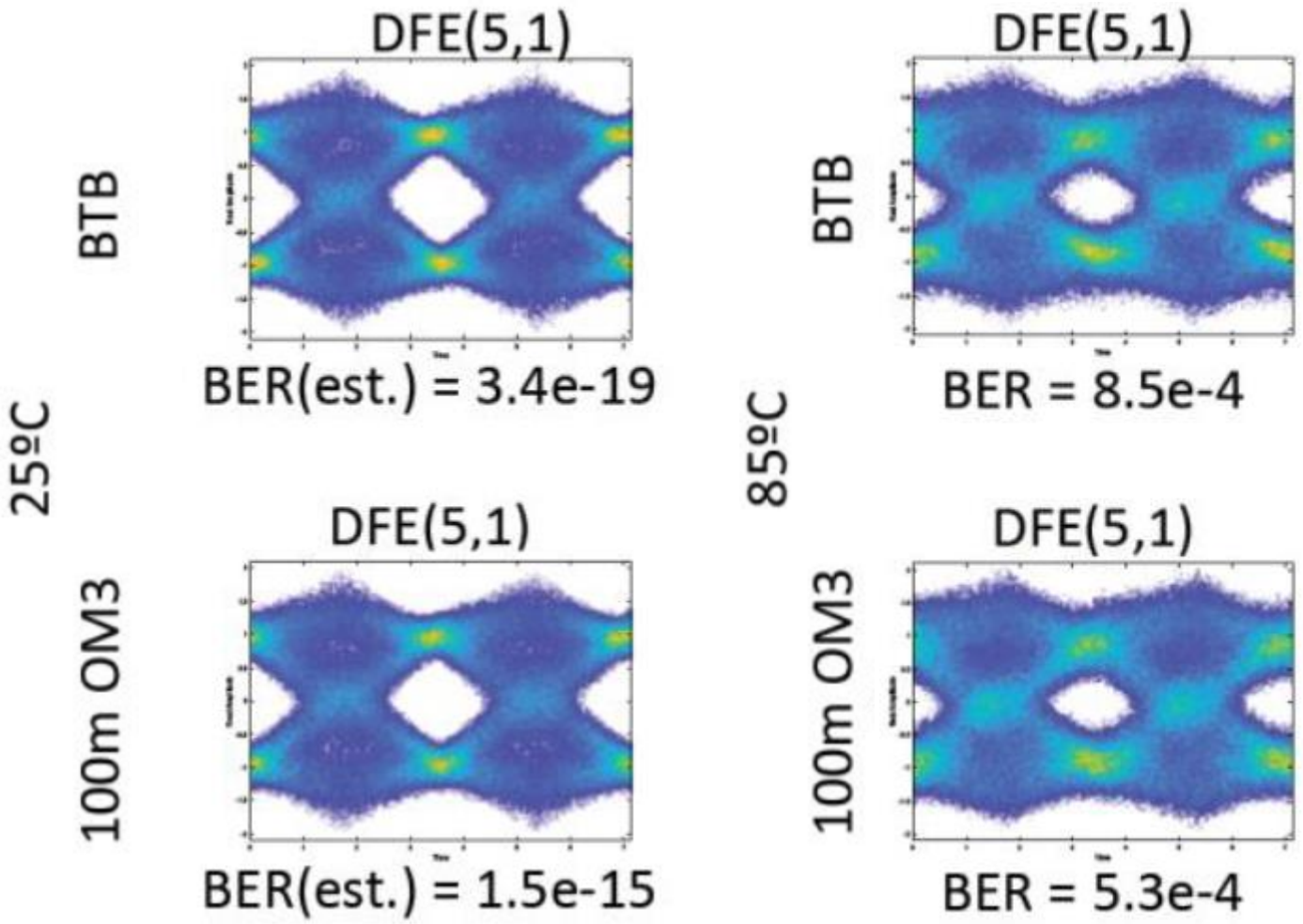
BER eye



Test w/o pre-emphasis shows BER <10^{-7} both for back-to-back and 30m OM3 transmission.
With driver pre-emphasis further improvement is possible

