MMF Capabilities for 400-Gigabit Ethernet, and Beyond

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400 Gb/s Ethernet Study Group

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List of Supporters

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Background: 850nm

- GaAs-based 850nm VCSELs, detectors
  - Basis for short-reach MMF links from 1-100Gb/s
  - Transceivers roughly ½ the cost, ½ the power of SM
  - GaAs detectors sensitive to <u>maximum</u> ~870nm
- OM3 / OM4 MMF optimized for 850nm
- 850nm VCSELs viable at 28Gb/s, not likely much more
- 25Gb/s reach on OM4 limited to ~100-150m by
  - Fiber: modal bandwidth, chromatic dispersion
  - VCSEL: rise/fall time, spectral width
  - Modal partition noise
- Default 1st-gen 400GbE = 16x25Gb/s (each direction)
  - line rate matches CEI-28 electrical interface
  - re-uses 2nd-gen 100GbE VCSELs, detectors, fibers
  - back-compatible with 4X100GbE (2nd-gen) modules
  - 32 fibers per bidirectional link ➔ new connectors

Background: Higher Speed VCSELs → InGaAs

- 25Gb/s 850nm VCSELs rumored to use InGaAs quantum well active material, rather than GaAs
  - Compressive strain leads to higher speed, lower threshold
  - But addition of Indium leads to longer wavelength, so keeping at 850nm implies very thin wells and/or InAlGaAs
  - Thus the benefits of InGaAs at 850nm are limited
- VCSELs at 860-1200nm can use much more Indium, without compromising, and achieve higher performance
- Directly-modulated VCSEL products at 40-56Gb/s are more feasible at ~860-1200nm than at 850nm
  - more 25Gb/s margin at ~860-1200nm

Advantages of Longer Wavelength

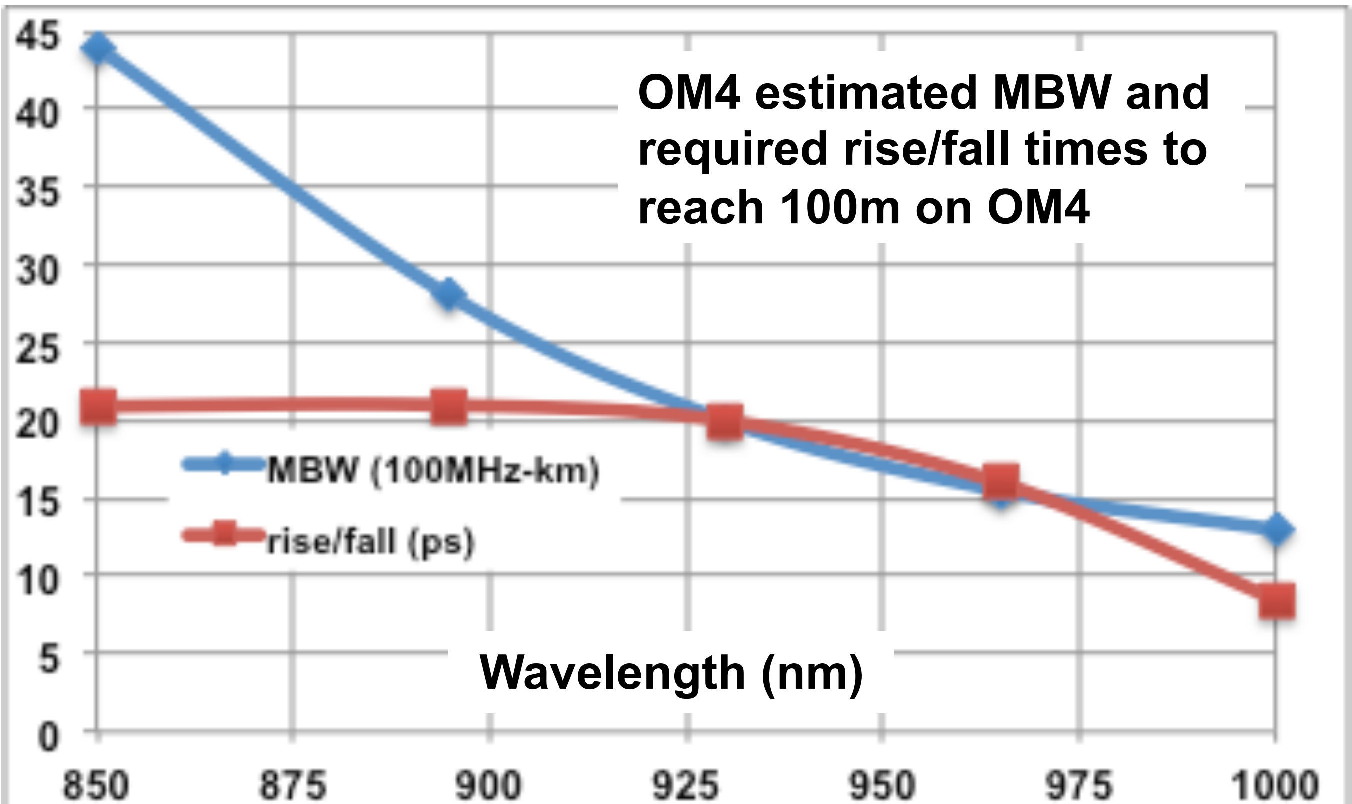
- VCSEL related
  - Higher speed (from higher differential gain)
  - Lower operating current density
  - Lower operating voltage (nearly 0.3V lower at 1060nm than 850nm)
  - Higher reliability
  - Improved thermal dissipation (GaAs in mirrors better than AlGaAs)
  - Higher temperature stability (higher well/barrier offset)
  - Single-mode emission at larger aperture (lower current density)
  - More binary-material content (GaAs replaces AlGaAs)
- Fiber related
  - Lower chromatic dispersion (and slightly lower attenuation)
  - Higher potential modal bandwidth (fewer modal groups; needs wavelength optimization to realize)
- Other
  - Higher eyesafe power
  - Higher Rx responsivity (lower photon energy; 1mW at 1060nm has about 1dB more photons/sec as 1mW at 850nm)

