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Early 1060 nm VCSEL data

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200 Gb/s per Wavelength MMF PHYs Study Group Ad Hoc Meeting

Supporters

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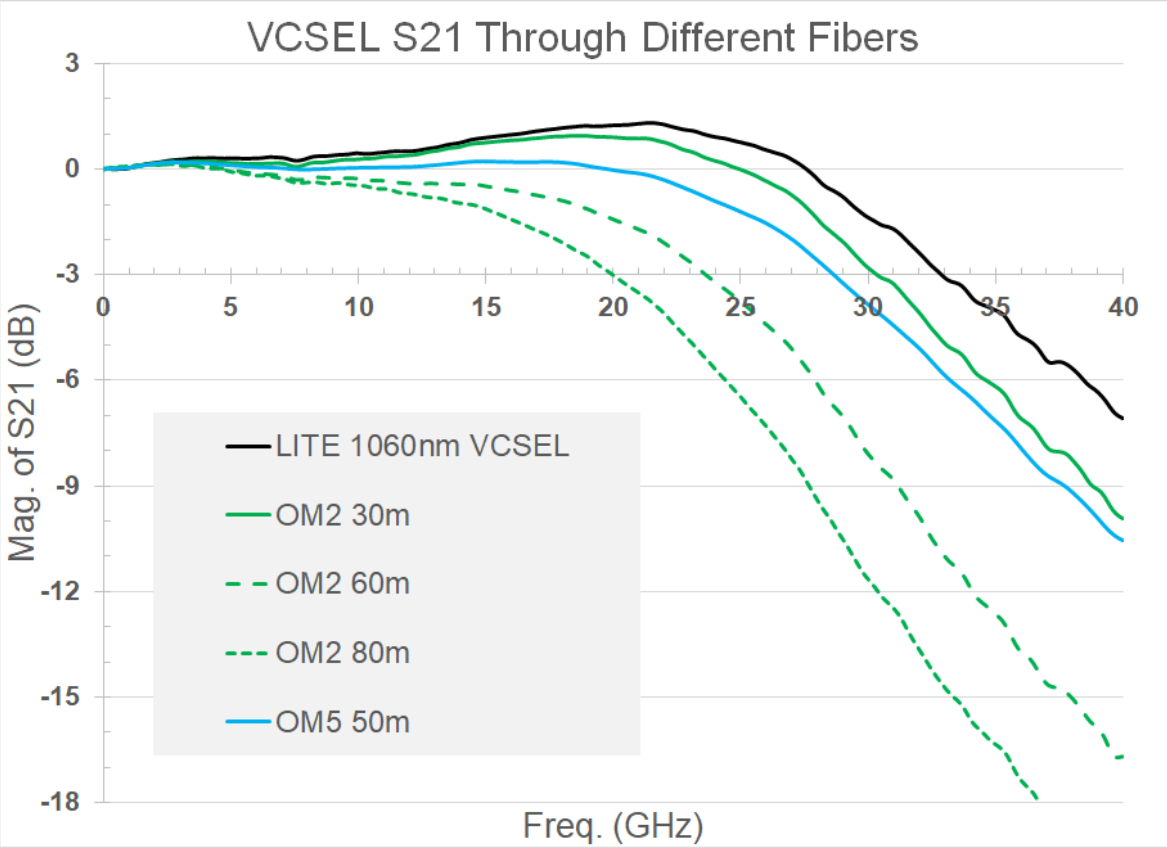
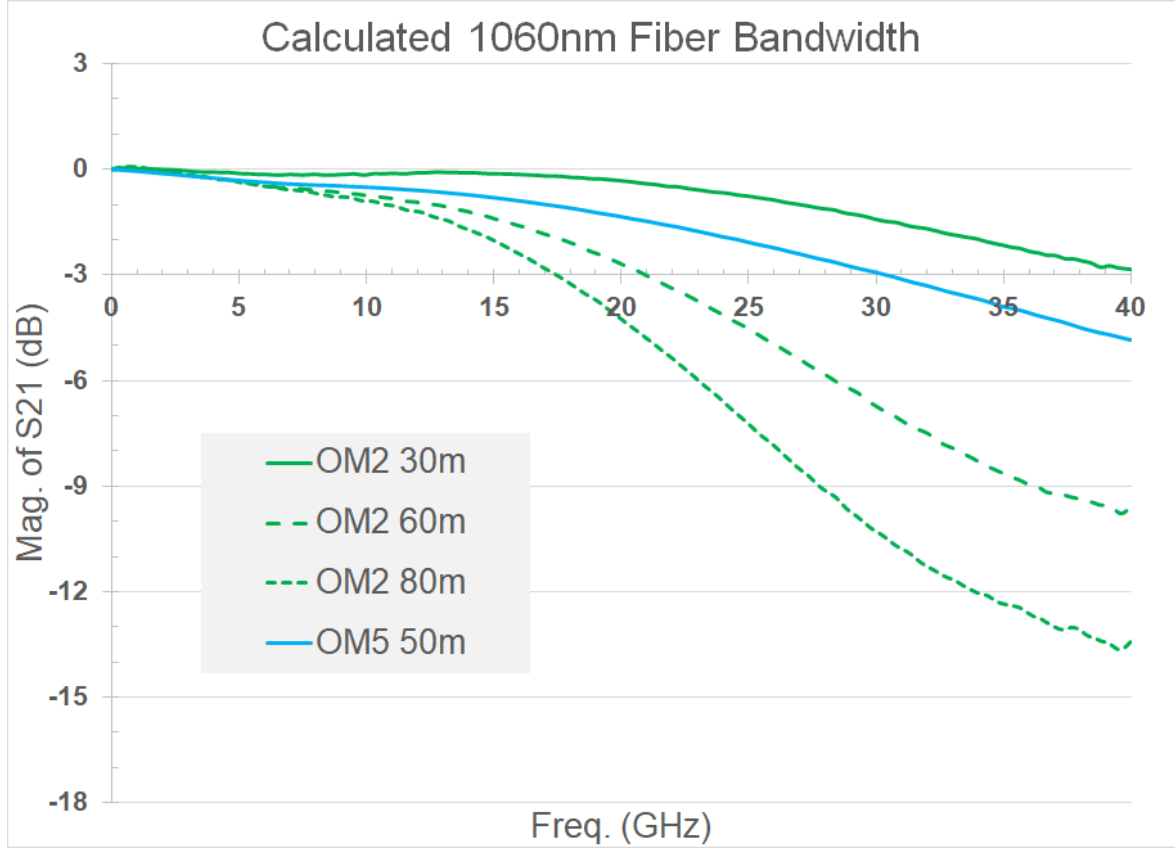
1060nm Fiber Bandwidth Measurements – Existing Standard Fiber