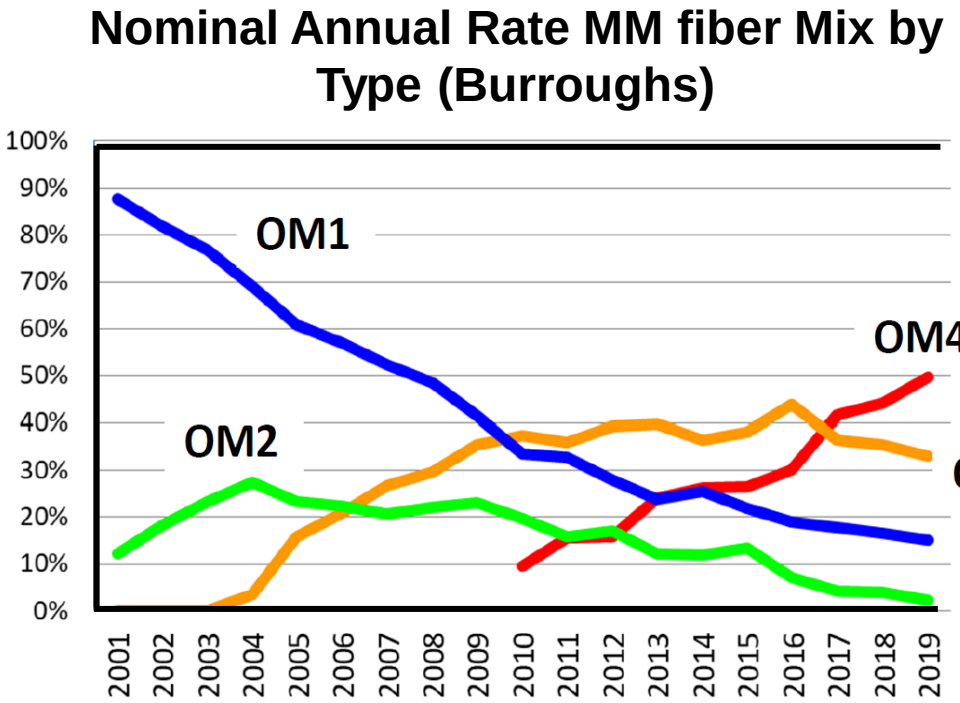
→ Moderate impact of OM3 fiber length at 112Gb/s

