100GE SMF WDM Grid Q&A

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Questions

- What is LAN WDM?
- Does un-cooled (CWDM) result in low cost 100GE optics?
- Is LAN WDM like DWDM (OTN) systems?
- What is the implication for monolithic optics integration of choosing CWDM?
- What is the implication for 40km optics if 10km grid is CWDM?
- Is un-cooled CWDM DML feasible for 10km?
- Does un-cooled CWDM EML have benefits for 10km?
- Should 4km + High Loss be a 100GE SMF objective?
- What should be the focus for 100GE SMF standards specifications?

- Reference 1: Infinera Mux Loss Comparisons
- Reference 2: CubeOptics Mux/DeMux Loss Comparisons
- Reference 3: Kotura Mux/DeMux Loss Comparisons
- Reference 4: CyOptics Mux/DeMux Loss Comparisons

What is LAN WDM?

LAN WDM is effectively low power low cost (1 TEC) Dispersion Compensation [1]

- LAN WDM decreases the required 100GE 10km Link Budget similar to Dispersion Compensation, but at much lower power and cost
- EML: LAN WDM 10km Link Budget decrease over CWDM = 1.5dB [1]
- DML: LAN WDM 10km Link Budget decrease over CWDM = 1.9dB [1]
- A 4x25G Dispersion Compensation IC would use a MLSE algorithm and consume significantly more power then a TEC for same Link Budget decrease
- (What does LAN in LAN WDM stand for? Local Area Network)

[1] cole_01_0308 (p8, p9)

Does un-cooled (CWDM) result in low cost 100GE?

No! Un-cooled does not result in low cost 100GE optics

- …but, un-cooled (with other factors) results in low cost 1G, 2.5G, 10G optics
- Transmit Optical Sub-Assembly (TOSA) cost contributors
  - Laser chip(s)
  - Passive optical components
  - Cooling (TEC if cooling required)
  - Package (may cost more if cooling required)
  - Assembly
  - Testing
- TEC cost as percentage of total 10km TOSA cost
  - ~300% of 1G TOSA
  - ~50% of 2.5G TOSA
  - ~20% of 10G TOSA
  - ~1% → 4% of 4x25G TOSA
- For 100GE optics, cooling cost is not significant

Link Budget is the most important cost factor in 100GE optics [1]

[1] cole_01_0308 (p12)

Is LAN WDM like DWDM (OTN) systems?

No! LAN WDM was optimized for 100GE and is different from DWDM (OTN) systems

- DWDM $\Delta\lambda < 1nm \rightarrow 2nm \leq$ LAN WDM $\Delta\lambda \leq 4nm \rightarrow 20nm =$ CWDM $\Delta\lambda$
- LAN WDM optical Mux/DeMux size and cost for thin-film, hybrid PLC, or InP implementations are the same as CWDM optical Mux/DeMux [1]
- LAN WDM does not have stringent frequency stability requirements
- LAN WDM laser chip yield is within 10% of CWDM laser chip yield due to wavelength tuning [2] (which is very different from DWDM laser chip yield)
- Does this yield apply to monolithic laser arrays?
- Yes! LAN WDM lasers on a monolithic chip have the proper grid spacing; a single common wavelength temperature tuning (1 TEC) brings them onto grid
- Does this apply to discrete lasers mounted on a single hybrid PLC?
- Yes! Lasers for each channel can be binned according to offset from the grid, so each set of 4 can be wavelength temperature tuned (1 TEC) onto grid, same as monolithic arrays. This requires managing laser chip inventory, and results in minor decrease in chip yield.

[1] references 1, 2, 3, 4 (p13, p14, p15, p16, respectively of this presentation)

[2] johnson_01_0108 (p6, p7)

What is the implication for optics integration of CWDM?

Adoption of CWDM grid standard will prevent monolithic optics integration [1]

- Only possible integration will be discrete lasers mounted on a hybrid PLC
- Is monolithic optics integration for real?
- Yes! Monolithic laser arrays on LAN WDM grid can be developed using today's standard InP processes [1]
- Why are there no Ethernet products that use monolithic laser arrays?
- Because there is no standard for which monolithic integration makes sense
  - successful datacom optics are serial, i.e. use a single laser source (there is nothing to integrate)
  - 10GE-LX4 uses an even wider wavelength window then CWDM (75nm vs. 60nm) and is not suitable for monolithic integration
- 100GE will be a major driver of optics integration innovation unless that is deliberately prevented by adoption of CWDM as a standard

[1] cole_01_0308 (p14)

What is the implication for 40km if 10km is CWDM?