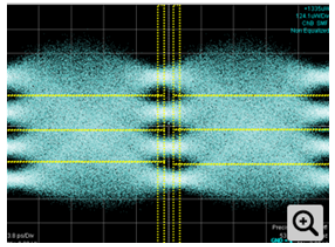
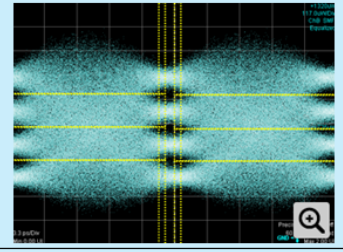
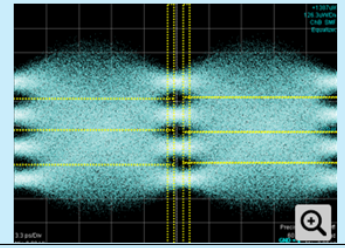
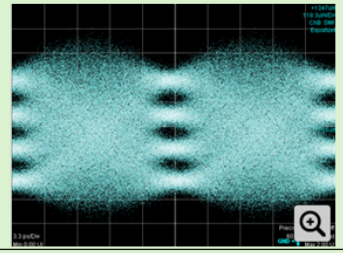
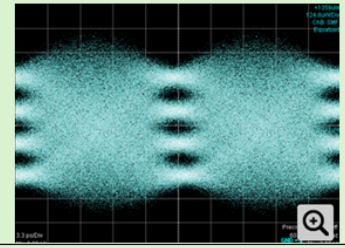
- Measuring bandwidth limitations for different fiber samples with 50um core
- OM2 and OM5 fibers purchased off-the-shelf. Seem to be typical samples based on the data sheets
  - (Not selected for best-case or worst-case dispersion)
- 30m OM2 sample is good for demonstration purposes
- Received fiber samples improved or optimized at 1060 nm and will measure in next few weeks
- Lumentum can provide 1060nm VCSEL on high-speed board for fiber measurements