50Gbaud100m OM3 850nm VCSEL

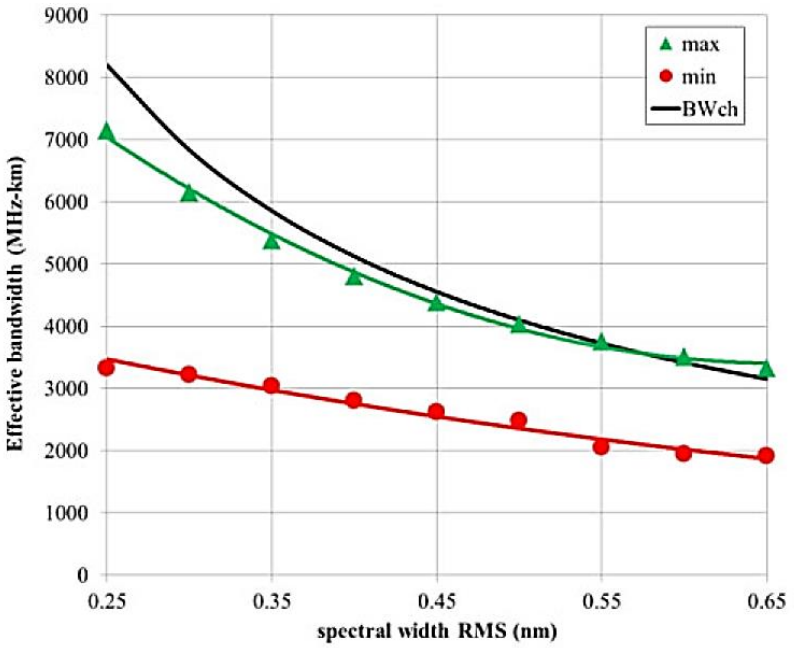


→ 100m OM3 50Gbaud transmission with margin

Multimode VCSEL over MM fiber trends

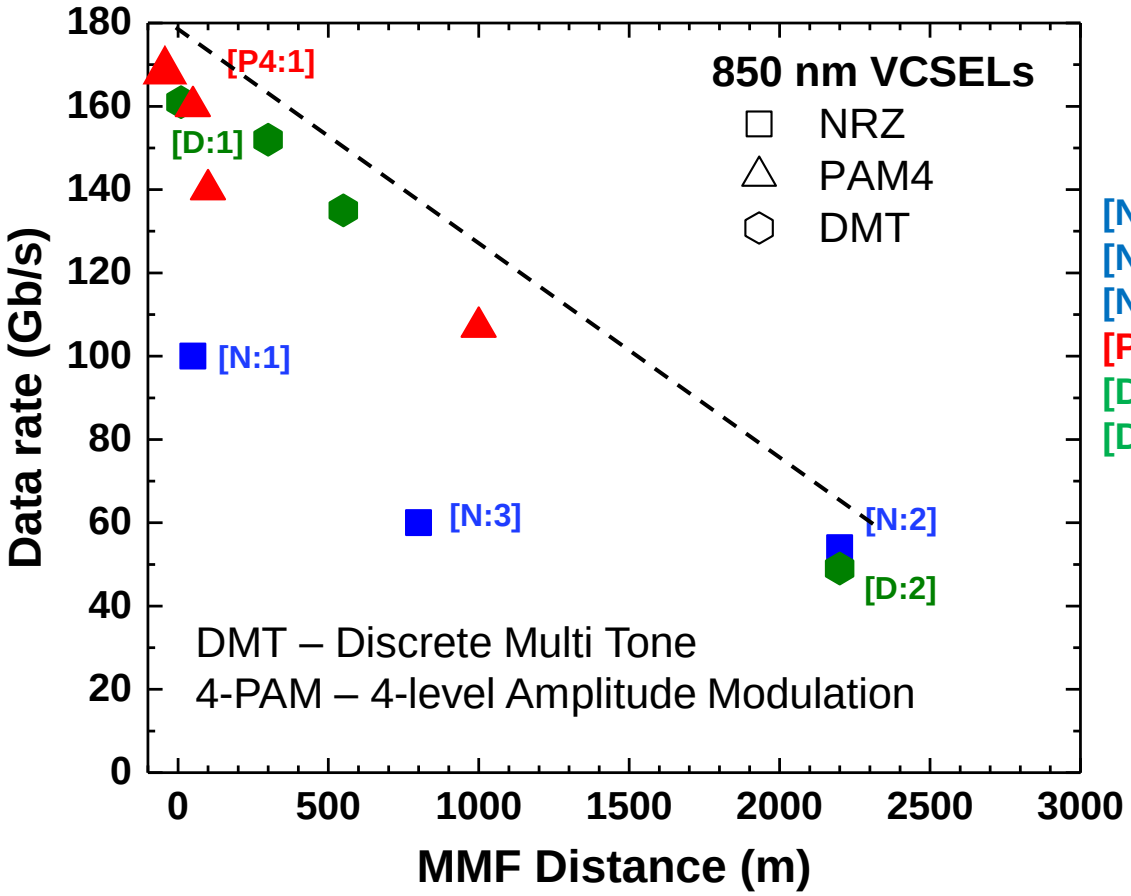


Molin et al ECOC 2013



- By 2025 new MMF fiber (OM4, OM5) having bandwidth limited by chromatic dispersion of glass will dominate
- Narrow spectrum VCSEL links ~doubling the bandwidth worst case
- Narrow spectrum SR 100G per wavelength >100m possible