Development and volume can not be shared between 40km optics and 10km optics [1]

- 40km has to use LAN WDM because of dispersion and noise reasons
- Given the modest initial volumes anticipated for 100GE, it is not commercially viable to develop two different optics technologies at the same time
- Since 40G volumes are a fraction of 10km, the higher volume 10km reach will be developed first
- 40km introduction will significantly lag 10km introduction
- Proof is the small amount of time 10km CWDM advocates have devoted to 40km standards work versus ≤10km standards work

[1] cole_01_0308 (p13)

Is un-cooled CWDM DML feasible for 10km?

No! Un-cooled 10km CWDM DML is not feasible because of high Dispersion Penalty

- 10km CWDM DML has significantly higher Link Budget versus 10km LAN WDM DML (Δ=1.9dB) which makes it exceed eye safety limit [1]
- The only feasible 10km CWDM DML must have properties similar to an EML:
  - low chirp
  - high output power
  - high extinction ratio
  - all the above when hot to enable un-cooled operation
- Anticipated results from research into such 25G DML can not be used for standards specifications today

[1] cole_01_0308 (p5)

Does un-cooled CWDM EML have benefits for 10km?

No! Un-cooled CWDM EML has no significant benefits for 100GE 10km applications

- Finisar presented 100G 10km un-cooled EML optics to HSSG one year ago [1], but did not pursue this alternative after finding no benefits
- Conclusions were based on comparing two Next Gen 100GE 10km SMF alternatives: 1) cooled LAN WDM DML vs. 2) un-cooled CWDM EML
  - Cooled DML cost is lower (cooling cost is not significant; see page 5)
  - Cooled DML DC power is similar to un-cooled EML DC power (see below)
- Approximate cooled DML DC Power (assuming 33% TEC efficiency):
  - DML diode bias = BIAS_PWR (nominal unit of DC power)
  - DML Driver = BIAS_PWR
  - DML total DC power = 4 x BIAS_PWR
- Approximate un-cooled EML DC Power:
  - EML diode bias = 2 x BIAS_PWR (assuming 50% modulation + other loss)
  - EML Driver = 2 x BIAS_PWR
  - EML total DC power = 4 x BIAS_PWR

[1] cole_01_0307 (p8, p9)

Should 4km + High Loss be a 100GE SMF objective?

<u>No! There is no reason to change the 100GE 10km SMF objective to a non-standard 4km + High Loss objective</u>

- 10km LAN WDM solutions have similar Dispersion Penalties to 4km CWDM [1]
- Significant cost savings are only associated with a standard loss 3/4km (or less) 100GE objective as in cole_01_1107 (co-authored by Finisar, OpNext, Excelight)
- CWDM (un-cooled) does not equal low cost 100GE optics (see page 5)
- When 100GE volumes are high and proposed new 100GE technologies mature, 802.3 can consider adding a 3rd 100GE short reach objective.
- This will then be done on the basis of extensive data which will allow
  - selection of the best short reach technology (LAN WDM? CWDM? Serial?)
  - selection of the best short reach objective (1km? 2km? 3km? 4km?)
  - achieving of lowest cost for high volume applications
- 10km reach objective is the best choice given the information 802.3ba has today

[1] cole_01_0308 (p15)

What should be the focus for 100GE SMF standards?

Focus should be 100GE SMF standards specifications based on technology understood today

- Consensus agreement is that 1st Gen 100GE SMF optics are 4x25G cooled EML,[1] so most time should be spent on standards specifications for this solution for 10km and 40km.
- Development of 4x25G cooled DML for use in a low dispersion window (LAN WDM) is understood, so additional time should be spent on standards specifications to permit this solution as an alternative for Next Gen 100GE 10km SMF.
- Major challenge is how to specify the 10km Power Budget to permit 4x25G cooled DML without unnecessary penalty for 4x25G cooled EML

[1] cole_01_0308 (p5)

Answers

- LAN WDM is effectively low power low cost (1 TEC) Dispersion Compensation
- Un-cooled (i.e. CWDM) does not result in low cost 100GE optics
- Link Budget is the most important cost factor in 100GE optics
- LAN WDM was optimized for 100GE and is different from DWDM (OTN) systems
- Adaptation of CWDM grid standard will prevent monolithic optics integration
- Development and volume can not be shared between 40km optics (which have to be LAN WDM) and 10km CWDM optics
- Un-cooled CWDM DML is not feasible today for 10km because of Dispersion
- Un-cooled CWDM EML offers no significant benefits for 100GE 10km
- There is no reason to change the 100GE 10km objective to a non-standard 4km + High Loss objective
- 802.3ba Task Force focus should be 100GE SMF standards specifications based on technology understood today: 1) cooled EML, 2) cooled DML, on same 10km and 40km LAN WDM grid