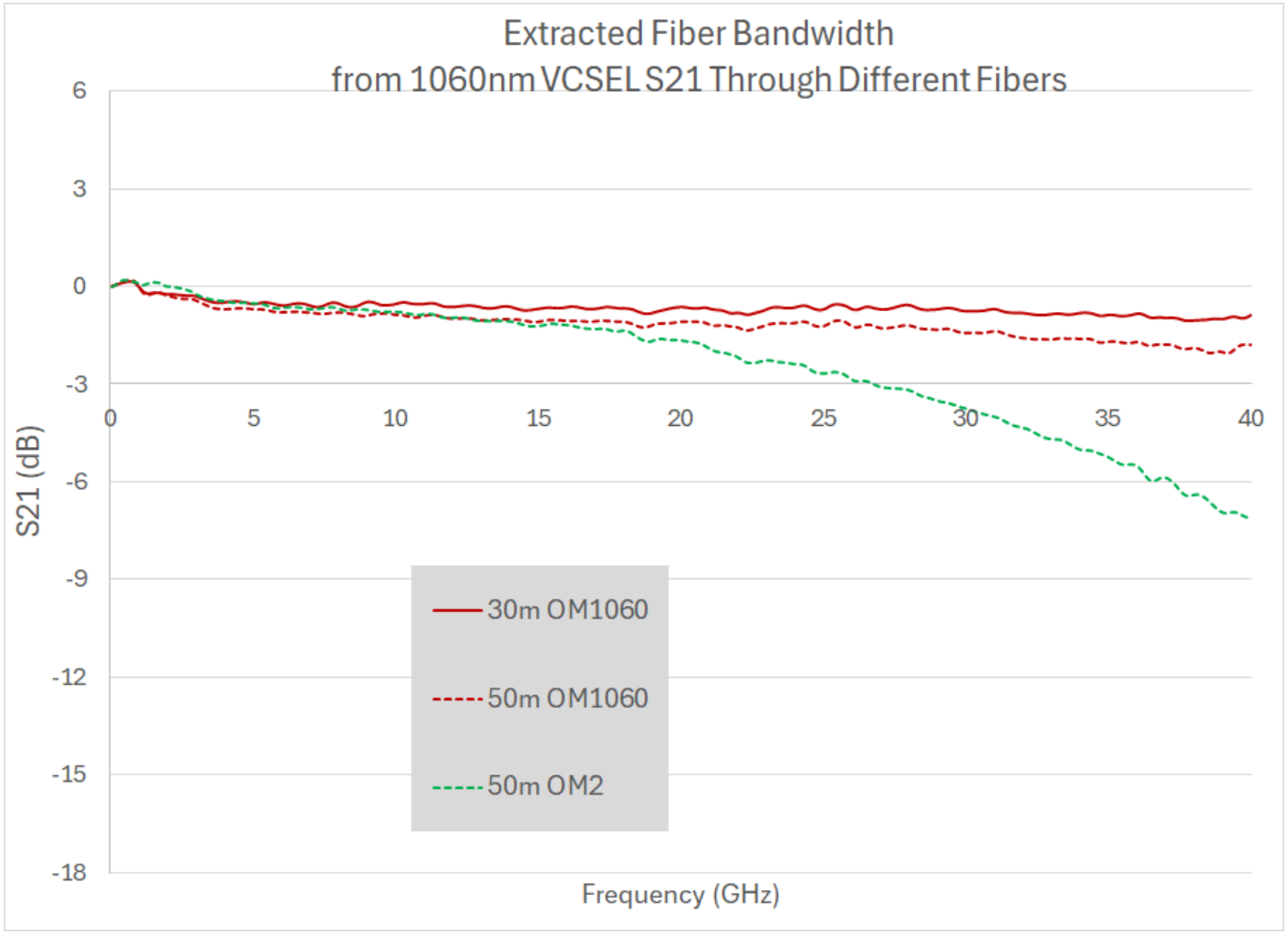
1060nm 60GBd PAM4 Filter Equivalents – Existing Standard Fiber

