Merits of Selecting CWDM for 10km SMF PMD

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Motivation and contents of this presentation

- Motivation
  - Enable lowest cost, compact transceiver supporting the 10km SMF PMD in the first and future generations
  - Specify a wavelength grid which minimizes cost, size, & power dissipation both in year 1 and subsequent years
- Class 1 Eye Safety is feasible with CWDM
- Laser Technologies Technology & Cost transition
- CWDM vs. LAN-WDM Merit/Demerit
  - Wavelength Yield
  - Optical MUX / DMUX
  - Link Budget
  - Power consumption & size
  - Cost

CWDM Meets Eye Safety Requirement

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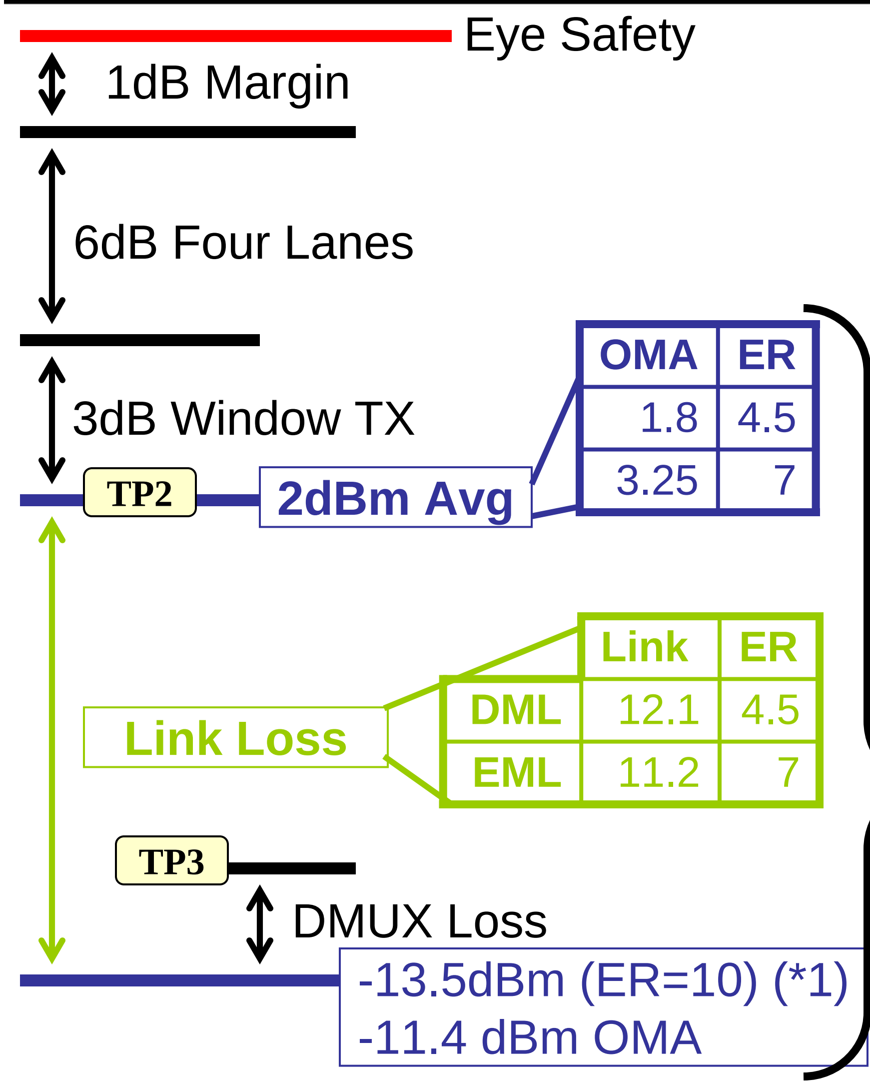


OMA	ER
1.8	4.5
3.25	7

	Link	ER
DML	12.1	4.5
EML	11.2	7

- CWDM Budget meets eye safety requirement, Class 1
- CWDM feasible *today* via Cooled or Uncooled EML (EA-DFB)
- Establishes migration path for uncooled EML or DML for next gen. interfaces

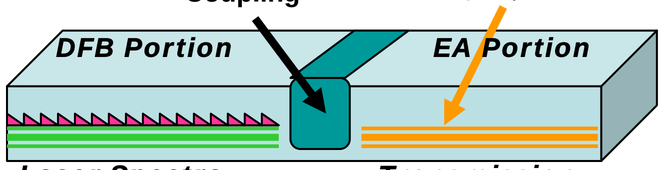
EML: 3.25 – 11.2 = -7.9 OMA > 11.4 OMA

DML: 1.8 – 12.1 = -10.3 OMA > 11.4 OMA

[1] Sensitivity same as minimum specified in cole_03_0108.pdf

Transmitter Technology Evolution: Laser

EML/EA-DFB

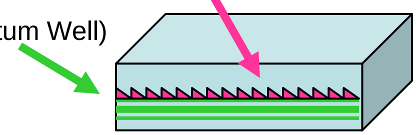


Merit
- Higher Extinction ratio
- Better chirp/dispersion characteristics

Demerit
- Lower output power
- More costly in size, power, relative $

Feasibility
- Cooled 25G demonstrated
- Uncooled 25G demonstrated
  - S. Makino, et al, OFC2008, PDP21, Feb, 2008 and live demonstration at OFC2008
  - HSSG, gokhale_01_0107[1], Jan, 2007