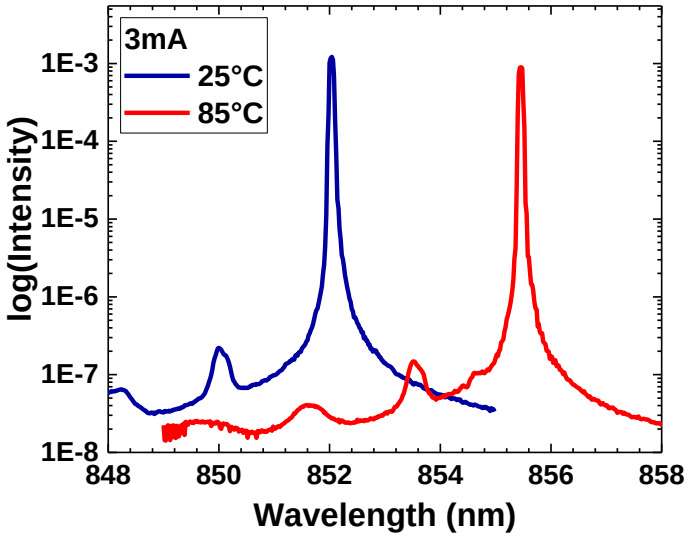
850nm MMF data transmission

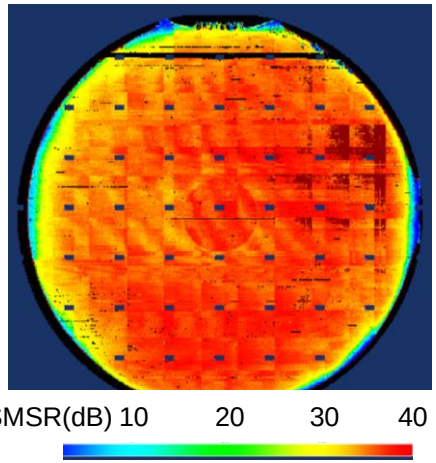


[N:1] Ledentsov OFC (2020)
[N:2] Stepniak EL Lett (2016)
[N:3] Ledentsov Jr, OFC PDP (2019)
[P4:1] Lavrencik OFC (2020)
[D:1] Kottke JlT (2018)
[D:2] Lu JoSTQ (2015)

- Record data transmission lengths over OM4 and OM5 MMF are reached using single mode VCSELs
- 2.4km OM4 at 54Gbaud

4” Single Mode VCSEL technology

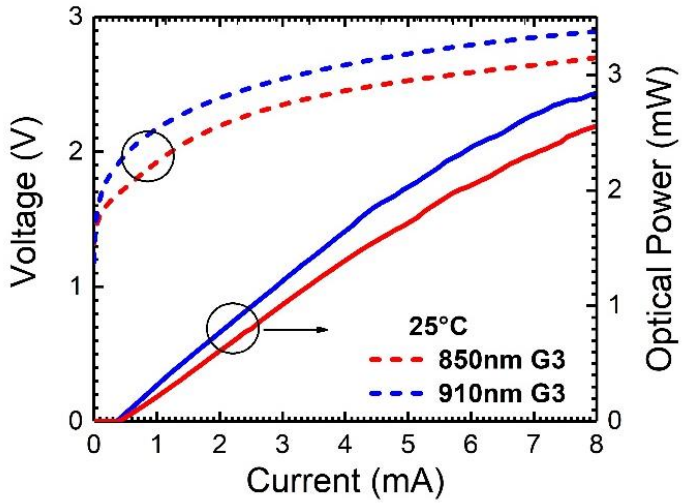




Side mode suppression ratio between the first and the second VCSEL modes is within 30-40dB range for >95% of the wafer
3mA current