Reference 1: Infinera Mux Loss Comparisons

John Jaeger
Radha Nagarajan

Mux Type	Loss Type	Loss Value
4 Channel Power Combiner Wavelength Independent (includes all WDM grids) (can be discrete, hybrid or monolithic based)	1/4 Intrinsic	6 dB
	Coupler Excess	1 dB
	Total	7 dB
4 Channel Thin Film WDM Combiner Wavelength Dependent ≥200GHz (includes LAN WDM and CWDM)	1/4 Intrinsic	0 dB
	Coupler Excess	3 dB
	Total	3 dB
8 Channel InP AWG (monolithic) Wavelength Dependent ≥200GHz (includes LAN WDM and CWDM) (at ≥200GHz there is no need for flat top AWG)	1/4 Intrinsic	0 dB
	Coupler Excess	3 dB
	Total	3 dB

Data from multiple publications and manufacturer specifications including:

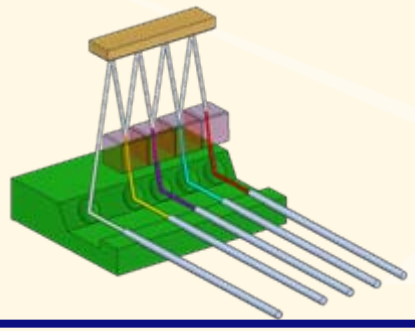
ThreeFive Photonics BV, Argo A4D10, Sept. 2002

Low-Loss, Compact, and Polarization Independent PHASAR Demultiplexer Fabricated by Using a Double-Etch Process, J. H. den Besten, IEEE Photonics Technology Letters, Vol. 14, No. 1, Jan. 2002

Reference 2: Cube Mux/DeMux Loss Comparisons

Thomas Paatzsch (COO)
Ingo Smaglinski (CTO)

Thin Film (TFF) Zig-Zag Mux/DeMux	LAN WDM ≥800GHz	CWDM 20nm
Insertion Loss Max	1.5 dB (0.9 dB typical)	1.5 dB (0.9 dB typical)
Adjacent channel Isolation	30 dB	30 dB
Non-adjacent channel Isolation	40 dB	40 dB
Operating Temperature	-40°C to +85°C	-40°C to +85°C
Size: Mux	11 x 13 x 6.5 mm3	11 x 13 x 6.5 mm3
Size: Mux/DeMux	13 x 13 x 9 mm3	13 x 13 x 9 mm3
Reliability	Telcordia 1221	Telcordia 1221
Cost	🍌	🍌
Availability	Q2, 2008	in production since 2004



← Discrete TFF Mux (input fibers replaced by discrete lasers in a single package approach)

There is no difference between TFF passive Mux/DeMux components for LAN WDM and CWDM applications

Reference 3: Kotura Mux/DeMux Loss Comparisons

Arlon Martin (VP, Sales & Marketing)

SOI PLC Mux/DeMux (Hybrid)	DWDM 50 - 100 GHz	LAN WDM 400 - 800 GHz	CWDM 20 nm
Filter Loss (dB) Mux or DeMux	2.0 → 2.5 (AWG) 3.0 → 3.5 (Grating)	2.5 → 3.0 (Grating)	2.5 → 3.0 (Grating)
Size (mm x mm) (4 channel device)	5 x 20 (AWG) 2 x 8 (Grating)	2 x 8 (Grating)	2 x 8 (Grating)
Polarization dependent Loss (dB)	< 0.5 (with compensation)	< 0.5	< 0.5
Temp Stability Requirement (°C)	+-0.1	+-0.5 (approximate)	not required
Absolute wavelength accuracy	+-50GHz (AWG) +-20GHz (Grating)	+-20 GHz	+-20 GHz
Independent Mux/Demux Temp Tuning Requirement	YES	NO	NO

← 4nm grid PLC Mux (12 channel)

There is no significant difference between LAN WDM and CWDM Mux/DeMux SOI PLC implementations

Reference 4: CyOptics Mux/DeMux Loss Comparisons

John Johnson

Mux Type	Loss element	LAN WDM ≥4nm	CWDM 20nm
Silica Hybrid PLC [1]	Input coupling	3.0	3.0
	Filter	2.5	2.5
	Output coupling	0.5	0.5
	Total [3]	5.5	5.5
Monolithic InP AWG [2]	Input coupling	1.0	1.0
	Filter	4.0	4.0
	Output coupling	1.0	1.0
	Total [3]	6.0	6.0

[1] Silica PLC DeMux has 4dB Total Loss, same for LAN WDM and CWDM

[2] Monolithic InP Power Combiner has 7.5dB Total Loss

[3] Hybrid PLC and Monolithic Mux implementations have higher total loss then discrete implementations. CWDM lasers (especially un-cooled) have no output power margin left in 10km applications, so Hybrid PLC and Monolithic integration are not feasible CWDM cost reduction paths (unlike LAN WDM.)