- 24GHz for 30m OM2 and 22GHz for 50m OM5

LITE 1060nm VCSEL, 60GBd PAM4					
BTB	Eyes				
	Outer_ER(dB)	3.36			
	TDECQ(dB)	2.47			
	Ceq(dB)	0			
30m OM2	Eyes		**Filter 24GHz**	Eyes	
	Outer_ER(dB)	3.05		Outer_ER(dB)	3.06
	TDECQ(dB)	1.87		TDECQ(dB)	2.55
	Ceq(dB)	0.29		Ceq(dB)	1.09
50m OM5	Eyes		**Filter 22GHz**	Eyes	
	Outer_ER(dB)	3.02		Outer_ER(dB)	2.91
	TDECQ(dB)	NA		TDECQ(dB)	NA
	Ceq(dB)	1.15		Ceq(dB)	1.08

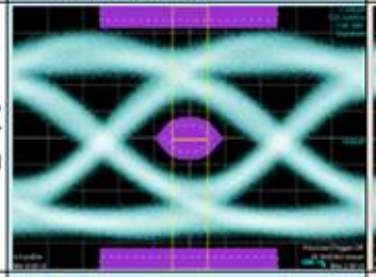
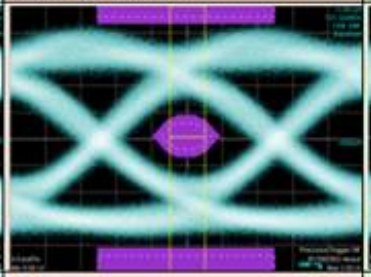
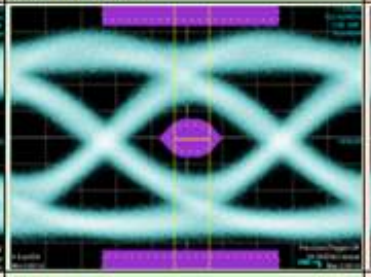
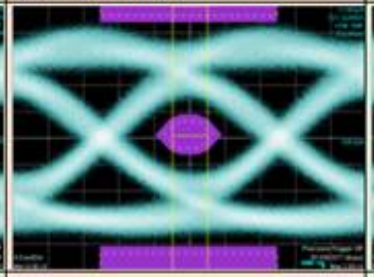
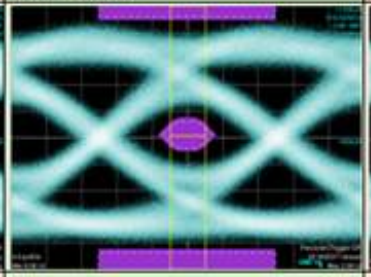
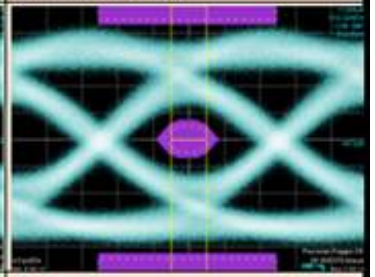
1060nm Fiber Bandwidth Measurements – New 1060nm Fiber

- Measuring bandwidth limitations for different fiber samples with 50um core (different VCSEL to pages 3 & 4)
- Comparing OM2 (best at 1060nm from standard fibers) with sample of 1060nm optimized
- Additional measurements ongoing to extract estimated fiber bandwidth