DML



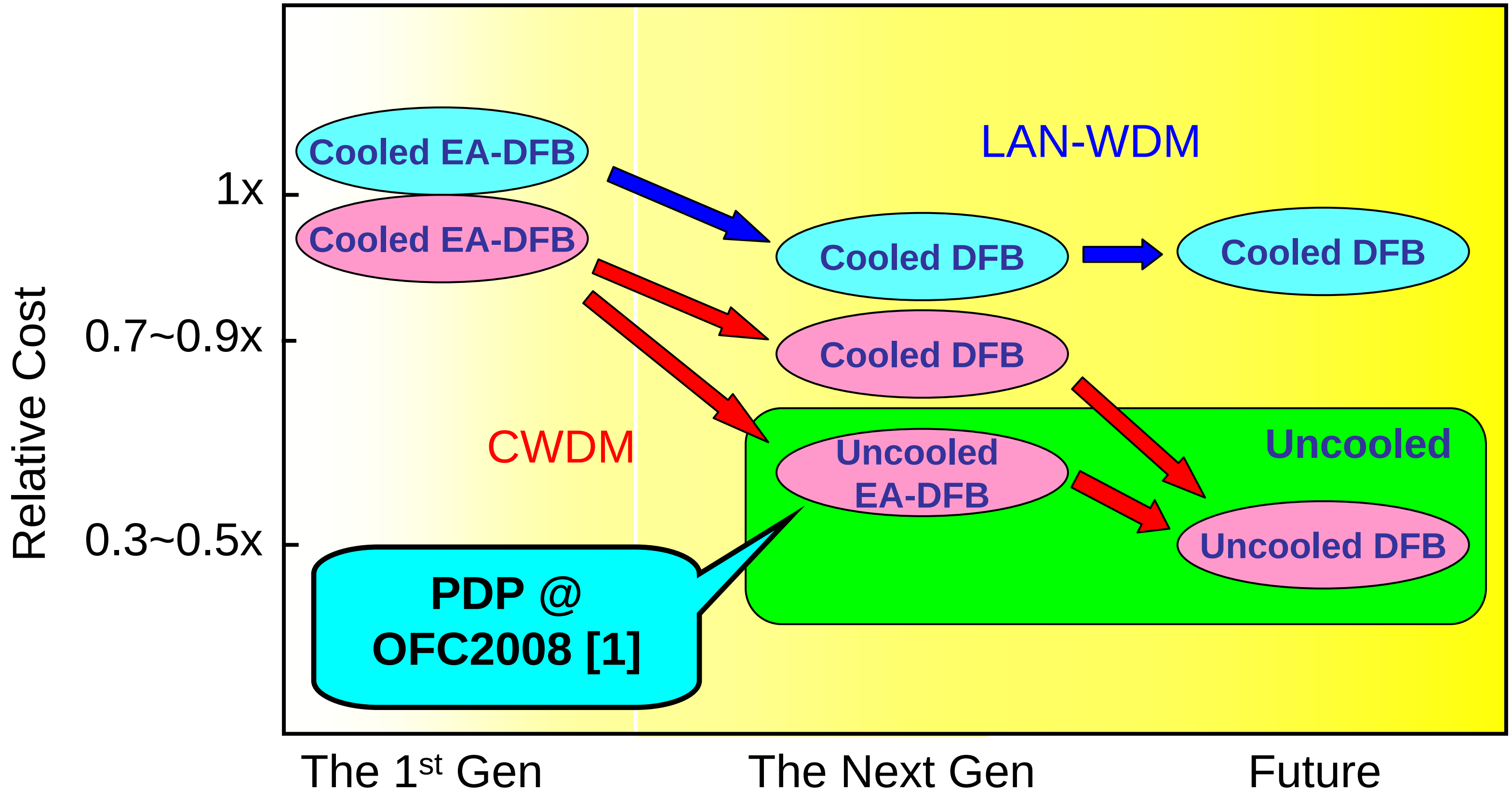
Merit
- Higher output power
- Less costly in size, power, relative $

Demerit
- Lower extinction ratio
- Dynamic chirp increases CD penalty

Feasibility
- Cooled 25G demonstrated
  - HSSG, isono_01_1107, Nov, 2007
- Uncooled 25G: need break through for low chirp operation

Scenario for cost reduction for the future

- Uncooled solutions will achieve the lowest cost but uncooled is only supported by the CWDM wavelength grid



[1] S. Makino, et al, OFC2008, PDP21, Feb, 2008 and live demonstration at OFC2008