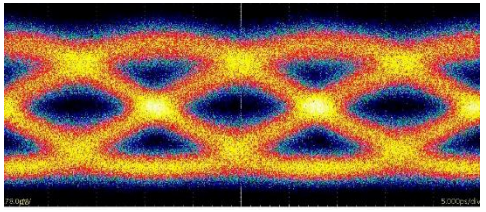
OFC 2020

- 4’’ wafer technology >100 000 chips
- High yield (>95%) and uniformity



Fiber-coupled light-current-voltage (LIV) curves of the VCSELs

60 Gbit/s 800m MMF at no pre-empasis/equalization

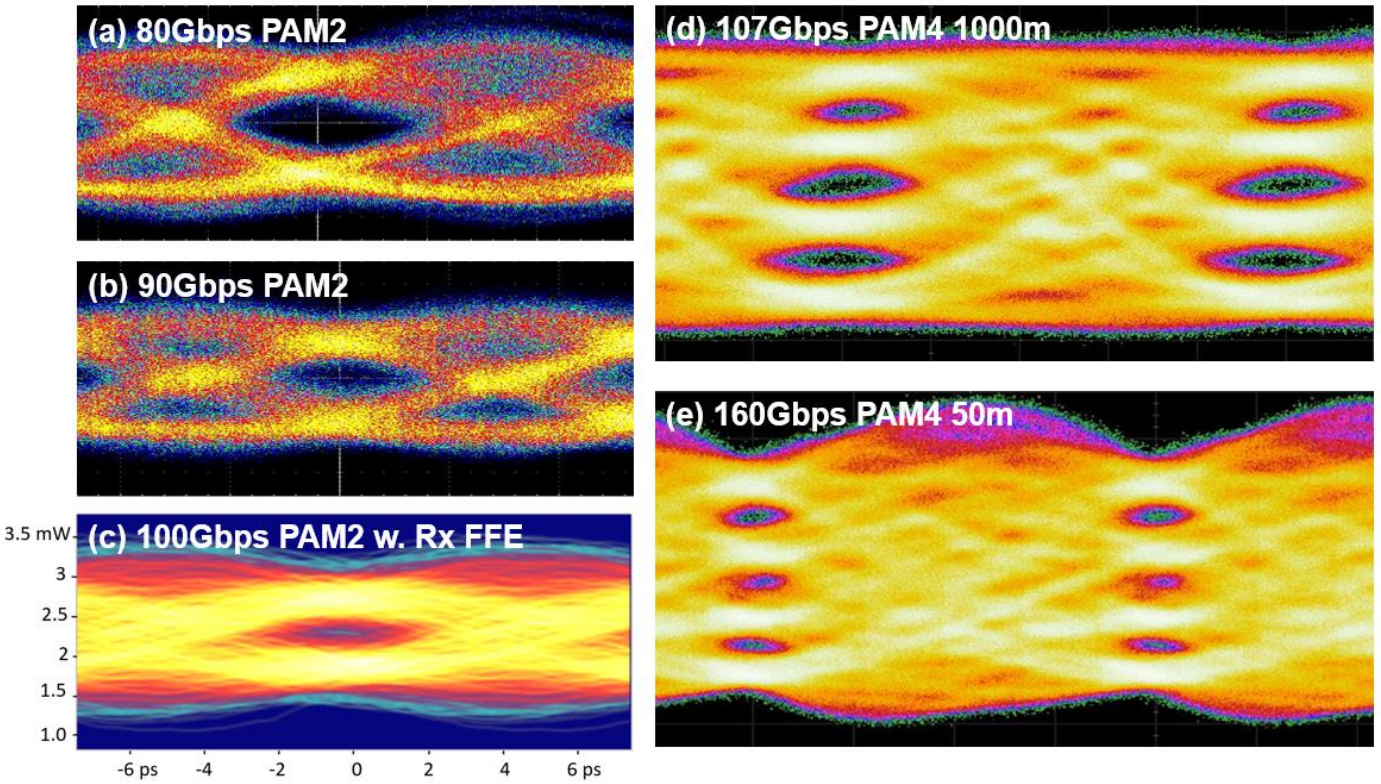


VCSEL chips up to 100Gbaud (850nm, 910nm)