1060nm Eye Diagrams – New 1060nm Fiber

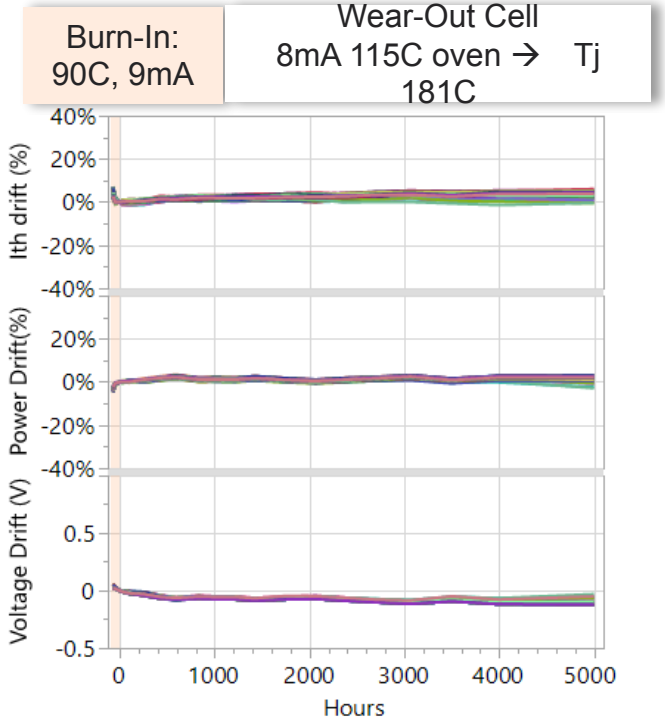
- 50m OM1060 shows little degradation at 50Gb/s NRZ

I_Bias (mA)	10					
Pre-cursor	-1.22, 2					
Post-cursor	0.8					
Fiber	1m OM5 (B2B)	10m OM1060	30m OM2	30m OM1060	50m OM2	50m OM1060
50Gbs NRZ Eye Digram						
ER (dB)	4.44	4.4	4.17	4.29	3.9	4.12
Eye margin (%)	15.6	14.5	11.6	13.3	6.9	11.1
Tr (ps)	10.9	11.05	11.8	11.57	13.08	12.35
Tf (ps)	11.99	12.15	12.62	12.49	13.57	13.08
Crossing (%)	48.26	48.15	48.51	48.43	48.97	48.65

1060nm Application – High Temperature Reliability

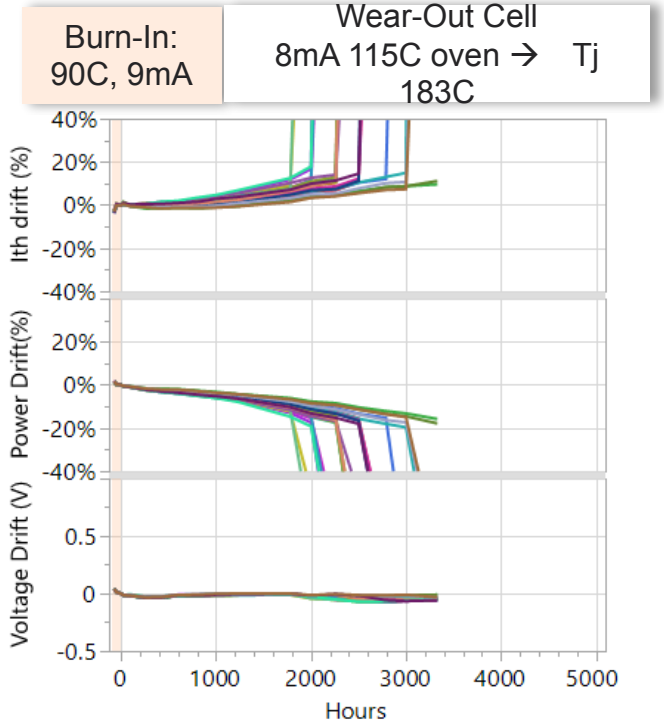
- Highly accelerated wear-out testing of VCSELs using the *same Epi and device structure designs* (as much as possible) except lasing at 1060nm and 850nm
- Not to say 850nm cannot meet the reliability requirement, but to try to compare the intrinsic reliability benefits for the higher In% quantum wells and lower energy photons