Wavelength Grid Comparison

Item		CWDM	LAN WDM
Specification	Grid	1271 - 1331	1312 center
	Pitch	20 nm	2 – 4 nm
	Tolerance	+/- 6.5 nm	+/- 0.36 – 0.8 nm
Laser for 1st generation		Cooled EA-DFB	
Laser development	Technical Issue	25G 1310nm EA-DFB 25G Operation is the major challenge Wavelength grid is very minor challenge	
Laser Manufacturing	Wafer fabrication	4 kinds wafer	
	Wavelength yield	100%	Lower yield
	Wavelength test	No	Required
Laser Availability		Same	
Optical MUX/DMUX		Compact	Large and/or high cost
Link Budget		1~2dB worse CD 1~2dB less O-Mux loss	Moderate to Difficult Gen 1 to Gen Future
Future	Integration LD/PD and O-MUX/DMUX	Hybrid (low loss, w/o TEC)	Monolithic (high loss, with TEC)
	LD Type	Cooled DFB Uncooled EA-DFB Uncooled DFB	Cooled DFB

Wavelength Yield & Testing Impact: Discrete

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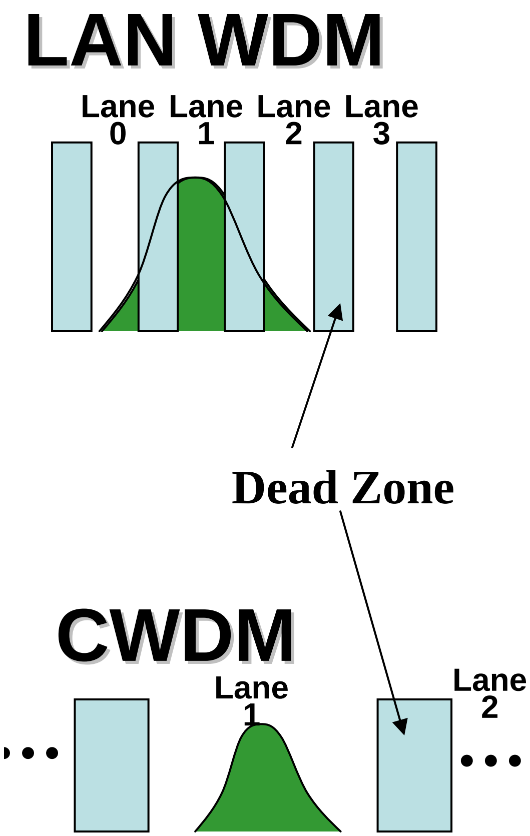
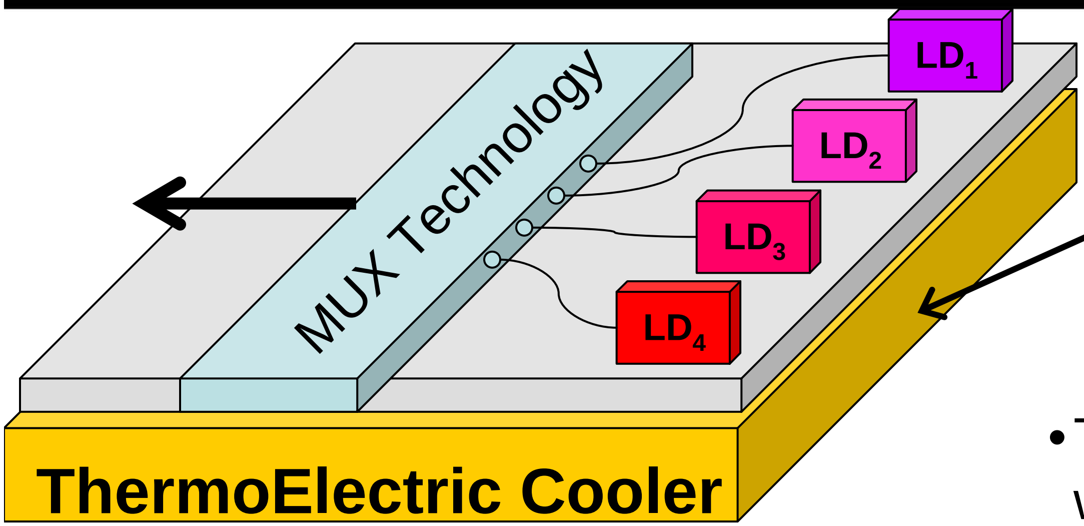


- According to “johnson_01_0108.pdf”, +/- 7degC temperature shift is needed to achieve 90% wavelength yield
  - Each wafer will likely have some additional offset versus the target wavelength reducing yield
  - Assumes 1dB additional MUX loss is the spec limit
    - Could yield 2dB more severe optical link budget due to optical MUX + DMUX losses
  - Wavelength testing required

- Wavelength yield is 100%
- No wavelength testing required

For more background see traverso_01_0108.pdf

Hybrid Wavelength Yield



TEC can only be set to a single temperature – thus the attached devices must be kept at a common temperature.

CWDM

- TEC can be removed for non-waveguide MUX tech.
- Due to 100% wavelength yield, easy assembly & test

LAN WDM

- All lasers must be kept at the same set temperature
  - Reliability, power dissipation impacted if multiple TECs used
  - MUX technologies like AWG must be cooled to maintain proper wavelength
- This means that wavelength tuning via temperature is no longer possible
  - Test each chip – then mix & match chips with similar temperatures
    - Only chips that lase at temperature T_0 used – impacts yield, testing, & assembly
  - Instead of 90% wavelength yield – now yield drops **severely**!