→ 100Gb/s NRZ

→ 160Gb/s PAM4 50m MMF

OFC 2020

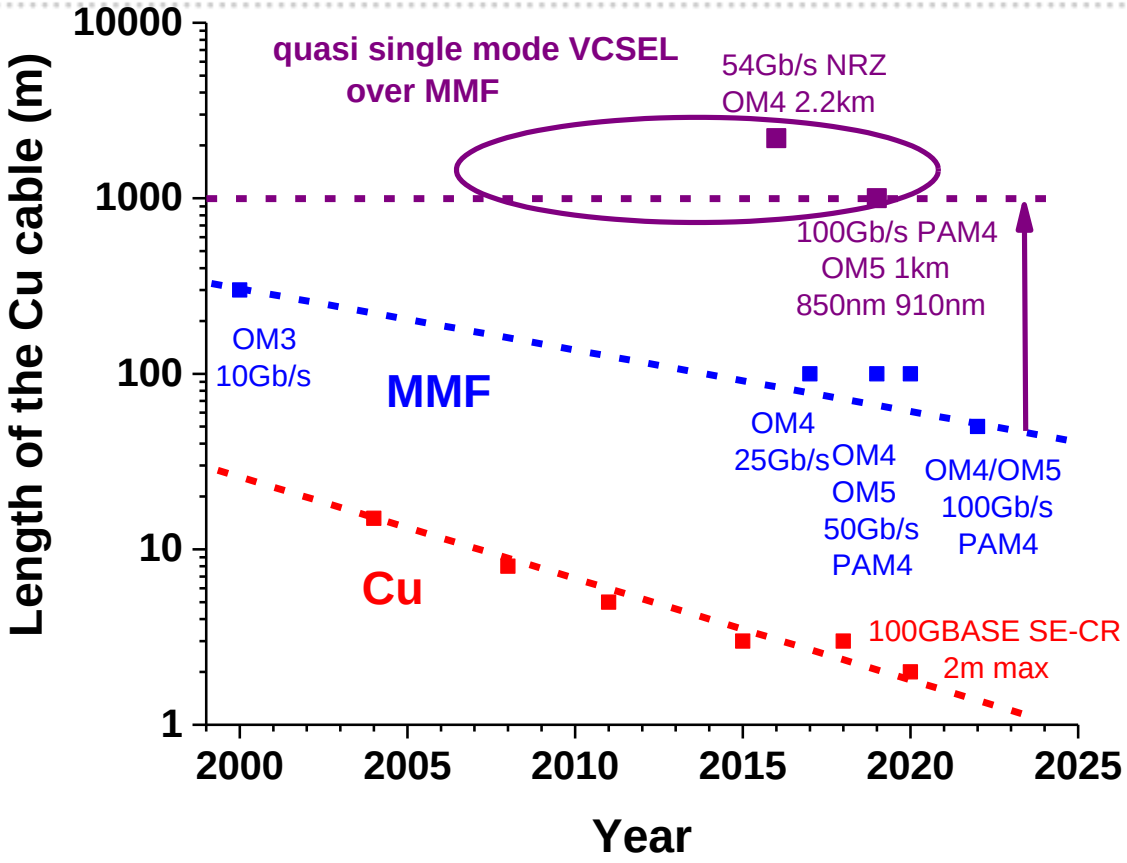


→ **Quasi-Single Mode VCSEL: >160 Gb/s PAM4 over 50m MMF**

→ **107 Gb/s PAM4 over 1 km of MMF: 910nm, 850nm** (VIS-Georgia Tech)

→ 100 Gb/s NRZ over 50m MMF (CTU-Georgia Tech, CTU-VIS)

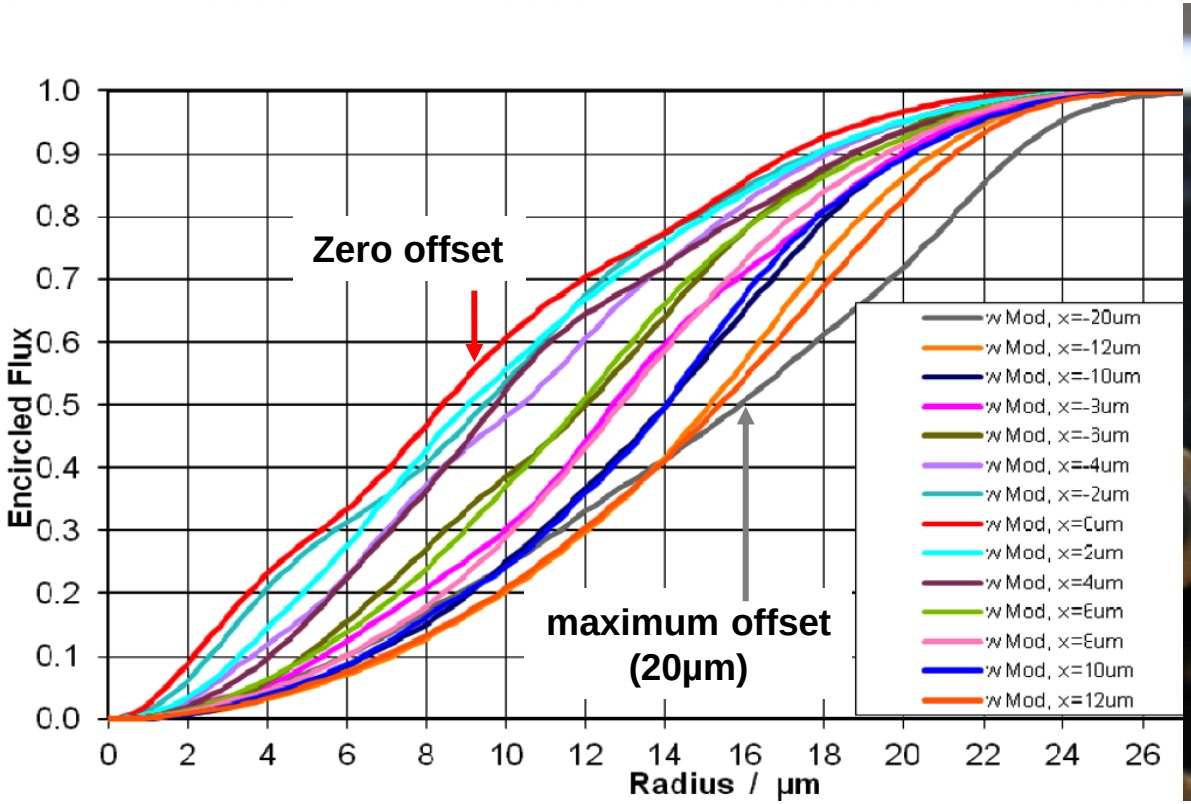
Multimode fiber transmission: VCSEL trends