1060nm ~5um Aperture



1060nm cell: 86 units – longest running cell ongoing
No failures and minimal drift to 5,000hrs
Tj 181C far above max operating in scale-up rack Tj~130C

850nm ~5um Aperture

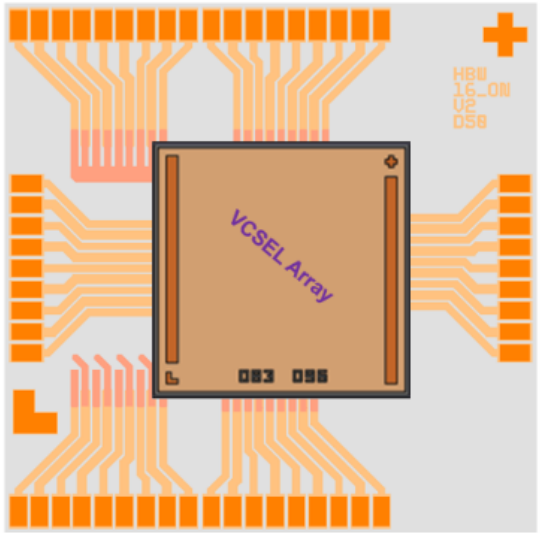


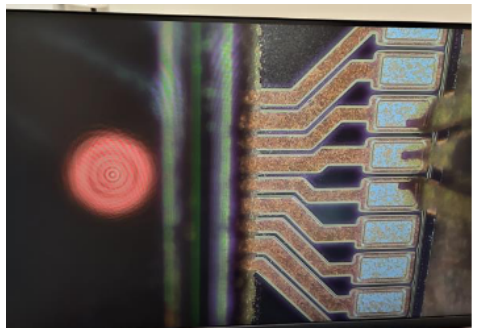
Example 850nm 22 units at similar accelerated stress conditions
Wafer passes 100G requirement for 20yrs at 8mA 85ºC
Power & Ith observed >600hrs with catastrophic failures >1,600hrs

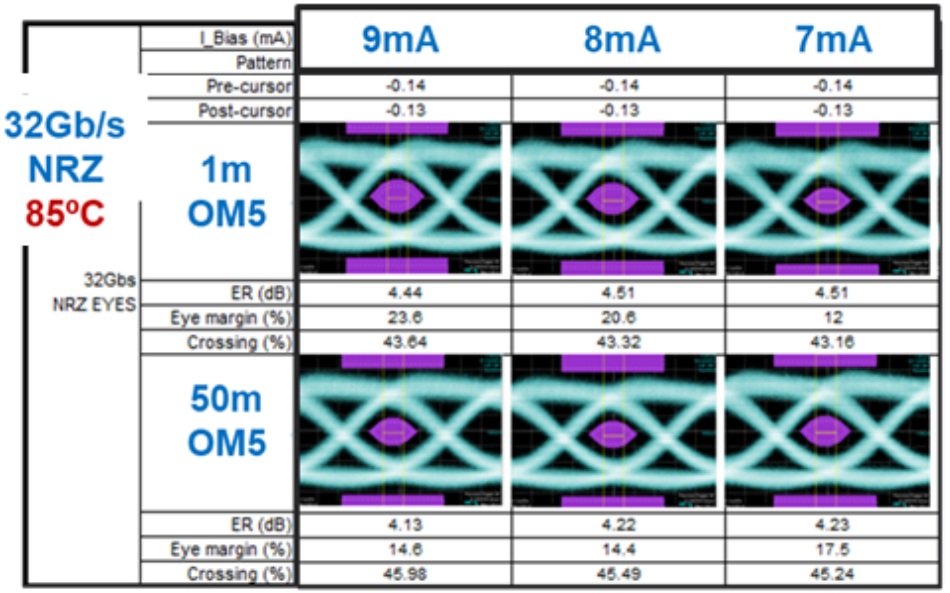
1060nm Application – Bottom-Emitting 2D Arrays