10km SMF Link Budgets: Uncooled EML can achieve same budget as Cooled EML

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• CWDM grid with uncooled EML requires less budget than LAN-WDM grid with cooled DML.

10km SMF 25G TP2 → TP3 Entries in dB	CWDM Cooled EML λ = 1271nm ER = 7dB	CWDM Uncooled EML λ = 1271nm ER = 7dB	LAN WDM Cooled EML λ = 1318nm ER = 7dB	LAN WDM Cooled DML λ = 1318nm ER = 4.5dB
Fiber Loss (G. 652 A&B)	**4.7**	**4.7**	**4.2**	**4.2**
ER penalty (vs. ER=10dB)	**1.0**	**1.0**	**1.0**	**2.5**
CD	**1.0(*2)**	**1.0(*2)**	**0.4**	**1.6**
Connector & Other losses	**3.0**	**3.0**	**3.0**	**3.0**
Total budget	**9.7**	**9.7**	**8.6**	**11.3**

 # Above table from cole_03_0108(p3), Jan, 2008
[1] Updated form uncooled DML(ER=3.5dB) to cooled DML(ER=4.7dB), similar to LAN WDM case
[2] α = +1.0 case, positive α is easier fabricated than negative for EML

10km SMF Power Budgets (Updated **cole_03_0108, p4)**

- CWDM grid with uncooled EML requires less budget than LAN-WDM grid with cooled DML.

10km SMF 25G λs Power in dBm (Average)	CWDM Cooled EML λ = 1271nm ER = 7dB	CWDM Unooled EML λ = 1271nm ER = 7dB	LAN WDM Cooled EML λ = 1318nm ER = 7dB	LAN WDM Cooled DML λ = 1318nm ER = 4.5dB
TX Min / Max	**1.2 / 4.2(*1)**	**1.2 / 4.2(*1)**	**0.1 / 3.1**	**2.8 / 5.8**
TP2 TX Min 2.5dB Mux loss	**-1.3(*)**	**-1.3(*)**	**-2.4**	**0.3**
TP2 4λ TX Max (TX Min + 9dB)	**7.7(*1)**	**7.7(*1)**	**6.6**	**9.3**
Link Budget (dB)	**9.7(*1)**	**9.7(*1)**	**8.6**	**11.3**
TP3 RX Min 2.5dB DeMux loss	**-11**	**-11**	**-11**	**-11**
RX Min / Max (ER =10dB)	**-13.5 / -16.5**	**-13.5 / -16.5**	**-13.5 / -16.5**	**-13.5 / -16.5**

 # Above table from cole_03_0108(p4), Jan, 2008 **[1] Updated by previous foil**

TOSA Power Dissipation and Cost Comparison between cooled and uncooled

• CWDM allows lower power consumption and low cost TOSA because of uncooled laser source.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Power and cost saving by moving from cooled to uncooled</th></tr>
<tr><th>Cooled</th><th>Uncooled</th></tr>
<tr><td rowspan="3">EML</td><td>ATC</td><td colspan="2">-2.0W</td></tr>
<tr><td>Amp</td><td colspan="2">+0.6W</td></tr>
<tr><td>Total</td><td colspan="2">-1.4W</td></tr>
<tr><td rowspan="3">DFB</td><td>ATC</td><td colspan="2">-1.6W</td></tr>
<tr><td>Amp</td><td colspan="2">+0.6W</td></tr>
<tr><td>Total</td><td colspan="2">-1.0W</td></tr>
<tr><td colspan="2">TOSA Cost (TOSA Type)</td><td>Box Type ></td><td>CAN Type</td></tr>
</table>

[Note] EA model: EA bias + EA driver modulation + LD bias (+TEC)
DFB model: LD bias + LD driver modulation (+TEC)

Cooled

Uncooled

Transceiver Size and Power Dissipation

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	Item	1st Generation (Discrete)		Next Generation (Hybrid)		Future (Hybrid)	
Electrical I/F		10-lane x 10G					
CWDM	Light source	Cooled EML		Un-cooled EML(*1)		Uncooled EML/DML	
	TOSA	Discrete	4.0W	Hybrid w MUX	2.6W	Hybrid w MUX	2.6W
	Driver	Discrete	4.8W	Quad	4.0W	Quad	3.0W
	ROSA w TIA	Discrete	1.2W	Hybrid w DMUX	0.8W	Hybrid w DMUX	0.8W
	Gear Box	Gearbox (SiGe)	8.0W	Gearbox (SiGe)	8.0W	Gearbox (CMOS)	4.5W
	Power dispassion	~ 18 W		~ 15 W		~ 11 W	
	TRX size	Double XENPAK (72x121x17mm^3, ~20W)					

	Item			Next Generation (Hybrid)		Future (Hybrid)	
Electrical I/F				4-lane x 25G			
CWDM	Light source			Un-cooled EML(*1)		Uncooled EML/DML	
	TOSA			Hybrid w MUX	2.6W	Hybrid w MUX	2.6W
	Driver			Quad	4.0W	Quad	3.0W
	ROSA w TIA			Hybrid w DMUX	0.8W	Hybrid w DMUX	0.8W
	Gear Box			Quad CDR (SiGe)	4.5W	Quad CDR (CMOS)	2.5W
	Power dispassion			~ 12 W		~ 9 W	
	TRX size			Double XENPAK (~20W)		XENPAK (36x121x17^3, ~10W)	