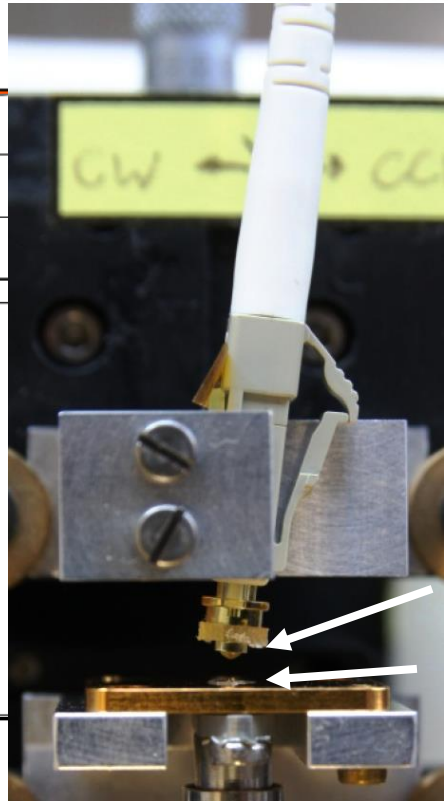


>50Gbaud 1km MMF transmission

- Multimode fiber links shrink with the transmission speed due to a high **chromatic dispersion at 850nm and a large spectral width (rms ~0.6nm)**
- **Single mode VCSEL is an option to extend 100G MMF fiber links up to >1km when the distance is limited by the chromatic dispersion (OM5, OM4, ~OM3)**