InGaAs VCSELs and detectors

- 860-1200nm InGaAs VCSELs are **NOT** "1310nm VCSELs"
  – Extending VCSEL wavelength to 1310nm region must incorporate Nitrogen into the active material ➔ loss in performance
- 860-1200nm InGaAs VCSELs better than "850nm VCSELs"
  – Adding Indium into the active material ➔ improved performance, as outlined in previous slide
- 840-1300nm InGaAs 10Gb/s detectors: commercial products
  – Similar to standard InGaAs 1260-1355nm detectors, but with (straightforwardly)-modified top conductive layer(s)
  – Extend to 28Gb/s and faster, similarly as for GaAs or other InGaAs detectors

Reaching 100m on OM4 at longer wavelengths

- Lower MBW requires faster rise/fall times, which should be achievable at the longer wavelengths
- Used "Example MMF Link Model" posted as supporting petrilla_04_0513; changed wavelength, MBW, responsivity
- 100m on OM4 up to about 960nm



Longer-wavelength Gen1 options for 400GbE

- 16x25Gb/s at ~950nm
  - 100m reach on OM4
  - back-compatible with 4X100GbE (2nd-gen) modules*
  - ~200m reach on "OM4-950" (OM4-quality MMF optimized for 950nm) with 16ps rise/fall time
  - **200m reach objective?**
  - 100m reach on "OM4-1060"
  - Better-suited for future-gen faster line rate (CEI-56)
- 16x25Gb/s at ~1060nm
  - <100m reach on OM4
  - back-compatible with 4X100GbE (2nd-gen) modules*
  - ~250m reach on "OM4-1060" with 16ps rise/fall time
  - **200m reach objective?**
  - Better-suited for future-gen faster line rate (CEI-56)

* Requires broadband (840-1060nm) detectors on 100G modules

CWDM option for 400GbE

- 16x25Gb/s CWDM at e.g. 850, 885, 920, 955nm
  - 100m reach on OM4 (fast rise/fall for longest wavelength)
  - 4 fibers each direction!
  - NOT back-compatible with 4X100GbE (2nd-gen) modules
  - Back-compatible with 4X100GbE (3rd-gen-CWDM) modules (100GbE on duplex OM4 fiber!)
  - Detectors: broadband InGaAs (840-965nm)
  - Gen1 readiness?? If not, then Gen2?
- 16x25Gb/s CWDM at e.g. 1000, 1040, 1080nm, 1120nm
  - <100m reach on OM4
  - 4 fibers each direction!
  - NOT back-compatible with 4X100GbE (2nd-gen) modules
  - ~150m reach on “OM4-1060” (16ps rise/fall time)
  - Back-compatible with 4X100GbE (3rd-gen-CWDM) modules (100GbE on duplex OM4 or “OM4-1060” fiber!)
  - Detectors: same InGaAs as for SMF; diameter for MMF
  - Probably not Gen1; maybe Gen2?

Gen2/3 options for 400GbE

- 8X50Gb/s at 850nm – VERY UNLIKELY
- 8X25Gsym/s w/ 2X PAM/QAM at 850nm – UNLIKELY
- CWDM with wavelengths less than 850nm – VERY UNLIKELY

- 8X50Gb/s at ~1060nm
  - 50Gb/s needed with introduction of CEI-56
  - 100m reach on “OM4-1060” (based on ~250m at 25Gb/s)
  - 8 fibers each direction

- 8X25Gsym/s w/ 2X PAM/QAM at ~1060nm
  - 50Gb/s
  - 200m? reach on “OM4-1060” (based on ~250m at 25Gb/s)
  - 8 fibers each direction

New MMF worth considering

- "OM4-XXXX"
  - relatively straightforward development (tweaked OM4)
  - >200m reach at 25Gb/s at optimal wavelength
  - 100m reach at 25Gb/s at ±110nm from optimal wavelength
  - fibers not meeting spec could be "OM3-XXXX" for 100m
  - CWDM over reduced distance

- CWDM over "OM4-1060"
  - 100m reach for 955-1165nm range @25Gb/s (≥16ps r/f)
    - 955, 985, 1015, 1045, 1075, 1105, 1135, and 1165nm (8 λ's, 30nm spacing)
  - est. 50m reach @50Gb/s
  - est. 75m reach @25Gsym/s w/ 2X PAM/QAM
  - Longer reaches for 4 wavelengths and/or tighter λ spacing

1.6Tb/s and 6.4Tb/s MMF possibilities

- 400Gb/s
  - 8 wavelengths at 50Gb/s over 50m duplex “OM4-1060”
  - 8 wavelengths at 25Gsym/s (2X PAM/QAM) over ~75m duplex “OM4-1060”
- 1.6Tb/s
  - same as 400Gb/s over 4+4 fibers
- 6.4Tb/s
  - same as 400Gb/s over 16+16 fibers

Summary

- MMF / VCSEL platform has delivered optical links at ~1/2 the cost/power of SMF links from 1Gb/s to 100Gb/s
- Technically-viable approaches can extend the platform to at least 6.4Tb/s – MMF has legs!!
- Approaches focus on
  - longer-wavelength VCSELs (higher speed)
  - longer-wavelength-optimized fibers (longer reach)
  - use of off-peak wavelengths in fibers (for CWDM)
  - CWDM mux/demux optics for MMF

- 200m reach objective merits 400G HSSG consideration