[1] S. Makino et al., OFC2008, PD paper; 10km transmission under uncooled operation

10km PMD Transmit Characteristics

Table 53-5: LX4 Wavelengths

Lane	Wavelength ranges	PMD Service Interface transmit bit stream	PMD Service Interface receive bit stream
L_0	1269.0 – 1282.4 nm	tx_lane<0>	rx_lane<0>
L_1	1293.5 – 1306.9 nm	tx_lane<1>	rx_lane<1>
L_2	1318.0 – 1331.4 nm	tx_lane<2>	rx_lane<2>
L_3	1342.5 – 1355.9 nm	tx_lane<3>	rx_lane<3>

Table xx-y: CWDM Wavelengths

Suggested Table for CWDM Grid

Lane	Wavelength Ranges	PMD Service Interface transmit bit stream	PMD Service Interface receive bit stream
L_0	1264.5 - 1277.5 nm	tx_lane<0>	rx_lane<0>
L_1	1284.5 - 1297.5 nm	tx_lane<1>	rx_lane<1>
L_2	1304.5 - 1317.5 nm	tx_lane<2>	rx_lane<2>
L_3	1324.5 - 1337.5 nm	tx_lane<3>	rx_lane<3>

LAN-WDM is the best solution for 40km Objective

- LAN-WDM is a great solution to minimize Chromatic Dispersion
  - traverso_01_0307.pdf, cole_01_0407.pdf,
- LAN-WDM is the best choice for 40km transmission as a client to client TDM interface
  - DWDM & optical transport will desire a more spectrally efficient PMD
    - takeda_01_0907.pdf, woodward_01_0707.pdf
- By standardizing both LAN-WDM & CWDM, the industry is open to more innovation and cost reduction in the future

Summary

- CWDM allows for 100% wavelength yield today
  - LAN-WDM requires temperature shift of +/-7degC to achieve advertised yield
- CWDM allows for quickest transition to hybrid packaging and reducing cost
  - LAN-WDM is difficult to implement on a single TEC bench
- CWDM allows a migration path for uncooled optics & therefore reduced power dissipation
  - LAN-WDM optics must always be cooled
- CWDM enables high density systems with 100GbE uplinks today
  - Lasers do not need to be driven as hard for CWDM vs. LAN-WDM
- CWDM enables high density 100GbE multi-port systems in the future
  - Low power dissipation using uncooled technology

Backup slides

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CWDM DML Feasibility (Fujitsu)[*1]

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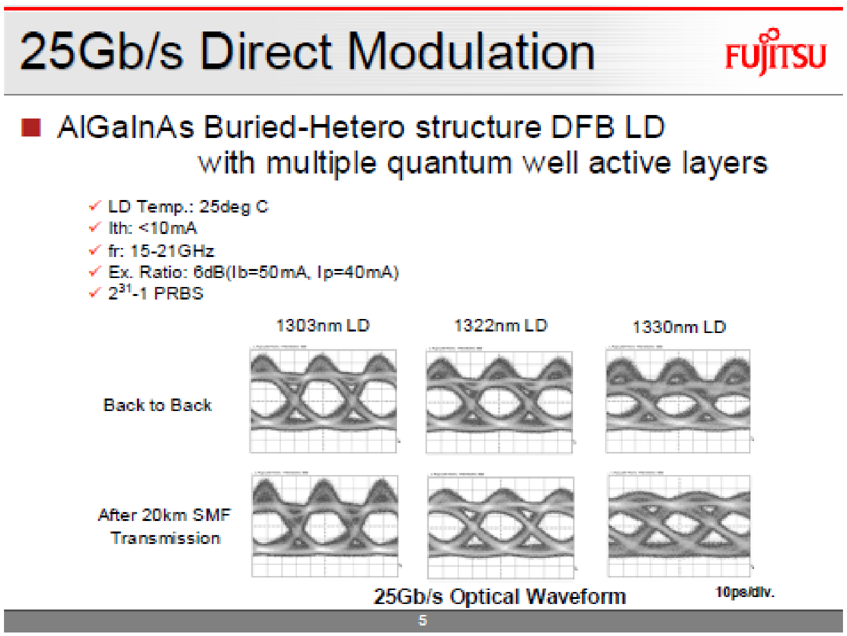
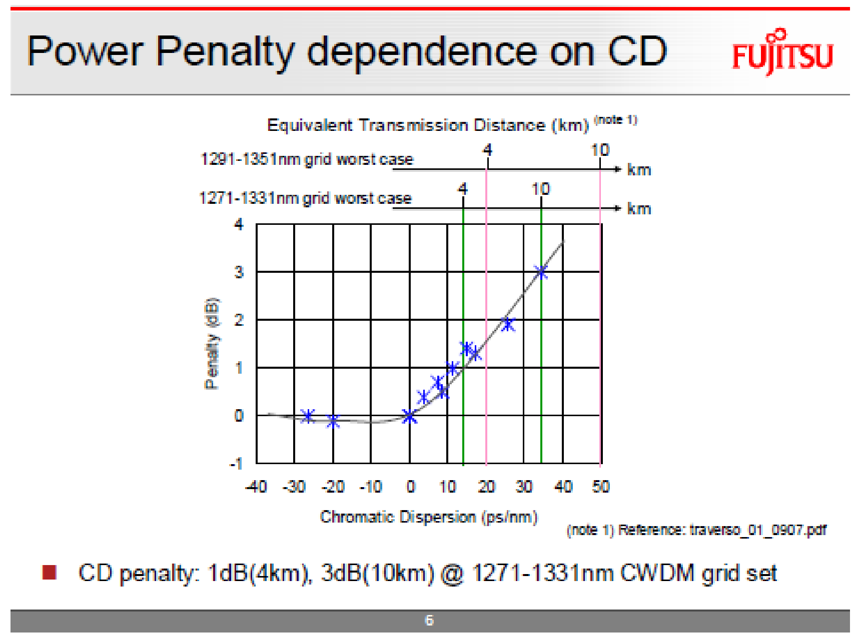
- 25Gbps, 10km transmission is demonstrated (equivalent to chromatic dispersion for CWDM)
  - 10 km transmission penalty: 3dB
  - Extinction ratio: 6dB