- 2D Parallel optical interconnect for scale-up applications operating reliably at high heat-sink temperatures
- 1060nm enables bottom emitting implementation
- Measured eye-diagrams on right of one emitter in the 80 emitter array up to 105ºC Silicon sub-mount temp
- Speed is limited by the long traces of the sub-mount; plan to demo using driver close to VCSELs April 2026

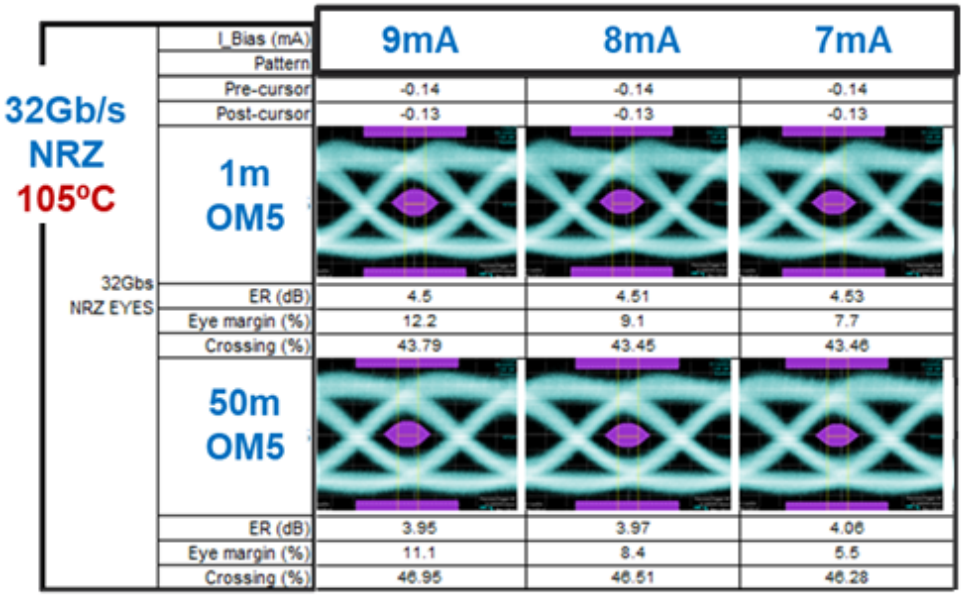
VCSEL Array on Silicon
16 emitter addressable







I_Bias (mA)	9mA	8mA	7mA
Pattern			
Pre-cursor	-0.14	-0.14	-0.14
Post-cursor	-0.13	-0.13	-0.13
ER (dB)	4.44	4.51	4.51
Eye margin (%)	23.6	20.6	12
Crossing (%)	43.64	43.32	43.16
ER (dB)	4.13	4.22	4.23
Eye margin (%)	14.6	14.4	17.5
Crossing (%)	45.98	45.49	45.24



I_Bias (mA)	9mA	8mA	7mA
Pattern			
Pre-cursor	-0.14	-0.14	-0.14
Post-cursor	-0.13	-0.13	-0.13
ER (dB)	4.5	4.51	4.53
Eye margin (%)	12.2	9.1	7.7
Crossing (%)	43.79	43.45	43.46
ER (dB)	3.95	3.97	4.06
Eye margin (%)	11.1	8.4	5.5
Crossing (%)	46.95	46.51	46.28

Voltage swing range ~630mV

Summary and Next Steps

- Summary
  - Current devices capable of 60 GBd operation
  - Tested with various OM2 and OM5 fibers
  - New data with 1060 VCSEL and 1060 optimized MMF at 50 Gb/s NRZ over 50 m
  - Reliability testing shows good lifetime for 1060 nm VCSELs
  - Proof of concept for back-side emitting VCSELs on a sub-mount at 32 Gb/s NRZ over temperature

- Next Steps
  - Test current 1060 nm VCSELs with newly received 1060 nm bandwidth improved fiber (this month)
  - Communicate requirements for 1060 MMF to IEC (well before April IEC meeting)
  - New 1060 nm VCSEL devices for 200G testing (4+ months)
  - Evaluate back-side emitting array with closely coupled driver (4+ months)