Single mode VCSEL over OM4 MMF: encircled flux



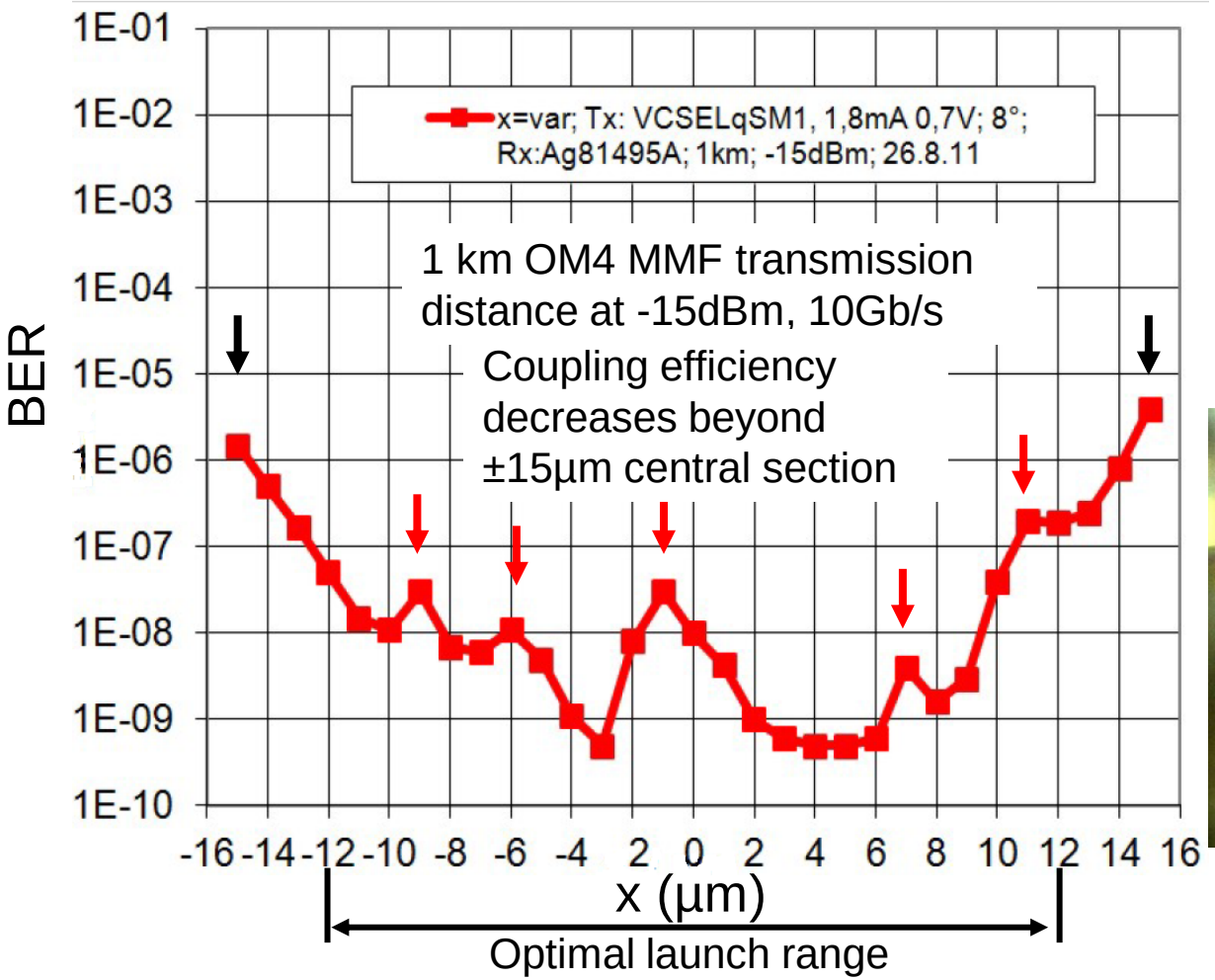


Encircled flux distribution in the 50 µm core MM fiber as a function of the radial launch offset distance. 8° inclination angle of the fiber. Precision motion is provided with piezo-driven axis

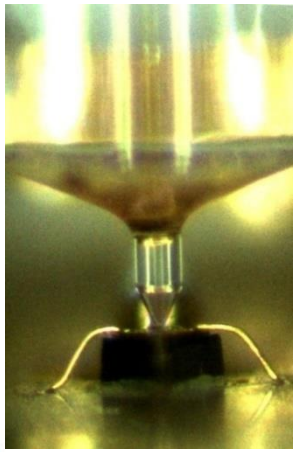
Proc. SPIE 8276, 82760K (2012)

- → Encircled flux condition is fulfilled
- → The modes of the MM fiber are uniformly filled with VCSEL light

Single mode VCSEL 1km OM4 MMF: BER



BER as a function of the offset in the 50 µm core MM fiber as a function of the radial launch offset distance at 8° inclination angle (850nm SM fiber launch).



850nm SM VCSEL on HF-connector coupled to 4.4 µm-core SM (850 nm) fiber.

Proc. SPIE 8276, 82760K (2012)

→ Focused excitation spot - reproducible spikes in BER at certain offsets

→ “Central defect” in the worst-case launch does not play any major role.

Single mode VCSELs: pros and contras

Concern	Response	Comment
MM Fiber has a central defect. SM VCSEL transmission can be not stable	In normal lunch conditions SM VCSEL excites many mode groups: no preference for the mode affected by the central defect	Modern fibers OM4 and OM5 do not show strong impact of the central defect Transmission studies with focused beam VCSEL launch did not confirm negative impact of the central launch
SM VCSEL is not standardized by IEEE	IEEE standards specify only RMS spectral width (<0.6nm) and do not prohibit SM VCSEL	First IBM study of SM VCSEL transmission over MMF (2004) used devices from three manufacturers by selecting “randomly” SM VCSELs
RMS spectral width may not be sufficient	Side mode suppression ratio is to be introduced	The same RMS can result in different spectral spacings of the hopping modes

→ No standardization work on SM VCSEL transmission over MMF

→ Standard will not evolve within at least 3 years (only customized solutions)

Single mode VCSEL technology concerns

→ *"Single mode VCSEL is not reliable"*

- ***Small aperture VCSELs are more reliable at the same current density*** *(Finisar)*

→ *"Single mode VCSEL can't reach power necessary power without current overstress"*

- ***The power of 2.8mW may be excessive as it includes 3dB fiber transmission penalty*** (1km MMF at 107Gb/s SM VCSEL: 3dB fiber attenuation margin as compared to 100-500m distances)
- ***Surface grating*** *(Finisar-II-VI, TUB,…)*
- High speed VCSEL with ***closely spaced multiple small apertures is demonstrated without spectral broadening*** (*TUB, J. Lott et al*)
- ***50Gbaud multicore single mode VCSELs*** (*VIS – TUB, T. Heuser et al*)
- ***Mode stabilization at large aperture by photonic crystal processing*** 25Gbaud SM VCSEL at 10kA/cm^2 over 1km without penalty (*VIS-UIUC*)
- ***1.4 km 40Gbaud data transmission at no equalization*** using **leaky-design** single mode VCSELs (**up to ~5µm aperture diameter**, VIS)

with further efforts longer distances will be reached

Proposal

- To include objective of *100G data transmission over at least 100m of MMF using 850nm VCSEL with a reduced spectral width*

- Decide on the maximum OM4 and OM5 MMF transmission distance at the Task Force stage