[1] HSSG, isono_01_1107, Nov, 2007

CWDM Uncooled EML Feasibility (1) (Hitachi CRL / opnext)[*1]

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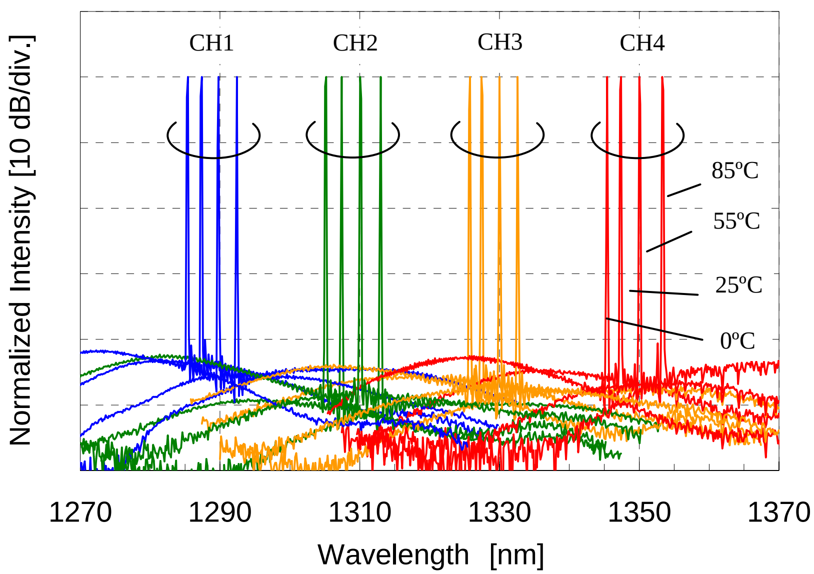
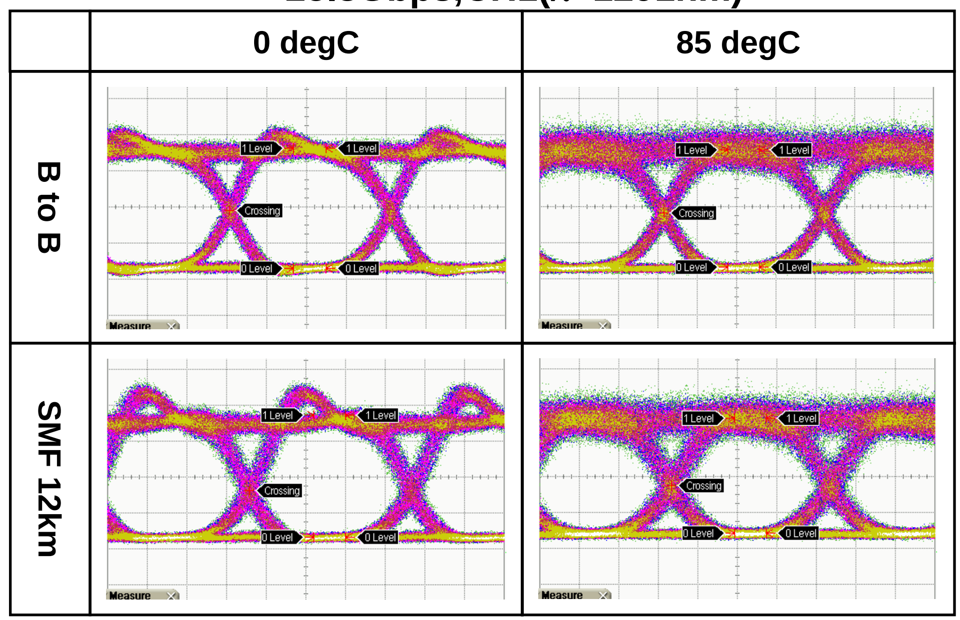
- Uncooled 4-λ CWDM 25-Gbps EML over 10-km Transmission is demonstrated
  - 12 km SMF transmission
  - Extinction ratio: > 9 dB



25.8Gbps,CH1(λ=1291nm)



[1] S. Makino, et al, OFC2008, PDP21, Feb, 2008 and live demonstration at OFC2008

CWDM Uncooled EML Feasibility (2) (Apogee, present Cyoptics)[*1]

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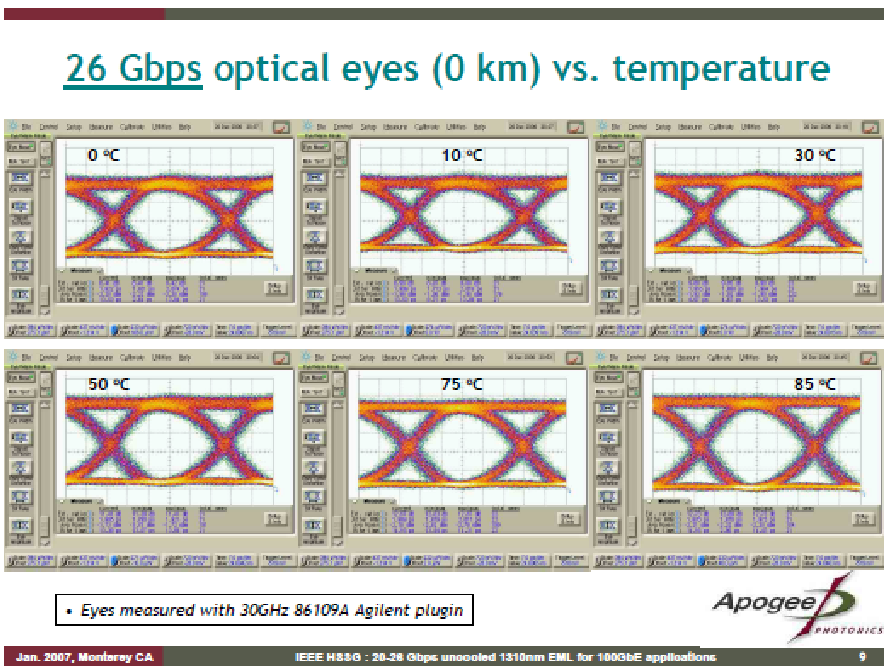
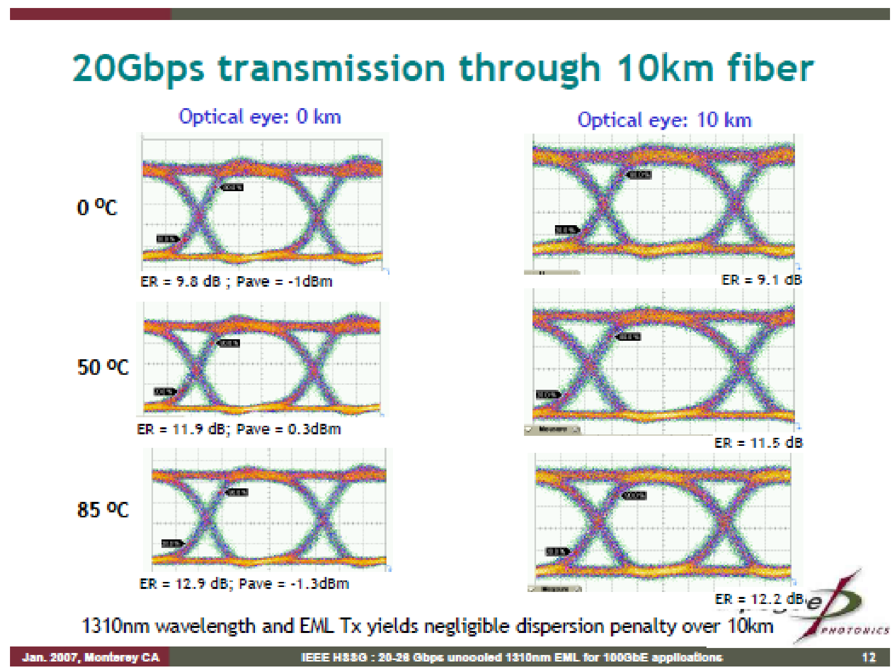
- Uncooled EML operation under 20Gbps(10km transmission) and 26Gbps(BtoB) is demonstrated
  - 10 km transmission penalty: negligible
  - Extinction ratio: > 9 dB





[1] HSSG, gokhale_01_0107[1], Jan, 2007

Power Dispassion

	Item	1st Generation (Discrete)		Next Generation (Hybrid)		Future (Hybrid / Monolithic)	
CWDM	Light source	Cooled EML		Cooled DML(*3)		Uncooled EML/DML(*4)	
	O-MUX/DMUX	Zig-Zag (7x15x5mm^3)		Zig-Zag into TOSA/ROSA			
	TOSA	Discrete	6.0W(*1)	Hybrid w MUX	3.5W	Hybrid w MUX	2.5W
	Driver	Discrete/Quad	2.0W(*2)	Discrete/Quad	2.0W(*2)	Discrete/Quad	2.0W(*2)
	ROSA w TIA	Discrete	1.2W(*2)	Hybrid w DMUX	1.2W(*2)	Hybrid w DMUX	1.0W
	Gear Box	Dual 5:2 (SiGe)	6.5W(*2)	Dual 5:2 (SiGe)	6.5W(*2)	Dual 5:2 (SiGe)	6.5W(*2)
	Power dispassion	~ 16 W		~ 14W		~ 12W	
	Comment			Cost reduction (existing LX-4)		lower power dispassion	
LAN WDM	Light source	Cooled EML		Cooled EML/DML		Cooled DML	
	O-MUX/DMUX	3-port (100x120x8mm^3)		Unrealistic into TOSA/ROSA		Monolithic integration	
	TOSA	Discrete	6.0W(*1)	Hybrid w MUX	4.5W(*2)	Monolithic w MUX	4.5W
	Driver	Discrete/Quad	2.0W(*2)	Discrete/Quad	2.0W(*2)	Discrete/Quad	2.0W(*2)
	ROSA w TIA	Discrete	1.2W(*2)	Hybrid w DMUX	1.2W(*2)	Monolithic w DMUX	2.0W
	Gear Box	Dual 5:2 (SiGe)	6.5W(*2)	Dual 5:2 (SiGe)	6.5W(*2)	Quad CDR (CMOS)	3.0W
	Power dispassion	~ 16 W		~ 15W		~ 16.5W	
	Comment	Very large O-MUX/DMUX		Hard to hybrid integration		Required TE-cooler for O-MUX/DMUX	

[1] HSSG, traverso_01_0907, Sep, 2007
[2] HSSG, cole_01_0307, Mar, 2007
[3] HSSG, isono_01_1107, Nov, 2007; 10km transmission with 3dB penalty
[4] S. Makino et al., OFC2008, PD paper; 10km transmission under uncooled operation

Optical MUX / DMUX (2): Comparison (TF Filter)

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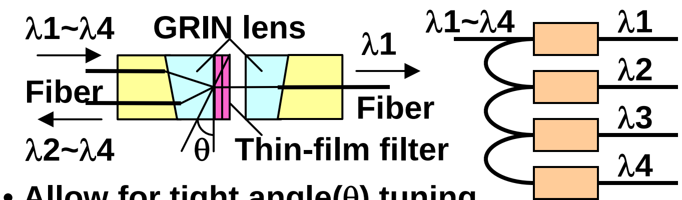
- LAN WDM filter technology is similar to DWDM
- CWDM O-MUX/DMUX is twice low-cost and ten times compact
- This leads to significant impact for TRX dimension

Item	CWDM	LAN WDM	Note
Grid	1271 - 1331	1312 center	
Pitch	20 nm	2 – 4 nm	
Pass band	+/- 6.5 nm	+/- 0.35 – 0.74 nm	
LD linewidth(*1)	+/- 0.1 nm (EML), +/- 0.2 nm (DML)		@25G
Number of layers(*2)	50~100	150~200	TF filter
Assembly tolerance(*2)	**Relax**	**Very tight**	See right figure
Cost(*2)	**x1**	**> x2**	Similar to DWDM
O-MUX / DMUX Size(*3)	**7 x 15 x 5 mm^3** (Zig-Zag type)	**100 x 120 x 8 mm^3** (3-port type)	

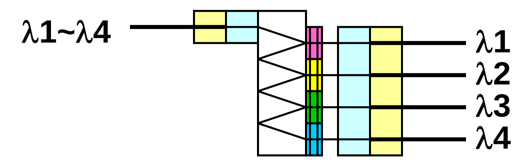
[1] HSSG, jiang_01_0507, May, 2007
[2] http://www.cubeoptics.com/img/FCKeditor/File/cwdm_white_paper.pdf
[3] From some maker's web site, commercially available

1) 3-port type (single λ add or drop)

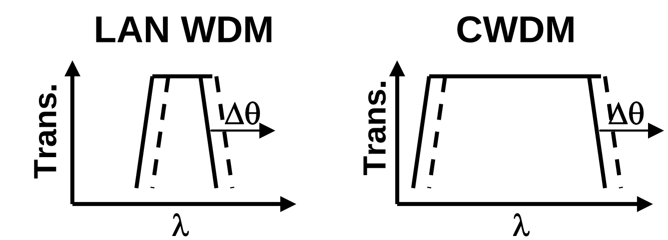


- Allow for tight angle(θ) tuning
- Large module size due to cascade connect.

2) Zig-Zag type (4λ, very compact)

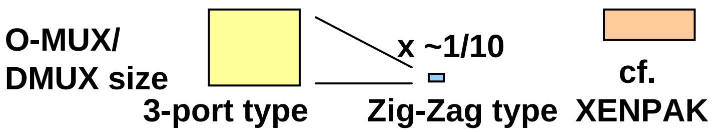


- Very compact with large incident angle



- Need tight angle tuning
- Center WL shifted
- S- and P-plane split

- Relax angle tuning
- Higher yield
- Compact



Potential Language for Wavelength Grid Motion

Motion #x: Adopt CWDM wavelength grid in traverso_01_0308 slide 14 as the basis for the 10km SMF PMD objective.

For:

Against: